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Measuring and reporting on forest landscape pattern, fragmentation and connectivity in Europe: methods and indicators.

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This report has been prepared in the policy context of monitoring progress towards halting the loss of biodiversity by 2010. It contributes to the design and implementation of two indicators: 'landscape-level forest spatial pattern' (MCPFE 4.7) and 'fragmentation and connectivity of ecosystem' (EEA/SEBI2010).

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ABSTRACT

This report presents and demonstrates possible solutions to implement two headline policy indicators listed under the biodiversity criteria: the EEA/SEBI2010 Indicator 13 'fragmentation and connectivity of ecosystem' and the MCPFE 4.7 Indicator 'Landscape level forest spatial pattern. Focus is clearly on large regions assessment and on the change in the forest landscape structure (spatial pattern), not its function or quality.

A brief review of knowledge enabled to select important concepts and principles to address spatial pattern processes likely to have ecological effects. It is proposed to make the assessment at local level with relatively fine-grained data and the reporting per spatial units which best capture local processes without loosing too much information. In some cases, forest losses must be disaggregated from forest gains and treated separately. Measures for MCPFE 4.7 are based on (1) the morphology of the forest cover in terms of core forest (interior forest with a 100m edge width) and forest edge, also providing an insight on connectors, and on (2) the landscape context of forest in its close (50 ha) surroundings (natural context or mixed forest-non forest interface zones with agriculture and/or infrastructure). The temporal stability of core forest (*i.e.* forest potentially staying in the same conditions), the increase of edges and the loss of forest in a natural context are measured. For the SEBI2010 indicator 13, fragmentation is looked upon when associated to core forest loss and each of the four spatial pattern processes (attrition, perforation, shrinkage, fragmentation/breaking-apart) that potentially contribute to four effects (sample, area, edge, isolation) on forest habitat and species is quantified. Measures on forest connectivity combine the landscape and organism dimensions; they account for the habitat availability and inter-patch functional distances.

The measures were based on the application of three methods and GIS techniques. Data inputs were forest-non forest masks, the forest spatial pattern maps obtained by applying the mathematical morphology based software GUIDOS, the landscape patterns maps obtained by applying the landscape mosaic index and the equivalent connectivity area index derived from the Conefor Sensinode software. The analysis was conducted to demonstrate the methods with the only readily available, harmonized, relatively fine-grained and bi-temporal European-wide land cover data from CORINE Land Cover (100 m spatial resolution, 25 ha minimum mapping unit) of years 1990 and 2000. Forest habitat maps do not exist over large regions. For each measure, local spatial information was aggregated per province (NUTS level 2 or 3, 564 provinces in total) and results were presented on the basis of European-wide maps and tabular data. Indicator layers can be queried on line at the map viewer of the European Forest Data Centre (EFDAC): http://efdac.jrc.ec.europa.eu/.

The additional delivery of a European-wide snap-shot of hot-spot provinces was proposed to identify provinces where changes in spatial pattern (particularly forest loss, loss of forest in natural context, core forest fragmentation, forest connectivity loss) were significant (both in area and proportionally to the forest). Ecological impacts of spatial pattern processes would be more likely in those provinces. With the data at hand used for demonstrating the methods, 106 hot-spot provinces were flagged. It will be now essential to further compare local change in forest spatial pattern with net forest area change, and add complementary field-based data on forest quality.

I. INTRODUCTION

I.1 Objectives and structure of the report

This study aims to contribute to the European-wide implementation of the EEA/SEBI2010 Indicator 'fragmentation and connectivity of ecosystem' (SEBI2010, 2007 and EC Biodiversity Communication, 2006) and the MCPFE 4.7 Indicator 'Landscape level forest spatial pattern' (MCPFE, 2007) in the perspective of monitoring progress towards halting the loss of biodiversity. It is conducted at a relatively fine-grained scale of observation and uses for demonstration readily available harmonized land cover datasets. The report focus is on providing methods and proposing indicators for measuring and reporting the changes in the forest landscape structure (pattern) over large regions.

The report is structured into four chapters:

- In the first chapter, the European forest context is briefly introduced. Landscape level spatial pattern, fragmentation and connectivity are defined and the land spatial transformation process over time is characterized. Four landscape pattern processes leading to change in biodiversity, and important concepts (core, edge) are described on the basis of two conceptual models.
- The second chapter introduces the data and associated forest definition, temporal and spatial resolution, and the spatial administrative framework for reporting the indicators. Three available methods are presented and measures are proposed to implement each of the three headline indicators: (1) local spatial pattern measures based on morphology and on the landscape context of forest; (2) core forest fragmentation (including loss); (3) change in forest connectivity. Hot-spots of spatial pattern changes are defined.
- The third chapter provides results on the European-wide implementation of the three indicators. After a brief overview of the European forest cover and pattern distribution, the change analysis is more focused on forest losses. For the first indicator, local changes in spatial patterns based on the forest cover morphology in particular for core forest and edge forest are assessed. The close surroundings of the forest in terms of natural/semi-natural, artificial and/or agricultural lands are documented to derive landscape forest pattern types. For the second indicator, four spatial pattern processes in core forest loss (attrition, shrinkage, perforation, fragmentation/breaking apart) are measured to report on core forest fragmentation. For the third indicator on connectivity, the overall change of the forest matrix, in particular the forest availability and its topology (distance) is reported. For each indicator measure, the local information, often generated at pixel level is aggregated at province level and hot-spot provinces with significant pattern changes are derived. Results are presented on the basis of maps and tabular data. The final aim is to provide a European-wide snap-shot of provinces where ecological impacts of spatial pattern processes are more likely.
- The last chapter includes the conclusions and shortly discusses the limitations of the results.

I.2 European context and definitions

The importance of quantifying and monitoring forest changes is since long recognized in international political processes not only for timber resource availability but also for forest biodiversity conservation and sustainable management. In Europe, there was a long period of deforestation in the second half of the XIX century and first part of the XX century, and then for decades there has been a marked trend of expanding forest (Rudel et al, 2005) that now slowed down. Still in the 1990-2000 period, a 0.46% annual increase equivalent for 903000 ha/year (and 0.4% annual increase in 2000-2005) was reported for Europe excluding Russian federation (MCPFE, 2007). Large-scale assessments for biodiversity paid more attention on changes in forest area, composition and habitat quality (indicators like forest tree species composition, threatened species, regeneration, naturalness, deadwood in MCPFE, 2007). Such assessments conducted at national levels are mostly derived from on-the-ground field sampling and are reported for example in the State of forests reports of the Ministerial Conference on the Protection of Forests in Europe (MCPFE, 2003 and 2007). For more than a decade, reporting on landscape level forest spatial pattern processes (indicator 4.7 of MCPFE, 2003 and 2007) and on fragmentation and connectivity of ecosystem (indicator 13 in the Pan-European initiative SEBI2010, 2007 as a follow-up of the EC Biodiversity Communication, 2006) is increasingly sought beyond the traditional area and quality measures. However, large-scale assessments are not yet available.

In the context of the coordination of efforts to reduce biodiversity loss by 2010 (Countdown2010, http:/www.countdown2010.net/), the definition of targets and resources for indicators design, implementation and delivery in 2010 are extremely limited (Mace and Baillie, 2007).

Spatial pattern, fragmentation and connectivity are defined as follows:

- Generically, landscape level forest spatial pattern refers to the spatial arrangement or configuration of forested ecosystems across the landscape. The change of the landscape level forest pattern over time is due to the cumulative impact of local spatial forest losses and gains.
- Forest fragmentation is often used in the broader sense of the term and refers to the entire process of forest loss and isolation. More narrowly it refers solely to the change in the spatial configuration of forest remnants resulting from deforestation. 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). Fragmentation is therefore one type of spatial pattern process over time associated with forest loss.
- Connectivity particularly raises the important distinction between structural and functional measures. Structural connectivity refers to the degree of habitat connectedness. Functional connectivity, while related to structural connectivity, refers more directly to the “degree to which the landscape facilitates or impedes movement of organisms among resource patches” (Tailor et al, 1993). Structural connectivity is essential for conservation management (Vos et al, 2002) 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 viability and survival of species, for the control of invasive species and diseases. The lack of connectivity and increase of forest isolation reduces the capability of organisms to move from one forested 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).

Local spatial processes in forest loss were characterized as suggested by Forman (1995) and again by Bogaert el al, 2004 (figure 1):

a) Attrition is the disappearance of patches,

b) Shrinkage is the result of a decrease in the size of remaining patches,

c) Perforation occurs when holes are made in a habitat, i.e. an extensive forest perforated by logged areas. Perforations are an ecologically important type of fragmentation because they introduce potential edge effects deeper into intact forests, in comparison to the erosion of forest patch perimeters (Riitters, K.J. and Coulston, J. 2005),

d) Fragmentation is in the narrow sense of the term, the breaking up of habitat patch into smaller parcels and includes the two processes referred as dissection and fragmentation in Bogaert et al, 2004 since their discrimination depends on the scale of observation.

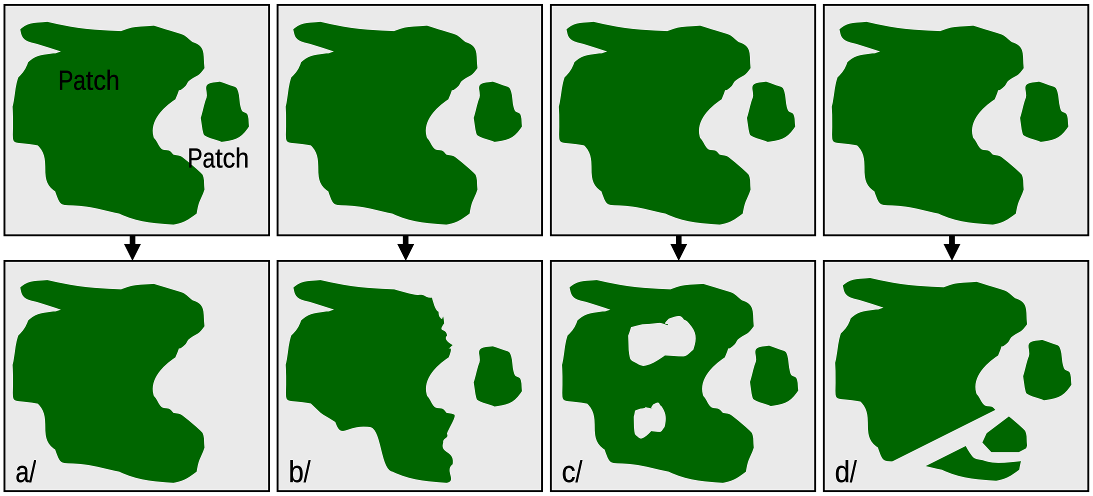


Figure 1. Four spatial pattern processes in forest loss: (a) Attrition (patch removed), (b) shrinkage, (c) perforation, (d) fragmentation/breaking apart.

Similarly, local spatial pattern process in forest gain could be characterized according to Bogaert et al, 2004 by (1) enlargement of the patch due to increase of size or aggregation of a new patch or (2) creation of a new patch.

I.3 Potential effects of landscape pattern change on biodiversity

The bibliographic knowledge on the effects of forest loss and fragmentation on biodiversity comes from models, theory and several experimental works (Debinski and Holt, 2000; Larsson et al, 2001; Lindenmayer and Franklin, 2002; Lindenmayer et al, 2002; Parviainen 2003; Kupfer, 2006). The interpretation of effects (positive or negative towards halting biodiversity loss) is out of the scope of this study since effects are species and scale dependent (Rutledge 2003). Habitat loss has a much larger effect than habitat fragmentation on the distribution and abundance of species (Fahrig, 2002) but Koper and Schmieglow (2006) show how pattern and amount are inextricably linked. We can assume that local forest loss and spatial pattern processes potentially have ecological impacts on species and habitats as shown in the conceptual model initially developed by Zuidema et al., 1996 and further described in Kupfer et al, 2004. On the basis of island biogeography theory, metapopulation models, and source-sink dynamics, four primary effects of forest fragmentation were identified. We proposed to combine this vision with Forman's (figure 2): (1) sample effects due to the total loss of forest habitat patch, (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 forest edge habitat (remnants subject to edge effects and the effects of edges on interiors). Information is clearly needed at forest habitat level and the spatial distribution of forest habitats over large regions in Europe is not available. Broadly speaking, forest land cover could be used as proxies for a preliminary assessment.

Sample and area effects relate more to the change of the forest landscape matrix and are primarily due to loss of forest habitat, changes in spatial pattern and in habitat quality. This study will not inform on quality (for example, 100 ha of native deciduous forest that is enlarged with a 50 ha of non-native plantation).

i. Landscape structure-area effects–concept of core forest: forest-dependent species should be maintained in areas as large as naturally possible and as protected as possible from external influences. Because of edge effects, species in a forest patch and their functions are confined to a core. Core forest is defined as the area of the remnant minus an edge of a certain width. Core areas thus indicate interior areas of a forest patch, which retain similar abiotic and biotic conditions to pre-fragmented conditions and do not experience strong influences from neighboring patches of other land cover categories (Rutledge 2003). Speaking very broadly, core forest patches potentially provide more suitable habitat –or 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. Generic edge widths sizes used in the Woodland Valuation Canadian model (Rowsel, 2003) to define core interior forest are 100 m, 150m and 200m. 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 edges; he mentioned sizes for wide edges (160m, 120 m) and narrow edges (20 m). 100m edge width corresponds to edge effects of many interior species (Forman and Alexander, 1998, Harper et al., 2005, Laurance, 2008) and permeability distance for invasive species. Core forests are an indicator for the overall stability of the forest ecosystem.

ii. Landscape structure-sample effects-attrition (patch removal): where forest cutting occurs (forest fragments in productive valley bottoms cleared for intensive agriculture, productive forest cuts for forestry, less productive forest removed for urban development), will determine the initial sample effects of forest-dependent species loss, in particular when core forest disappear. 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.

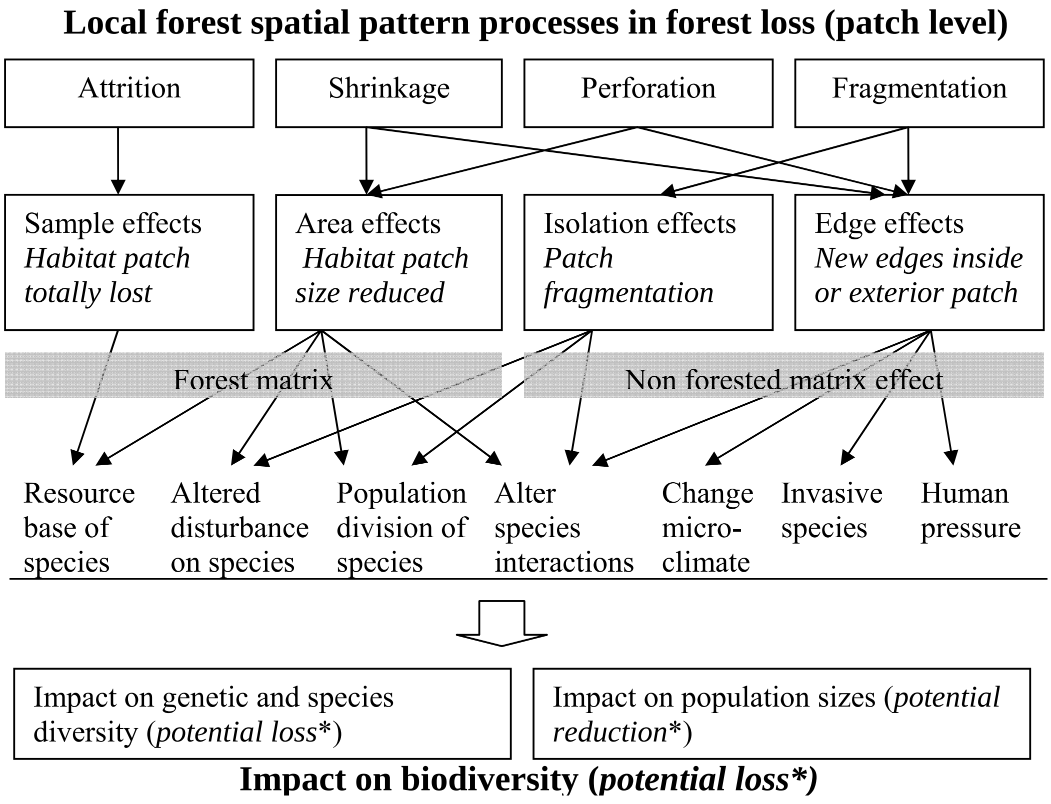


Figure2. Combining Forman's (1995) and Zuidema's (1996) visions on the four potential effects of pattern and fragmentation on species and habitats (* *loss/reduction are scale and species-dependent)*

Edge and isolation effects depend more on new adjacent land cover types (agricultural, urban or natural/semi-natural non forested lands) that create a more or less permeable interface with the forest remnants. Generalist forest species will probably better accommodate a reduction in core forest habitat embedded in natural non forested lands than with new urban or agricultural lands in their close surroundings.

iii. Landscape structure-edge effects- edge length and interface type: 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. Edge length potentially link to the amount of forest edge habitat. New perforations in core habitat patch potentially introduce edge effects (internal fragmentation process) into core. Edge effects also depend on the permeability of the new forest-non forest interface. 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. Forest-non forest interfaces may be categorized as more or less permeable depending on the similarity of adjacent habitat types (Lidicker and Peterson, 1999). Forest interfaces with natural-semi natural non forested lands are probably more permeable than interfaces with developed (artificial) lands.

iv. Landscape structure-isolation effects-connectivity. The connectivity among forest patches is an aspect of landscape structure that depends on their location (distance) from a species-level perspective. Functional connectivity depends on habitat availability, dispersal ability of the species and their response to the nature of the matrix. The cumulative impacts of forest gains and losses may change forest connectivity. Isolation therefore depends on connectivity, which is more complicated than simple distance.

I.4 Data and measures: requirements and short review of knowledge

Spatial pattern processes relevant for biodiversity assessment tend to be local. Most species of insects, mammals and birds are sensitive to fragments sizes of 1, 10 and 100 ha (Farina, 1998). 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 loosing too much information.

To address local forest loss and fragmentation, spatially continuous land cover data derived from remote sensing are preferable to field plot data (Gustafson, 1998; Kupfer, 2006). Available spatially discontinuous field based forest measurements from national forest inventories or from more recent Forest Focus Biodiversity surveys on ICP-Forests level I plots in the BIOSOIL project at http://forest.jrc.ec.europa.eu/) are not suitable. Due to time constraints (reporting year 2010), this study wished to use readily available, harmonized, multi-temporal forest cover maps (including also other land cover types for characterizing forest-non forest interfaces) over Europe. The European-wide harmonized CORINE Land Cover datasets for years 1990 and 2000 (CLC1990, CLC2000) and soon available for 2006 are based on high resolution Landsat imagery. They are an interesting European-wide data source at a rather fine scale (25 ha minimum mapping unit), informing on forest but also on agricultural and artificial surfaces, despite their limitations due to the forest definition and the mapping methodology. European-wide multi-temporal land cover maps derived from Landsat TM (25m) or from MODIS (300m) will be better alternatives for the future but were not currently readily available.

CORINE Land Cover was used for area change analysis using a 1km^2 grid in the study ‘Land Ecosystem Accounts for Europe’ (LEAC, 2006). Area estimates for forest creation and consumption including their conversion to other land covers, were aggregated at European level but there was no geographical local details on forest losses and gains. This study stated that the general positive balance of forest gains and losses as aggregated in national statistics hides the still on-going clearance of forest due to infrastructure development, to intensive agriculture and/or modification of river courses (LEAC, 2006). Forest losses are indeed more than offset by the establishment of new plantations and natural regeneration, and by the transformation of other wooded land into forest as already said in MCPFE, 2007. Most likely however, the net forest area increase is not uniformly distributed on the national territory, justifying an additional European-wide study on local forest spatial patterns.

Regarding measurements, large-scale forest fragmentation studies were so far mostly based on mono-temporal data (1 km global land cover maps in Riitters et al, 2000; 1 km European forest probability map in Puumalainen et al, 2002; 180m WIFS and CLC based forest map in Uuttera et al, 2003; 30m national land cover maps of the United States in Heilman et al, 2002 and Riitters et al 2002, 2004). 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 and Marks, 1995) or with area density scaling measures from the "amount-adjacency" model based on image convolution (forest proportion and connectivity within a landscape window (Riitters et al, 2002). More recently, a new method based on mathematical morphology (Vogt and Soille, 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. 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. Another approach based on the landscape mosaic indicator (derived from the *Landscape Pattern Types* (LPT's) after Wickham and Norton 1994 and Riitters et al, 2000 and 2009) has the advantage to function in a tri-polar space. It classifies a land-cover pixel according to the land-cover composition in a fixed-area neighborhood surrounding that pixel (for example forest, developed/artificial, and agriculture). 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 (Riitters et al. 2000).

Few large scale studies are found on pattern changes over time. For example, forest density was measured over time using multiple window sizes from approximately 2 to 5000 ha (Wickham et al, 2007 and 2009). The focus was clearly of the forest proportion in the window and its change across scales of observation. The multi-scale forest density maps were classified using thresholds of 40% (patch forest), 60% (dominant forest) and 90% (interior forest) and the loss and gain of each forest density category across scales were reported. Bogaert et al, 2004, was more interested in local spatial pattern processes but concentrated in the sequence of short-term spatial processes in a long-term transformation process. For a focal land cover class, he applied traditional pattern geometry (number of patches, area and perimeter) to identify the dominant process among 10 processes derived from Forman, 1995, Collinge and Forman, 1998 and Jaeger, 2000 (aggregation, creation, enlargement, attrition, fragmentation, dissection, perforation, shift, shrinkage, deformation). Losses and gains were not addressed separately nor their compensation/cumulative impacts. The dominant spatial process over one short time period was considered exclusive and was not quantified.

Finally on connectivity measures, Kindlmann and Burel, 2008 distinguished two basic groups of definitions: structural connectivity where connectivity is based entirely on landscape structure, with no direct link to any behavioral attributes of organisms, and functional connectivity which considers organisms' behavioral responses to individual landscape elements (patches and edges) and the spatial configuration of the entire landscape. Structural connectivity is assessed through measures based on (i) presence, absence, or configuration of corridors and stepping-stones, (ii) distance, (iii) graph theory, (iv) habitat availability and (v) contagion or percolation. Functional connectivity will apply measures based on (i) the probability of movement between patches, (ii) immigration rates or rate of re-observation of displaced individuals or (iii) matrix permeability. In their conclusions, Kindlmann and Burel, 2008 stated that they are too many connectivity measures in literature and that there is a need for more research on interlinking various connectivity metrics. Also, they advised to move from the idea of ‘‘Connectivity= f(landscape)’’ to the approach of ‘‘Connectivity =f(landscape, organism)’’. Connectivity has thus two dimensions: landscape and the organism considered. Only a combination of these two will yield a meaningful value of connectivity. A recent approach from Saura and Torne, 2009 based on previously quoted structural measures (like distances, habitat availability and graph theory) and functional measures (probability of dispersal according to dispersal distance) may represent a first attempt in doing the landscape, organism combination. Its implementation over large regions with standard computer processing capacity was never tested.

II DATA AND METHODOLOGICAL APPROACH

II.1 Data, forest definition and reporting units

The CORINE Land cover data (CLC) was the only ready-to-use, validated, multi-temporal, consistent and harmonized land cover data available at a relatively fine scale over the European territory and the last decades (25 minimum mapping unit and 100m spatial resolution, and roughly for the years 1990 and 2000). The change analysis covered 21 European countries (figure 3 and table 1) while for year 2000, United Kingdom, Sweden, Finland, Greece, Malta, Cyprus were also available (27 countries).

Country name	Code	Provinces number	Nuts level
Austria	AT	9	2
Belgium	BE	11	2
Bulgaria	BG	28	3
Czech republic	CZ	14	3
Germany	DE	41	2
Denmark	DK	15	3
Estonia	EE	5	3
Spain	ES	50	3
France	FR	96	3
Hungary	HU	20	3
Ireland	IE	8	3
Italy	IT	103	3
Lithuania	LT	10	3
Luxembourg	LU	1	3
Latvia	LV	6	3
Netherlands	NL	12	2
Poland	PL	45	3
Portugal	PT	28	3
Romania	RO	42	3
Slovenia	SI	12	3
Slovakia	SK	8	3

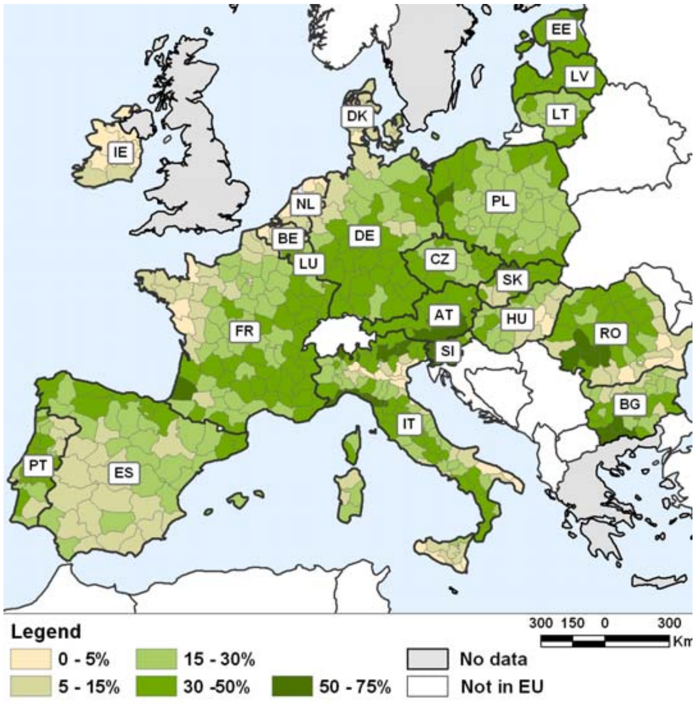


Table 1: Countries, provinces with Nuts level for the change analysis in 1990-2000
Figure 3: Forest proportion in 2000 per provinces

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 forest land cover type describes land that is dominated by trees. As a rule in CORINE Land Cover, a canopy closure or aerial crown density of at least 30 percent is required before a tract of land will be classified as forestland cover type, the minimum mapping unit is 25 ha and the trees high is at least 5m. The standing forest classes (broadleaves, coniferous, mixed) includes young plantation when at least 500 stems by ha is reached. It does not include other wooded land, young plantations less than 500 stems/ha, clear cuts, burned areas, forest nurseries. Forest land cover data is not equivalent to land use. Forest logging is usually not considered a forest loss in land use, but just a temporary change in land cover. Under this point of view, the CLC definition is very different from the international forest standard definition (FAO FRA 2005). Forest land use data are spatially discontinuous and 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. Forest, according to the FAO standard definition is land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 percent. It includes areas under reforestation and temporarily unstocked areas due to human intervention (clear-cuts and other management systems) or natural causes, which are expected to regenerate. Although the forest land cover data and the forest land use data are highly correlated, one should not expect them to be equivalent or be alarmed by differences. Forest land cover data probably gives an interesting and useful perspective from an ecological point of view. Forest loss and 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). Forest fragmentation due to land development (urban sprawl and transport infrastructure) is more permanent over time. When forests are converted to other uses, the new forest area taking its place elsewhere does not necessarily provide the same ecosystem functions and services because acres exiting (forest loss e.g., deforestation) or entering (forest gain e.g., afforestation, reforestation) the forestland base (core and edge part) can represent quite different forest conditions.

CORINE land cover (CLC2000 and CLC1990) provides 44 land cover classes (Bossard et al, 2000). For the morphological analysis of the forest cover, we reclassified the land cover data into forest (classes 3.1.1, 3.1.2 and 3.1.3 respectively broadleaves, coniferous and mixed forest) and non forest. The non-forested landscape matrix was characterized by the CLC class 1 (urban and artificial surfaces), by class 2 (agricultural lands) and by CLC classes 3 and 4 except classes 3.1.1 to 3.1.3 (natural/semi-natural non forested lands). 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.

The CLC vector layers for years 2000 and 1990 covering 27 and 21 European States respectively, used a 25 ha minimum mapping unit, the raster layers have 100m spatial resolution. The CLC layer referred to for year 1990 has poorer quality and time inconsistencies when compared to the CLC layer of year 2000. Landsat images span from 1986-1998 for year 1990 while the time span is about one year for year 2000, the geometric accuracy of both CLC data is 100m but it is below 50 m for year 1990 and below 25m for year 2000, the thematic accuracy is 85 % at CLC level 3 products for both but validated in 2000 (CLC, 2006). To reduce the amount of “false” or non-real” change by intersecting CLC2000 and CLC1990, the revised version of the CLC1990 where the geometry and thematic content was checked against CLC2000 and corrected, was used in this study. The overall thematic accuracies at level 1 would be needed for class 1 (artificial) and 2 (agriculture) while the overall accuracy at level 3 would be needed for the forest classes. The CLC2000 over Italy was validated with ortho-photos and field plots: overall accuracies 97% and 89% respectively for the CLC level1 and 2, with 96 % for user accuracy per class 1 and 2 and accuracies of 96%, 76% and 80% respectively were reported for class 3.1.1, 3.1.2 and 3.1.3 (APAT/report 36, 2005). Accuracy assessments were however not made available for all countries and for 1990. 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 4) and the rule on the minimum size of linear features (above 100m) lead to a loss of information. As a result, the forest proportion may be underestimated (Uuttera et al, 2003) and also forest pattern processes are only broadly described.

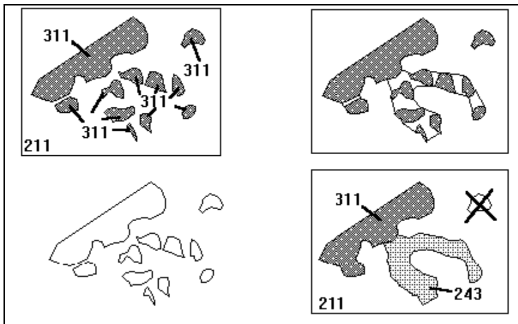


Figure 4: Loss of forest patches due to the 25 MMU and the 300m distance rule for aggregating units below25 ha (forest parcel into CL211:arable land). (CLC311: coniferous forest, CLC243: agricultural land interspersed with natural vegetation) (Bossard et al, 2000)

The spatial framework selected for reporting the headline indicators was the province administrative level. It was chosen to place the result in a policy and management relevant context, and because it is probably local enough to still capture the spatial pattern processes. Alternatives like environmental regions and fixed area grids were used in a regional case study (Estreguil et al, 2009). The NUTS system was used (Nomenclature of territorial units for statistics at http://ec.europa.eu/eurostat/ramon/nuts/home_regions_en.html). To reduce the standard deviation of the sizes of the provinces (NUTS level 3), NUTS 2 was chosen instead of NUTS 3 for Austria, Belgium, Germany and Netherlands as it was already done in other studies over Europe (LEAC, 2006).

II.2. Three available methods

II.2.1 Morphological Spatial Pattern Analysis (MSPA, Guidos)

Mathematical morphology (Matheron, 1967; Soille, 2003) encompasses methods that may be useful for characterizing spatial patterns in ecological research and biodiversity assessments. A recent method using mathematical morphology analysis (Soille and Vogt, 2009) was implemented into a stand alone freeware called GUIDOS available at http://forest.jrc.ec.europa.eu/. It classifies and maps automatically at pixel level six mutually exclusive land cover (here forest) spatial pattern classes from any binary (here forest-non forest) map (figure5):

1. 'Core forest': inner part of a forested region, beyond a certain distance (edge size parameter) to the forest-non forest boundary; a pixel is labeled core if the center and 8 neighboring pixels are forest.
2. 'Islet forest': forested region that is too small to contain core forest.
3. 'Edge forest': exterior perimeter of a cluster of core forest pixels also referred as external edge.
4. 'Edge forest of perforation': interior perimeter of a cluster of core forest pixels that is perforated by non forested landscape ('holes' inside forests), also referred as internal edge
5. 'Connector forest': a set of forested pixels without core forest (line) that connects at least two different core forest units (bridge) or connects to the same core forest unit (loop).
6. 'Branch forest': a set of forested pixels without core forest (line) that is connected at one end only to a connector, an edge or a perforation.

Data inputs into GUIDOS were the binary forest-non forest raster masks of CLC 1990 and of CLC 2000. The edge size parameter was fixed at 100 m following the literature review in section I.3. For each year, the binary forest-non forest mask was classified into one forest spatial pattern map with six main forest spatial pattern classes. Each pattern map automatically provides the pixel-level local morphology of the forest cover.

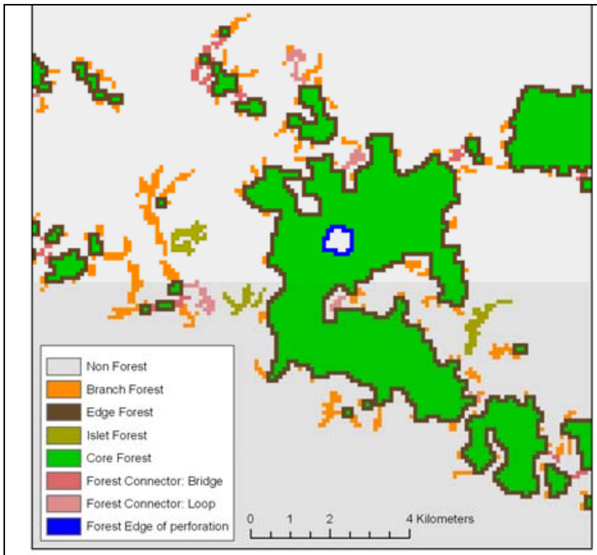


Figure 5: Forest spatial pattern classes derived from morphological analysis at pixel level

The edge size is fixed by the operator and represents the distance to the forest-non forest borderline that enables the delineation of the interior part of forest patches.

II.2.2 Landscape mosaic index

The landscape mosaic index (after Wickham and Norton 1994 and Riitters et al, 2000 and 2009) was implemented with Geographic Information System techniques to categorize the landscape context of forest lands. Landscape pattern types are defined in a tri-polar space by applying convolution filters *i.e.* placing a "window" on each pixel of land cover, calculating the pattern index within the window, and putting the result on a new map at the same location. The window size corresponding to the close surroundings of the focal class was fixed at 49 ha (7 x 7 pixels). Each pixel is classified into a landscape pattern type according to the proportion of three main land cover types in the window, namely natural/semi-natural lands (CLC classes 3 and 4), agricultural lands (CLC class 2) and urban/artificial lands (CLC Class 1) - fifteen possible landscape forest pattern types were defined (Table 2 and figure 6). Finally the forest mask was applied.

By using a 7x7 neighboring window, the penetration distance of effects from non natural/semi-natural lands, if any, is assumed to be maximum 300m inside a forest patch. For example, forest with adjacent agricultural lands (agricultural-forest edge type) will be classified as Na and penetration of species from farmland inside the forest patch is expected up to maximum 300m. Forest classified as NN means forest within a 100% natural landscape context, and there are potentially no or only minor effects from agricultural and/or artificial lands in its 49 ha surroundings. One raster map of the landscape forest pattern types is available for each year (1990, 2000) and helps visualizing the interface zones (figure7).

	U (1)	**Ua (2)**	**Uan (3)**	**Un (4)**		**A (5)**	**Au (6)**	**Aun (7)**	**An (8)**
%U	[80 - 100]	[60 – 90[	[60 -80[	[60 – 90[		[0 – 10]	]10 – 40]	]10 – 30]	[0 – 10]
%A	[0 -10]	]10 – 40]	]10 – 30]	[0 – 10]		[80 -100]	[60 – 90[	[60 -80[	[60 – 90[
%N	[0 – 10]	[0 – 10]	]10 – 30]	]10 – 40]		[0 – 10]	[0 – 10]	]10 – 30]	]10 – 40]

	NN(9)	**N (10)**	**Na (11)**	**Nua (12)**	**Nu (13)**		**Mix (14)**	**very low natural Mix(15)**
%U	0	[0 – 10]	[0 – 10]	]10 – 30[	]10 – 40]		U<60 and A<60	A<60 and U<60
%A	0	[0 -10]	]10 – 40]	]10 – 30[	[0 – 10]			
%N	100	]80 -100[	[60 – 90[	[60 -80[	[60 – 90[		[10-60[	[0-10[

Table 2: Landscape types definition with proportions of land cover classes

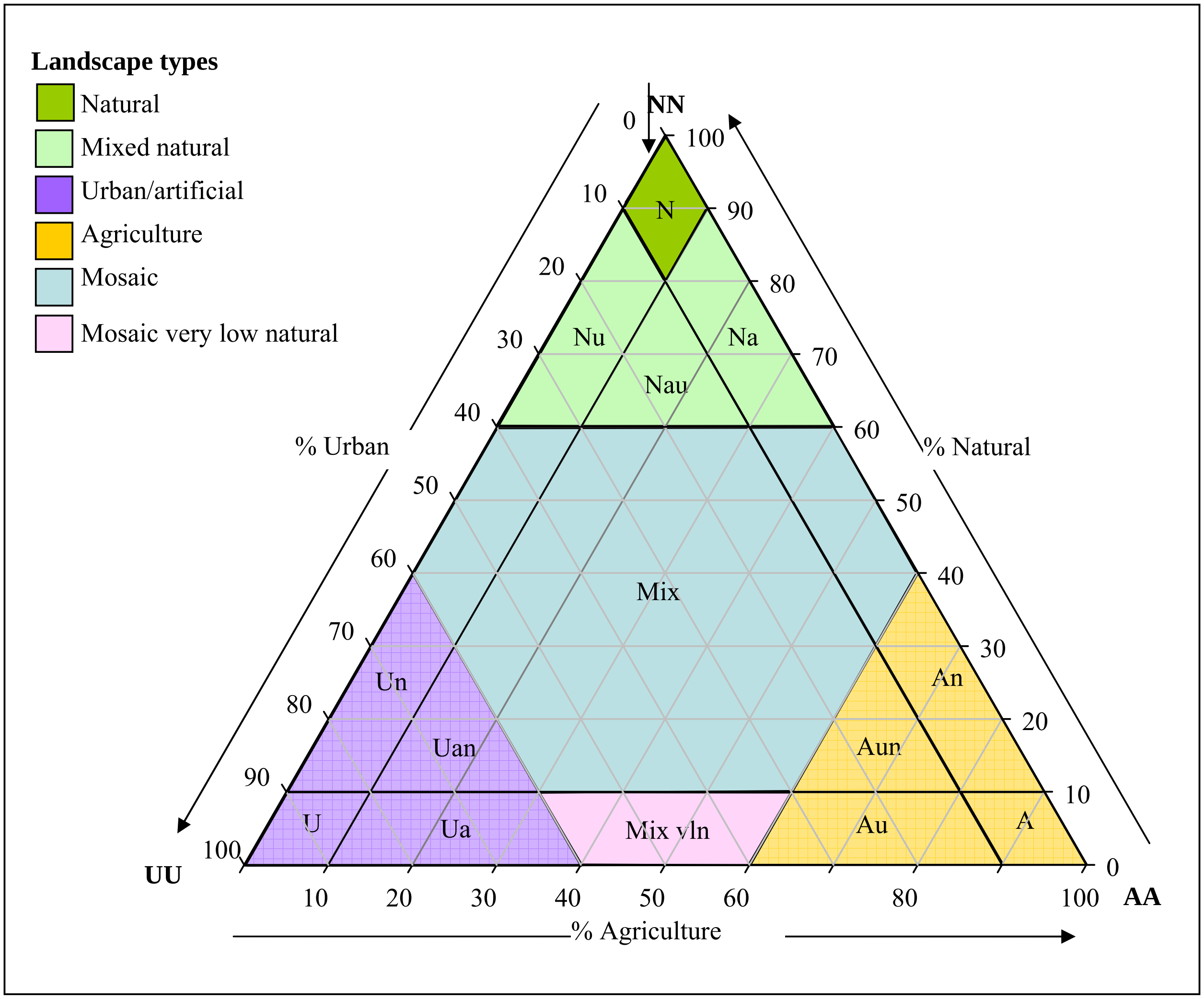


Figure 6: Landscape types in a tri-polar space

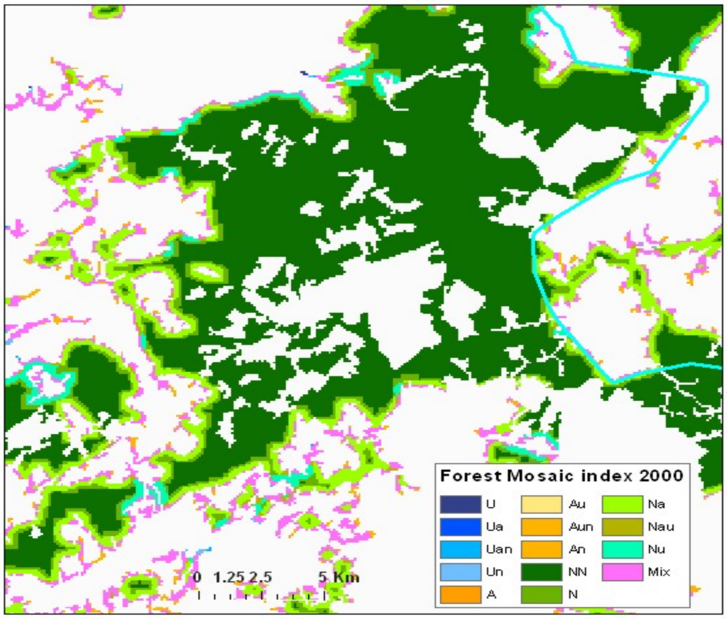


Figure 7: Forest landscape pattern types from landscape mosaic index applied to forest

II.2.3 Forest connectivity index (Conefor)

The method to measure connectivity uses the Probability of forest Connectivity (PC) index calculated with an adapted version of the software Conefor Sensinode (Saura and Torne, 2009 at http://www.conefor.udl.es). The method (figure 8) is based on topology (inter patch distances) and patch attributes (area) for forest dwelling species with a specific dispersal ability. 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 (forest patches) and links between nodes. Each link between every two patches is characterized by a probability of dispersal, obtained as a function of distance (a decreasing exponential function of the Euclidean (straight-line) edge-to-edge distance, matching to a probability of 0.5 for the average dispersal distance of 1, 5, 10, and 25 km). The matrix (non-forest landscape) is treated as homogeneous.

Conefor sensinode is a stand alone application which has been updated for large data processing and in particular to perform batch processing as the number of province does not allow a one by one process (version 2.3.4 not publicly released) (Saura et al, 2009). The data preparation consists in creating for each province, one shape file per year with the forest polygons extracted from CLC database (value 311, 312, 313), dissolved, simplified in their boundaries (25 m) and identified with a unique ID. Conefor Input extension for ArcGis9.X. is used to create for each province:

- a node file (stantard ASCII text file) with the list of polygons ID and their area,
- a distance file (also text file) with the edge-to-edge Euclidean distance between each node (polygon).

a)

$$PC = \sum_{i=1}^{n}\sum_{j=1}^{n} a_i \cdot a_j \cdot p_{ij}^{*}$$

p_{ij} = exp $^{-kdij}$
a_i, a_j = area of patch i,j
p_{ij} * = product of p_{ij} for all the links in the optimal path between patches i and j

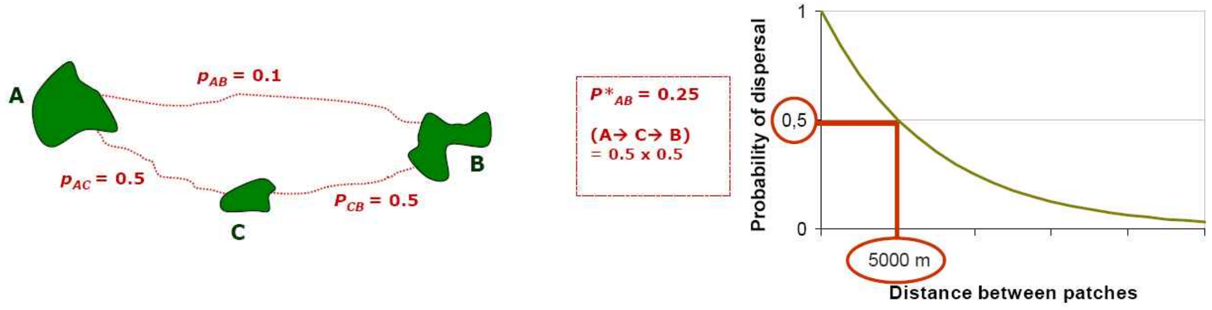


Figure 8: The Probability of Connectivity measure for 5km dispersal distance (here 5000 m) (PC).

II.3. Indicator measures

As a follow-up of sections I. and II.1, we can summarize important concepts to address spatial pattern processes likely to have ecological effects and to propose simple and feasible measures for implementing the two headline indicators MCPFE 4.7 on landscape level forest spatial pattern and the SEBI2010 indicator 13 on forest fragmentation and connectivity. For biodiversity purposes, it will be essential to further complement local change in forest spatial pattern with field-based assessments of forest quality. This will not be done in the current study.

The assessment should be done at the local scale and reported per spatial units which best capture local processes without loosing too much information, forest losses should be disaggregated from forest gains and treated separately for certain measures.

For measures relevant for the indicator MCPFE 4.7, the morphology of the forest cover in terms of core forest area (more interior forest with a 100m edge width) and forest edge area is important to quantify and monitor over time. Its temporal stability means that the forest potentially stayed in the same forest conditions. The landscape context of forest (more natural or more mixed with agriculture and/or infrastructure) and forest-non forest interface zones types are also important. The reduction of natural forest landscape pattern type is of particular interest.

For measures relevant for the SEBI2010 on forest fragmentation, fragmentation due to local forest loss will be reported by core forest loss and the four spatial pattern processes (attrition, perforation, shrinkage, fragmentation/breaking-apart). For measures on forest connectivity, the change in forest connectivity will combine the landscape and organism dimensions. The change of the forest matrix will be considered after the cumulative impact of losses and gains over the time frame of interest.

Input data to develop indicators are the forest masks, the forest spatial pattern maps based on morphology (section II.2.1), the forest landscape patterns maps based on landscape context from the landscape mosaic index (section II.2.2) and the connectivity measures calculated with the PC index (section II.2.3). Those data were available for two points in time (1990 and 2000). Reporting units to aggregate the measures were the NUTS level 2 or 3 province level. All indicator measures were implemented with standard Geographical Information Systems (ArcGis 9.x or equivalent).

II.3.1 Indicators on forest spatial pattern

II.3.1.1 Local forest patterns based on forest cover morphology

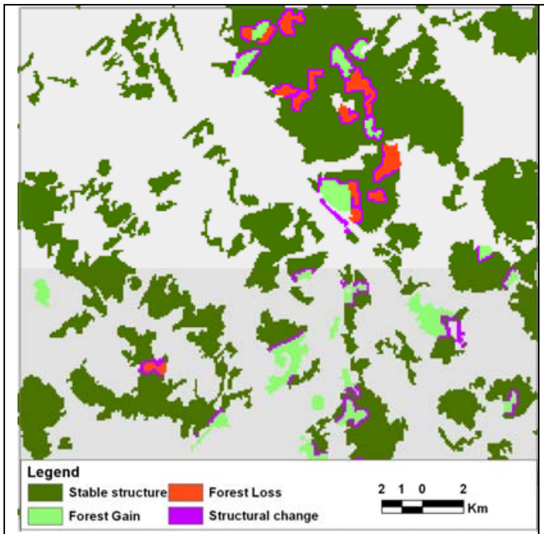
The forest amount (in ha and equivalent proportion of land) and the share of each GUIDOS forest pattern class (core, edge forest, edge forest of perforation, bridge, loop, branch, islets) in the forest cover was documented per province for each year. The spatial distribution of core forest patches was further documented by:

- The area weighted core forest average patch size (AWACFS) index which is based on the identification of core forest patches and accounts for their number and their size. The larger the patch is, the higher its contribution in the calculation. The index formula is:
  AWACFS = $\sqrt{[\Sigma(c_i)2 / \Sigma c_i\ ]}$, with c_i – area of the core unit i, i=1 to n.
- The distribution of the number of core forest units per ranges of patch sizes (<25 ha, 25-100 ha, 100-500 ha, 500-1000ha, >1000 ha). The overall gain or loss of small units (below or above 100 ha) and of large units (above 1000 ha) is a relevant information for species with specific area ranges requirements.

Edge forest types include all non-core GUIDOS forest pattern classes except islets. They are part of the perimeter of core patches (perforation, branch, edge classes) or connect core patches (connector as loop and bridge). The forest proportion of edge forest type in general, and of connectors in particular was calculated.

The change analysis in the 1990-2000 time period first provided (figure 9) (i) the proportion of forest loss (with respect to the forest area in 1990) and (ii) the proportion of forest gain (with respect to the forest area in 1990). Regarding pattern, measures were: the forest proportion with stable forest spatial pattern in the sense that the pixel level GUIDOS forest pattern class kept the same pattern class in the 1990-2000 period. Similarly the proportion of stable core forest and the proportion of stable edge forest type were calculated. Unstable core pattern means a structural change from core forest to an edge type of pattern or to non forest. They potentially links to changes in the resource base available for interior species or/and their living conditions (*i.e* closer to edges). Unstable edge forest type means that edges turn into core, into islet or into non-forest.

Finally, core forest loss and core forest gain were also quantified. Two spatial pattern processes in core forest gain were the creation of new core forest patches and the enlargement of existing core forest patch (ha and %). Four spatial pattern processes (attrition, perforation, shrinkage, fragmentation/breaking apart) in core forest loss were described in detail in the section II.3.2 on core forest fragmentation. The net forest edge area change after the cumulative impact of forest losses and gains was measured by the change of edges length. An increase of edge forest type will determine a possible increase of edge forest habitat.



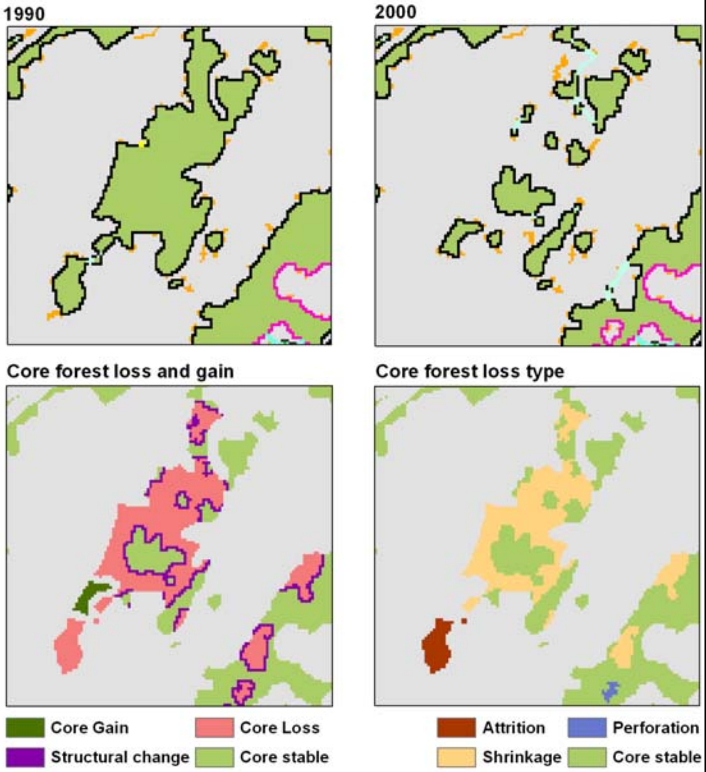


Figure 9: Local forest change:
(Above: forest loss, forest gain and pattern change (stable: same pattern class) and structural change (change in pattern class).
(Right side: core forest loss and gain, stable core pattern and structural change. Pattern processes in core forest loss)

II.3.1.2 Local forest patterns based on landscape context

Measures are based on the landscape forest pattern types maps of year 1990 and 2000 (section II.2.2). To simplify, three main landscape forest pattern types were generated from the initial 15 pattern categories (table 2 and figure 6) and their forest proportion was reported for each year:

- Natural forest landscape pattern (NN and N aggregated): forest with at least 80% natural/semi-natural lands (and less than 10% artificial or agriculture) in its close surroundings; forest habitats and species in this natural landscape forest context are considered suffering no or minor edge effects from agricultural and/or artificial lands, forest-non forest interface zones are natural.
- Mixed forest landscape pattern (Nu, Nau, Na aggregated): forest with 60% to 89% natural/semi-natural lands and more than 10% as artificial and/or agricultural lands in its close surroundings; forest habitats and species in this mixed pattern (forest-non forest mixed interface zones) are potentially suffering edge effects from agricultural and/or artificial lands,
- "Some natural" forest landscape (Mix, Aun, Uan): forest with less than 60% natural lands and the rest as agriculture or/and artificial in its close surroundings; forest habitats and species are in a pre-

dominantly non-forested landscape context, and most probably suffering dominant edge effects from agricultural and/or artificial lands.

Over time, areas of each landscape forest patterns types change due to naturally-occurring phenomena as well as clearly anthropogenic causes. Over a short time period, human-induced changes to landscape patterns (forest harvesting, agriculture and artificial development) are measured rather than the natural heterogeneity of landscapes that is potentially more stable. Measures were the net change in the forest proportion of natural forest landscapes and the proportion of natural forest landscapes in 1990 turning into a more mixed pattern in 2000 (mixed and/or "some natural"). The later characterizes the "*mitage*" of the natural forest landscape, due to the spread of agricultural and/or artificial lands, and mainly concerns edges.

II.3.2 Indicators of core forest fragmentation

For loss and fragmentation, the focal class is the core forest GUIDOS pattern class (forest patch minus a 100 m edge width). An alternative could be the natural forest landscape pattern. Core forest loss and measure for each of the four pattern processes were quantified in ha and proportionally to the core forest cover in 1990 (patch number for the last process) (figures 9 and 10). The forest conversion towards natural, urban or agricultural lands was also documented.

- Attrition (figure 9): Attrition refers to core patches totally removed. This process potentially induced sample effects on species. After identifying each core forest patch in each province in 1990 and in 2000, the ones that were present in 1990 and totally replaced by no forest in 2000 are flagged and the total core forest area lost by attrition is reported.
- Perforation (figure 9): New perforations in core forest refer to new non forest "holes" made in core forest patch, process that potentially introduce area and new edge effects on interior species. A simple comparison of core forest in 1990 and forest morphological spatial patterns in 2000 allows identifying the new perforations that occurred during the period 1990-2000. Core forest area lost by perforation is not the GUIDOS "forest edge of perforation".
- Shrinkage (figure 9): The erosion (shrinkage) of core forest patch at the periphery of a forest patch potentially induced area effect on species. A simple comparison of the forest spatial pattern maps in 1990 and 2000 allows extracting the areas that were core forest in 1990 and no forest in 2000.
- Fragmentation of core forest patches (figure 10): It refers to the breaking apart of core forest patches into smaller core units and/or islets. The measures consist in the proportion of core forest patches that became fragmented in the 1990-2000 period (in figure 11, one from 12 patches in 1990) and in percentage of increase in number of forest patches with respect to the total number of core forest patches (above 25 ha) in 1990 (*i.e.* fragmentation intensity) (in figure 11, 3 new patches in 2000 from 7 patches above 25 ha in 1990). Technically, each core forest patch is identified in 1990 (and in 2000) with a unique ID, its area and the province it belongs to. By combining the 2 "patch" images, the number of patches generated in 2000 from each patch in 1990 is recorded when the number of units (islet or core) is at least two.

A similar assessment could be done with the natural forest landscape pattern class (NN) as a focus for the fragmentation process, instead of the core forest class.

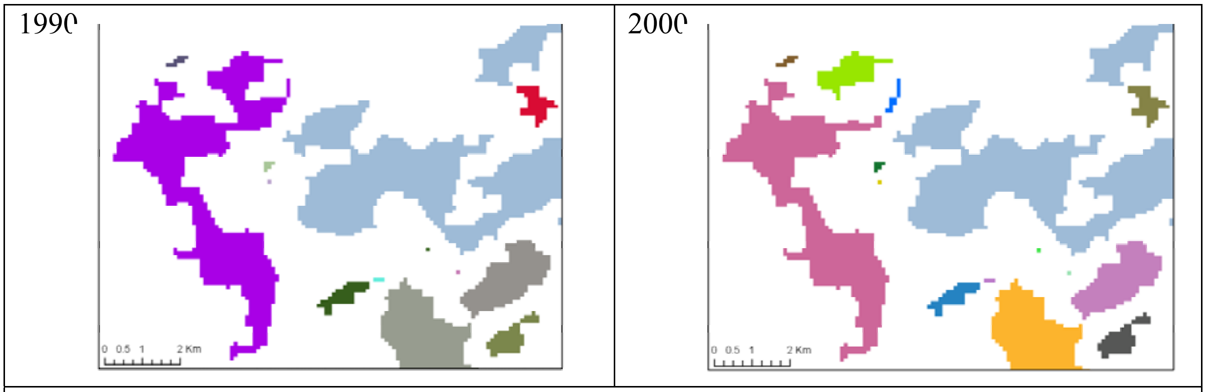


Figure 10: Breaking apart of one core forest patch in 1990 (left, purple patch) in two smaller core patches (right side, rose and green patches) and two islets (brown and blue patches)

II.3.3 Indicators of forest connectivity

Forest connectivity as measured from the PC index (see section II.2.3) obviously depends on the forest amount and its spatial pattern in each province. The Equivalent Connected Area (ECA), which equals the square root of numerator of the PC index (PC), enables to account for the forest amount (Saura, Estreguil et al, in prep.). It is defined as the size of a single patch (maximally connected) that would provide the same probability of connectivity (PC) than the actual forest landscape pattern. The forest connectivity in each province was calculated by ECA for each year for each average dispersal distance (1, 5, 10 and 25 km) and the change of forest connectivity was obtained from the change of ECA (CECA (T_1,T_2):

$$\mathrm{ECA} = \sqrt{\mathrm{PC}} \quad ; \quad \mathrm{CECA}\,(T_1\text{-}T_2) = \frac{\mathrm{CECA}\,(T_2) - \mathrm{CECA}\,(T_1)}{\mathrm{CECA}\,(T_1)}$$

An increase in connectivity means that the habitat is getting more abundant and/or better connected for the species, while a decrease in connectivity means a reduction in habitat availability and/or a reduction in connections at the dispersal distance considered. Species that have short dispersal distance are more sensitive to habitat area (intra-patch connectivity) than to inter-patch connectivity; the contrary is true for species with medium dispersal ability. Species with high dispersal ability are more concerned by the overall habitat availability in the region, regardless of its spatial configuration.

In addition, the physical forest connections between core forest patches can be identified and their forest proportion quantified by the forest proportion of GUIDOS forest connector bridges. Small and/or elongated and thin non core forest fragments are potentially vulnerable to disappear due to their shape and size. They potentially offer stepping stones in the non-forested landscape for the dispersal of forest-dependent species between core forest patches and can be quantified by the forest proportion of GUIDOS islets.

II.3.4 Summary table of indicators and relevance to policy indicators

The summary table of indicators (table 3a and 3b) provides the complete set of measures for the single year reporting and for the change in time reporting. Reporting can be done by any available geographical spatial frame-work (administrative units, environmental strata, etc…). These indicators were implemented for European reporting in the context of the SEBI2010 context (the first indicator based assessment report available at http://www.eea.europa.eu/publications/progress-towards-the-european-2010-biodiversity-target and EEA, 2009 and EEA, 2007) and for regional reporting per environmental strata and fixed area grid in the context of the EBONE research project of the 7th EC Framework Programme (http://www.ebone.wur.nl and Estreguil et al, 2009). The next chapter illustrates the European-wide results obtained for the implementation of some indicators aggregated at province level.

Policy indicators	***Indicators***	***Proxies for biodiversity (or potential link)***
	Forest cover (area and % of land)	Habitat availability
MCPFE 4.7 (morphological forest class definition : edge width 100m)	**Core forest**	**Interior habitat**
	Forest proportion of core forest	Interior habitat
	Area weighted core forest patch size	Area-demanding species
	Number of core forest patches per ranges of patch sizes	Species per ranges of area-requirements
	Forest edges	**Edge habitat**
	Forest proportion of forest edge type (perforated, branch, connectors, without islets)	Edge habitat & edge effects on interior habitat
	Forest proportion of each specific edge class:	
	Forest proportion of MSPA perforated forest	Edge effects on interior habitat
	Forest proportion of MSPA branch forest	Search time for interior species
	Forest proportion of MSPA connector forest: loop	Structural connectivity of interior habitat
	Forest proportion of MSPA connector forest: bridge	
	Forest islets	**Stepping-tone**
	Forest proportion of MSPA islet forest	**Non-core habitat**
MCPFE 4.7 (patterns of forest landscape mosaic: 50ha neighborhood of forest)	**Forest landscapes**	**Type of edge effects**
	Forest proportion of natural forest landscape (forest in a natural context)	No/minor effects from agriculture and artificial
	Forest proportion of mixed forest landscape (forest interfacing with agriculture and /or build-up surfaces)	Effects from agriculture and artificial surfaces
	Forest proportion of “some natural” forest landscape (forest embedded in agricultural and/or build-up lands)	Strong effects from agriculture and artificial
SEBI2010 Indicator 13 (Connectivity of forest land : area, distance)	**Forest connectivity** (equivalent connected area)	**Connectivity for faunistic species with different dispersal abilities**
	for low dispersal ability:1km dispersal distance	
	for medium dispersal ability: 5, 10 km dispersal distances	
	for high dispersal ability: 25 km dispersal distances	
SEBI2010 Indicator 13 (Connecting forest elements for forest interior land)	**Structural connecting elements:**	
	Forest Proportion of MSPA connector forest: bridge	Physical structural connections, that may be more vulnerable
	Forest Proportion of MSPA islet forest (non-core fragments)	Potential stepping-stones if appropriate non-forest matrix

Table 3a: Summary table with policy headline indicators, corresponding measures and possible proxies for biodiversity

Policy indicators	*Indicators*	***Proxies for biodiversity (or potential link)***
MCPFE 4.7 : forest pattern trend (forest pattern defined according to morphology of forest cover applying a 100m edge width)	**Forest cover accounts**:	**Habitat spatial dynamics**
	Proportion and area of forest loss	Loss of habitat
	Proportion and area of forest gain	Gain of habitat
	Forest pattern stability:	**Stable habitat conditions** (not qualitative)
	Forest proportion with stable spatial pattern	Stable habitat conditions
	Stable core forest proportion	Stable interior habitat conditions
	Stable edge forest type proportion	Stable edge habitat conditions
	Accounts per forest pattern types	
	Core forest accounts: Proportion and area of core forest loss Pattern of loss: attrition, shrinkage, perforation, fragmentation Proportion and area of core forest gain Pattern of gain: new patch, enlargement	**Loss of interior habitat** Attrition: loss of stepping stones Shrinkage, perforation: loss of interior habitat Gain of interior habitat New stepping stones
	Edge forest accounts: Net forest edge area change	**Area change of edge habitats**
MCPFE 4.7 : forest landscape pattern trend (patterns defined according to the landscape context of the forest applying a 50ha neighborhood)	Net change of **natural forest landscape**	Area change of **forest in a natural neighborhood** (no/minor edge effects)
	Spread of agricultural or urban lands into previously natural forest landscape	New edge effects from agriculture and build-up into forest with previously a natural/semi-natural neighborhood
SEBI2010 Indicator 13 (Fragmentation in broad sense: loss and associated pattern processes incl. breaking apart)	**Core forest fragmentation** (loss and spatial pattern of loss)	**Loss and fragmentation of interior habitat**
	Core forest loss (total area)	Area effects on species : reduction of habitat availability
	Core forest loss by attrition	Local sample effects on species
	Core forest loss by perforation	Local edge effects in intact interior part
	Core forest loss by shrinkage	Local area effects on species
	Core forest fragmentation intensity	Division of habitat, isolation effects on species
SEBI2010 Indicator 13 (Forest connectivity : area, distance between patches)	**Change in forest connectivity** (equivalent connected area) for	**Isolation effects for faunistic species** with
	1km average dispersal distance	Low dispersal abilities
	5km average dispersal distance	Medium dispersal abilities
	10km average dispersal distance	Medium dispersal abilities
	25km average dispersal distance	High dispersal abilities

Table 3b: Summary table with policy headline indicators, corresponding “change in time” measures and possible proxies for biodiversity

II.4. Hot-spots of change in spatial pattern

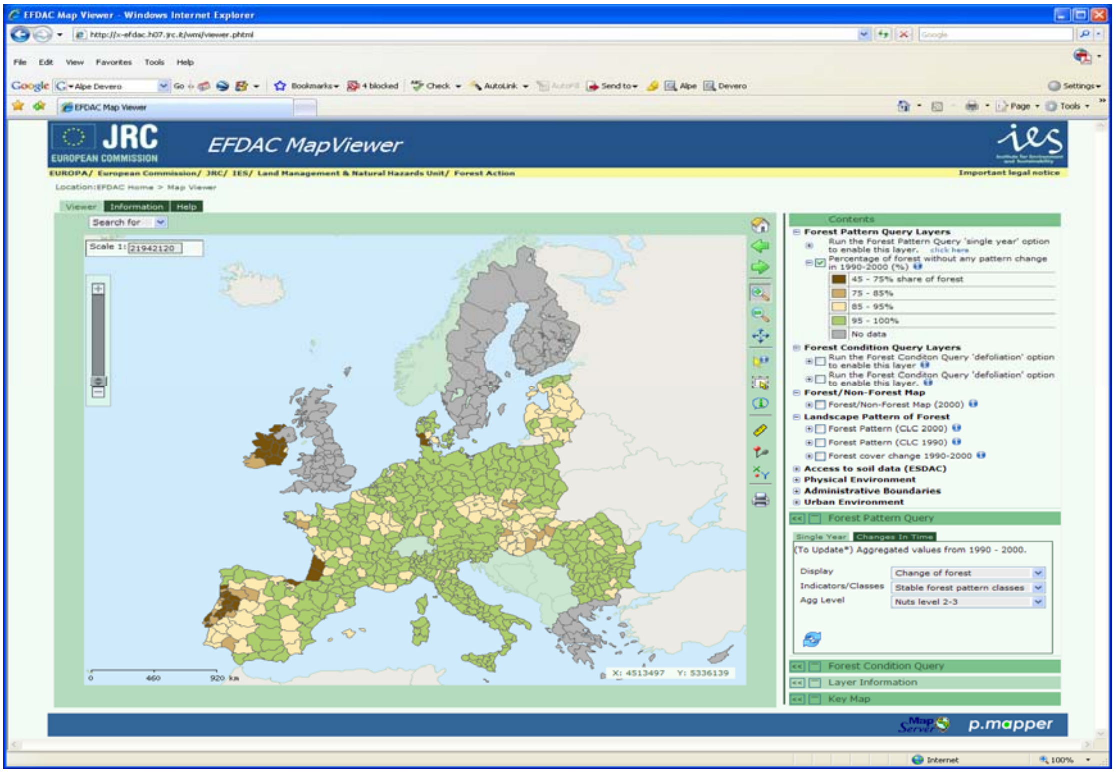
The “hot-spot “terminology is here not applied in the sense of biodiversity hot spots. One reporting unit (one province) was considered a hot spot of change in spatial pattern if acknowledging one spatial pattern process in a relatively more significant manner than in the rest of the reporting units (provinces). Spatial pattern processes of main interest within the current study were forest loss, core forest fragmentation (including core forest loss and the four spatial pattern processes *i.e.* attrition, shrinkage, perforation, breaking-apart), loss of natural forest landscape pattern, increase of forest edges and decrease in forest connectivity.

Since no generic target or critical values of spatial pattern change exist in literature, an histogram for each spatial pattern process was drawn and value of significance was taken from the cumulative frequency of provinces when percentile 0.95 was reached (in few cases, at percentile 0.05). In most cases, the spatial pattern change measure was considered both in area and proportionally to the forest amount in the province since large percentiles losses are in some cases the result of having a small amount of forest and in this case only provinces with low forest cover would be identified.

In concrete terms, hot-spots provinces of forest loss will be provinces where forest loss was high (in area or percentage). Additional criteria will be where forest gain at the province level did not compensate forest loss (therefore with a negative net forest cover change balance). The stability of the forest spatial pattern will be detailed for these hot-spots provinces.
Hot-spots of core forest fragmentation will identify provinces where core forest loss was high (in area or percentage) or a specific pattern process was significant *i.e.* where loss by attrition or perforation or shrinkage (both in area and in percentage) or the fragmentation intensity was relatively much higher than in other provinces (above histogram percentile 0.95). Additional criteria will be the compensation of core forest loss by core forest gain at the province level.
Hot-spots for loss of natural landscape pattern will identify the 5 % of provinces with highest net loss. Low forest coverage and net forest cover change will be documented.
Hot-spots for increase of forest edges will identify the 5 % provinces with highest increase in edge length. Low forest coverage and net forest cover change will be documented.
Finally, hot-spots for connectivity loss will identify the 5 % of provinces with highest decrease in equivalent connected area for each dispersal distance (1km, 5 km, 10km and 25 km). Low forest cover and net forest cover change will be documented to relate trends in connectivity with change in forest area. In the former case, provinces with highest connectivity loss due to low forest cover will be identified. In the latter case, provinces with forest area gain but connectivity loss will be identified.

III. EUROPEAN-wide indicators results

Pixel-level forest spatial pattern maps for year 1990 and year 2000, as well as forest cover change maps can be viewed with the map viewer of the European Forest Data Centre, available on line at http://efdac.jrc.ec.europa.eu/. In addition, all indicators layers listed in table 3 can be queried and viewed using the option “Forest Pattern Query”. This chapter aims demonstrating the implementation of some indicators listed in table 3 and aggregated per province (Nuts2/3). It will also provide a European-wide snap-shot of the forest pattern status and trends in the time period 1990-2000, of core forest fragmentation processes and the trends in forest connectivity. Finally the identification of hot-spots provinces for each main process is also demonstrated.



(To Update*) Aggregated values from 1990 - 2000.

Display: Change of forest
Indicators/Classes: Stable forest pattern classes
Agg Level: Nuts level 2-3

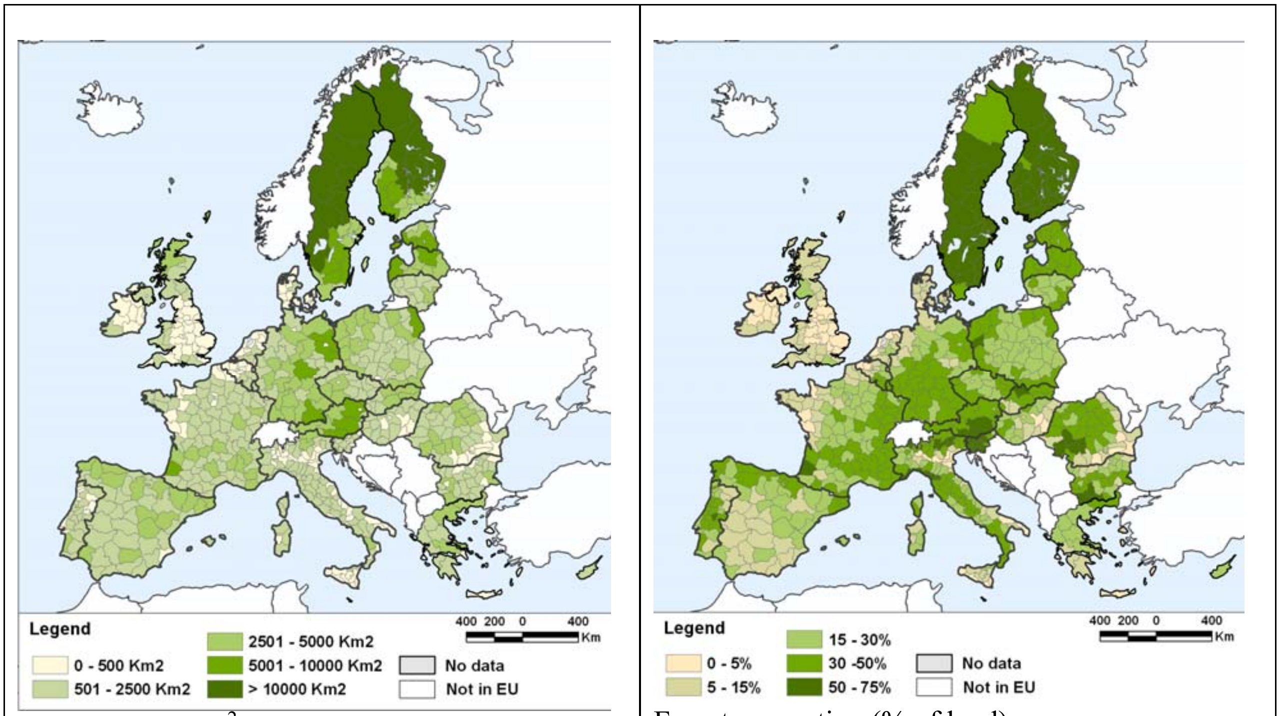
Figure 11: Interface of the EFDAC map viewer with, on the bottom right side, the window on the "Forest Pattern Query"

III.1 Overview of forest cover and forest pattern in Europe

This section aims to describe the forest amount and its spatial configuration for year 2000 per province. Figure 12a provide details on the forest amount both in area and proportion of land, and on the spatial forest configuration from the area-weighted core forest pattern and forest proportion with a natural landscape forest context. Others European-wide snap-shots of indicators related to forest pattern (based on morphology, on landscape context, on connectivity) are shown (figure 12b).

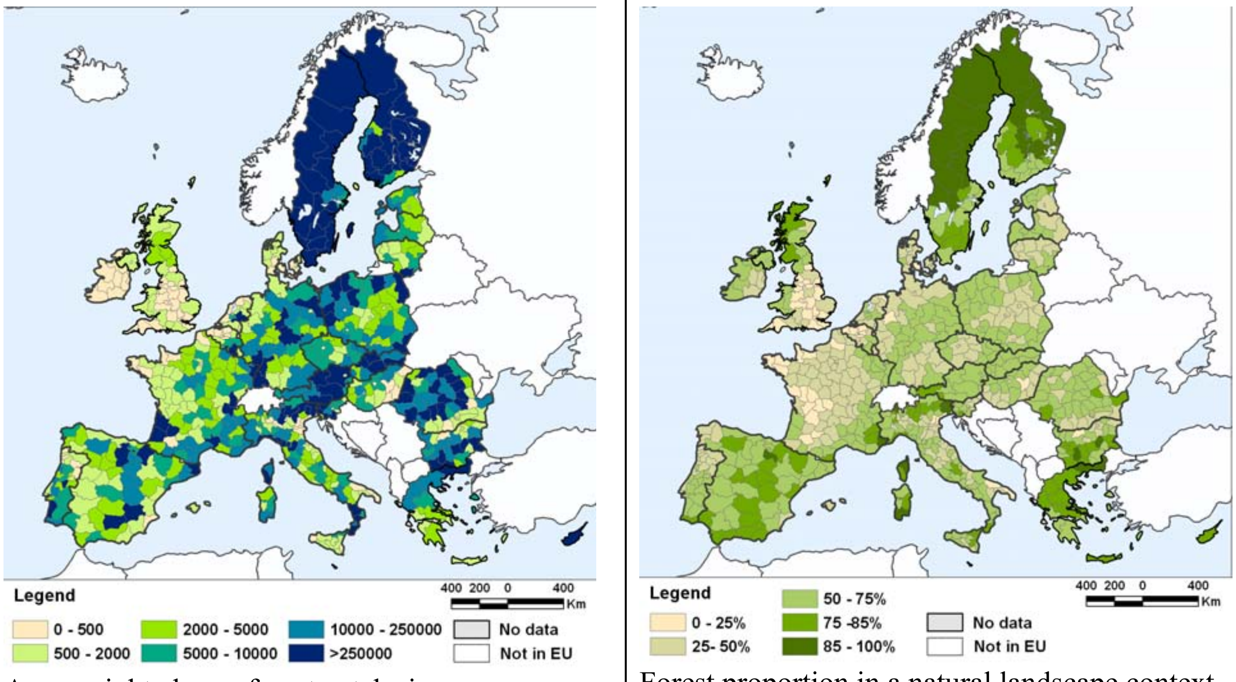
Forest proportion when aggregated per province still gives a good overview of the contrast between on one hand, the relatively high forest cover in provinces from the boreal and nemoral environmental zones (Nordic and Baltic countries) or in mountainous environments, and on the other hand, the rather moderate to low forest cover in the rest of the provinces. Lowlands, in particular in the north-west and central Atlantic zones, the south-western Slovakia, eastern Hungary and eastern Romania had low forest cover. In the Mediterranean part except again provinces with some mountainous areas, the proportion of forest is rather low.

The indicator area weighted core forest patch size clearly put in evidence those provinces where the number of larger core forest patches was the highest (index above 250,000 ha). Within the most forested provinces (above 50%), the median value found for the area weighted index is 88,525 ha (minimum at 1,460 and maximum at 547,833 ha). Within the less forested provinces (below 15% and 15-30% forest cover), the median value found for the area weighted index is respectively 370 and 3330ha. Forested countries in the middle range (30-50%) have a median value of 13,500 ha (minimum at 125 and the maximum at 43,630 ha). The spatial arrangement of the forest also dictates the proportion of core forest – and therefore also other pattern classes - regardless of the total forest amount in the province. The forest proportion of edge forest and of forest connectors (figure 12b) are similar in some Baltic provinces and in some provinces in the centre of France and Italy but in the last cases, the area-weighted core forest patch and the forest proportion in a natural context are both much lower than in the Baltic provinces.



Forest area in km^2

Forest proportion (% of land)



Area weighted core forest patch size

Forest proportion in a natural landscape context

Figure 12a: Forest amount (top) and forest spatial pattern for core and for natural forest landscape pattern (bottom) per province for year 2000.

By comparing figures on forest amount and pattern, it is quite interesting to note that provinces with high forest proportion in a natural context are mainly in boreal and mountainous dominated provinces spread over Europe, regardless of the forest amount. For example in the Iberian peninsula, few provinces with a low to average forest proportion, show a spatial arrangement of core forest units as well as the forest proportion in a natural context (above 75%) potentially favourable to area-demanding forest-dwelling species. This was also confirmed by the indicator “forest connectivity” (figure 12b) in particular for species with high dispersal capability (25 km).

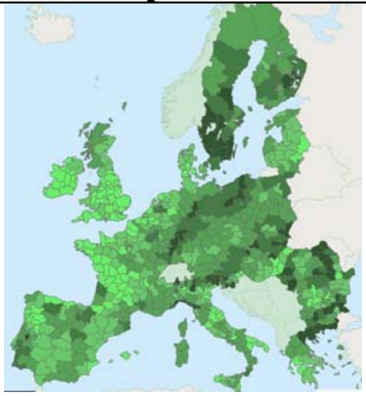
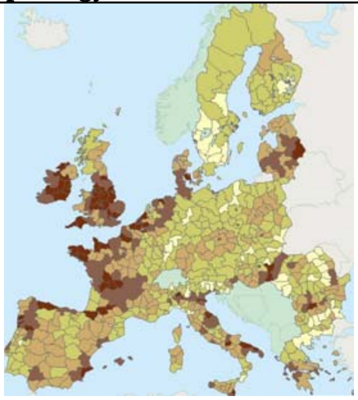
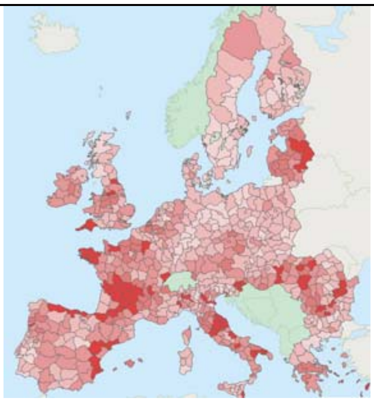
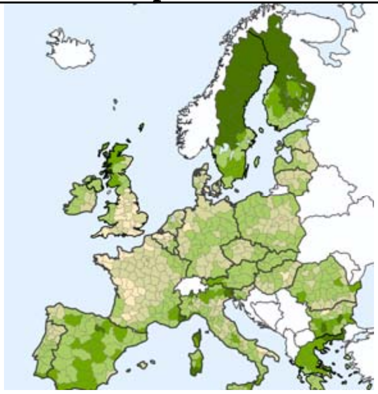
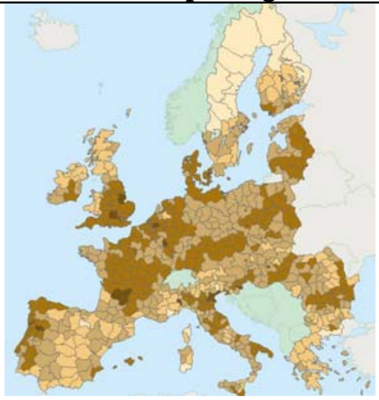
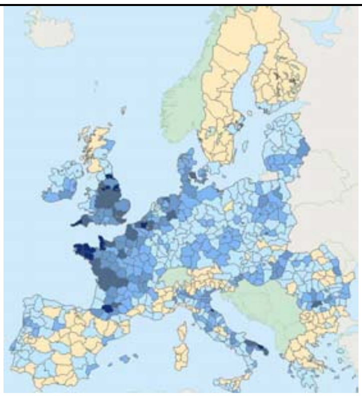
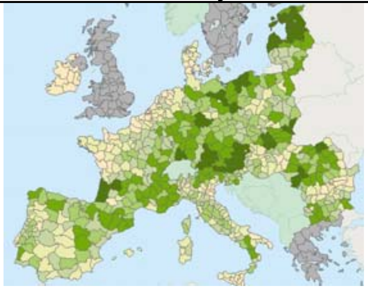
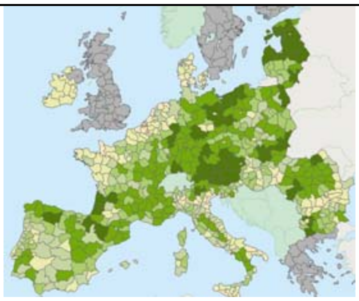
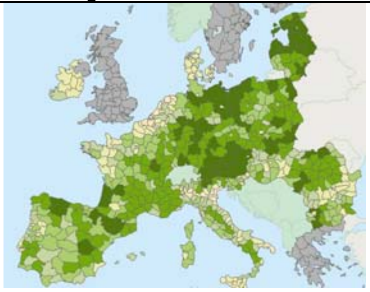
Local forest pattern based on morphology of the forest cover		
 Forest proportion of core	 Forest proportion of edge (non-core minus islet)	 Forest proportion of connectors (bridges between core)
Local forest pattern based on the 50 ha landscape neighborhood of forest		
 Forest proportion in a natural landscape context	 Forest proportion in a mixed landscape context	 Forest proportion in a “some natural” landscape context
Forest connectivity based on forest area and functional distance between patches		
 Forest connectivity for 1 km dispersal ability	 Forest connectivity for 5 km dispersal ability	 Forest connectivity for 25 km dispersal ability

Figure 12b: Snap-shot of pattern related indicator layers (top: based on forest patch morphology, middle: based on landscape neighborhood of forest, down: based on forest connectivity (forest availability and inter-patch distances)

III.2 Forest cover and pattern dynamics

III.2.1 Forest accounts and hot-spot provinces of loss

Figure 13 shows the local spatial distribution of forest gain and loss in two provinces with low to moderate forest cover, one in the Mediterranean zone and one on the Atlantic zone for the 90-2000 time frame. Aggregation of local loss and gain per province as well as the net forest cover change and hot-spot provinces of forest loss (in area and in forest proportion) is shown for Europe in figure 13b.

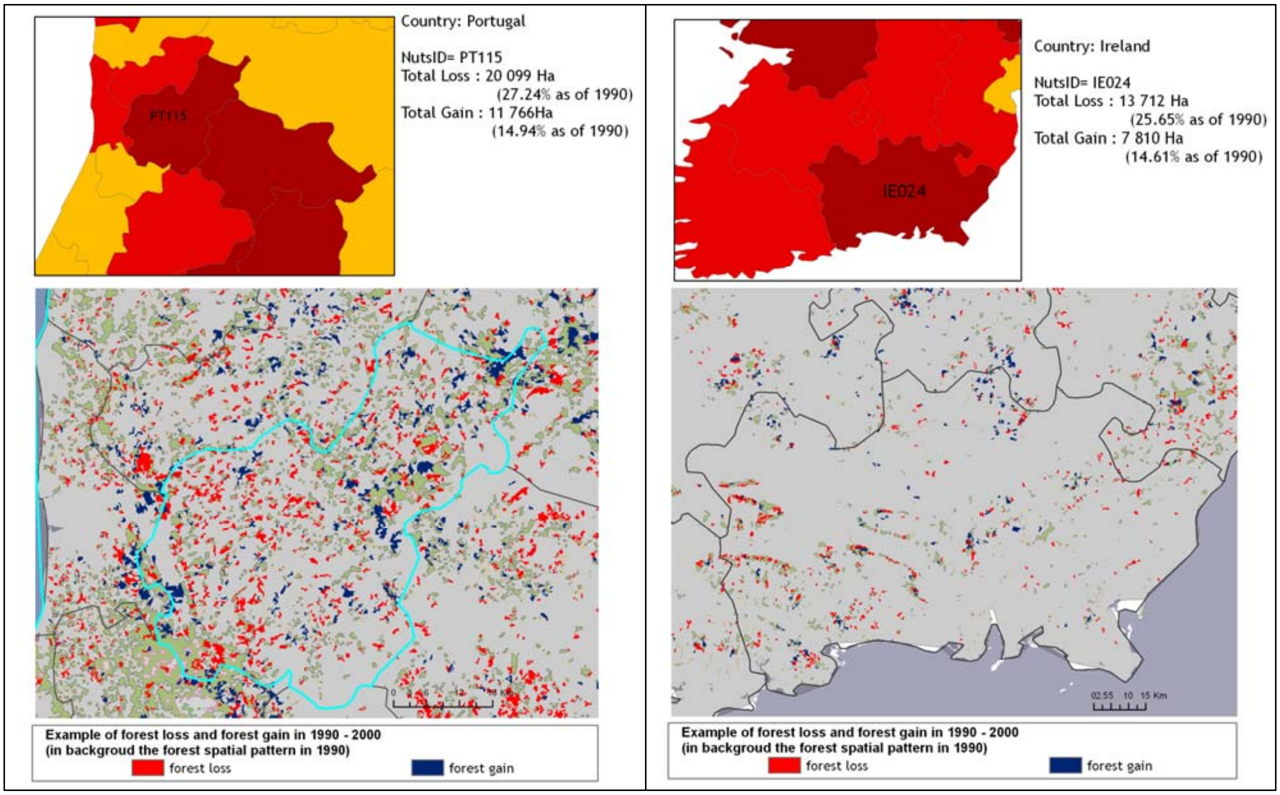


Figure 13a: Local forest gain and loss in two hot-spot provinces for forest loss

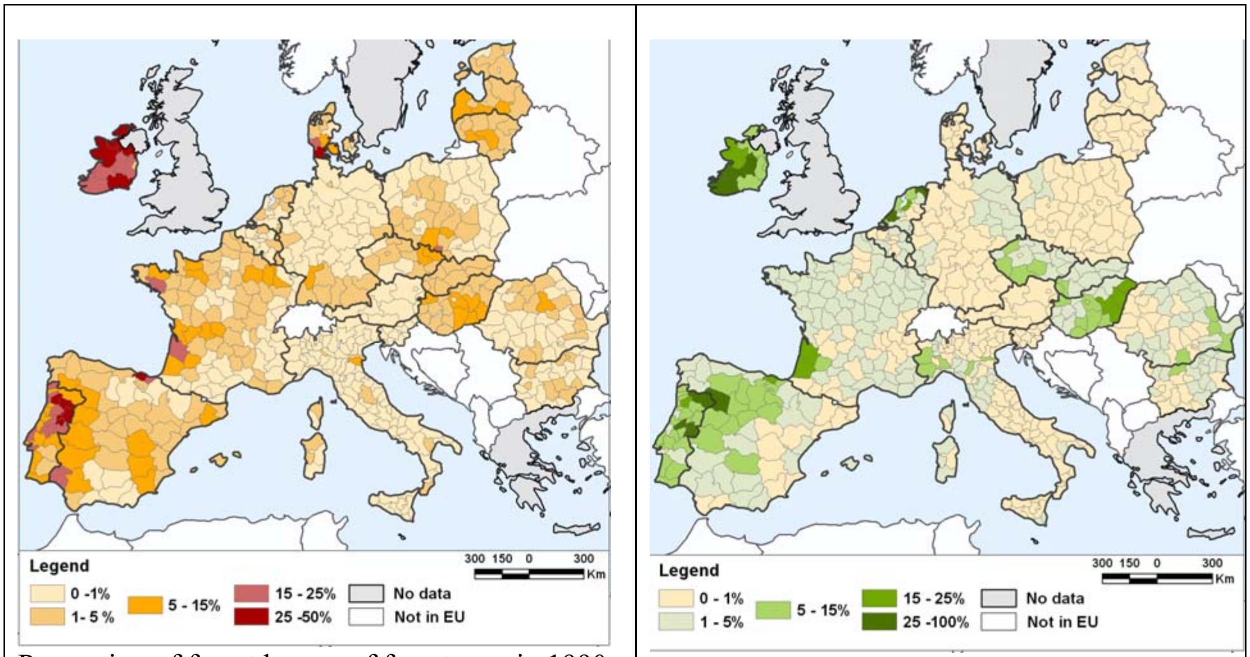
Forest gain is occurring in all provinces and is in average 2.9%. Half of the provinces have less than 1% gain mostly located in central and eastern part of Europe. In 15% of the provinces (often with low forest cover apart few cases), forest gain is above 5%: Portugal, west part of Spain, Ireland, South west France, Netherlands, Hungary and Czech Republic. Similarly the average percentage of forest loss is 2.7%. Forest loss is below 5 % for most provinces. In more than half of the provinces, forest loss represent less than 1% of forest area in 1990.

In the 1990-2000, forest gain compensated forest losses for more than half of the provinces resulting in a rather stable forest cover area (net forest cover change between -1 and 1%). The forest cover balance was negative (below -1%) for over 100 provinces (20 % of the total provinces. Ten countries had few provinces with a negative forest balance below -5%, located in Ireland, Denmark, Portugal, Spain, Italy, France, Germany, Poland, Latvia and Lithuania.

Hot-spot provinces of forest loss were identified by considering highest losses in percentage and in area, then the compensation of losses by gains was an additional criteria for selecting hot-spots (figure 13b and table 4). The 29 provinces (5% of the total provinces) where the loss was the highest in percentage of forest cover (above 13% loss) were located in 5 countries:

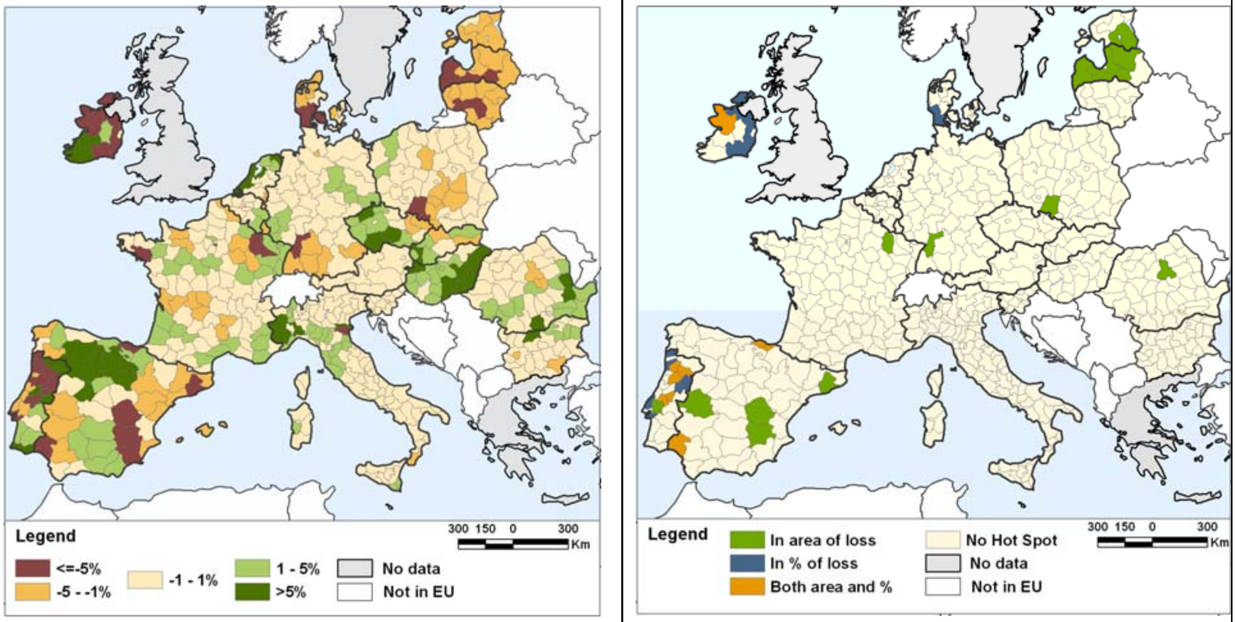
- losses in 16 North-Portuguese provinces were between 13% and 40% of the forest cover

- losses in 7 Irish provinces were between 16% to 28%
- losses in 3 Spanish provinces were between 15% to 23%
- losses in 2 Danish provinces were between 25% to 43%
- losses in one French province represented 14% of the forest cover



Proportion of forest loss as of forest area in 1990

Proportion of forest gain as of forest area in 1990



Net forest cover change 1990-2000

Hot-spot provinces of forest loss

Figure 13b: forest area dynamics in 90-2000: gain, loss, and net cover area change.

Among those 29 provinces, only 7 provinces had a positive net forest cover change (gains compensated losses): 3 in Ireland, 1 in France and 3 in Portugal. In 26 provinces, forest loss occurs pre-dominantly (precisely at 85%) towards natural/semi-natural land cover types.

The 29 provinces (5% of the total provinces) where the loss in area was the highest (above 14,319 ha) were located in 9 countries: Estonia and Latvia (respectively 1 and 4 provinces), France (3 provinces), Romania, Poland and Germany (1 province each), Ireland (1 province), Portugal and Spain (8 and 9 provinces). This criterion (loss in area) enables to consider provinces with moderate to high forest cover. Among the 29 provinces, 6 provinces had a positive net forest cover change balance (2 in Spain, 2 in the French Landes, 2 in Portugal).

A total of 36 hot-spot provinces of high forest losses (in area and/or in forest percentage) not compensated by gains within the province are listed in table 4 and details are provided in annex 1. In addition to forest loss and gain (ha and %) and net area change, forest with a stable spatial pattern (in ha and in %) was also detailed. The local pattern of forest losses and gains in two hot-spots provinces of forest loss, IE024 in south-eastern Ireland and PT115 in northern Portugal, with forest losses not compensated by forest gains were provided in figure 13a. Among other ecological effects, area effects on forest dependent species are expected due to the probable reduction of habitat amount and quality (the new habitat gained may not be in the same conditions than the habitat lost) in those provinces. A similar exercise to derive hot-spot provinces of forest gain could easily be implemented.

Forest loss in area only		Forest loss in proportion only		Forest loss both in area and proportion	
NUTSCode	NUTS name	NUTS Code	NUTS name	NUTS Code	NUTS name
EE008	Louna-eesti	DK009	Sonderjyllands amt	IE013	West (irl)
FR412	Meuse	DK00A	Ribe amt	PT115	Tamega
DE12	Karlsruhe	IE011	Border	PT117	Douro
LV003	Kurzeme	IE022	Mid-east	PT165	Dao-lafoes
LV008	Vidzeme	IE024	South-east (irl)	PT166	Pinhal interior sul
LV009	Zemgale	PT111	Minho-lima	PT16C	Medio tejo
LV007	Pieriga	PT113	Ave	ES212	Guipuzcoa
PL520	Opolski	PT114	Grande porto	ES213	Vizcaya
PT185	Leziria do tejo	PT167	Serra da estrela	ES615	Huelva
RO074	Harghita	PT168	Beira interior norte		
ES421	Albacete	PT16A	Cova da beira		
ES423	Cuenca	PT16B	Oeste		
ES432	Caceres	PT172	Peninsula de setubal		
ES511	Barcelona				

Table 4: hot-spot provinces of forest loss (colors as in figure 13b) not compensated by gain.

III.2.2 Changes in forest pattern based on morphology

III.2.2.1 Local forest spatial pattern changes

The comparison of local forest spatial patterns is feasible at pixel level by displaying the raster forest pattern maps for year 1990 and year 2000 as shown in figure 14. Core forest loss and increase of edge forest are clearly visible and main local spatial pattern processes are patch shrinkage, new perforations in the core forest patch and the breaking-apart of the core forest patch into smaller core patches.

The forest proportion of each GUIDOS forest spatial pattern class was calculated for each year (see in the EFDAC map viewer/single year); the core forest pattern class is clearly dominant in the forest cover and is followed by the edge forest class. The short time period (1990-2000), the data resolution and mapping techniques used in CLC (100m raster but 25 ha MMU) does not allow to address changes for each spatial pattern class derived from GUIDOS. Classes like branch, islet, and connectors have too small forest proportion to have a real meaning when aggregated at province level. The aggregation of pixel-level GUIDOS pattern classes per province was therefore done for the most represented morphological categories *i.e.* core forest and the edge forest type (by merging branch, edge, edge of perforation, bridge /loop connectors).

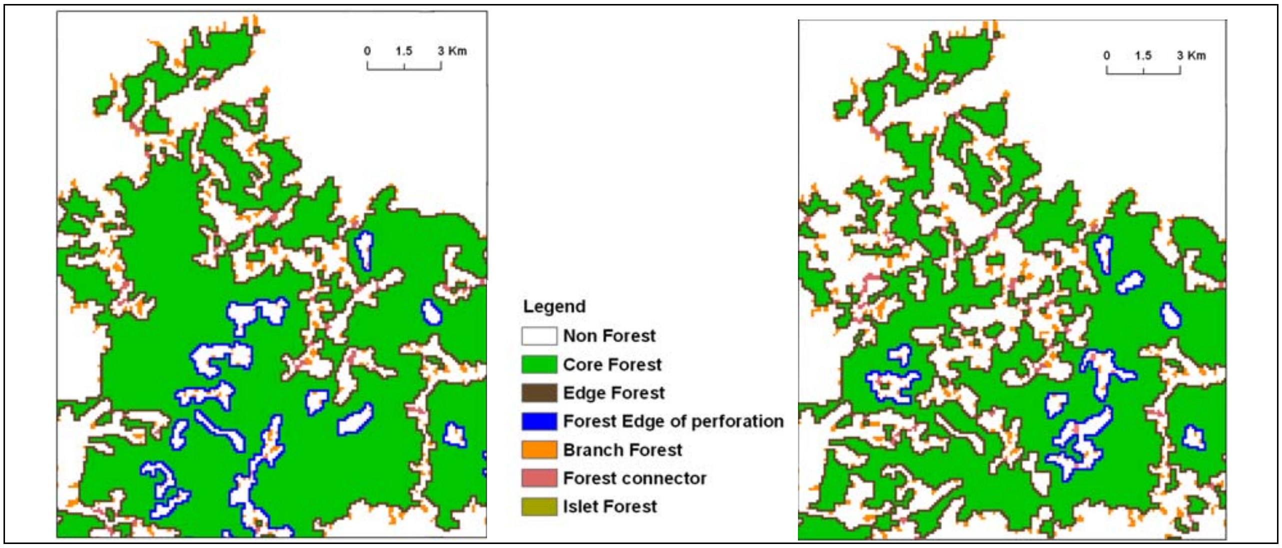


Figure 14: Forest spatial pattern from GUIDOS in 1990 (left) and in 2000 (right)

III.2.2.2 Stability of forest spatial pattern

Figure 15 a (and previously figure 9) illustrates the cumulative effects of forest gains and losses on the morphology of the forest cover. Partly, the forest cover kept a stable morphology (i.e. the forest pattern class (core, edge, perforation, islet, branch, loop, and connector) stayed the same, partly it changed morphology in the sense of change in forest pattern class (for example core forest turned into edge) and partly it was removed (forest to non forest). Figure 15a provides also the area weighted average core forest patch size and the distribution of core forest patches (in patches number) per ranges of patch size (below 100 ha, 100-1000ha, >1000 ha) per provinces for each year. This Danish province is a hot-spot province for forest loss (table 4), the forest area loss (-43%, equivalent to 10,311 ha and 0.2% gain) affected the spatial configuration of the forest as follows: core forest proportion decreased while edge forest proportion increased; only half of the forest cover in 1990 kept a stable pattern; the area weighted average core forest patch size decreased meaning that in average, the size and number of core forest patches was reduced, the number of forest patches below 100 ha decreased. We further observed that in few Irish provinces, large core units increased and units of smaller size have all decreased in number. In some forested Baltic provinces like in Latvia, large core units decreased and units of smaller sizes were gained (not shown).

When aggregated at province level (figure 15b), the forest proportion with a stable forest spatial pattern varies between 45% and 100%. Most provinces (85%) have 90% of their forest cover with a stable spatial pattern. In the Baltic countries, the western part of Spain, the Czech Republic, Slovakia and Hungary, stable forest pattern proportion is below but still above 75%. 28 provinces have the lowest stable forest pattern proportion (below 75%) and are located in Portugal, Spain, France (Landes and Gironde), Ireland and Denmark. Provinces with low forest cover tend to be within this last category, that’s why for hot-spots provinces of forest loss, stable forest pattern was reported in area and in proportion (table 4). Similar analysis was done for the stable core forest proportion (core remains core) and stable edge forest types (edge types stay edge types) (figure15b).

Denmark, Nuts code: DK009

Forest cover 1990 (2000): 6% (3.5%) *i.e.* -43% (- 10311 ha)
- Core forest 1990 (2000): 50% of forest (45%)
- Edge forest types 1990 (2000): 48% (54%)
- MSPA edge forest 1990 (2000): 37% (41%)
- Islet forest 1990 (2000): 0.5% (0.2%)

Stable forest pattern: 52% (stable core 51%, stable edge 55%)
Area weighted core forest patch size 1990 (2000): 308 ha (234 ha)
Nb patches below 100 ha 1990 (2000): 230 (189)

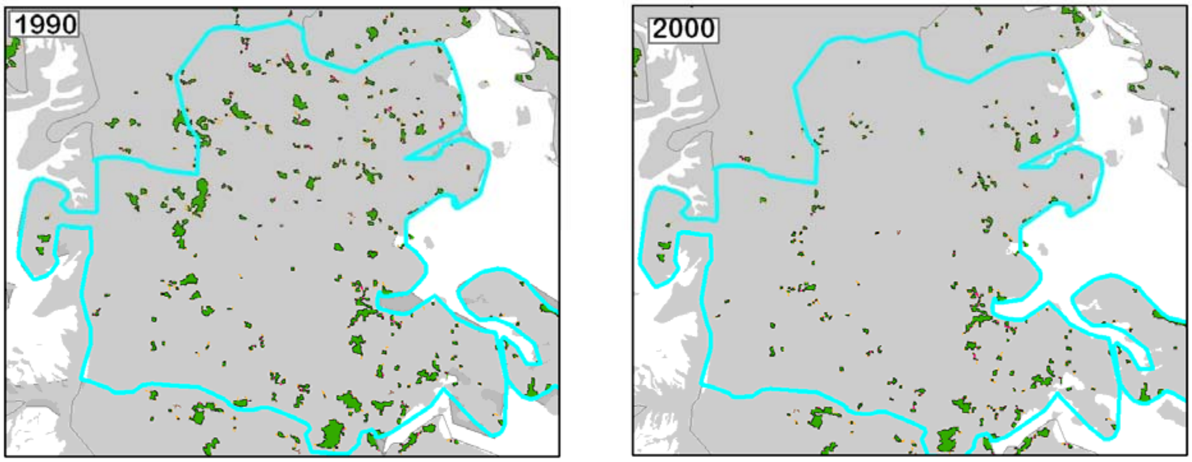


Figure 15a: Local forest pattern change aggregated for a hot-spot Danish province.

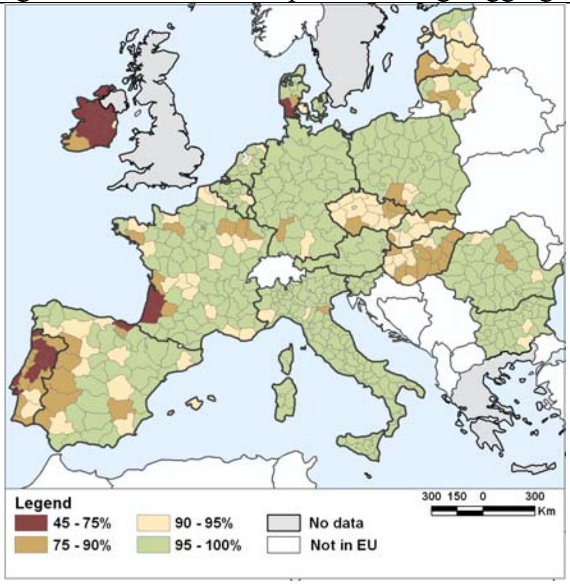
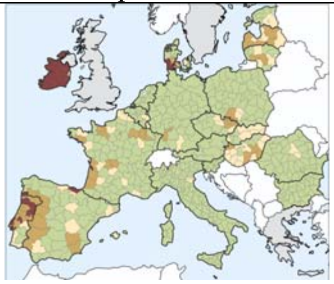
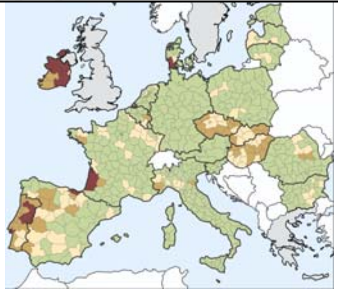


Figure 15b: Forest proportion with stable spatial patterns (right side: stable core and stable edge)



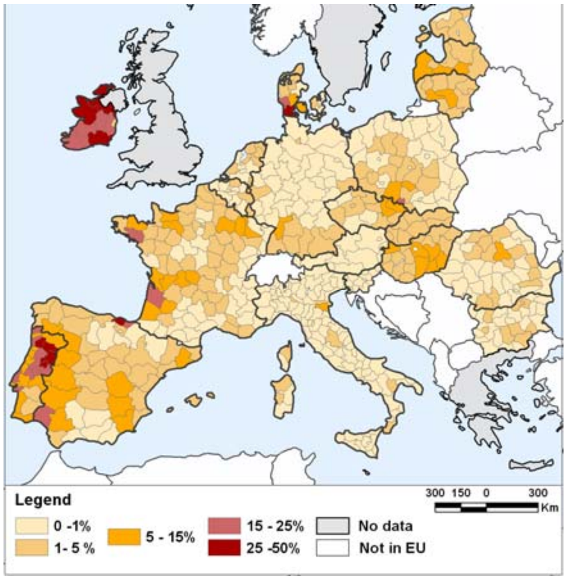
Core forest proportion with stable core



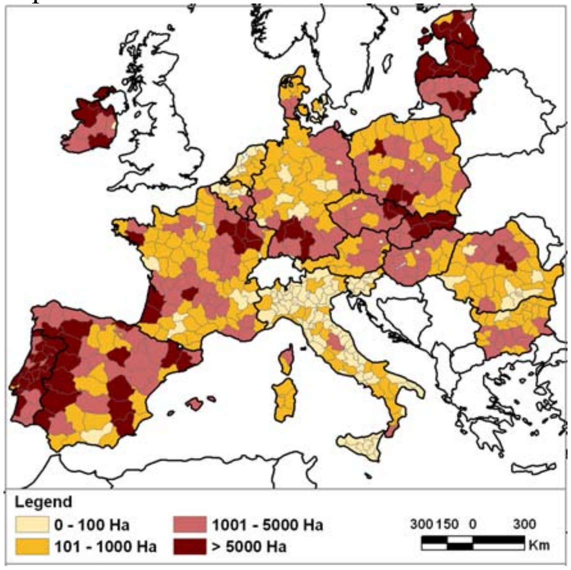
Edge forest proportion with stable edge

III.2.2.3 Core forest accounts and hot-spot provinces of core forest loss

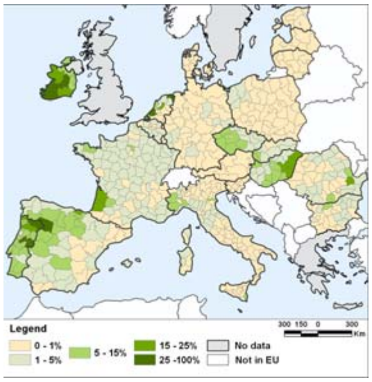
Core forest loss is the total core area in 1990 that became no forest in 2000. To focus on the interior areas of forest patches, core forest areas that changed pattern class in 2000 (core to edge forest for example) are not considered. Similarly, core forest gain refers to new core forest areas entering the forest base. Core forest loss, core forest gain and net core forest change are reported per province both in area (ha) and in percentage of core forest area in 1990 (figure 16). Core forest loss towards natural non forested lands is discriminated from land use conversions to urban or agricultural land cover types.



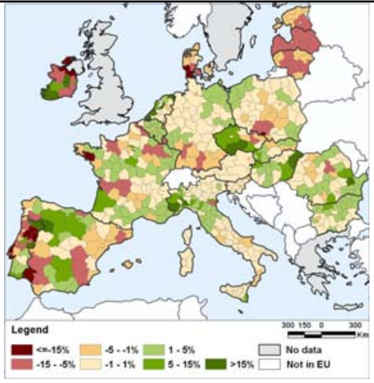
Proportion of core forest loss as of core in 1990



Core forest loss area in 1990-2000



Proportion of core forest gain as of core in 1990



Net Core forest cover change

Hot-spot provinces of core forest loss

Figure 16: Core forest dynamics (area estimates only shown for core forest loss)

Among the available 564 provinces, 101 had less than 25 ha core forest loss during the period 1990-2000: very small provinces (less than 10,000 Ha) delineating big urban centers (Paris, Berlin, Wien,…) or specific cases like Spanish Melilla and Ceuta, provinces in Italy (mainly in the North, in Sicily and some in the center and southern parts). In the remaining 463 provinces, core forest loss varies between 27 ha and a maximum of 44,395 ha in south-west France (Gironde). The distribution is skewed and the

median core forest loss was 888 ha. Only 5 % of the provinces had a loss above 10,125 ha and were located in south-west and north-east France, center Portugal, Spain (7 provinces), Latvia and Estonia. There is no correlation (0.36; chart not shown) between the initial total core forest area and the core forest area lost in 1990-2000. Percentages of core forest loss vary from 0 to 41% with a median value of 0.83%. Most provinces (95%) had less than 16.5% loss. Higher percentages were concentrated in few provinces mainly located in Western Europe and mainly with low forest cover: Ireland (mean=21%), Portugal (mean=16 %), Denmark (mean=23%), locally in Spain and France.
40 % of the provinces had a rather stable core forest total area (between -1% and 1%). The balance of gains and losses was negative for 20% of the provinces among which 5 % had a net forest loss below -10 % reaching a maximum loss of 49%. 5 % of provinces had a net forest gain above 12% reaching a maximum of 80%.

44 hot spot of core forest loss were selected (figure 16 and table 5, for details see annex2) from provinces with at least 25 ha core forest loss. They had significant core forest loss in area (above 10,125 ha) or in percentage (above16.5%):

- 25 hot-spots provinces have a low core forest cover in 1990 (below 100,000 ha) and high core forest loss percentage (average 24%), the loss of core forest may be more critical in provinces where the core forest cover is already very much fragmented like in Ireland or Denmark
- 12 hot-spots provinces have a moderate core forest cover in 1990 (100,000 – 250,000ha), with core forest area loss of 15,650 ha in average and 9.7% average percentage.
- 7 hot-spots provinces have a high core forest cover in 1990 (>250,000 ha) and there the core forest loss is high in surface (26,092 ha average)

In most hot-spots provinces (35), less than 1% of the core forest was converted to agricultural or urban lands. Maximum percentage (7%) was found in 2 small provinces by the Portuguese coast (Peninsula di Setubal and Gran Porto). Areas lost are small reaching a maximum of 3,393 ha (Caceres in Spain): the median area is 80 ha and 95% of provinces are below 1880 ha.
37 hot-spots provinces had a negative core forest change balance (3 color shades in table 5), meaning that core forest gain did not compensate core forest loss.

Core forest loss in area (not compensated by gain)		Core forest loss in proportion (not compensated by gain)		Core forest loss both in area and proportion (not compensated by gain)		Core forest loss (compensated by gain)	
NUTS	NUTS name	NUTS	NUTS name	NUTS	NUTS name	NUTS	NUTS name
DE12	Karlsruhe	DK00A	Ribe amt	ES213	Vizcaya	ES419	Zamora
ES421	Albacete	DK009	Sonderjyllands	PT165	Dao-lafoes	FR613	Landes
ES423	Cuenca	PT111	Minho-lima	PT166	Pinhal int.s	PT164	Pinhal int.n
ES432	Caceres	PT113	Ave	PT16C	Medio tejo	IE012	Midland
ES615	Huelva	PT115	Tamega			IE023	Mid-west
ES511	Barcelona	PT114	Grande porto			IE025	South-west (irl)
EE008	Louna-eesti	PT117	Douro			FR612	Gironde
FR412	Meuse	FR524	Morbihan				
PT185	Leziria do t.	FR411	Meurthe-et-mos				
LV003	Kurzeme	PT168	Beira interior n				
LV008	Vidzeme	PT167	Serra da estrela				
LV007	Pieriga	PT16A	Cova da beira				
LV009	Zemgale	PT16B	Oeste				
PL520	Opolski	PT172	Penins. de set				
RO074	Harghita	IE011	Border				
		IE013	West				
		IE022	Mid-east				
		IE024	South-east (irl)				

Table 5: hot-spot provinces of core forest loss (in area shaded in green, both in area and proportion shaded in orange, in proportion only shaded in grey, when not compensated).

Fragmentation related pattern processes associated to core forest loss are analyzed in detail in the next section. Core forest gain concerns more afforestation and reforestation which are extremely important for biodiversity. Core forest gain can occur in two main spatial pattern processes which are the creation of new core forest units and/or the enlargement of existing units (figure 17a). Gain through each pattern process was quantified both in area (not shown) and in percentile (figure17bc). Qualitative information on new habitat conditions is not provided by the CLC data

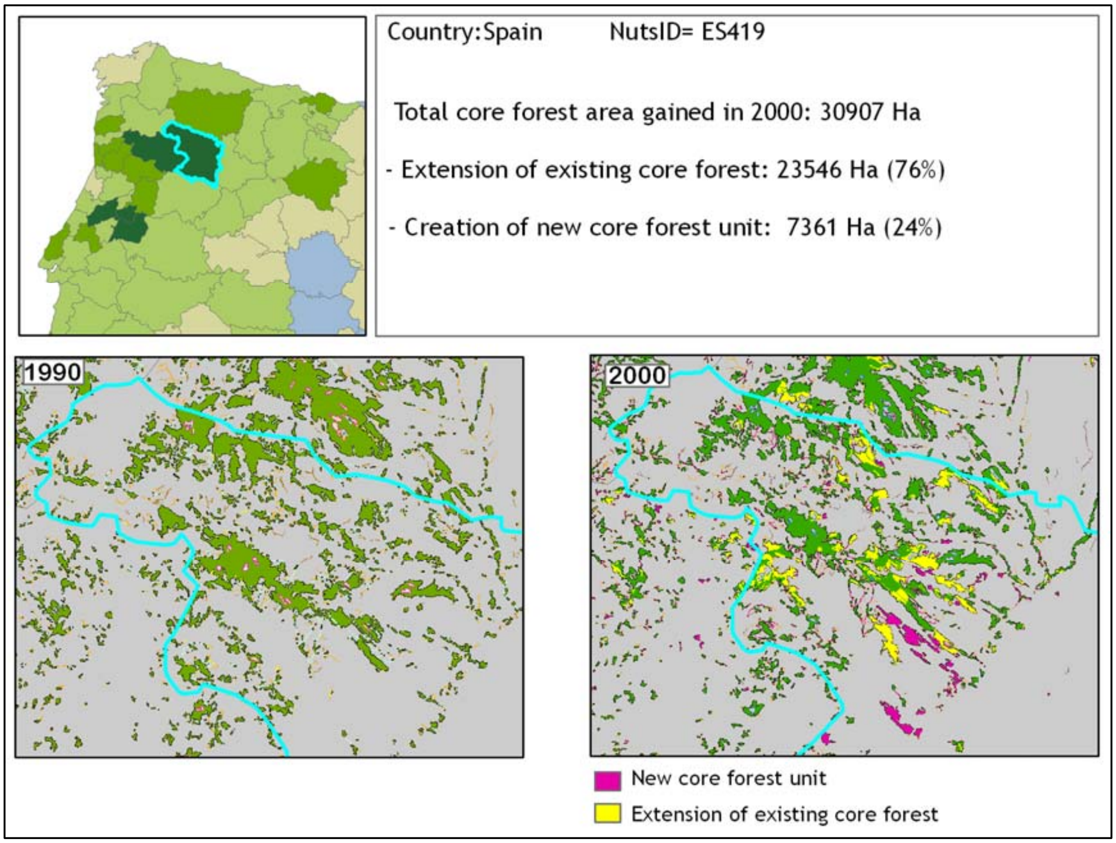


Figure 17a: Local pattern processes in forest gain

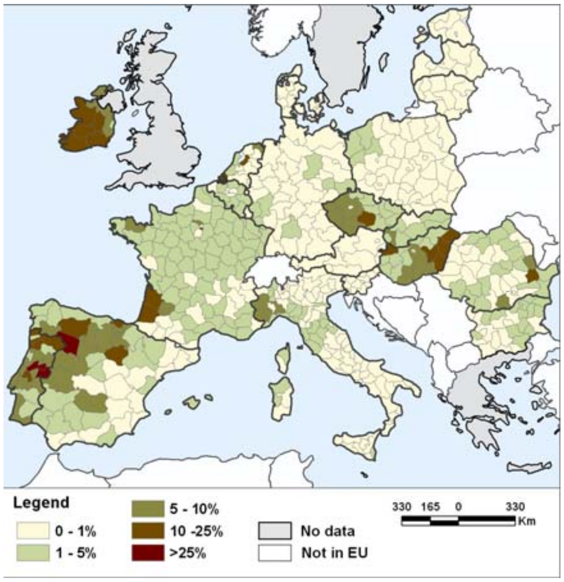


Figure 17b : Enlargement of existing core patches (% of gain with respect to core forest area in 1990

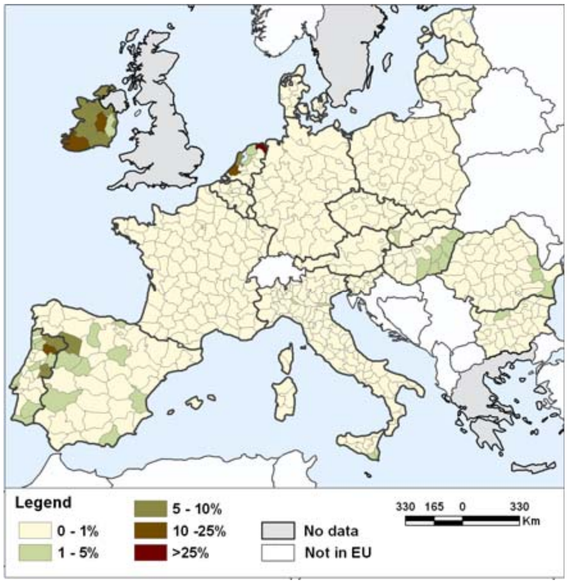


Figure 17c: Creation of new core patches (% of gain with respect of core forest area in 1990

III.2.2.4 Forest edge dynamics

The edge forest type includes the perforation, loop and bridge connectors, edge and branch GUIDOS pattern classes. For example in western Latvia (figure 18a), local spatial patterns of forest edges in 2000 compared to 1990 show a clear increase of forest edges. In this province, the forest/non-forest interface was pre-dominantly with natural/semi-natural lands (over 60%), then with agricultural lands.

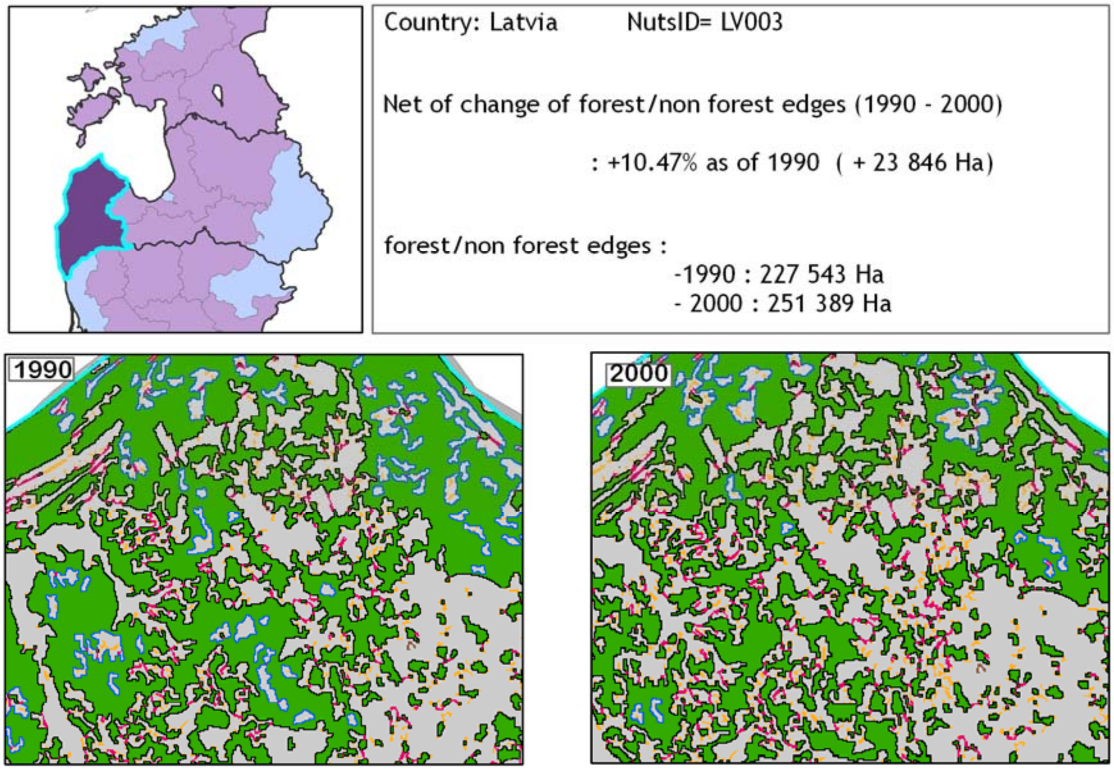


Figure 18a: increase of forest edges in Western Latvia as shown by GUIDOS pattern maps in 1990 and 2000 (each edge forest pattern class increased: edge, connector, branch, perforation).

When aggregated at province level (figure 18b), the net forest edge change ranges from a minimum edge decrease of -36% to a maximum edge increase of 91.5% (specific case of a very low forest cover). Table 6 provides the list of provinces (5% of the total population) with the highest increase in edge length (above 5.3%) and documents the net forest cover change and the forest proportion in the province. An increase in edge length can be due to forest gain and/or to fragmentation processes. In table 6 (details in annex3) apart few cases with a net forest loss (two provinces in Latvia, one in Germany, one in Portugal and one in Poland), the increase of forest edges was observed in provinces with a net forest gain. This means that the way that the forest losses and gains cumulated spatially and the net forest gain lead to an increase of edges. High percentages due to low forest cover are discriminated.

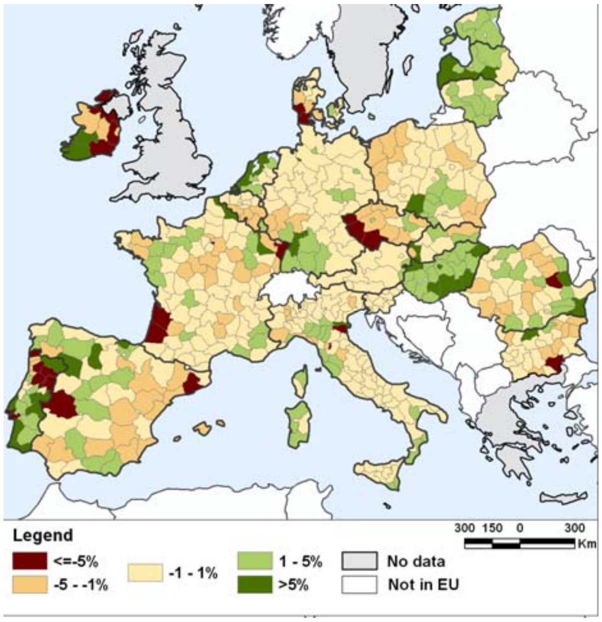


Figure 18b: Net change of forest edges length

Forest cover below 10%		Forest cover 10-50% and net forest gain		Forest cover 10-50% and net forest loss	
NUTS	NUTS name	NUTS	NUTS name	NUTS	NUTS name
NL11	Groningen	PT169	Beira interior sul	DE12	Karlsruhe
NL33	Zuid-holland	ES419	Zamora	PT16B	Oeste
IE023	Mid-west	HU323	Szabolcs-s.-b	LV003	Kurzeme
HU332	Bekes	NL23	Flevoland	PL520	Opolski
IE025	South-west (irl)	HU331	Bacs-kiskun	LV009	Zemgale
HU333	Csongrad	HU221	Gyor-moson-s.		
ITD37	Rovigo	ES414	Palencia		
NL12	Friesland	HU233	Tolna		
NL34	Zeeland	PT150	Algarve		
DE50	Bremen	PT118	Alto tras-os-montes		
NL32	Noord-holland				
BG121	Pleven				
RO023	Constanta				
RO024	Galati				

Table 6: provinces with highest increase in edge length

III.2.3 Change in forest pattern based on landscape context

III.2.3.1 Local forest landscape patterns

Local forest landscape patterns are defined according to the composition in terms of natural/semi-natural lands, artificial infrastructures and agricultural surfaces in the 50 ha surroundings of each forest pixel as described in section II.3.1.2. Three main forest landscape pattern categories are:

- "some natural forest landscape pattern" (natural lands less than 60%) in a pre-dominant agricultural context (*Aun*, *An*), in a pre-dominant artificial context (*Uan*, *Un*), or mixed (*Mix*),
- "mixed forest natural landscape" (*Nua, Na, Nu*) for natural lands between 60% and 90%, and rest depending on predominance of agricultural and artificial lands) and

- “natural forest landscape pattern” (*NN* and *N* for above 80% of natural lands and less than 10% of agricultural or artificial lands).

Figure 19a illustrates the different local types of forest/non forest interfaces: natural/semi-natural interfaces (forest edge of perforations potentially totally permeable classified as *NN* or slightly less natural as *N*), and mixed interfaces with agricultural lands (*Na*), with artificial surfaces (*Nu*) or with a mosaic of artificial and agricultural lands (*Nua*). The method also enables to identify small and/or elongated forest lands embedded in a mosaic of agriculture and/or artificial lands (*Mix, Aun, An, Uan, Un*).

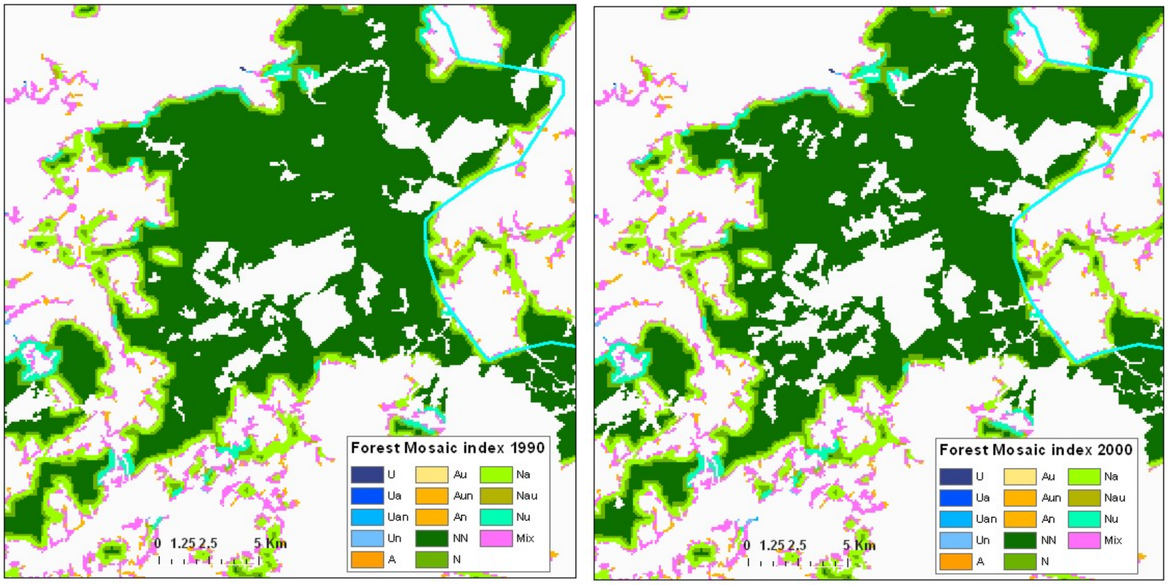


Figure 19a: local changes of forest landscape patterns between 1990 (left) and 2000 (right).

When forest patches are in a 100% natural/semi-natural lands (*NN*) *i.e.* interfering with a rather permeable non-forested matrix, the patch classified as natural forest landscape corresponds to the core forest patch plus its forest edge in the mathematical morphological analysis. When the non-forested matrix is less permeable (agriculture or artificial in the interface zone), the patch includes a natural forest landscape zone and forest edges which types are also characterized which is not the case in the morphological analysis. For example, in a Danish province with a low and fragmented forest coverage, core forest (12,136 ha) represented 50% of forest cover but forest with a 100% natural neighborhood (*NN*) represented solely 15 % of the forest cover (3,640 ha).

Over time, changes in the natural forest landscape are due to forest loss and/or gain and/or changes of forest/non-forest interfaces after land cover changes in the non-forested matrix. Figure 19a illustrates forest losses due to new perforations in the natural forest landscape pattern (*NN*): no edge zones were created meaning a permeable matrix in the perforations after probably forest harvesting and not land use conversions towards infrastructures or agriculture. Figure 19b illustrates for one hot-spot province the local forest landscape patterns in 1990 and 2000 resulting in 18 % reduction of the natural forest landscapes in the decade. Over the same decade, figures 19c and 19d respectively provide per province the net cover change of the natural forest landscape pattern (NN and N) and the proportion of natural forest landscape that was converted into mixed and/or “some natural” forest landscape:

- In average, rates of changes for the natural forest landscape are very low (below 1%). In most provinces, changes range from a 7% decrease to a 8% increase. Provinces with the highest net decrease (below – 7%) are listed in table 7 and annex4.
- The average proportion of natural forest landscape converted to other mixed forest landscapes is extremely low (0.3%) since it concerns mainly edges of patches. 95 % of provinces had the

conversion rate below 1.3 %. Maximum value was 10% in a Mediterranean urban zone. Provinces with the highest conversion rates (above 1.3%) are listed in annex5.

Three examples were selected from table 7 (annexes 4 and 5). In the Danish province (DK009), core forest was reduced by 43% (5,800 ha) while the natural forest landscape only decreased by 38% (-1,300 ha). Forest removal mainly explains both figure and the changes of forest/non-forest interfaces were mainly in a natural/semi-natural context (forest management). There was no significant spread of agricultural and/or urban lands into previously natural forest landscape (not in hot-spot list). In the Portuguese Douro province (PT117, figure 19b), the quantitative reduction of core forest and of the natural forest landscape was similar (respectively 19 % and 18 %); forest removal mainly explains the figure and the change in forest interface type i.e. the spread of agricultural and/or urban lands into previously natural forest landscape was 1.5 %. In another Portuguese province (PT113), the core forest was reduced by 6% while the natural forest landscape pattern by 14%. There the change of forest interface *i.e.* the spread of agricultural and/or urban lands into previously natural forest landscape was more significant (5%).

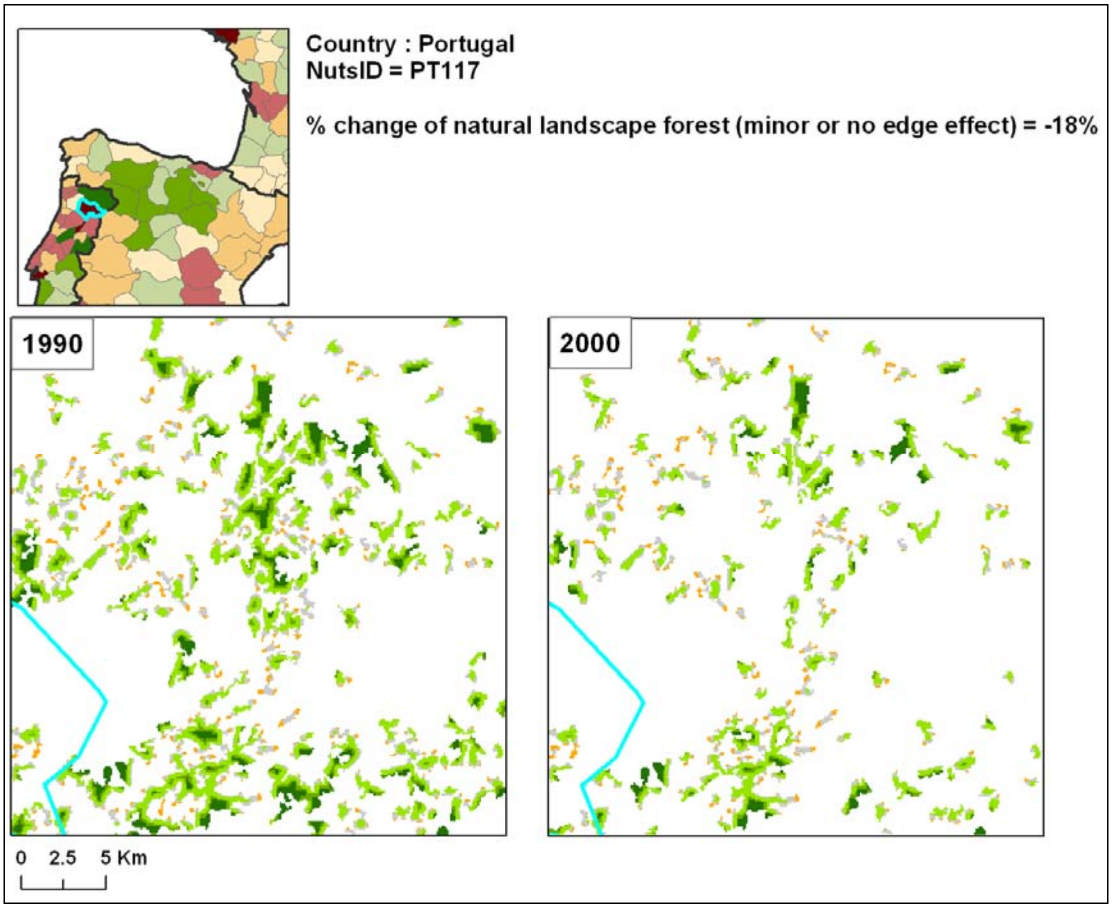


Figure 19b: net change of natural forest landscape pattern in 1990-2000 in Northern Portugal

Forest cover below 10%		Forest cover 10%-60%	
NUTS code	NUTS name	NUTS code	NUTS name
DK009	**Sonderjyllands amt**	PT167	Serra da estrela
DK00A	Ribe amt	PL227	Rybnicko-jastrzebski
IE011	Border	PT172	Peninsula de setubal
DK008	Fyns amt	**PT117**	**Douro**
ES618	Sevilla	FR524	Morbihan
PT171	Grande lisboa	ES615	Huelva
		PT165	Dao-lafoes
		PT113	**Ave**
		PT16B	Oeste
		PT166	Pinhal interior sul
		FR532	Charente-maritime
		PT161	Baixo vouga
		ES421	Albacete
		FR411	Meurthe-et-moselle
		PL520	Opolski
		FR632	Creuse
		ES620	Murcia
		PT112	Cavado
		DE12	Karlsruhe
		LT002	Kauno apskritis

Table 7: hot-spots provinces for loss of natural forest landscape pattern (per category, provinces ranked per decreasing loss)

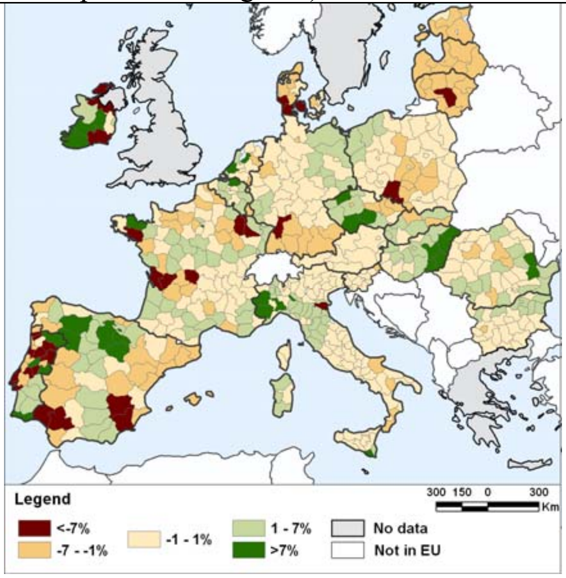


Figure 19c: Net natural forest landscape change (no or minor edge effects)

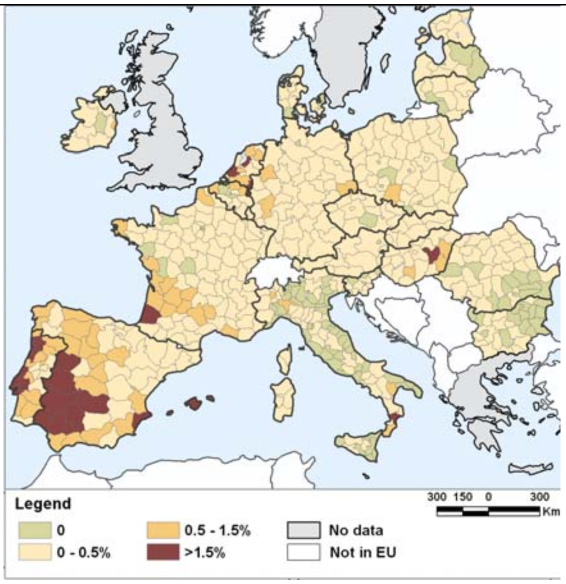


Figure 19d: Spread of agriculture or urban lands into previously natural forest landscape

III.3 Core forest fragmentation: loss and pattern processes

This section focuses on the fragmentation processes in core forest loss. Each of the four pattern processes is assessed separately: removal of units (attrition), erosion of existing forest units (shrinkage), introduction of new perforations in core forest patch and the breaking-apart (fragmentation in the narrow sense of the term) of core patches. Shrinkage can occur at the periphery of the patches or inside (enlargement of existing perforations) the patches. A synthesis of the hot-spots is finally given at the end of the section.

Shrinkage is by far the dominant pattern process in core forest loss. Perforation and attrition need some specific forest configuration to occur: small patches for attrition, more large continuous ones in the case of perforation. For example, attrition will be more frequent in provinces in Ireland and Denmark and perforations will be more frequent in provinces in uplands and mountainous regions and in boreal countries. Over Europe, the average size of patch removed was 11.3 ha, and maximum size was 1,263 ha. 95% of the patches affected by new perforations were at least 1,000 ha. Details on the shares of each spatial process within core forest loss can be retrieved per province from the EFDAC map viewer by querying in the spatial pattern category, the core forest loss indicator.

III.3.1 Core forest loss by attrition and hot-spots provinces

Figure 20a illustrates the spatial process and figures 20bc show the indicator aggregation per provinces. The total core forest area lost by attrition and aggregated per province is very low, in average 136 ha and for 95% of the provinces, below 736 ha. The maximum is 3,384 ha in Spain Caceres (ES432). Core forest area lost by attrition represents very low percentages of core forest loss, in average 0.4%, with a maximum at 19%. 95% of the provinces have percentages below 1.6%. Most provinces above this threshold had very low forest cover.

17 hotspot provinces were found (figure 24 and table 8 in section III.3.5); they had at least 736 ha core forest area lost by attrition or the loss by attrition represented at least 1.6 % of core forest area in 1990:
-10 provinces had a low core forest cover (<25000 ha): 6 provinces in Ireland, 2 in south Denmark and 2 in north-east Portugal. Due to low forest cover, percentages of core forest lost by attrition were high; also attrition represented a significant pattern process in the total core forest loss (in average 35% with a maximum of 47.8%).
-5 Spanish and 2 Portuguese provinces were selected due to their large area lost by attrition (in average 2200 ha, maximum 3400 ha).
In 5 hotspots located in the Iberian peninsula, the core forest patches that were removed and converted towards agricultural lands covered more than 100 ha: Tamega and Douro (north Portugal, respectively 143 and 205 ha), in Spain, Salamanca (328 ha), Huelva (352 ha) and Caceres (1,497 ha).

III.3.2 Core forest loss due to perforation and hot-spots provinces

Internal fragmentation processes like new perforations in core forest patches likely introduce internal edge effects into core forest patches. Figure 21a illustrates the local spatial perforation process in a German province. Figure 21bc gives the aggregated results per provinces in area and in percentages.
Highest area loss due to new perforations are found in south west France (Landes and Gironde respectively 35640 ha and 19015 ha) where forest management is intensive. Otherwise, areas are in average 321 ha and below 1200 ha in 95 % of the provinces.
Loss due to perforations represents very low percentages of the initial core forest area, also because the process occurs in provinces with relatively high forest proportion: above 1% for only 14 provinces and above 5 % for 3 provinces in south west France. Consequently, the hotspot provinces for perforation only applied the area criteria (above 1200 ha).

16 hot-spots provinces were retained for perforation (figure 21 and table 8 in section III.3.5), among which 15 have a moderate to high core forest cover (above 100,000 ha). They are spread from south west to north east Europe. In general, natural/semi-natural lands replace forest in perforation. Core forest conversions towards agriculture and artificial surfaces for more than 100 ha were found in only 4 hotspots: in France Lot et Garonne (102 ha), Gironde (505 ha) and Landes (1120 ha), in Portugal

Alentejo Litoral (254 ha). Only in Landes and Gironde, the conversion was exclusively towards artificial infrastructures and were respectively 359 ha and 216 ha.

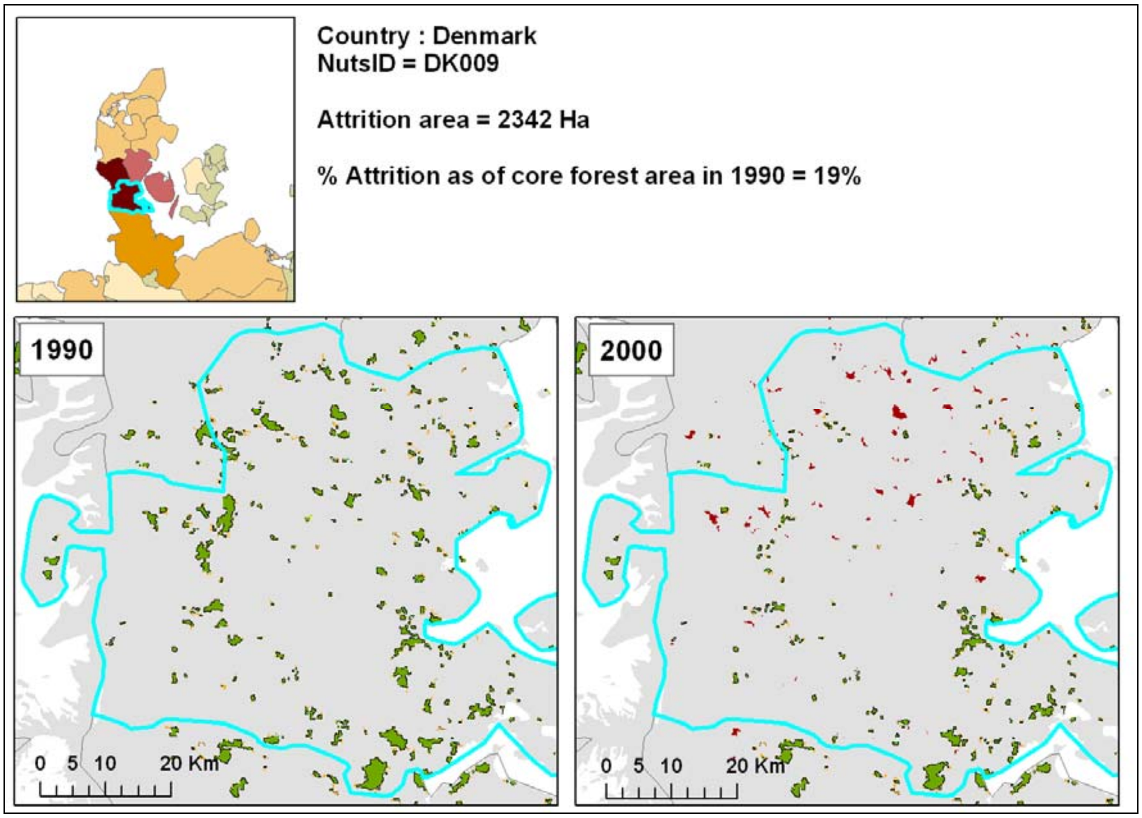


Figure 20a: Core forest lost by attrition in a Danish province (patches removed in red shade)

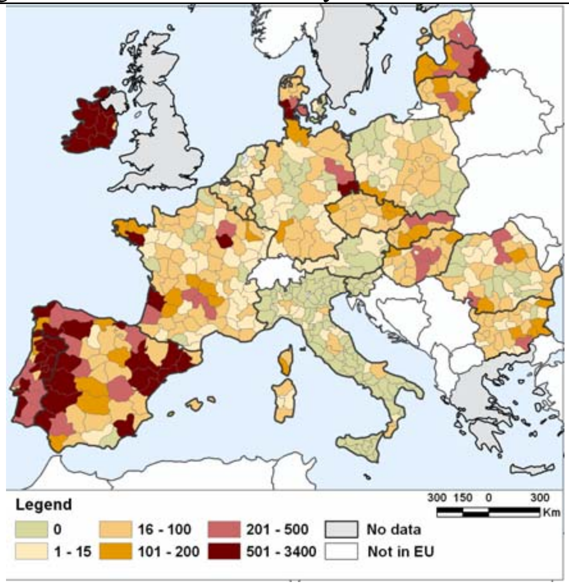


Figure 20b: Core forest area lost by attrition in 1990-2000 (ha)

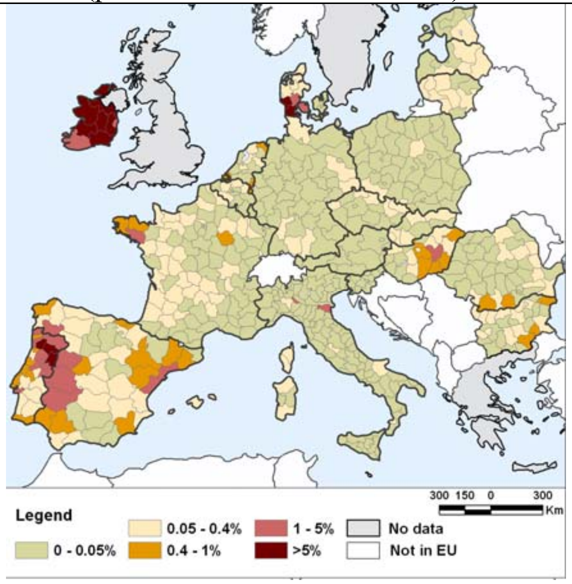


Figure 20 c: Core forest lost by attrition in 1990-2000 (% of core forest)

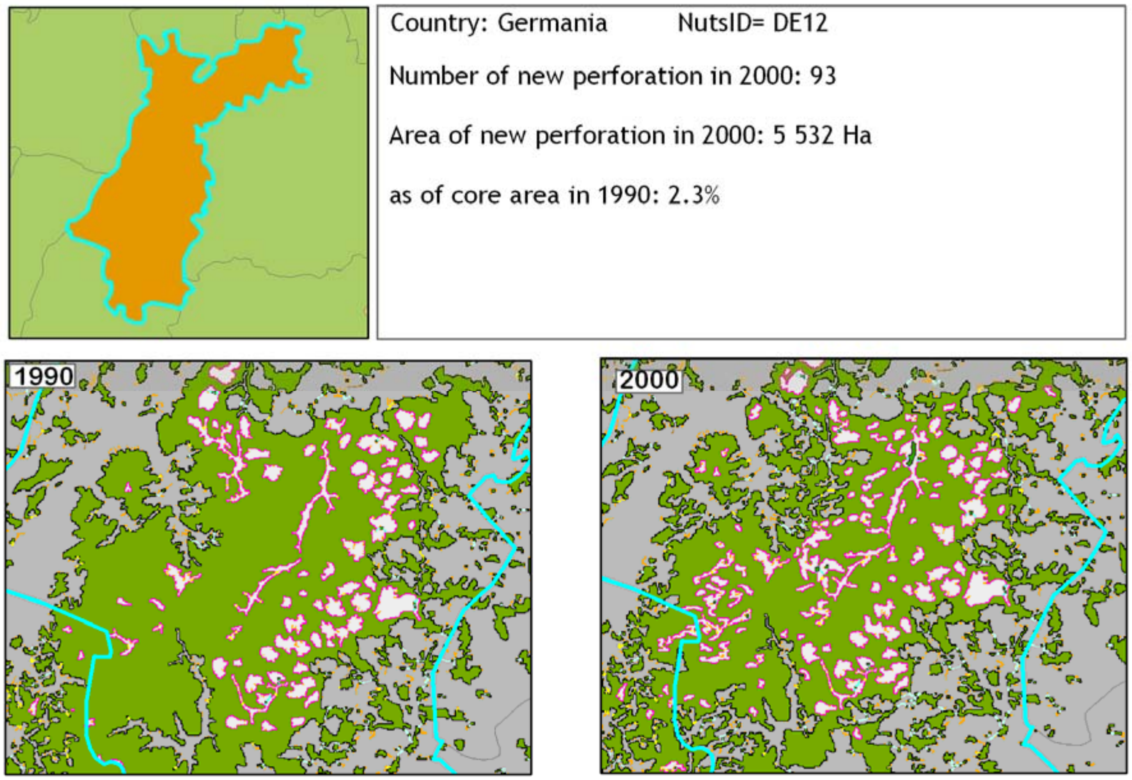


Figure 21a: Local perforation process in a German province

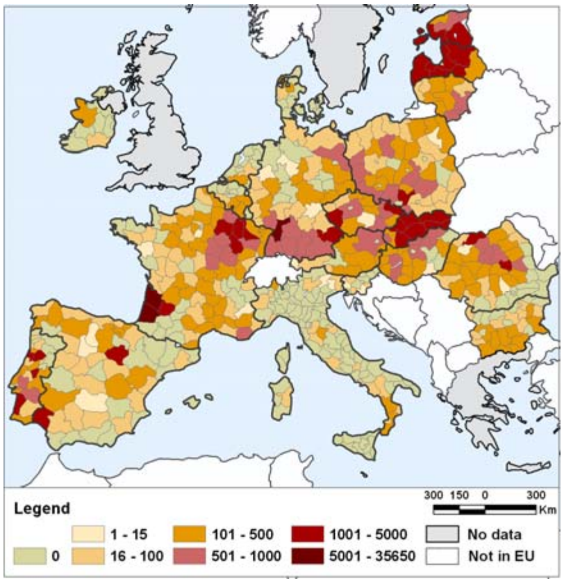


Figure 21b: New perforations in core forest in 1990-2000 (area, ha)

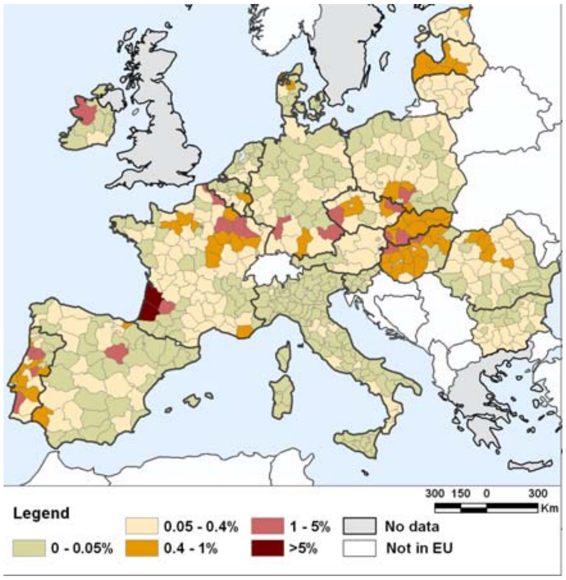


Figure 21c: New perforations in core forest (% of core forest)

III.3.3 Core forest loss by shrinkage and hot-spots provinces

Shrinkage of core forest patches is the most common pattern process of core forest loss. Figure22a illustrates the local spatial shrinkage process in a Spanish province. Figure22bc give the aggregated results per provinces in area and in percentages. Total areas lost by shrinkage per province are in average 1654 ha and below 7362 ha for 95 % of the provinces. Maximum was 33065 ha in Huelva, south west Spain. Average percentage of areas lost by shrinkage was 2.2% and below 12% for 95 % of the provinces. The maximum was 36.5 %.

The 38 hotspots provinces for shrinkage (figure 24 and table 8 in section III.3.5) were the ones with an area lost by shrinkage relatively high (above 7362 ha) or the percentage as of total core forest area relatively high (above 12%): 20 provinces had high percentage losses: 3 in Ireland, 2 in south Denmark, 13 in the north and center Portugal, 1 in Spain and 1 in Poland. In the remaining 18 provinces, the average area lost by shrinkage was 14,800 ha.

In 18 provinces in south-west Europe, mainly in Spain and Portugal, the forest conversion was towards agricultural and artificial surfaces for more than 100 ha. In 5 provinces (Barcelona, Leon in Spain, Tamega and Minho-lima in Portugal and Opolski in Poland), at least 80% of areas lost by shrinkage (at least 200 ha) were converted towards urban areas.

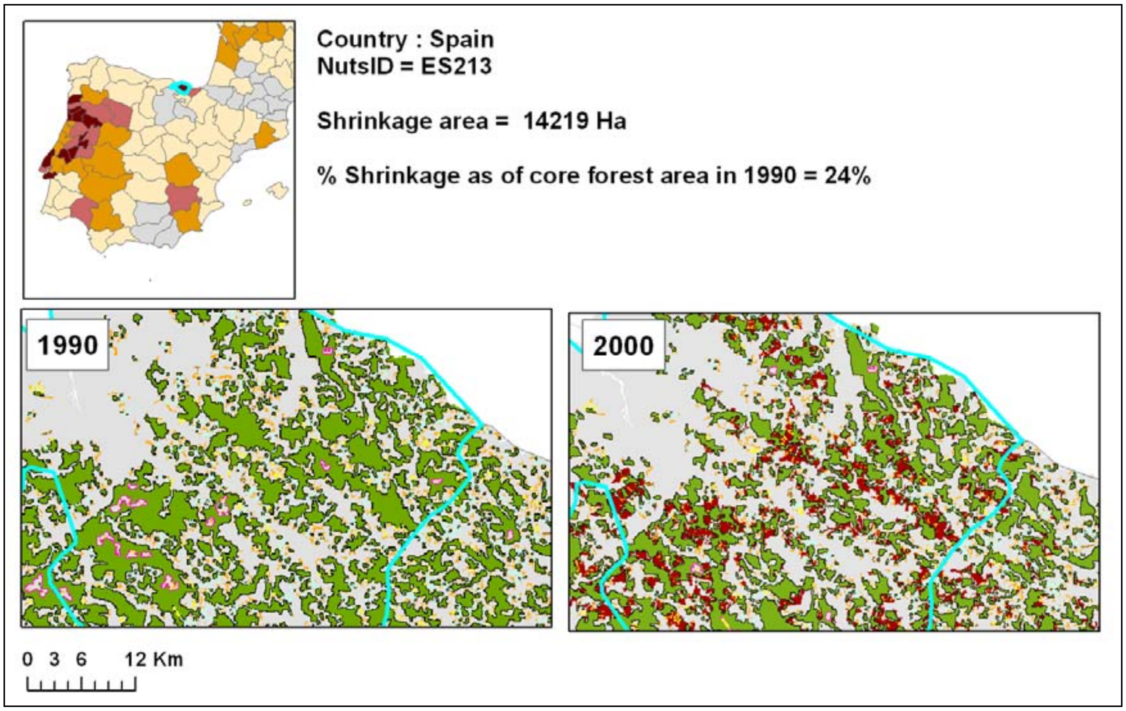


Figure 22a: Local shrinkage process in a Spanish province

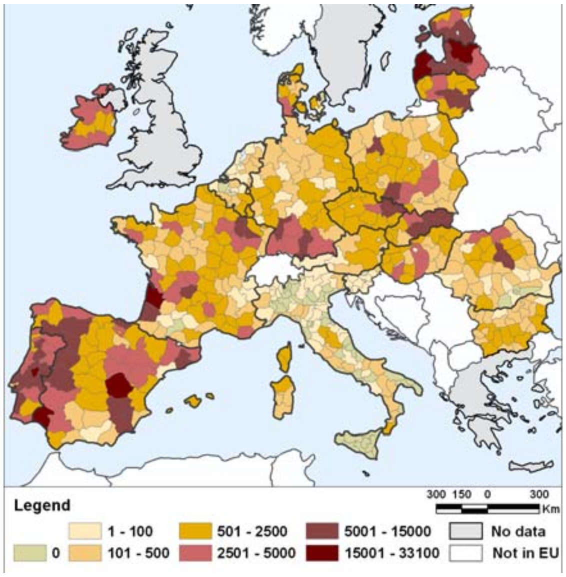


Figure 22 b: Core forest area lost by shrinkage (ha

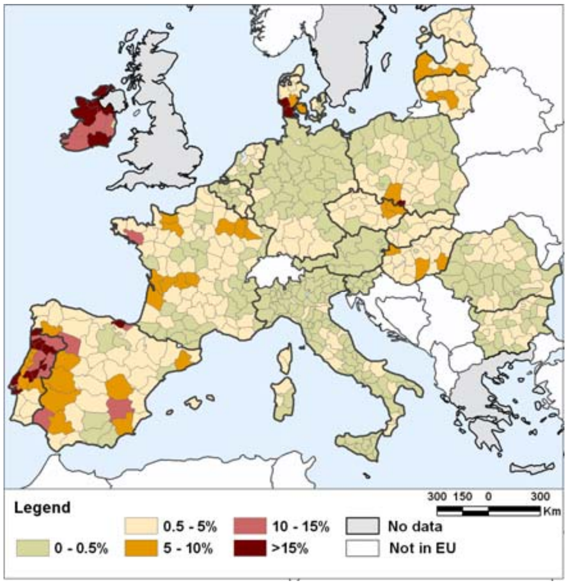


Figure 22c: Core forest lost by shrinkage (%)

III.3.4 Fragmentation (breaking-apart) of core forest patches

The fragmentation process refers to the breaking-apart of core forest patches into smaller patches (core and/or islets from GUIDOS classification). Figure 23a illustrates the fragmentation process in western Latvia. Per province, figure 23b shows the proportion of core forest units in 1990 that became fragmented in the 1990-2000 timeframe, and figure 23c shows the fragmentation intensity referring to the % of increase in number of forest patches resulting from the breaking-apart of core forest patches (above 25 ha) in 1990. The average increase of forest patches was 12 % and was below 56 % for 95% of the provinces. The maximum was 240 % in Portugal.
The 29 provinces above 56 % increase were located in Czech Republic (2 provinces), Denmark (1), France (2), Hungary (1), Latvia (4) and Lithuania (2), Poland (1), Portugal (12), Romania (1), Slovakia (1) and Spain (2). Among these provinces, 19 provinces had a forest cover between 30% and 60% of their land while the other 10 provinces had less than 30% core forest cover. The 6 highest values (above 100% increase) were found in 4 small provinces of Portugal (2) and Spain (2), in one province in Latvia and in Slovakia. In the Danish province, the forest coverage is low (4%) but continued to get fragmented with an increase of 66% in the number of core forest patches resulting from the breaking apart of core forest patches in 1990.

Fragmentation is in many places caused by forest harvesting and has 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). In South-western Europe, fragmentation due to land development with artificial infrastructures was found more frequent.

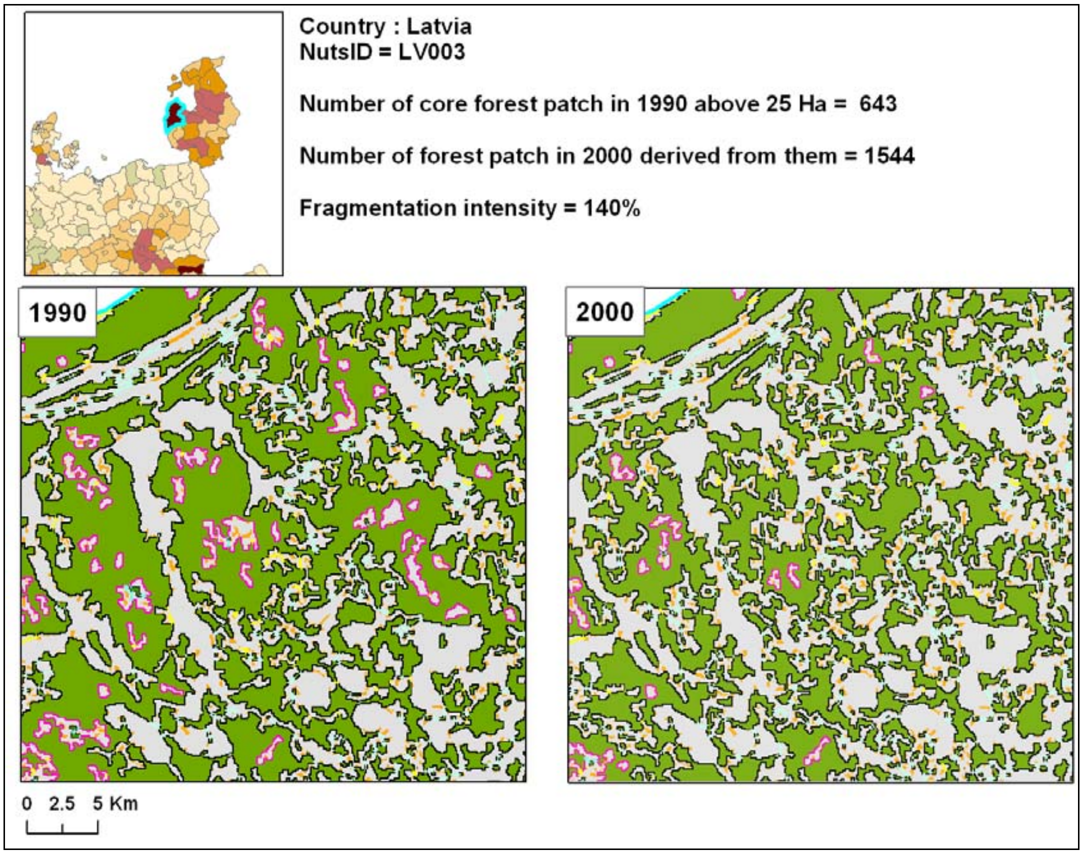


Figure 23a: Breaking apart of core forest patch into smaller patches in western Latvia

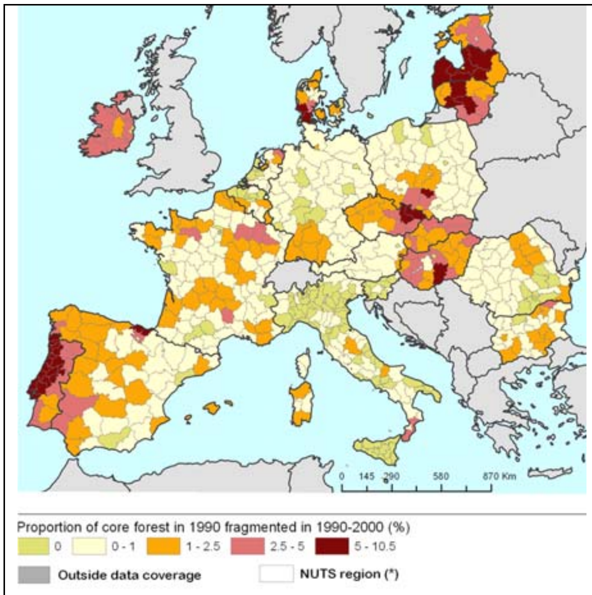


Figure 23b : proportion of core forest patches that became fragmented in 1990-2000

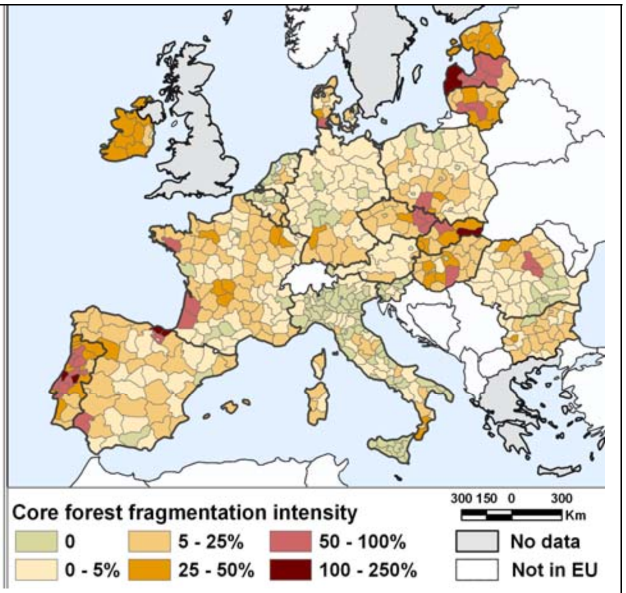


Figure 23c: Core forest fragmentation intensity (% of increase in patch number due to breaking-apart between 1990-2000)

III.3.5 Synthesis of hot-spot provinces of core forest fragmentation

The synthesis of hot-spots provinces derived for each of the four spatial pattern processes of core forest fragmentation (core forest loss from attrition, perforation, shrinkage and breaking-apart) is presented in figure 24 and listed in table 8 (details in annex 6).

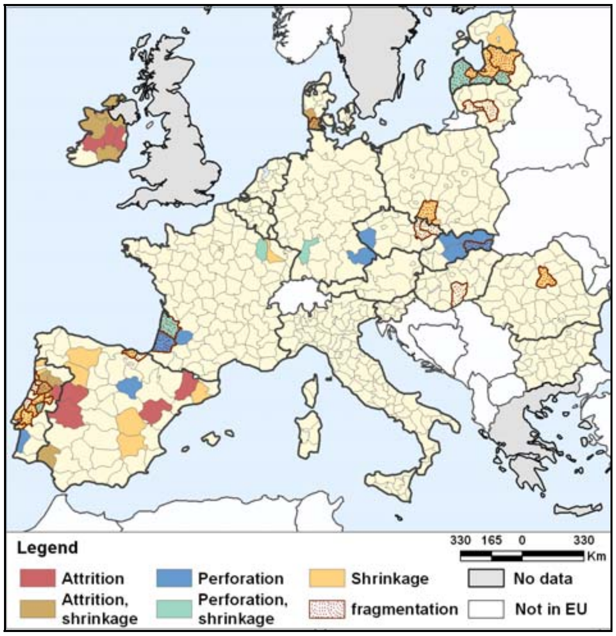


Figure 24: hot-spot provinces for core forest fragmentation

A total of 65 hot-spots provinces were identified when merging all spatial pattern processes. 4 hot spots of core forest loss were not hot-spot for any pattern process (PT118, south-west IE025, PT169, FR524-morbihan) and should be added to the list. Hot-spots were in Ireland, south Denmark, south west and North-east France, north and coastal zones in Portugal, several provinces in Spain, several provinces in the Baltic countries, few provinces in central Europe (South Germany, Poland and Hungary; East Slovakia, west and east Czech Republic, central Romania).

Perforation		Perforation and shrinkage		Attrition		Shrinkage	
CZ032	Plzensky kr	DE12	Karlsruhe	ES242	Teruel	EE008	Louna-eesti
DE22	Niederbayer	FR412	Meuse	ES415	Salamanca	ES213 *	Vizcaya
ES417	Soria	FR612 *	Gironde	ES432	Caceres	ES413	Leon
FR613 *	Landes	LV003 *	Kurzeme	ES513	Lleida	ES419	Zamora
FR614	Lot-et-garonne	LV009 *	Zemgale	IE012	Midland	ES421	Albacete
PT181	Alentejo litor	PT166 *	Pinhal interio	IE022	Mid-east	ES423	Cuenca
SK031	Zilinsky k			IE023	Mid-west	ES511	Barcelona
SK032	Banskoby			PT168	Beira interior	FR411	Meurthe-et-moselle
SK041	Presovsky					LV007 *	Pieriga
SK042 *	Kosicky k					LV008 *	Vidzeme
Attrition and shrinkage		Fragmentation * (breaking apart)				PL227	Rybnicko-jas
DK009 *	Sonderjyllands	CZ080	Moravsk. kr			PL520 *	Opolski
DK00A	Ribe amt	CZ071	Olomouc.kr			PT111	Minho-lima
ES615	Huelva	ES212	Guizpucoa			PT113	Ave
IE011	Border	HU331	Bacs-Kiskun			PT114 *	Grand porto
IE013	West	LT002	Kauno aps			PT164 *	Pinhal interio
IE024	South-east	LT007	Taurages ap.			PT167	Serra da estrela
PT115	Tamega	LT002	Kauno aps			PT16A *	Cova da bei
PT117	Douro	LT007	Taurages ap.			PT16B *	Oeste
PT165 *	Dao-lafoes	PT116	Entre Douro			PT16C *	Medio tejo
		PT161	Baixo Douro			PT172 *	Penin. de set
		PT163	Pinhal litoral			PT185 *	Leziria do
						RO074 *	Harghita

Table8: hot-spot provinces on core forest fragmentation (same color as in figure, * means also hot-spot for fragmentation)

- 8 North-western provinces with low forest coverage (6 in Ireland and 2 in Denmark)

Forest has a low and fragmented cover (less than 10% at province level); the low cover explains the high core forest loss percentages (above 20%). Mostly due to the forest spatial configuration, loss of core forest is occurring mainly through attrition. Fragmentation intensity is significant in south Denmark (DK009). In both countries, core forest is converted to natural/semi-natural non-forested land cover types creating mostly permeable forest-non forest interfaces, and is probably due to forest harvesting operations. According to MCPFE, 2007, plantations dominate the forest areas in those countries and may not offer the best conditions for biodiversity. In Ireland, core forest gains nearly compensate the core forest loss whereas in south Denmark, it seems not to be the case. Due to core forest loss and significant attrition process, potential area and sample effects on forest species will depend on forest quality and species requirements to be further checked in the field. The observed core forest spatial dynamics may be beneficial to some species – for example generalist and edge "ecotone" type of species, or pioneer organisms that accommodate or even like the heterogeneity of the cover - but other species may respond negatively to it (for example interior species that avoid open areas created by clear cuts and young stands and are affected by the loss of protective cover).

- 3 provinces in South west France: two with large forest cover

The Landes and Gironde provinces are known for their productive dense forest covering 55% and 42% of the province. At the scale of CLC data, the forest is mainly distributed in one main patch covering at least 80% of the core forest area. The high core forest loss (15%) is clearly driven by forest management and occurring almost exclusively by perforation except at the periphery of the main patches where shrinkage induces some fragmentation (north of Gironde and south of Landes). The core forest gain compensates largely the loss. In the other case more dominated by agriculture (Lot-et

Garonne), perforations are also significant. This study clearly identified places where the change in forest cover configuration (fragmentation, perforations and shrinkages) is driven by intensive forestry and potentially introduce area and edge effects in core forest. Generally speaking, Åberg (1996) considers intensive forestry and the resulting changes in habitat structure as the main reason for the decline of hazel grouse in Europe. Fragmentation of older forest connected with an increasing proportion of young stands due to intense forestry forms a threat to species like the forest grouse (Kurki 1997).

- The Mediterranean North and coastal zones of Portugal:

20 provinces with moderate (from 10 to 30%) to large (30%-60%) forest cover show more than 15 % of core forest loss apart few cases along the Douro river and the coast. What is striking here is the rate of permanent core forest convertion: among the 10 provinces with highest percentage of core forest loss and highest percentage of permanent core forest loss, 8 were from Portugal. Core forest loss seems to be more induced by urbanization and/or creation of arable lands (fires may be an additional cause). Core forest loss occurs mainly due to shrinkage of core forest patch, then removal of small patches (attrition) and in few cases of perforations; these processes potential induce area and sample effects on species. Fragmentation is also quite common in these provinces.

- 13 provinces within the Mediterranean Spanish wet and dry regions

They are spread in the north-western Castilla and Leon region, down to Extremadura (Caceres) and then in the north-eastern Catalunia region (Lleida and Barcelona provinces) and eastern Castilla-La Mancha (Albacete, Cuenca). Forest cover ranges from low (Albacete for example) to moderate (Viscaya in the Basque country). Pattern processes were mainly attrition and shrinkage with one case of perforation (Soria) and were not particularly explained by the low or large forest cover in the province. 2 provinces in particular (the eastern Caceres and Huelva on the south west coast) experienced similar processes than Portugal with a high percentage of permanent loss (28% and 5%).

- Provinces rather forested (20 to 40%) in central (among which the French Meuse in the Ardennes region, the German Karlsruhe including the Black Forest) and eastern European provinces (among which Eastern Slovakia within the Carpathians, the Moravian-Silesian part of the Czech Republic and the Polish Silesian lowlands). Shrinkages, perforations and fragmentation are the common pattern processes. Core forest loss percentages around 3-6% can reach in area 15,000 ha.
- The Baltic states with moderate to large forest coverage

Four provinces in Latvia and one province in Estonia with moderate forest cover (more than 40%) show rather low core forest loss (3 – 6 %) characterized by perforation, shrinkage and apart Estonia a significant fragmentation process. The provinces in Lithuania had less forest cover (25%) and a significant fragmentation process. In general, core forest gain did not compensate core forest loss in the decade 1990-2000 but core forest loss seems almost exclusively temporary (forest management). The impact of fragmentation resulting from clear-cutting as a harvesting method in the boreal forest landscapes was demonstrated for example on bird abundance (Siffczyk et al., 2003). Recommendations on the clear cut sizes and the share in total cutting area over time was implemented (for example, the clear cut size was reduced from 100 ha (1980-1990) to 40 ha (1990-2000) in a Swedish region and the share of clear-cuts was mentioned ca. 25% in EEA, 2005.

III.4 Change in forest connectivity and hot-spot provinces

We are now addressing connectivity of the forest cover by accounting for the cumulative impacts of forest losses and gains, the change in forest availability and the inter-patch distances. Figure 25 illustrates the local change in forest connectivity mainly due to forest shrinkage and the breaking apart of patches. The change in equivalent connected area is provided at province level for four dispersal distances (1 km, 5 km, 10 km, 25 km). In this case, the lowest the dispersal distance of the species, the highest is the change in connectivity. Figures 25b shows the change in equivalent connected area per province in 1990-2000 for each of the 4 dispersal distances.

We then focused on the decrease in forest connectivity over the 1990-2000 time frame. The 5% provinces with highest decreases were below 6.5 % for species with 25 km dispersal distance, below 7% for 10 km dispersal distance, below 7.6 % for 5 km dispersal distance and below 10% for 1km dispersal distance. Synthesis of hot-spots across dispersal distances are given in figure 25c and table 9 (details in annex 6). Connectivity was rather stable in half of the provinces in the time frame 1990-2000. For low dispersal distance, 5% of provinces with the most significant decrease were spread in the east and western part of the Iberian Peninsula, North Ireland, South Denmark, and locally in France and Lithuania. All provinces in the Baltic countries, central Poland, south Germany, central France and parts of Portugal and Spain had connectivity loss. Similar trends were acknowledged for higher dispersal abilities. When looking across dispersal abilities for the same province, the change index values usually varied in intensity and rarely in directions.

The 5 % of the provinces with an increase in connectivity were above 7 % for 25 km and 10 km, above 8% for 5 km and above 9 % for 1km. Further analysis is currently on going (Saura, Estreguil et al, in preparation). It particularly addresses the comparison of the change in connectivity in the case of net forest area gain and in the case of net forest area loss, and the consideration in the connectivity index of the permeability of the non-forested matrix.

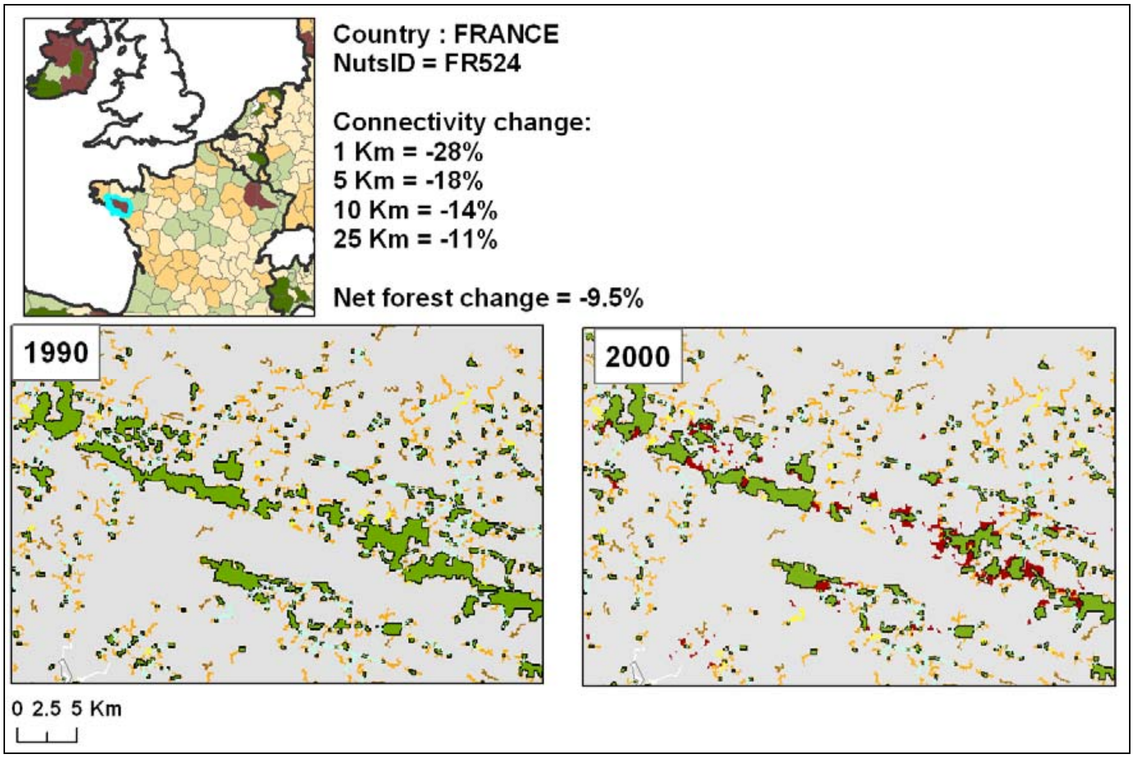
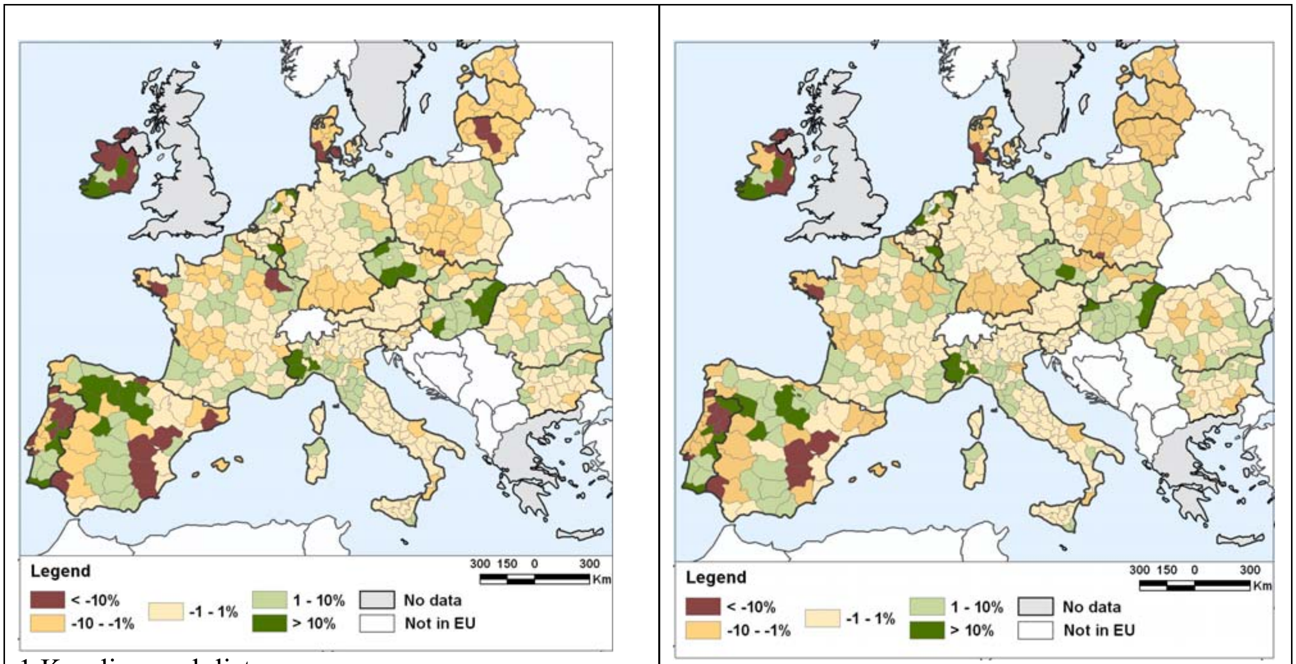
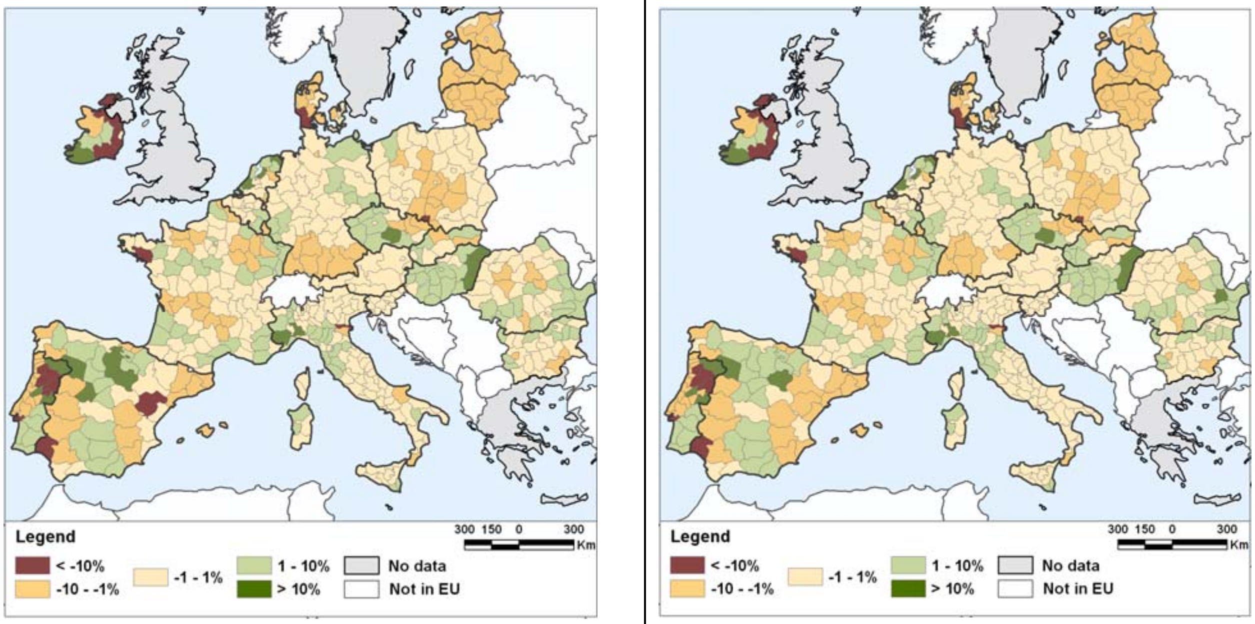


Figure 25a: Connectivity change for the 4 dispersal distances (in red, areas of forest loss)



1 Km dispersal distance

5 Km dispersal distance



10 Km dispersal distance

25 Km dispersal distance

Figure 25b: Change in connectivity per province in 1990-2000 for the 4 dispersal distances

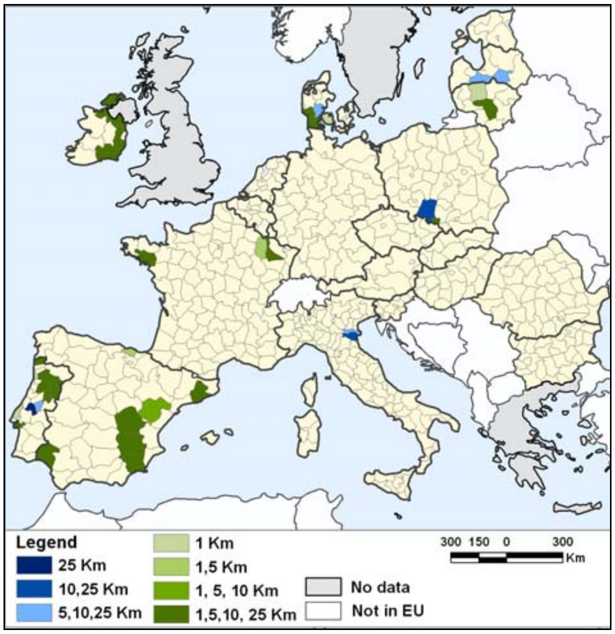


Figure 25c: Hot-spot provinces for decrease in forest connectivity

Forest cover below 10%		Forest cover 10%-60%	
NUTS code	NUTS name	NUTS code	NUTS name
IE011	Border	PT111	Minho-lima
IE022	Mid-east	PT114	Grande porto
IE024	South-east (irl)	PT115	Tamega
ITD37	Rovigo	PT117	Douro
ITD56	Ferrara	PT165	Dao-lafoes
IE011	Border	PT166	Pinhal interior s
		PT167	Serra da estrel
PT168	Beira interior n	PT16A	Cova da beira
		PT16B	Oeste
DK008	Fyns amt	PT16C	Medio tejo
DK009	Sonderjyllands	PT172	Peninsula de s
DK00A	Ribe amt		
DK00B	Vejle amt	PL227	Rybnicko-jastr.
		PL520	Opolski
		LT002	Kauno apskritis
		LT006	Siauliu apskritis
		LV009	Zemgale
		ES213	Vizcaya
		ES242	Teruel
		ES421	Albacete
		ES423	Cuenca
		ES511	Barcelona
		ES615	Huelva
		ES620	Murcia
		FR411	Meurthe-et-mo
		FR412	Meuse
		FR524	Morbihan

Table 9: Hot-spot provinces for decrease in connectivity for the four dispersal distances, in the timeframe 1990-2000.

IV. Discussions and conclusions

This study aimed to propose and demonstrate methods to assess and report European landscape level forest spatial pattern trends, forest fragmentation processes and change in connectivity as requested by two headline policy indicators (namely the MCPFE 4.7 and the SEBI2010 Indicator 13). Focus was clearly on large (European-wide) regions assessment and on the change in the forest landscape structure (spatial pattern), not its function or quality. The biodiversity context of this report led us to measure pattern changes with potential effects on habitats and species. This study on forest cover dynamics with particular insight on spatial pattern change is relevant to other forest protection issues, since forest is not only a habitat but also a climate modifier, water purifier, and flood regulator, and is now also important for biofuel production.

After a brief review of knowledge on important concepts and principles to address spatial pattern processes likely to have ecological effects, measures were listed including their roles as proxies in the biodiversity context for each headline policy indicator:

- Measures for MCPFE 4.7 were based on (1) the morphology of the forest cover in terms of core forest (interior forest with a 100m edge width) and forest edge including connectors, and on (2) the landscape context of forest in its close (50 ha) surroundings (natural context or mixed forest-non forest interface zones with agriculture and/or infrastructure). Forest spatial pattern maps were obtained by applying the mathematical morphology based software GUIDOS (Soille and Vogt 2009) while the forest landscape patterns maps were obtained by applying the landscape mosaic index (Riitters et al, 2009). Over time, the temporal stability of core forest meaning that the forest potentially stayed in the same habitat conditions, the increase of edge amount and the reduction of the natural forest landscape pattern type were reported.
- Fragmentation related measures for SEBI2010 indicator 13, were focused on local core forest loss; each of the four spatial pattern processes associated with this loss was quantified (attrition, perforation, shrinkage, fragmentation/breaking-apart). Each process potentially contributes one type of effects (sample, area, edge, isolation) on forest habitat and species.
- Connectivity related measures for SEBI2010 indicator 13 were based on the habitat availability and the inter-patch functional distances for different dispersal distances. Connectivity measures used the equivalent connectivity area index derived from the Conefor Sensinode software (Saura and Torne, 2009; Saura, Estreguil et al, in prep.)).

Three methods, each one with advantages and limitations, were necessary to address the headline policy indicators. The mathematical morphological analysis based on GUIDOS had the advantage to derive automatically and quickly for large datasets, pixel level –therefore local- morphological pattern classes without time-consuming manual GIS operations. Its strength lays mainly in the pixel-level discrimination of internal core forest edges (named perforations) from external edges (named edge), and of connectors features (particularly bridges from two different cores). Pattern classes like branches and loops were not really meaningful in this study. The pattern class “perforation” should be renamed since it refers to the edge of the perforation and not to the perforation itself. The identification of new perforations (in the sense of openings) into core forest was obtained with traditional GIS operations. In this study requiring data aggregation, core forest pattern on one hand and forest edge type of pattern on the other hand that was obtained by merging edge, branch, perforations and connectors pattern classes were the most pertinent. Regrettably the GUIDOS software solely functions with a binary simplification of land cover maps (forest/non-forest from CLC was used). The variability in habitat quality in both the forested and non-forested habitats cannot be directly accounted for. Working in multi-dimensional spaces is difficult and the requirements of large computing capacity are still limitations for large-scale assessments. The accounting and characterisation of forest-non forest interface zones is the strength of the second method, namely the landscape mosaic index. The latter has the advantage of functioning in a tri-polar space and could better relate to the permeability of the landscape (for example, it allows the discrimination between forest interfacing with non-forested semi-natural land and forest interfacing with built-up lands). The mosaic index was easily implemented in a GIS environment. For isolation issues, the GUIDOS based bridge connectors has the advantage to identify automatically at local level thin (forest) connections from one core to another that could correspond to vulnerable landscape elements. However, the simple count of bridges over a spatial unit of interest (province) would give a misleading message for connectivity. Bridges do not inform on the distance between core patches, nor on total core availability. The connectivity index obtained from the Conefor Sensinode software has the advantage to account for intra and inter-patch connectivity and was found more relevant here. It was optimized for large data processing and was for the first time applied over the whole European territory. The approach functions in a two-dimensional space and is currently amended for accounting for the resistance of the non forested matrix over large regions (Saura, Estreguil et al, in prep.).

The headline policy indicators do not primarily target the naturally-induced fragmented state of the forest landscape; the interest is more on monitoring changes in pattern, fragmentation processes and changes in connectivity that are most likely anthropogenic-induced. Thus, the assessment schemes requires multi-temporal (at least bi-temporal) land cover or habitat maps that are then partly processed with two available software’s (GUIDOS and Conefor), partly or further elaborated with GIS techniques. We faced the lack of forest habitat maps and also the lack of readily available European-wide multi-temporal fine-scale land cover maps with at least four classes : forest (and forest types), non-forested natural/semi-natural lands, agricultural and artificial surfaces. The approach was therefore demonstrated with the harmonized, relatively fine-grained and bi-temporal European-wide land cover data from CORINE Land Cover (100 m spatial resolution, 25 ha minimum mapping unit) of years 1990 and 2000. The lack of European-wide harmonized and fine scale data is a real concern to implement the two headline indicators. The 10 years span period in order to look at forest fragmentation in Europe is too short with the currently available CLC data; at least 30 to 50 years should be considered to find some more relevant ecosystem changes ; the soon available CLC data for 2006 is of course of interest in this respect. Like any land cover maps, CLC has its own limitations in terms of thematic and geometric accuracies. Technical inconsistencies between CLC 90's and 2000 are known and some of the changes presented are below the CLC accuracy assessment; they may be due to artifacts of the different products and may not refer to real evolution processes (see technical guide CLC, 2006). Land cover maps with at least 4 classes (agricultural, artificial, forest, non-forested natural/semi-natural lands) derived from sensors with medium spatial resolution (Modis or Meris) and from sensors with high spatial resolution (Landsat, SPOT, IRS data) should be made available to use as inputs for such approach and to make indicators assessment more robust. For example, the thematic upgrade of the European-wide JRC forest/non-forest mask available at 25m resolution for the years 1990, 2000 (Pekkarinen et al, 2008) and soon for 2006 would be very appropriate for testing our approach. Multi-scale issues are currently being studied over regional case studies using Earth-observation based land cover maps (25m resolution or 1 ha mapping unit) and in-situ based habitat maps (1m resolution over 1km^2 samples) in the EBONE European project (http://www.ebone.wur.nl, Estreguil et al, 2009).

Processes were illustrated locally at pixel level, and then aggregated for reporting purposes per administrative units (provinces of NUTS level 2 and 3). Results were presented on the basis of European-wide maps and tabular data. Indicator layers can be queried on line at the map viewer of the European Forest Data Centre (EFDAC): http://efdac.jrc.ec.europa.eu/. Change and management tend to be local, and the provinces do a better job in capturing the scale of the process. Good alternatives could be a fixed area grid or environmental strata as applied over regional case studies in the EBONE European project (http://www.ebone.wur.nl and Estreguil et al, 2009). It is quite obvious that the aggregation of results per reporting units leads to an important loss of information which affects the interpretation at the ecological level. However aggregation is mandatory in any reporting exercise and broad trends can still be identified.

The identification of hot spots provinces of significant local forest loss and/or specific spatial pattern change processes were proposed. The criterion of selection for hot-spots was based on the statistical distribution of each measure and retained 5% of the provinces (29 provinces out of 564) with highest change values (expressed in area or in forest proportion). Hot-spots provinces were identified for five – more or less correlated - process types : (1) forest loss not compensated by gain (36 hot-spot provinces), (2) core forest fragmentation (associated with local core forest loss and the four spatial pattern processes *i.e.* attrition, shrinkage, perforation, breaking-apart, for a total of 69 hot-spot provinces), (3) loss of natural forest landscape pattern (29 hot-spot provinces), (4) increase of forest edges (29 hot-spot provinces) and (5) decrease in forest connectivity for four different dispersal distances (for a total of 36 provinces). Hot-spots were mainly in Ireland and south Denmark, few in France, several provinces in Spain and Portugal, several provinces in the Baltic countries, few provinces spread in Central and Eastern Europe. A European-wide snap-shot of "where', 'how', and 'how much' those processes were occurring more significantly was provided. The merging of all hot-spots provinces from each pattern changes made a list of 106 hot-spot provinces over the initial 564. Each province was not a hot-spot for each process and there is some interesting correlation and comparison analysis still to be done among indicators (for example connectivity loss is not always associated with forest area loss). It is assumed that ecological impacts of spatial pattern processes are more likely in those hot-spot provinces but it will be essential to further document local change in forest spatial pattern with field-based data on forest quality.

This report was more focused on forest loss, in particular forest losses not compensated by gains at province level. It gave an insight on forest fragmentation pattern processes, loss of landscape natural forest pattern and loss of forest connectivity at province level. From an ecological point of view, the effects of such processes may be detrimental for certain species and benefic for others. Provinces with net forest gains and pattern of local forest gains should now be looked upon applying the same methodologies and adding forest quality data. Indeed, afforestation and the closure of the landscape matrix are common in Europe and in many cases produce important negative effects for forest biodiversity.

This study confirms also the need for forest land cover maps and not only for forest land use maps or statistics. Changes in forest cover are mostly due to forest management practices and are temporary, nevertheless have effects on species and are not reported in land use maps. Temporary losses need to be discriminated from permanent ones which denote a change in land use.

The approaches proposed in this study hopefully provide interesting value-added towards the implementation of the two headlines indicators over large regions. The broad results on forest pattern changes, fragmentation and connectivity obtained with the data available (the input map does not provide spatial details below 25 ha minimum mapping unit) are preliminary. The identification of places with significant forest losses and specific pattern processes could guide further ecological research. Our results should encourage the application of the methods and measures for large areas assessment and reporting.

Bibliography:

Andrén, H. 1999. Habitat fragmentation, the random sample hypothesis and critical thresholds. Oikos 84:306–308.

Betts, M. 2000. In Search of Ecological Relevancy: A Review of Landscape Fragmentation Metrics and Their Application for the Fundy Model Forest. Submitted to the Group 1 (Biodiversity) Working Group Fundy Model Forest. Greater Fundy Ecosystem Research Group (GFERG). University of New Brunswick, 38 pp.

Bogaert J., Ceulemans, R. and Salvador-Van Eysenrode, D. 2004. Decision Tree Algorithm for Detection of Spatial Processes in Landscape Transformation. Environmental Management Vol. 33, 1, pp. 62–73. DOI: 10.1007/s00267-003-0027-0.

Bossard M, Feranec J, Otahel J.,2000. The Corine Land Cover technical guide. An addendum. Technical report 40, European Environment Agency, Copenhagen. at http://reports.eea.europa.eu/tech40add/en.

CLC1990 and CLC2000. Data download of CLC 1990 (revised version 9) and CLC2000 version 9 at 100m resolution. at http://dataservice.eea.europa.eu/dataservice/

CLC, 2006. The thematic accuracy of Corine Land Cover 2000. Assessment using LUCAS. EEA, from Buttner, G and Maucha, G.. Technical report n7/2006, available at http://reports.eea.europa.eu/technical_report_2006_7/en/technical_report_7_2006.pdf.

Collinge, S. K., and R. T. T. Forman. 1998. A conceptual model of land conversion processes: predictions and evidence from a microlandscape experiment with grassland insects. Oikos 82:66–84.

Debinski, D. M., and R. D. Holt. 2000. A survey and overview of habitat fragmentation experiments. Conservation Biology 14:342-355.

EC Biodiversity Communication, 2006. SEC (2006) and indicator annexes online at http://ec.europa.eu/environment/nature_biodiversity/index_en.htm, accessed January 2009.

EEA, 2005. State of the Environment Report 2005 - Subreport 3 Halting biodiversity loss: Protecting forest biodiversity in sustainable forestry. Background note, prepared by Fischer,R. et al. European Environment Agency, Copenhagen at http://reports.eea.europa.eu/eea_report_2005_9/en/EEA_report_9_2005.pdf.

EEA, 2006. European Forest types. European Environment Agency. Technical report n 9/2006 from Barbati, A. Corona P.M. and Marchetti M.. ISSN 1725-2237. page110.

EEA, 2007. Halting the loss of biodiversity by 2010: proposal for a first set of indicators to monitor progress in Europe. At http://www.eea.europa.eu/publications/technical_report_2007_11. technical report EEA n◦ 11/2007

EEA, 2009. Progress towards the European 2010 biodiversity target: the first indicator based assessment report. Available at http://www.eea.europa.eu/publications/progress-towards-the-european-2010-biodiversity-target. Technical report EEA n◦ 4/2009 and indicator factsheets.

Estreguil C., Mouton, C. and Roche, P. 2009. Implementation of SEBI2010 Indicator Fragmentation and Connectivity of Ecosystems: preliminary results over one EBONE regional site. European Commission, 2009. JRC Pubsy reference 51373.

Fahrig, L., 2002. Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecological Applications. Volume 12, Issue 2. pp. 346–353.

Fahrig, L., 2003. Effect of habitat fragmentation on biodiversity. Annual review of Ecology, Evolution, and Systematics 34(1):487-515.

Farina, A. 1998. Principles and methods in landscape ecology. Chapmann & Hall, 235 pp

Fisher, J. and Lindenmayer, D.B. 2007. Landscape modification and habitat fragmentation: a synthesis. Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2007) 16,265-280.

Forman, R.T.T 1995. Land Mosaics. The ecology of landscapes and regions. Cambridge University Press, Cambridge 632pp.

Forman, R., and Alexander, L. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

Franklin, J. F. and Forman, R.T.T., 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. Landscape Ecology 1(1): 5-18.

Gustafson, E. J. 1998. Quantifying Landscape Spatial Pattern: What Is the State of the Art? Ecosystems 1: 143-156.

Harper KA, McDonald SA, Burton PJ, Chen J, Brosofske KD, Saunders SC , et al. 2005. Edge influence and composition in fragmented landscapes. Conservation Biology 19:768-782.

Heilman Jr., G. E., Strittholt, J. R., Slosser, N. C. and Della Sala, D.A. 2002, 'Forest fragmentation of the coterminous United States: Assessing forest intactness through road density and spatial characteristics', BioScience 52, 411–422.

Henein, K., Wegner, J. and Merriam,G. 1998. Population effects of landscape model manipulation on two behaviourally different woodland small mammals. Oikos 81:168–186.

Jaeger, J. A. G. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landscape Ecology 15:115–130.

Kindlmann,P. and Burel, F. 2008. Connectivity measures: a review. Landscape Ecology, 23:879-890. DOI 10.1007/s10980-008-9245-4.

Koper N, Schmiegelow FKK. 2006. A multi-scaled analysis of avian response to habitat amount and fragmentation in the Canadian dry mixed grass prairie. Landscape Ecology 21:1045-1059.

Kozak, J., Estreguil, C., Vogt, P. 2007. "Forest cover and pattern changes in the Carpathians over the last decades", European Journal of Forest Research, 126: 77-90. DOI: http://dx.doi.org/10.1007/s10342-006-0160-4.

Kupfer, J.A, Malanson, GP, Franklin S.B., 2004. Identifying the Biodiversity Research Needs Related to Forest Fragmentation. A report prepared for the National Commission on Science for Sustainable Forestry (NCSSF Research Project A7) and funded by the National Council for Science and the Environment (NCSE). http://www.ncseonline.org/ewebeditpro/items/O62F3754.pdf (accessed January 2009)

Kupfer, J.A, 2006. National assessments of forest fragmentation in the US. Global Environmental Change 16 (2006) 73-82. Doi:10.1016/j.gloenvcha.2005.10.003

Larsson,T.B. et al. 2001 . Biodiversity evaluation tools for European forests. A report from the FAIR EU project CT97-3575. Ecological bulletins 50. 150 pp & Appendices.

LEAC, 2006. Land accounts for Europe 1990-2000. Towards integrated land and ecosystem accounting. EEA report n11/2006. 107pp. ISBN 92-9167-888-0. EEA, Copenhagen, 2006. (http://www.eea.europa.eu/themes/landuse/land-and-ecosystem-accounting-leac)

Lambeck, R. J., 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11(4): 849–856.

Laurance WF. 2008. Theory meets reality: How habitat fragmentation research has transcended island biogeography theory. Biological Conservation 141:1731-1744.

Lidicker, W. Z. Jr and Peterson, J. A.. 1999. Responses of small mammals to habitat edges. – In: Barrett, G. W. and Peles, J. D. (eds), Landscape ecology of small mammals. Springer, pp. 211–227.

Lindenmayer D.B. and Franklin J.F., 2002. Conserving Forest Biodiversity, Island Press, Washington, DC (2002).

Lindenmayer, D.B. Cunningham, R.B. Donnelly C.F. and Lesslie, R., 2002. On the use of landscape surrogates as ecological indicators in fragmented forests. Forest Ecology and Management 159 (2002), pp. 203–216.

Mace and Baillie, 2007. The 2010 Biodiversity Indicators: Challenges for Science and Policy. Conservation Biology, vol21, 6, 1406-1413. DOI:10.1111/j.1523-1739.2007.00830x.

Matheron, 1967.

McGarigal K, Marks, B.J.1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. USDA Forest Service General Technical Report PNW-351

MCPFE, 2003. Improved Pan-European Indicators for Sustainable Forest Management. Vienna expert level meeting of the MCPFE http://www.mcpfe.org/system/files/u1/publications/pdf/improved_indicators.pdf (accessed May 2009).

MCPFE, 2007. “State of Forests and Sustainable Forest Management in Europe 2007”, presented at Warsaw, November 2007 MCPFE Conference. http://www.mcpfe.org/system/files/u1/publications/pdf/state_of_europes_forest_2007.pdf (accessed May 2009)

Parviainen J (editor). 2003. Special Issue: Maintaining Forest Biodiversity. Journal of Environmental Management 67: 1-98

Pekkarinen, A., Reithmaier, L., Strobl P. 2008. “Pan-European Forest/Non-Forest mapping with Landsat ETM+ and CORINE Land Cover 2000 data.” ISPRS Journal of Photogrammetry and Remote Sensing (doi:10.1016/j.isprsjprs.2008.09.004).

Puumalainen, J., Uuttera, J., Kennedy, P., Folving, S. 2002. Assessing forest fragmentation in Europe. Conference paper, ForestSAT Symposium 2005, Edinburgh, 5th-9th August 2002. http://www.forestresearch.gov.uk/fr/INFD-672EQR.

Riitters KH, Wickham JD, O’Neill RV, Jones KB, Smith E.R., 2000a. Global-scale patterns of forest fragmentation. Ecol Soc (formerly Cons Ecol) 4(2):3.

Riitters, K.H., Wickham, J.D., Vogelmann, J.E., and K.B. Jones. 2000b. National land-cover pattern data. Ecology 81:604-604.

Riitters KH, Wickham JD, O’Neill RV, Jones KB, Smith ER, Coulston JW, Wade TG, Smith JH, 2002. Fragmentation of continental United States forests. Ecosystems 5:815–822

Riitters KH, Wickham JD, Coulston JW., 2004. A preliminary assessment of Montreal process indicators of forest fragmentation for the United States. Environ Monitor Assess 91:257–276

Riitters, K., J. and Coulston, J., 2005. Hot Spots of Perforated Forest in the Eastern United States. Environmental Management Vol. 35, No. 4, pp. 483–492. doi: 10.1007/s00267-003-0220-1.

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

Rowsel, M., 2003. Woodland valuation system, version 2.0. Methods & rationale for assigning woodland value at the patch scale for consideration in planning and conservation in eastern Ontario. Eastern Ontario Natural Heritage Working Group publication. Report 81 pp at http://woodlandvaluation.eomf.on.ca/index.htm (accessed Sept 2007).

Rudel, T.K., Coomes, O.T. , Moranc, E. , Achard, F. , Angelsen, A., Xuf, J. and Lambin E. 2005. Forest transitions: towards a global understanding of land use change. Global Environmental Change Part A. Volume 15, Issue 1, April 2005, Pages 23-31 doi:10.1016/j.gloenvcha.2004.11.001 .

Rutledge, D., 2003. Landscape indices as measures of the effects of fragmentation: Can pattern reflect process? Department of Conservation, Wellington, New Zealand.

Saura,S. and Pascual-Hortal,L., 2007. A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study, Landscape Urban Planning, doi:10.1016/j.landurbplan.2007.03.005.

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

Saura, S., Estreguil, C., Mouton, C., Rodriguez-Freire, M. (in prep. 2009). Landscape connectivity trends for European forests (submitted to Ecological Indicators).

Soille, P., 2003. Morphological image analysis: principles and applications. 2nd edn. Springer-Verlag, Berlin.

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

SEBI2010, 2007. Streamlining European 2010 Biodiversity Indicators, on-line at: http://biodiversity-chm.eea.eu.int/information/indicator/F1090245995/ accessed January 2009.

Uuttera, J., Folving S., Kennedy, P. Ad Puumalainen J. 2003. Monitoring forest landscape diversity at European level: Case studies on forest types and fragmentation. Report 48pp. Joint Research Centre - European Commission publication reference EUR 20740 EN.

Taylor, P. D., L. Fahrig, K. Henein and G. Merriam, 1993. Connectivity is a vital element of landscape structure. Oikos 68(3): 571-573.

Vogt, P., Riitters, K., Estreguil, C., Kozak, J., Wade, T.G., Wickham J.D. 2007a Mapping Spatial Patterns with Morphological Image Processing. Landscape Ecology 22, pp. 171-177, DOI: http://dx.doi.org/10.1007/s10980-006-9013-2.

Vogt, P., Riitters, K., Iwanowski, M., Estreguil, C., Kozak, J., Soille, P. 2007b. Mapping Landscape Corridors. Ecological Indicators 7, pp. 481-488, DOI: http://dx.doi.org/10.1016/j.ecolind.2006.11.001

Vos, C.C., Verboom, J., Opdam, P.F.M., Ter Braak, C.J.F., 2001. Toward ecologically scaled landscape indices. The American Naturalist 183: 24.41.

Vos et al, 2002

Wickham, J. D. and D. J. Norton. 1994. Mapping and analyizing landscape patterns. Landscape Ecology 9:7-23.

Wickham, J.D., Riitters K.H., Wade T.G. and Coulston J. W. 2007. Temporal change in forest fragmentation at multiple scales. Landscape Ecology (2007) 22:481–489. DOI 10.1007/s10980-006-9054-6.

Zuidema, P.A., Sayer, J.A. and Dijkman, W. 1996. Forest fragmentation and biodiversity: the case for intermediate-sized conservation areas. Environmental Conservation 23: 290-297.

ANNEXES

Annex 1: hot-spot provinces of forest loss (in area shaded in green, both in area and proportion shaded in orange, in proportion only for the others) not compensated by gain (referred to table 4)

NUTS Cod	NUTS name	Stable pattern (ha)	Forest loss (ha	Gain (ha)	Stable (%)	Loss (%)	Gain (%)	Net change (ha)
DK009	SONDERJYLLAN	12454	10357	46	51.84	43.11	0.19	-10311
DK00A	RIBE AMT	19267	7022	117	69.15	25.20	0.42	-6905
EE008	LOUNA-EESTI	674636	22415	742	92.28	3.07	0.10	-21673
FR412	MEUSE	199178	15414	2879	88.54	6.85	1.28	-12535
DE12	KARLSRUHE	277116	17579	1445	89.30	5.67	0.47	-16134
IE011	BORDER	31795	13993	6680	64.35	28.32	13.52	-7313
IE013	WEST	33222	14391	11502	63.25	27.40	21.90	-2889
IE022	MID-EAST	24035	7039	3119	72.83	21.33	9.45	-3920
IE024	SOUTH-EAST (IR	34904	13712	7810	65.29	25.65	14.61	-5902
LV003	KURZEME	582069	39662	47	85.45	5.82	0.01	-39615
LV008	VIDZEME	701653	30853	20	90.52	3.98	0.00	-30833
LV009	ZEMGALE	366378	25383	65	86.46	5.99	0.02	-25318
LV007	PIERIGA	442931	21048	37	90.31	4.29	0.01	-21011
PL520	OPOLSKI	216631	16895	955	87.98	6.86	0.39	-15940
PT111	MINHO-LIMA	46080	12315	7926	71.75	19.18	12.34	-4389
PT113	AVE	23724	7224	5055	69.52	21.17	14.81	-2169
PT114	GRANDE PORT	14029	3806	2787	69.34	18.81	13.78	-1019
PT115	TAMEGA	45118	20099	11766	61.14	27.24	15.94	-8333
PT117	DOURO	34645	18267	7317	61.06	32.19	12.90	-10950
PT165	DAO-LAFOES	116690	29716	8373	74.05	18.86	5.31	-21343
PT166	PINHAL INTERIO	91196	24750	12078	71.07	19.29	9.41	-12672
PT167	SERRA DA EST	15737	7692	1564	60.99	29.81	6.06	-6128
PT168	BEIRA INTERIOR	30792	12280	5058	68.50	27.32	11.25	-7222
PT16A	COVA DA BEIRA	13698	11289	9784	48.14	39.67	34.38	-1505
PT16B	OESTE	33127	8833	6411	67.90	18.11	13.14	-2422
PT16C	MEDIO TEJO	60720	15179	10497	71.82	17.95	12.42	-4682
PT172	PENINSULA DE	34972	11838	2048	68.97	23.35	4.04	-9790
PT185	LEZIRIA DO TEJ	147619	19085	13924	81.67	10.56	7.70	-5161
RO074	HARGHITA	255113	15719	2200	89.71	5.53	0.77	-13519
ES212	GUIPUZCOA	70695	15567	9822	68.13	15.00	9.46	-5745
ES213	VIZCAYA	56075	24133	18046	54.32	23.38	17.48	-6087
ES421	ALBACETE	172653	15399	53	89.61	7.99	0.03	-15346
ES423	CUENCA	348335	24931	969	92.19	6.60	0.26	-23962
ES432	CACERES	179659	22297	13718	86.02	10.68	6.57	-8579
ES511	BARCELONA	299084	21004	90	92.39	6.49	0.03	-20914
ES615	HUELVA	262409	48551	9772	80.18	14.84	2.99	-38779

Annex 2: hot-spot provinces of core forest loss (in area shaded in green, both in area and proportion shaded in orange, in proportion only shaded in grey) not compensated by gain (referred to table 5)

NUTS code	NUTS name	Core loss (ha)	Core loss (%)	Core gain(ha)	Core gain (%)	Net core change (%)
DE12	Karlsruhe	15833	6.83	1091	0.47	-10.98
ES419	Zamora	11361	12.88	30907	35.05	24.99
PT111	Minho-lima	6036	21.72	4349	15.65	-4.84
PT113	Ave	3303	22.62	1996	13.67	-12.63
PT115	Tamega	8807	25.85	6583	19.32	-9.67
PT114	Grande porto	1671	18.44	1600	17.66	-7.68
PT117	Douro	7024	33.79	3250	15.63	-21.65
FR524	Morbihan	5294	16.53	588	1.84	-21.87
FR613	Landes	43461	12.87	65907	19.52	11.62
ES213	Vizcaya	14813	25.10	10284	17.43	-14.39
PT168	Beira interior n	5556	27.04	2283	11.11	-17.24
PT165	Dao-lafoes	16124	18.19	5255	5.93	-15.86
PT167	Serra da estrela	3907	26.61	1055	7.18	-24.73
ES423	Cuenca	19307	7.67	723	0.29	-8.38
PT164	Pinhal interior n	11649	16.35	20203	28.36	13.79
ES432	Caceres	11855	10.20	8263	7.11	-3.06
PT16A	Cova da beira	6712	41.46	5532	34.17	-9.90
PT166	Pinhal interior s	20664	20.28	8411	8.26	-13.88
PT16C	Medio tejo	11345	20.98	6943	12.84	-9.90
PT16B	Oeste	5605	20.04	3285	11.74	-16.45
PT185	Leziria do tejo	13196	9.89	9115	6.83	-4.55
ES421	Albacete	12593	10.50	33	0.03	-10.93
PT172	Peninsula de setu	7125	20.54	1360	3.92	-22.38
ES615	Huelva	36324	15.87	5807	2.54	-16.51
IE011	Border	5591	28.49	2880	14.68	-20.33
IE013	West	6832	28.40	5470	22.74	-9.15
IE012	Midland	2224	23.45	3437	36.23	15.74
IE022	Mid-east	2817	20.03	1609	11.44	-10.77
IE023	Mid-west	2413	19.92	3748	30.94	10.05
IE024	South-east (irl)	6016	27.97	3554	16.52	-14.79
IE025	South-west (irl)	4347	18.94	7978	34.77	16.26
LV003	Kurzeme	28203	6.22	33	0.01	-13.98
DK00A	Ribe amt	3833	23.61	61	0.38	-30.55
DK009	Sonderjyllands a	4976	41.07	17	0.14	-48.99
ES511	Barcelona	13273	6.18	33	0.02	-7.11
PL520	Opolski	13909	7.64	799	0.44	-11.66
FR412	Meuse	12465	7.93	2314	1.47	-9.95
FR411	Meurthe-et-mos	11494	9.49	1888	1.56	-11.35
FR612	Gironde	44395	15.53	58737	20.55	9.22
EE008	Louna-eesti	14975	3.55	374	0.09	-7.92
LV008	Vidzeme	19034	4.38	4	0.00	-10.20
LV007	Pieriga	13274	4.36	6	0.00	-9.73
LV009	Zemgale	16063	6.43	21	0.01	-14.46
RO074	Harghita	10135	5.26	1526	0.79	-7.53

Annex3: provinces with highest increase in edge length (referred to table 6)

NUTS code	NUTS name	Net edge change (%)	Net forest cover change (%)	Forest cover (%)
NL11	Groningen	91.56	88.06	1.65
PT169	Beira interior sul	24.90	25.97	30.89
NL33	Zuid-holland	23.64	24.21	1.75
ES419	Zamora	13.77	20.20	16.66
HU323	Szabolcs-szatmar-bereg	12.89	14.54	13.08
NL23	Flevoland	12.29	17.02	11.60
HU331	Bacs-kiskun	12.27	5.46	13.81
DE12	Karlsruhe	11.90	-5.20	42.47
IE023	Mid-west	11.50	10.68	3.93
HU332	Bekes	10.90	11.15	2.90
PT16B	Oeste	10.52	-4.96	18.36
LV003	Kurzeme	10.47	-5.82	47.15
IE025	South-west (irl)	9.94	12.11	5.14
HU333	Csongrad	8.75	9.18	6.36
PL520	Opolski	8.22	-6.47	24.63
ITD37	Rovigo	7.79	6.05	0.46
NL12	Friesland	7.65	4.15	2.33
NL34	Zeeland	7.61	9.95	1.62
HU221	Gyor-moson-sopron	7.32	5.94	16.23
DE50	Bremen	7.31	4.74	2.45
NL32	Noord-holland	7.20	7.90	4.30
ES414	Palencia	7.12	7.05	15.53
BG121	Pleven	6.80	7.60	7.19
HU233	Tolna	6.31	3.16	16.94
RO024	Galati	6.25	7.05	7.91
LV009	Zemgale	6.00	-5.97	36.99
PT150	Algarve	5.79	7.42	18.75
RO023	Constanta	5.50	4.41	3.50
PT118	Alto tras-os-montes	5.37	12.98	13.39

Annex 4: Hot-spots provinces for highest net natural forest landscape loss (referred to figure 23 and table 7)

NUTS code	NUTS name	Net natural forest landscape change %	Net core forest change	Forest cover %
DK009	Sonderjyllands amt	-38.05	-42.92	3.51
PT167	Serra da estrela	-22.18	-23.75	22.44
PL227	Rybnicko-jastrzebski	-19.75	-12.86	20.19
PT172	Peninsula de setubal	-18.47	-19.31	25.34
PT117	Douro	-18.23	-19.30	11.20
FR524	Morbihan	-16.66	-9.52	14.22
DK00A	Ribe amt	-16.58	-24.78	6.66
ES615	Huelva	-14.85	-11.85	28.43
PT165	Dao-lafoes	-14.50	-13.54	38.95
PT113	Ave	-14.39	-6.36	25.16
PT16B	Oeste	-13.57	-4.96	18.36
IE011	Border	-12.78	-14.78	3.42
DK008	Fyns amt	-12.63	-6.31	6.59
PT166	Pinhal interior sul	-10.38	-9.87	60.78
FR532	Charente-maritime	-10.13	-3.14	14.70
PT161	Baixo vouga	-9.97	-6.30	44.54
ES421	Albacete	-9.37	-7.97	11.89
ES618	Sevilla	-9.29	-4.10	6.61
PT171	Grande lisboa	-9.17	-5.77	6.93
FR411	Meurthe-et-moselle	-8.99	-6.51	30.37
PL520	Opolski	-8.87	-6.47	24.63
FR632	Creuse	-8.84	-3.93	28.96
ES620	Murcia	-8.58	-6.98	10.25
IE024	South-east (irl)	-8.21	-11.04	5.03
PT168	Beira interior norte	-7.89	-16.07	9.34
ITD56	Ferrara	-7.81	-10.18	1.16
PT112	Cavado	-7.70	-5.64	30.40
DE12	Karlsruhe	-7.49	-5.20	42.47
LT002	Kauno apskritis	-7.22	-6.28	24.88

Annex 5: hot-spots provinces for spread of agriculture or artificial lands into previously natural forest landscapes (referred to figure 23)

NUTS code	NUTS name	Natural forest landscape converted to other	Net core forest change	Forest cover (%)
PT114	Grande porto	10.36	-5.04	24.14
PT171	Grande lisboa	6.32	-5.77	6.93
PT113	Ave	5.16	-6.36	25.16
PT16B	Oeste	5.00	-4.96	18.36
PT172	Peninsula de setubal	4.81	-19.31	25.34
NL33	Zuid-holland	4.37	24.21	1.75
PT161	Baixo vouga	3.63	-6.30	44.54
ES432	Caceres	2.85	-4.11	10.07
HU322	Jasz-nagykun-szolnok	2.41	7.71	4.08
ES521	Alicante / alacant	2.39	-1.68	6.16
ES618	Sevilla	2.31	-4.10	6.61
ES431	Badajoz	2.24	-3.31	5.81
NL23	Flevoland	2.16	17.02	11.60
ES613	Cordoba	2.12	2.20	9.45
PT112	Cavado	2.10	-5.64	30.40
PT116	Entre douro e vouga	2.09	-3.38	48.86
ES530	Illes balears	2.09	-2.49	18.69
NL42	Limburg (nl)	2.04	-1.23	13.82
ES615	Huelva	1.96	-11.85	28.43
ITF63	Catanzaro	1.91	-0.67	40.59
PT163	Pinhal litoral	1.84	-4.77	42.92
FR613	Landes	1.77	4.70	58.25
ES422	Ciudad real	1.62	3.97	6.01
PT115	Tamega	1.61	-11.29	25.13
PT185	Leziria do tejo	1.58	-2.86	40.92
ES415	Salamanca	1.54	0.54	12.94
PT117	Douro	1.44	-19.30	11.20
PT111	Minho-lima	1.44	-6.83	26.69
BE22	Prov. Limburg (b)	1.38	0.69	15.06

Annex 6: Hot-spot provinces for core forest fragmentation (perforation, shrinkage, attrition, fragmentation in the sense of breaking-apart). Color coding as in figure 24 and table 8.

NUTS code	NUTS name	Perf (ha)	Perf. (%)	Shrink. (ha)	Shrink. (%)	Attrit. (ha)	Attrit. (%)	Frag. (%)	Core loss(ha)	Core loss (%)
CZ032	Plzensky kr	2137	1.24	1376	0.80	47	0.03		3560	2.06
CZ080	Moravsk. kr							80	7139	6.25
CZ071	Olomouc.kr							81	7136	6.08
DE12	Karlsruhe	5532	2.39	10127	4.37	174	0.08		15833	6.83
DE22	Niederbayer	3584	1.83	287	0.15	11	0.01		3882	1.99
DK009	Sonderjyllan	0	0.00	2634	21.74	2342	19.33	66	4976	41.07
DK00A	Ribe amt	0	0.00	2982	18.37	851	5.24		3833	23.61
EE008	Louna-eesti	1179	0.28	13547	3.21	249	0.06		14975	3.55
ES212	Guizpucoa							156	9301	15.57
ES213	Vizcaya	57	0.10	14219	24.10	537	0.91	181	14813	25.10
ES242	Teruel	191	0.10	3169	1.72	1554	0.85		4914	2.67
ES413	Leon	317	0.10	8970	2.87	596	0.19		9883	3.16
ES415	Salamanca	43	0.05	5935	6.69	2259	2.55		8237	9.29
ES417	Soria	1654	1.10	4007	2.65	108	0.07		5769	3.82
ES419	Zamora	45	0.05	11106	12.59	210	0.24		11361	12.88
ES421	Albacete	0	0.00	12525	10.44	68	0.06		12593	10.50
ES423	Cuenca	385	0.15	18530	7.36	392	0.16		19307	7.67
ES432	Caceres	0	0.00	8471	7.29	3384	2.91		11855	10.20
ES511	Barcelona	35	0.02	11982	5.57	1256	0.58		13273	6.18
ES513	Lleida	0	0.00	4644	2.38	1875	0.96		6519	3.34
ES615	Huelva	1316	0.57	33065	14.45	1943	0.85		36324	15.87
FR411	Meurthe-et-	1407	1.16	9947	8.21	140	0.12		11494	9.49
FR412	Meuse	1832	1.17	10541	6.71	92	0.06		12465	7.93
FR612	Gironde	19015	6.65	24856	8.70	524	0.18	78	44395	15.53
FR613	Landes	35638	10.55	7413	2.20	410	0.12	81	43461	12.87
FR614	Lot-et-garonne	3039	4.98	234	0.38	103	0.17		3376	5.54
HU331	Bacs-Kiskun							56	4837	7.82
IE011	Border	0	0.00	3565	18.17	2026	10.33		5591	28.49
IE012	Midland	0	0.00	1369	14.43	855	9.01		2224	23.45
IE013	West	408	1.70	4852	20.17	1572	6.54		6832	28.40
IE022	Mid-east	0	0.00	1632	11.60	1185	8.43		2817	20.03
IE023	Mid-west	0	0.00	1688	13.93	725	5.98		2413	19.92
IE024	South-east	70	0.33	4168	19.38	1778	8.27		6016	27.97
LT002	Kauno aps							60	8371	6.76
LT007	Taurages ap.							62	4368	5.87
LV003	Kurzeme	3297	0.73	24785	5.46	121	0.03	140	28203	6.22
LV007	Pieriga	1258	0.41	11872	3.90	144	0.05	70	13274	4.36
LV008	Vidzeme	1608	0.37	17146	3.94	280	0.06	66	19034	4.38
LV009	Zemgale	1648	0.66	14171	5.67	244	0.10	77	16063	6.43
PL227	Rybnicko-j.	0	0.00	3767	15.74	18	0.08		3785	15.82
PL520	Opolski	898	0.49	12950	7.12	61	0.03	64	13909	7.64
PT111	Minho-lima	0	0.00	4830	17.38	1206	4.34		6036	21.72
PT113	Ave	0	0.00	2719	18.62	584	4.00		3303	22.62
PT114	Grand porto	90	0.99	1428	15.76	153	1.69	61	1671	18.44
PT115	Tamega	88	0.26	6980	20.49	1739	5.10		8807	25.85
PT116	Entre Douro							63	2548	9.59
PT117	Douro	0	0.00	4305	20.71	2719	13.08		7024	33.79
PT161	Baixo Douro							84	5684	9.53
PT163	Pinhal litoral							113	5341	9.64

PT164	Pinhal int.	347	0.49	10490	14.72	812	1.14	63 11649	16.35
PT165	Dao-lafoes	1241	1.40	13032	14.70	1851	2.09	61 16124	18.19
PT166	Pinhal int.	2665	2.62	17919	17.59	80	0.08	240 20664	20.28
PT167	Serra da estr	80	0.54	3148	21.44	679	4.62	3907	26.61
PT168	Beira int.	0	0.00	2899	14.11	2657	12.93	5556	27.04
PT16A	Cova da bei	0	0.00	5903	36.46	809	5.00	96 6712	41.46
PT16B	Oeste	131	0.47	5233	18.71	241	0.86	75 5605	20.04
PT16C	Medio tejo	33	0.06	10961	20.27	351	0.65	66 11345	20.98
PT172	Penin. de set	228	0.66	5430	15.65	1467	4.23	87 7125	20.54
PT181	Alentejo lit.	2308	1.31	7077	4.01	665	0.38	10050	5.69
PT185	Leziria do	992	0.74	11688	8.76	516	0.39	67 13196	9.89
RO074	Harghita	550	0.29	9205	4.78	380	0.20	67 10135	5.26
SK031	Zilinsky k	2598	0.95	4362	1.60	298	0.11	7258	2.66
SK032	Banskoby	2801	0.84	6349	1.91	117	0.04	9267	2.78
SK041	Presovsky	1937	0.67	7855	2.71	225	0.08	10017	3.46
SK042	Kosicky k	2031	0.96	5481	2.60	54	0.03	107 7566	3.58

Annex 7: Hot-spot provinces for decrease in connectivity for the four dispersal distances, in the timeframe 1990-2000. (Referred to figure 25 and table 9)

NUTS code	NUTS name	CECA 1 km	CECA 5 km	CECA 10 km	CECA 25 km	Net forest change	Forest %
DK008	Fyns amt	-11.05	No HS	No HS	No HS	-6.31	6.59
DK009	Sonderjyllands	-36.96	-43.30	-44.20	-43.77	-42.92	3.51
DK00A	Ribe amt	-26.00	-26.50	-26.61	-26.08	-24.78	6.66
DK00B	Vejle amt	No HS	-7.88	-7.86	-7.76	-7.90	9.60
ES213	Vizcaya	-16.54	-8.25	No HS	No HS	-5.90	42.80
ES242	Teruel	-11.65	-14.78	-10.53	No HS	-1.93	22.29
ES421	Albacete	-15.24	-10.58	-9.51	-8.69	-7.97	11.89
ES423	Cuenca	-16.37	-10.17	-8.53	-7.32	-6.34	20.65
ES511	Barcelona	-10.83	-7.95	-7.33	-6.93	-6.46	39.06
ES615	Huelva	-15.25	-15.54	-14.28	-13.02	-11.85	28.43
ES620	Murcia	-13.38	-9.76	-8.51	-7.63	-6.98	10.25
FR411	Meurthe-et-mo	-11.67	-8.84	-7.85	-7.03	-6.51	30.37
FR412	Meuse	-10.67	-8.25	No HS	No HS	-5.57	34.28
FR524	Morbihan	-28.18	-18.26	-14.50	-11.65	-9.52	14.22
IE011	Border	-11.42	-12.75	-13.35	-13.84	-14.78	3.42
IE022	Mid-east	-19.83	-14.25	-13.28	-12.74	-11.88	4.83
IE024	South-east (irl)	-22.56	-19.73	-17.23	-14.10	-11.04	5.03
ITD37	Rovigo	No HS	-9.97	-10.84	-11.00	6.05	0.46
ITD56	Ferrara	No HS	No HS	-7.27	-8.43	-10.18	1.16
LT002	Kauno apskritis	-12.64	-9.52	-8.09	-7.03	-6.28	24.88
LT006	Siauliu apskritis	-10.68	No HS	No HS	No HS	-4.33	22.17
LV009	Zemgale	No HS	-7.85	-7.25	-6.60	-5.97	36.99
PL227	Rybnicko-jastr.	-17.06	-13.94	-13.33	-12.92	-12.86	20.19
PL520	Opolski	No HS	No HS	-7.10	-6.74	-6.47	24.63
PT111	Minho-lima	-18.15	-10.03	-8.55	-7.59	-6.83	26.69
PT114	Grande porto	-13.12	No HS	No HS	No HS	-5.04	24.14
PT115	Tamega	-20.24	-17.90	-15.01	-12.63	-11.29	25.13
PT117	Douro	-33.90	-31.47	-27.54	-23.57	-19.30	11.20
PT165	Dao-lafoes	-21.24	-15.81	-14.82	-14.19	-13.54	38.95
PT166	Pinhal interior s	No HS	-9.89	-9.84	-9.81	-9.87	60.78
PT167	Serra da estrel	-24.22	-23.94	-23.60	-23.10	-23.75	22.44
PT168	Beira interior n	-17.04	-23.00	-21.00	-18.32	-16.07	9.34
PT16A	Cova da beira	-27.82	-14.26	-10.36	-7.65	-5.29	19.64
PT16B	Oeste	-11.57	No HS	No HS	No HS	-4.96	18.36
PT16C	Medio tejo	No HS	No HS	No HS	-6.52	-5.54	34.37
PT172	Peninsula de s	-30.36	-23.44	-22.06	-20.75	-19.31	25.34

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Abstract

This report presents and demonstrates possible solutions to implement two headline policy indicators listed under the biodiversity criteria: the EEA/SEBI2010 Indicator 13 ‘fragmentation and connectivity of ecosystem’ and the MCPFE 4.7 Indicator ‘Landscape level forest spatial pattern. Focus is clearly on large regions assessment and on the change in the forest landscape structure (spatial pattern), not its function or quality.

A brief review of knowledge enabled to select important concepts and principles to address spatial pattern processes likely to have ecological effects. It is proposed to make the assessment at local level with relatively fine-grained data and the reporting per spatial units which best capture local processes without loosing too much information. In some cases, forest losses must be disaggregated from forest gains and treated separately. Measures for MCPFE 4.7 are based on (1) the morphology of the forest cover in terms of core forest (interior forest with a 100m edge width) and forest edge, also providing an insight on connectors, and on (2) the landscape context of forest in its close (50 ha) surroundings (natural context or mixed forest-non forest interface zones with agriculture and/or infrastructure). The temporal stability of core forest (i.e. forest potentially staying in the same conditions), the increase of edges and the loss of forest in a natural context are measured. For the SEBI2010 indicator 13, fragmentation is looked upon when associated to core forest loss and each of the four spatial pattern processes (attrition, perforation, shrinkage, fragmentation/breaking-apart) that potentially contribute to four effects (sample, area, edge, isolation) on forest habitat and species is quantified. Measures on forest connectivity combine the landscape and organism dimensions; they account for the habitat availability and inter-patch functional distances.

The measures were based on the application of three methods and GIS techniques. Data inputs were forest-non forest masks, the forest spatial pattern maps obtained by applying the mathematical morphology based software GUIDOS, the landscape patterns maps obtained by applying the landscape mosaic index and the equivalent connectivity area index derived from the Conefor Sensinode software. The analysis was conducted to demonstrate the methods with the only readily available, harmonized, relatively fine-grained and bi-temporal European-wide land cover data from CORINE Land Cover (100 m spatial resolution, 25 ha minimum mapping unit) of years 1990 and 2000. Forest habitat maps do not exist over large regions. For each measure, local spatial information was aggregated per province (NUTS level 2 or 3, 564 provinces in total) and results were presented on the basis of European-wide maps and tabular data. Indicator layers can be queried on line at the map viewer of the European Forest Data Centre (EFDAC): http://efdac.jrc.ec.europa.eu/.

The additional delivery of a European-wide snap-shot of hot-spot provinces was proposed to identify provinces where changes in spatial pattern (particularly forest loss, loss of forest in natural context, core forest fragmentation, forest connectivity loss) were significant (both in area and proportionally to the forest). Ecological impacts of spatial pattern processes would be more likely in those provinces. With the data at hand used for demonstrating the methods, 106 hot-spot provinces were flagged. It will be now essential to further compare local change in forest spatial pattern with net forest area change, and add complementary field-based data on forest quality.

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