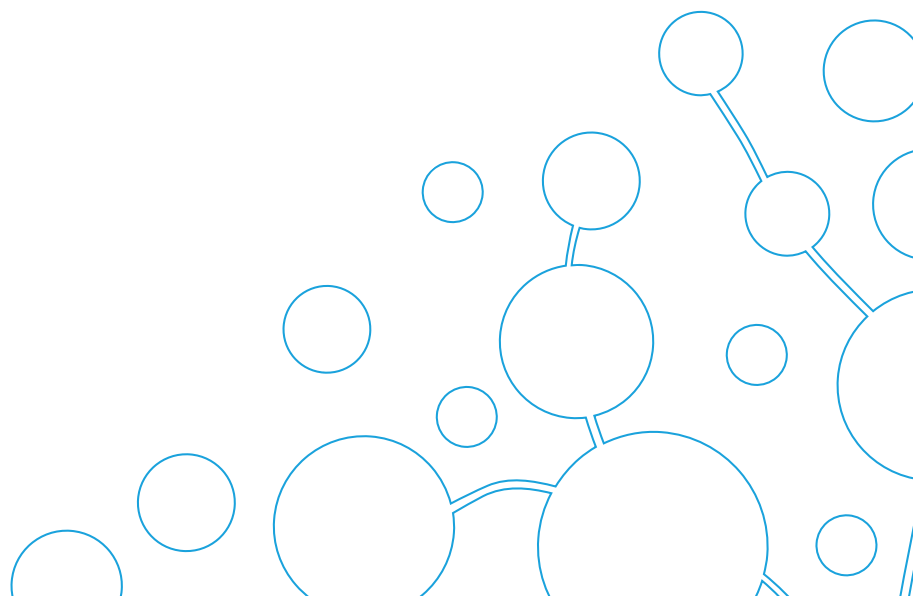


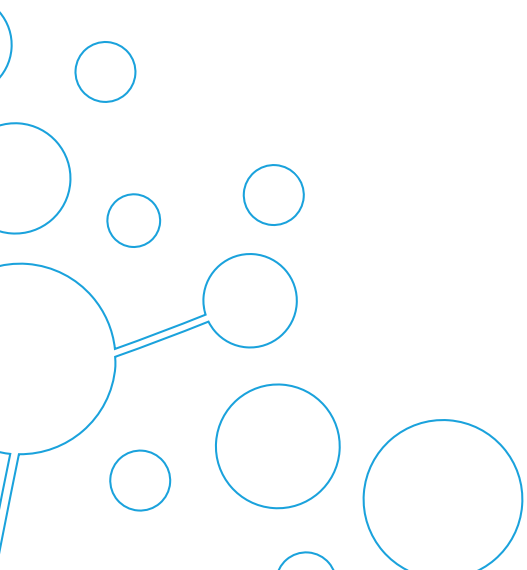
*Pilot Study:*  
**Forest Fragmentation Indicator**





# Forest Fragmentation Indicator

## *Pilot Study*



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# 1 Background

The FOREST EUROPE Expert Level Meeting (ELM) in January 2015 decided to start the participatory process of updating the pan-European indicators for sustainable forest management (SFM). Based on this decision, the Advisory Group on Updating the pan-European Indicators was established and its two meetings followed in Madrid (11 February 2015 and 10 March 2015). Simultaneously, two online consultations with national focal points and stakeholders were organised. The updating work was accomplished at the workshop in April 2015 and its results, among other changes, also three new quantitative indicators, namely the 2.5 land degradation, **4.7 forest fragmentation** and 4.10 common forest bird species indicator, were presented to the next ELM in July 2015. The ELM accepted all these new indicators and suggested them to be included in the updated set of pan-

European indicators for SFM.

Subsequently, this set of *Updated Pan-European Indicators of SFM* was annexed to the Madrid Ministerial Declaration and endorsed by signatories. Within this annex, the indicator 4.7 was complemented with the footnote “*Requires to be further developed and tested.*” This requirement was transformed into the FOREST EUROPE Work Programme as the activity 4.2.3. “*Pilot studies on the new indicators (2.5 Forest land degradation, 4.7 Forest fragmentation, 4.10 Common forest bird species) shall be elaborated to determine if the data are available and reliable and if the indicators are feasible for reporting.*”

The short name of the adopted indicator 4.7 is “Forest Fragmentation” and the full-text name is “Area of continuous forest and of patches of forest separated by non-forest lands”.

# 2 Conceptual Issues

Forest Fragmentation indicator replaced the earlier pan-European indicator “*Forest landscape pattern*” used in earlier set of *Improved pan-European Indicators for SFM* as adopted by the MCPFE Expert Level Meeting 2002 in Vienna, used in State of Europe’s Forests reports in 2007, 2011 and 2015 (FOREST EUROPE 2015). The excessive complexity of the Forest landscape pattern

indicator with its evolving components (forest landscape fragmentation pattern components; forest connectivity index) led to the setting of a simpler indicator. This simplification is reflected in the adopted full-text title of the indicator. The indicator should characterize spatial distribution of forests and this way bring an additional information to other indicators in the pan-European set.

## 2.1 FOREST EUROPE initial settings for the Forest fragmentation indicator

Within the context of pan-European criteria and indicators for SFM, the fragmentation indicator 4.7 was approved as an indicator of the Criterion 4, i.e. as an indicator of biodiversity. Therefore, fragmentation should be defined from the viewpoint of biodiversity.

The full-text name of the forest fragmentation

indicator is “*Area of continuous forest and of patches of forest separated by non-forest lands.*” Further development of methods and thresholds of distinguishing between continuous forest and patches of separated forest is needed as these were not set up initially.

## 2.2 Habitat fragmentation concepts

Habitat (or forest) fragmentation is a popular buzzword - it is generally considered to be detrimental to biodiversity, but many times without an exact understanding why (Fahrig 2018). The focus of the original habitat fragmentation concept was on the anthropogenic fragmentation of pristine habitats (especially rainforests), a problem identified on a global scale (Woodward & Jacob 2012). However, the forest fragmentation in general (both pristine and managed) is usually considered as one of the most serious threats to biodiversity (Bierregaard et al. 2001), despite the lack of reasons for such an opinion. Actually, in the European cultural landscape, many non-forest habitats may be much more fragmented than forests (for example, grasslands fragmented by forests and arable lands) and this fact is simply accepted, without a special effort to increase the connectivity of these habitats (e.g. via establishing biocorridors). The complexity increases considering the fact that diverse land cover features represent diverse types of barriers for the exchange of genetic information in populations of individual species.

Fragmentation of any habitat consists of the following changes:

- **Breaking** up of one patch of habitat into several smaller patches separated by a matrix of different habitats, which also results in:
  - **decrease in the average size of a habitat patch** (Didham 2010 considers this to be the dominant effect of fragmentation), which may become too small for the survival of viable population, metapopulation or individuals of some species (see chapter 1.2.1),
  - **increase of the isolation** of one habitat fragment from each other and/or isolation of species populations (see chapter 1.2.2),
  - **decrease of the habitat interior**: (ratio of edges' length to the total habitat area will increase, which has a negative influence on some species, see chapter 1.2.3),
  - **decrease in the total area of the habitat** - some authors place this phenomenon as the first, even above the habitat's area breaking up (see chapter 1.2.4.)

- 
- Some authors suggest that fragmentation should include also **other types of habitat pattern change**, such as **perforation** (emergency of patches of a new habitat in the continuous matrix of the original habitat), **shrinkage** (decrease of habitats area without breaking it up) or **attrition** (destruction of some fragments), while the others suggest to consider them separately (Forman, 1995; Collinge, 2009) because their ecological effect is different.

In general, there are two main possible approaches (Fischer & Lindenmayer 2007) of defining and assessing habitat/forest fragmentation:

- **Species-oriented approach** focuses on individual species within a habitat, their responses to habitat fragmentation (e.g. species' ability to survive in smaller patches of a habitat) and their abilities to penetrate barriers of various type (impenetrable

barriers may hamper species migration and exchange of genes within fragmented populations, disturb species' living cycle, etc.). From this viewpoint, there is no "fragmentation in general", each species needs to be assessed separately, because what represents severe fragmentation for one species (or group of species), may be completely harmless for the another.

- **Pattern-oriented approach** is based on land cover and its patterning. In extremes, this approach can be totally independent as for biodiversity, but it may be combined with modelling species occurrences. This approach is more abstract and its link to the real biodiversity is much looser (or even missing) than in the previous approach. However, pattern analyses are more feasible and require less data than the analyses of fragmentation impact on particular species.

## 2.2.1 Decrease in the (average) size of a habitat patch

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Individuals (and populations<sup>1</sup>, if significantly isolated one from each other, see the next chapter) of some species need certain minimum habitat areas for their long-term survival. Reduced patch area reduces food availability, reduces colonisation by missing species, and alters reproductive behaviour of species and their predator-prey or competitive interactions, thus limiting maximum population size. In extreme cases, it increases the risk of population's local extinction (Hanski & Ovaskainen 2000).

Smaller patches are also more vulnerable to catastrophic events as there is an increased

probability that these events would destroy the entire patch leaving thus local populations without a habitat they depend on.

At the community level, reduction in patch area typically results in large changes in species composition (Ewers & Didham 2006a). Different species have differing resource and area requirements, and differing dispersal (migration) abilities. Highly dispersive species are less affected by area reduction, because their dispersal abilities can 'rescue' small populations that would otherwise get extinct in small patches.

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<sup>1</sup> Local small population (e.g. inhabiting one patch of habitat), survival of which depends on migration from other small populations may be considered to be a part of metapopulation (Hanski, Gilpin 1991). A metapopulation go extinct when the rate of extinction of local populations exceeds the rate of migration and recolonization (Margules, Pressey 2000).



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However, the influence of the patch size is heavily species-dependent. Majority of the most iconic large species (large carnivores, ungulates) are definitely not forest species, quite contrary, they are able to live in a mosaic landscapes or even fully in non-forest areas (steppes, tundras, etc.). According to PECBMS,

only 34 of 170 European common bird species are considered forest species, while 39 species are categorised as “farmland” and 96 species are as “other” (species living in a mosaic landscapes or able to survive in both habitats). For small species, the minimum size of a patch is usually small as well.

## 2.2.2 Isolation of fragments and/or populations

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Isolation of habitat patches (fragments) by a matrix (barriers) reduces species’ populations connectivity and decreases their viability. However, geographic isolation (i.e. pattern) is not an overwhelming quality and needs to be interpreted in the light of matrix **permeability for the species** of interest<sup>2</sup>, the dispersal abilities of this species and the time-scale over which effects of isolation might become apparent. The original fragmentation concepts derived from the island biogeography theory is not suitable for very complex human-modified landscapes (Didham 2010).

Population connectivity is vital for gene exchange. If a (meta)population is split into several smaller isolated populations not bearing sufficient genetic diversity, its genetic diversity can be maintained through migration of individuals between patches. If migration is not possible, the species’ population is threatened by inbreeding and genetic drift.

The ability of species to migrate between habitat patches<sup>3</sup> depends on both species’ traits and matrix quality (what habitats or other types of barriers the matrix consists of). This ability then influences populations’ dynamics, species diversity and ecosystem processes in

particular habitat patches (Didham 2010).

In general, there are two types of connectivity: **structural** and **functional connectivity**. Structural connectivity is related to landscape pattern and results from the density and complexity of corridors, the distance between patches, and the structure of the matrix. In contrast, functional connectivity is often defined by the extent to which individual species of interest can move through a matrix (Uezu et al. 2005).

The assessment of structural connectivity (i.e. pattern-based approach) is much more feasible than the species-based approach, which is necessary for the assessment of functional connectivity. However, only the species-based approach can provide a realistic view of the situation in a fragmented landscape. To make this approach more feasible, the assessment of barriers can be narrowed to their impact on key species or umbrella species (or their groups) in the area of interest. The same non-forest habitat may represent impenetrable barrier for some species, other species may cross this barrier with difficulties (risk of being killed by predators, traffic or exhaustion, increased stress), while other without problems.

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<sup>2</sup> Ideally, all species living in a habitat should be taken into consideration, however, it would not be feasible. Therefore, various “key species” or “umbrella species” may be assessed instead.

<sup>3</sup> Habitats of some larger species (e.g. large carnivores, ungulates) may consist of several habitat types, both forest and non-forest.

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For the purposes of an indicator for SFM, the issue of species-specific barriers is too complex, however, some basic principles can be employed (e.g. the existence of green infrastructure).

For example, the penetrability of a barrier for particular species can be assessed based on:

- type of the barrier (e.g. grassland, arable land, waterbodies, high mountains, roads, fences, built-up areas),
- barrier width, height, density (e.g. mesh density of fences), etc.,
- risks to organisms while crossing the barrier (e.g. traffic, predation, exposure to sun/wind, starvation during crossing, etc.),
- existence of corridors and “stepping stones<sup>4</sup>”.

The ability of species to penetrate various types of barriers depends, for example, on its:

- ability to fly, swim or walk, both actively (animals) or passively (seeds/pollen, small animals),
- size (smaller species can penetrate fences, can migrate passively on floating or wind-driven material but they may have problems with long distances,

- ability to find remote patches of suitable habitats, etc.

From the practical forestry viewpoint, barriers between forest patches can be roughly categorised as follows:

- Non-forest habitats (grasslands, arable lands, water bodies, etc.) – the organisms’ ability to cross these habitats can depend on so-called matrix contrast (Didham 2010), i.e. how much the habitats’ environment differs from the forest as well as on species’ abilities. These types of barriers may be both artificial and natural.
- Line structures such as roads, railways, fences – the organisms’ ability to cross them many times depends on the parameters of these structures (e.g. traffic intensity, fence properties, existence of green bridges, etc.). From this viewpoint, forest roads can be considered negligible barriers, as they are rather narrow, often with unsealed surfaces, with very low traffic intensities. Many species use forest roads as a part of their habitat.
- Built-up areas (cities, villages, tourist resorts, etc.).

### 2.2.2.1 Barrier-crossing structures

To allow species to cross barriers of various types, special structures, both artificial and semi-natural, may be used. Optimally, fragmentation indicator should reflect the existence of such structures to promote mitigating fragmentation via special measures. These structures, such as overpasses (e.g. green bridges) and underpasses (e.g. tunnels,

culverts, bridges) increasing permeability of roads and railways, and bio corridors and stepping-stone corridors across inhospitable habitats, cannot be easily identified via remote sensing. Therefore, their inclusion into the fragmentation assessment would require additional external data sources.

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<sup>4</sup> Stepping stones or stepping stone corridors; a series of small, non-connected habitats which are used to allow migration of organisms through providing shelter, food, or rest. Each species (species group) may require different pattern of stepping stones.

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The ambiguous understanding of habitat connectivity and its benefits have resulted also in the debates regarding the question if corridors can increase connectivity (Simberloff

et al. 1992; Beier & Noss 1998). Some authors warn of undesirable effects of corridors, e.g. spreading of invasive species (Proches et al. 2005).

### 2.2.3 Edge effect and forest interior area

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Forest interior is the part of a forest patch, which is not influenced by the edge effect (e.g. penetration of sunlight, wind, dry air and non-forest species from the forest margin). Edge effect occurs at any forest edge, and within a forest it occurs also at the edges of forest patches of a different age (e.g. edge of mature forest and recently felled areas or thickets).

Therefore, this concept is not fully compatible with the decision that recently felled areas are to be considered a forest (see chapter 2.3). There are also natural edges between forest patches and natural non-forest habitats such as waterbodies, rock outcrops, etc.

As a patch size decreases, the relative area of an edge habitat increases, resulting in negative effects on so-called forest-interior (edge-avoiding) species and positive effects on edge-preferring species (Wu 2009). Forest-interior species (sometimes also called old-growth forest species) are those preferring forest-interior microclimate, which is, in general, more stable, shady, less windy, etc. It may be difficult to distinguish forest-interior species from “area-sensitive species” requiring larger patches of forest but not avoiding edges (Villard 1998) or from species preferring trees of certain age or particular species (Imbeau et al. 2003).

Penetration depth of edge effects can vary widely from tens of metres for variables like soil moisture (Laurance et al. 1997) to several kilometres, in cases of survival the most sensitive species in tropical rain forest (Curran et al. 1999). Guidelines for forestry practice<sup>5</sup> usually consider the depth of edge influences from 100 to 250 metres.

Quantification of edge impact has to distinguish between two different components of the edge effect: edge width (i.e. the distance over which a statistically important difference in a variable can be identified between the matrix and the patch) and edge magnitude (i.e. the degree of difference in a variable between patch interior and matrix interior (Didham 2010)).

As large-scale disturbances, creating a shifting mosaic of forest successional stages, have always been natural in temperate and boreal forests (Wu 2009), negative perception of edge effect within these forests is disputable<sup>6</sup>. Therefore, the probability of the existence of species fully dependent on forest interior is quite low in these regions. Moreover, from biodiversity viewpoint, forest edges (and edges in general) are often considered as valuable habitats (Kark 2017) hosting specialised ecotone species.

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<sup>5</sup> E.g. the extension notes issued by the ministries responsible for forests in Canadian provinces:

British Columbia: <https://www.for.gov.bc.ca/hfd/pubs/Docs/En/En21.htm>

Ontario: [http://www.lronline.com/Extension\\_Notes\\_English/pdf/forInterior.pdf](http://www.lronline.com/Extension_Notes_English/pdf/forInterior.pdf)

<sup>6</sup> Báldi (1996) concluded that in temperate forests the diversity of birds increases towards forest edges while in tropical forests it decreases. It may reflect the fact that temperate forests are naturally patchy and their species are adapted to such conditions.

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## 2.2.4 Decrease in the total area of habitat

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As habitat fragmentation inevitably<sup>7</sup> includes some habitat losses (large continuous habitats are divided into several smaller patches of the total area lower than the original “continuous forest”), many authors do not distinguish between the fragmentation itself and the habitat loss.

Other authors suggest that fragmentation definition should be restricted to describing just one of five precise ways in which individual units of habitat are divided (perforation, dissection, fragmentation, shrinkage and attrition<sup>8</sup>; Forman 1995; Collinge

2009) because each of these processes has its own ecological effect. On the other hand, habitat loss and habitat fragmentation are not independent and habitat loss inevitably acts via the change in habitat arrangement (Didham 2010).

The need to consider forest loss in Forest Fragmentation indicator within the framework of pan-European set of criteria and indicators is limited due to the existence of indicator 1.1 (Forest area) monitoring area of forest gains and losses.

## 2.2.5 Defining fragmentation as a process

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Articles reviewed in this study do not suggest any definition comprehensively reflecting all the above-mentioned aspects of habitat fragmentation.

Quite contrary, standard habitat fragmentation definitions just describe fragmentation as a process that breaks up the habitat into fragments.

*Habitat fragmentation is defined as a process during which large expanse of habitat is transformed into a number of smaller patches of smaller total area isolated from each other by a matrix of habitats unlike the original (Fahrig 2003).*

Wikipedia (the English version) provides more explicit definition:

*Habitat fragmentation describes the emergence of discontinuities in an organism's preferred habitat, causing population fragmentation and ecosystem decay<sup>9</sup>.*

This definition defines fragmentation from the viewpoint of an organism (e.g. one individual, species or community) and ecosystem (i.e. mutually interconnected organisms and their environment), which can be considered to be useful approach. The source of this definition is unknown.

The **CBD's** ad hoc Technical Expert Group on Forest Biological Diversity developed for its own Report an **indicative definition of forest fragmentation**:

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<sup>7</sup> Inevitably in case of large natural habitats. If we consider also afforestation or natural forest expansion on agricultural land, then, in European conditions, we can imagine the fragmentation of some forest patches without decrease in total forest area when the losses would be outweighed by gains.

<sup>8</sup> Perforation refers the emergence of matrix patches within still continuous habitat, dissection means division of continuous habitat into two parts by some linear structure (e.g. road), shrinkage refers to the reduction of areas of the already existing patches (number of patches remains unchanged), and attrition refers to destruction of some patches.

<sup>9</sup> [https://en.wikipedia.org/wiki/Habitat\\_fragmentation](https://en.wikipedia.org/wiki/Habitat_fragmentation)

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*[Forest fragmentation is defined as] any process that results in the conversion of formerly continuous forest into patches of forest separated by non-forested lands<sup>10</sup>.*

This definition is of the same type as the above-quoted definition (Fahrig 2003) of habitat fragmentation, focusing on geometric aspect of fragmentation, while the biodiversity

viewpoint is not included. However, considering the applicability in the pan-European context, available data sources and methods of their interpretation/processing allow only the assessment of pattern (geometry), and thus this definition is sufficient for the purposes of the pan-European indicator for SFM.

## 2.2.6 Threshold between a continuous forest and a patch

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The full-text name of the forest fragmentation indicator refers to an *area of continuous forest and of patches of forest separated by non-forest lands*. It suggests having defined some thresholds, to distinguish between a patch (a fragment) and a continuous forest. However, the literature reviewed within the framework of this pilot study does not provide explicit thresholds for such discrimination. Breaking up the originally larger area of habitat into two or more parts is always considered to be fragmentation, regardless of the size of the original forest and of the resulting patches.

There would be a possibility to define the threshold based on the existence of some

(predefined) minimum area of forest interior within a patch (i.e. a patch would have to be large enough to contain predefined area of forest interior after the edges were subtracted). However, the width of the margin considered as forest edge can vary from tens of metres to several kilometres based on the assessed variable (Laurance et al. 1997, Curran et al. 1999). For this reason, this possibility is only theoretical.

To avoid introducing a single (unsubstantiated) threshold, for the purpose of the pan-European reporting, the experts decided to use scale of five patch-size classes (see chapter 3).

## 2.3 Recently felled forest areas and fragmentation

There is quite a widespread opinion that forest felling results in fragmentation. Especially clearcut areas are often considered as fragmentation, forming barriers preventing migration of forest species. However, there are several arguments against this approach:

- Temporarily unstocked areas (forest clearings) and early stages of even-aged forest (lower than 5 meters and/or covering less than 10% of land) are considered to be forest by the FAO FRA definition of forest<sup>11</sup>, (adopted also by FOREST EUROPE),

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<sup>10</sup> <https://www.cbd.int/forest/definitions.shtml>

<sup>11</sup> Forest: Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

Note 2: It also includes areas that are temporarily unstocked due to clear-cutting as part of the forest management practice or natural disasters, and which these are expected to be regenerated within 5 years. Local conditions may, in exceptional cases, justify that a longer time frame is used.

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therefore, they should not be considered as a non-forest land.

- Forest clearings and early stages of even-aged forest represent just temporary and rather short-term stages of the existence of forest, that return to closed forest higher than 5 metres usually sooner than causing biodiversity decline.
- From the ecology viewpoint, forest clearings and early stages of even-aged forests are rather similar to some types of patches naturally occurring in forests as an inevitable part of patch dynamics (shifting mosaic). These patches provide shelter (young thickets) or food (herbaceous and shrubby clearings) for many species.
- For the majority of species, forest clearings do not represent significant barriers (matrix

contrast is low) because, for example, soils remain almost the same as in forest, stumps and other types of deadwood are usually present allowing thus temporary survival of many forest species.

Indeed, the recently felled areas reduce the extent of forest interior and represent barriers for specialised forest-interior species. However, the same applies to natural gaps (e.g. windblown and burned areas) in boreal and temperate forests, which also represent barriers for forest-interior species. For the species closely dependent on specific tree species (or specific tree microhabitats), the parts of the forest formed by other tree species (or without necessary microhabitats) may represent a barrier equally important as non-forest land.

## 2.4 Natural versus artificial fragmentation

Fragmentation can be caused by both natural and artificial factors. While human-induced fragmentation is broadly recognised and sometimes over-estimated, natural fragmentation (resulting e.g. from natural disturbances such as large windthrows, forest fires, climate-change) is many times overlooked, despite the effects of both of them can be very similar. It is broadly assumed that organisms are evolutionary adapted to natural mosaic

landscapes (e.g., through traits that confer increased dispersal ability, or decreased resource specialisation), but this is not typical in landscapes fragmented by recent human influence (Didham 2010). However, many European landscapes have become patchy centuries ago, and gradually become adapted through the selection of species tolerant to this patchiness (the probability of surviving of intolerant species in such landscapes is low).

## 3 Setup of the Forest Fragmentation Indicator

The preceding pan-European indicator - Forest Landscape Pattern - covered a few forest landscape fragmentation patterns (core natural, mixed natural, some natural) aimed to identify extent to which forest land is surrounded by natural, semi-natural, agricultural or artificial features; in addition, this was complemented by forest connectivity index considering the permeability between forest patches, classified into categories (poorly connected, intermediate, highly connected). The principle of this indicator was implemented also into Streamlined European Biodiversity Indicators (SEBI) - indicator on the fragmentation of natural and semi-natural areas<sup>12</sup>.

Considering the full-text name of the Forest fragmentation indicator in the set of *Updated pan-European Indicators for SFM* - "Area of continuous forest and of patches of forest separated by non-forest lands", as well as the experience from implementation of Forest landscape pattern as preceding indicator, the work of the FOREST EUROPE Expert Group on the Implementation of the Updated pan-European Indicators for SFM led to the following findings for the implementation of this indicator:

- **Data source** - Corine Land Cover (CLC) should be used as default input data source; CLC are the only nationally produced time series (1990, 2000, 2006, 2012, 2018) of land cover maps, employing harmonized methods and legend in the region;
- **Forest as land cover** - four CLC classes should be included; 311 - Broadleaved forest, 312 - Coniferous forest, 313 - Mixed forest, 324 - Transitional woodland-shrub (the formations for which it is applicable largely comply with forest definition);
- **Methods** - Forest Fragmentation should be characterised by the extent of forest in assessment unit, expressed by the Forest Area Density at Fixed Observation Scale (FAD-FOS); FAD represents an intuitive, yet comprehensive characteristic. FAD should be complemented by Accounting providing geographic maps and derived statistics in five forest patch size classes (100, 1,000, 10,000, 100,000, > 100,000 hectares);
- **Scale** - a fixed observation scale of ~500 hectares was suggested (corresponding to 23x23 pixels of CLC data with spatial resolution of 100m);
- **Fragmentation classes** - two classes should be distinguished: continuous forest and patches of forest separated by non-forest lands; classes comply with full name of indicator; a threshold 40% for FAD was suggested to distinguish between continuous forests and patches of separated forests;
- **Generalization** - single fragmentation class should be assigned to each forest patch; the arithmetic average of FAD values at pixel-level of the given forest patch should be considered (average per patch);

<sup>12</sup> <https://www.eea.europa.eu/data-and-maps/indicators/fragmentation-of-natural-and-semi-1/assessment-1>

- 
- **Trend reporting** - indicator should be reported at country and regional level, in a form of tabular statistics on forest fragmentation classes and spatially explicit maps on trend derived from the selected datasets;
  - **Status reporting** - indicator should be reported at country and regional (EU-28, Europe) level, in a form of tabular statistics on forest fragmentation classes and spatially explicit maps on status derived from the selected datasets;

Following the principles mentioned in chapter 2.3, the FOREST EUROPE Expert Group on the Implementation of the Updated pan-European Indicators asked to consider recently felled areas as a part of forest and thus not contributing to fragmentation within the framework of the fragmentation indicator; for the purpose of forest fragmentation assessment this is reflected in inclusion of CLC class 324 (Transitional woodland-shrub) into the forest land cover.

For the implementation of the Forest Area Density method, to limit the classification of the adjacent forest patches as separated forests if these are close to large patches of forest, a threshold 40% for FAD was agreed to distinguish between continuous forests and patches of separated forests. As a result of the

proposed setting, forest locations with forest area represented less than 40% (FAD<40%) in their ~500 ha surroundings were agreed to be classified as fragmented (separated), while those with higher density are considered “continuous”, regardless the sizes of particular patches.

For the implementation of the patch Accounting method, the experts agreed on the use of five patch-size classes (1-100 ha, 101-1,000 ha, 1001-10,000 ha, 10001-100,000 ha and > 100,001 and more), in order to avoid introduction of a single (unsubstantiated) threshold.

This approach combining two methods will provide a comprehensive information on the forest fragmentation in a particular country or region. Details of technical implementation of Forest Area Density method at fixed observation scale including average per patch generalization and of Accounting method can be found in dedicated algorithm technical basis document (Vogt et al. 2019).

To support the implementation of Forest Fragmentation indicator, the European Commission – Joint Research Centre developed the tool for data analysis - the command-line version of GuidosToolbox (GTB), the GuidosToolbox Workbench (GWB, Vogt et al. 2017)<sup>13</sup>.

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<sup>13</sup> <https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/> & <https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/>



## 4 Data Availability

The CORINE Land Cover (CLC) inventory was initiated in 1985 (reference year 1990). Updates have been produced in 2000, 2006, 2012, and 2018. It consists of an inventory of land cover in 44 classes. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena<sup>14</sup>.

CLC covers the following territories:

33 territories in 1990 products - Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, France, Guernsey, Gibraltar, Croatia, Hungary, Ireland, Italy, Jersey, Lithuania, Luxembourg, Latvia, Monaco, Montenegro, Malta, Netherlands, Poland, Portugal, Romania, Serbia, Slovenia, Slovakia, San Marino, Turkey, Vatican City.

44 territories in 2000 and later products: Albania, Austria, Bosnia and Herzegovina, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Guernsey, Gibraltar, Croatia, Hungary, Ireland, Iceland, Italy, Jersey, Liechtenstein, Lithuania, Luxembourg, Latvia, Monaco, Montenegro, North Macedonia, Malta, Netherlands, Norway, Poland, Portugal,

Romania, Serbia, Sweden, Slovenia, Slovakia, San Marino, Turkey, United Kingdom, Vatican City, Kosovo (EEA-39 + Gibraltar, Guernsey, Jersey, Monaco, San Marino, Vatican City).

The following complementary data were identified as possible inputs for the forest fragmentation assessment (e.g. for countries not covered by CLC):

- Copernicus HRL<sup>15</sup>, 20m spatial resolution (Copernicus HRL 2012 and 2015 coverage is the same as CLC2012),
- global forest cover maps<sup>16</sup>, annual data from 2001 to 2015, 30m spatial resolution,
- ESA Climate Change Initiative (CCI) land cover maps<sup>17</sup>, annual data from 1992 to 2015, 300m spatial resolution,
- forest map of Russia, 230m resolution,
- national spatial data.

The analytical tools developed at European Commission - Joint Research Centre - the command-line version of GuidosToolbox (GTB)<sup>18</sup>, the GuidosToolbox Workbench (GWB)<sup>19</sup>, are freely available.

<sup>14</sup> <https://land.copernicus.eu/pan-european/corine-land-cover>

<sup>15</sup> <https://land.copernicus.eu/pan-european/high-resolution-layers>

<sup>16</sup> <https://www.globalforestwatch.org/map/>

<sup>17</sup> <https://www.esa-landcover-cci.org/?q=node/175>

<sup>18</sup> <https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/>

<sup>19</sup> <https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/>

## 5 Data Reliability

The national CLC databases are produced by the Eionet network of National Reference Centres Land Cover (NRC/LC), coordinated and integrated by EEA. CLC is produced by the majority of countries by visual interpretation of high resolution satellite imagery. In a few countries semi-automatic solutions are applied, using national in-situ data, satellite image processing, GIS integration and generalisation<sup>20</sup>. CLC represents land cover map of Europe based on standard methodology and nomenclature, striving to provide consistent information on land cover across Europe.

The accuracy of FAD and Object Accounting methods implemented for monitoring of forest fragmentation depends on the accuracy of input data. The reinterpretation approach in LUCAS project showed the total reliability of CLC2000 at 87.0 +/- 0.8 %, concluding that the 85 % accuracy requirement specified in the Technical Guidelines of CLC2000 was fulfilled. The two largest CLC classes (arable land and coniferous forest) were estimated to have a high level of reliability (between 90 and 95 %). Two other agricultural classes also enjoyed a high level of reliability: agro-forestry and permanently irrigated land. The lowest class-level reliability (below 70 %) was obtained for the sparse vegetation class, which highlights difficulties in interpreting this category. The analysis revealed that subjectivity of

photointerpretation could be noticed in 18 % of the samples. The most subjective CLC classes are, as follows: agriculture with significant amount of natural vegetation, transitional woodland, shrub, complex cultivation patterns and mixed forest.<sup>21</sup>

Although the sets of CLC classes and definitions apply across the whole assessed territory, the quality of classification and legend interpretation depend on individual interpreters at national level. The overall expected 85% classification accuracy and results of the above mentioned accuracy assessment suggest that CLC classification as well as any derived product have accuracy limitations.

The standard error for the difference between two assessments is larger than the standard error of either assessment. The uncertainty of the difference between two assessments is greater than the uncertainty in either assessment, but less than their sum. With equal sample size, standard error of the difference of two assessments is computed as the square root of the sum of the squares of the standard errors of individual assessments.

The changes detected in derived products as forest fragmentation characteristics should be considered in this context and changes of less than 15% are only indicative.

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<sup>20</sup> <https://land.copernicus.eu/pan-european/corine-land-cover>

<sup>21</sup> [https://land.copernicus.eu/user-corner/technical-library/technical\\_report\\_7\\_2006.pdf](https://land.copernicus.eu/user-corner/technical-library/technical_report_7_2006.pdf)

## 6 Feasibility

The increasing public availability of satellite imagery (Landsat, Sentinel) allows for spatial analysis of land cover. CLC is integrated into Copernicus Land Monitoring Service. The vast majority of data and information delivered by the Copernicus Space infrastructure and the Copernicus services are made available and accessible to any citizen and any organisation around the world for free, full and open access basis. Copernicus Data and Information Services are available through the DIAS or the Conventional Data Hubs.<sup>22</sup>

Analytical tools are also publically available. The GuidosToolbox and command-line version GuidosToolbox Workbench are available for free download at respective websites<sup>23</sup>. Recent availability of data and analytical tools allow for the implementation of this indicator; results of pilot assessment can be found in

Vogt et al. 2019b<sup>24</sup>. However, future land cover products cannot be reliably foreseen. In the period 2000-2018 the CLC classifications were produced in six years intervals and more frequent production of regionally harmonized and nationally validated time series of products is not expected.

Analysis of diverse national inputs or products would reduce mutual comparability of results of the forest fragmentation assessment.

Forest fragmentation characteristics suggested for the Forest Fragmentation indicator are pattern oriented, simple and understandable, based on geometry of areas classified as forests. However, their interpretation from the viewpoint of impact on biodiversity remains limited due to diversity of forest species and their requirements on their habitats.

## 8 Conclusions

Forests and woody vegetation in other wooded land, thanks to their longevity, structural complexity and special microclimate, represent habitat for many plant and animal species. Often diversified vertical structure and plant species mixture form an environment for the survival of diverse animal species.

Forests and woody vegetation formations form stabilizing landscape elements, especially in highly populated areas characterized by intensively managed anthropic landscape features with limited conditions for survival of many species.

The overall interest to manage land in a sustainable manner has led to the development of regional concept of SFM within MCPFE process. Implementation of SFM is monitored by a set of regularly revised indicators for SFM, covering relevant issues of sustainability in forest management.

Results of this pilot study may support evaluation of the relevance of Forest fragmentation indicator for SFM in the next revision process of the pan-European indicators for SFM.

<sup>22</sup> <https://www.copernicus.eu/en/access-data>

<sup>23</sup> <https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/> & <https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/>

<sup>24</sup> <https://doi.org/10.6084/m9.figshare.c.4779500>

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Isolation of habitat patches (fragments) by a matrix of barriers may reduce species' populations connectivity and thus decrease their viability. Building on this principle, a simplified indicator was suggested to monitor trends in forest fragmentation expressed in terms of forest area density and distribution of forest patches in areal classes.

Recent availability of spatially explicit satellite data and analytical tools allow implementing an indicator on spatial distribution of forests. Corine Land Cover (CLC) has been identified as a default input data source for forest fragmentation indicator as CLC classifications are the only nationally produced time series (1990, 2000, 2006, 2012, 2018) of land cover maps, employing harmonized methods and legend in the region. Although in the period 2000-2018 the CLC classifications were produced in six-year intervals, the existence and quality of future land cover products cannot be reliably foreseen, alternative data sources are also considered, including national datasets on spatial distribution of forests.

The sets of CLC classes and definitions apply across the whole territory covered by CLC products. Anyway, the quality of classification and legend interpretation depend on individual interpreters at national level. It must be kept in mind that image interpretation has limitations, the overall expected CLC classification accuracy is 85% and limits also the reliability of the derived products and their use for evaluation of SFM.

Designed forest fragmentation characteristics - area of continuous forest and of patches of forest separated by non-forest lands, expressed by means of forest area density with threshold 40% (applied to the average per patch), assessed at fixed observation scale

-500 ha, and number of patches in 5 patch-size classes with thresholds 100, 1,000, 10,000 and 100,000 ha - are pattern oriented, simple and understandable, based on geometry of areas classified as forests, allowing for indication of trends in spatial distribution of forests over landscapes. Such implementation approach for the Forest fragmentation indicator was proposed considering that use of 100 meters resolution forest mask and assessment of forest area density at ~500 hectares observation scale may provide enough detail and limit excessive generalization at the national or European level, and that the 40% forest density threshold corresponds to forest occurrence with limited isolation for many forest related species. Information on size of forest patches expressed by assignment to 5 patch-size classes with 100, 1,000, 10,000 and 100,000 ha thresholds is even more intuitive, anyway, it should be interpreted carefully as the distance of patches is not considered in this categorization.

Still, the interpretation of impact on biodiversity by components of Forest fragmentation indicator remains limited due to the diversity of forest species and their requirements on their environment. In general, the appearance of new forest patches or extension of existing forest patches in areas with low forest density may result in positive effects on overall biodiversity and abundance of forest related species in the area. On the other hand, in areas with high forest cover, such effect of forest extension may be limited, also some conversion of larger forest patches to smaller may be marginal or compensated by new appearance of forests nearby (see e.g. Fahrig 2018). It should be also considered, that highly fragmented forests may pose difficulties to their management.

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<https://www.copernicus.eu/en/access-data>  
<https://doi.org/10.6084/m9.figshare.c.4779500>

### ***List of acronyms***

CLC – Corine Land Cover  
DIAS – Copernicus Data and Information Access Services  
EEA – European Environmental Agency  
ELM – Expert Level Meeting (FOREST EUROPE meeting at the level of experts)  
ESA – European Space Agency  
FAD – forest area density  
FAO – The Food and Agriculture Organization of the United Nations  
FOREST EUROPE – The Ministerial Conference on the Protection of Forests in Europe  
FOS – fixed observation scale  
FRA – Global Forest Resources Assessment  
GIS – geographic information systems  
GTB – GuidosToolbox (<https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/>)  
GWB – GuidosToolbox Workbench (<https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/>)  
HRL – high resolution layers  
LUCAS – Land use and land cover survey  
MMU – minimum mapping unit  
PECBMS – Pan-European Common Birds Monitoring Scheme  
SEBI – Streamlined European Biodiversity Indicators  
SFM – sustainable forest management

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