EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate D – Sustainable Resources
Bio-Economy Unit

Measuring *Forest Spatial Pattern* with mathematical morphology.

Available in the free software *GuidosToolbox*. This is a living document, please check for the latest version at: **https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/**

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1. Background

Spatial patterns of forest patches are usually summarized in patch-based metrics. This type of metrics suffers from intrinsic limitations valid for all summary indices: a) they provide a single average value only and do not account for the variability of the feature under evaluation, and b) they cannot provide any spatially explicit information. Moreover, patch-based metrics cannot account for the spatial configuration of the forest patches in the landscape. For example, when calculating forest patch attributes, the distance between and/or the spatial aggregation of individual forest patches is not accounted for. Yet, these features are a key aspect in forest maps and of high importance for landscape planning and policy making. While summary statistics and single value indices can always be derived from a given map, they do not permit the localization of hotspots, nor can they describe the spatial heterogeneity of the forest patches in a given landscape or country. Due to the lack of spatial information, single value indices also tend to average out geographic variations. For example, forest growth in the western part of a country and loss in the eastern part may not show up in a total forest area indicator.

The analysis of a spatial forest map provides the basis for the derivation of spatial forest attributes that cannot be derived from statistical forest data or NFI plot-data alone.

Scope of this report and for consideration:

Illustration of a map analysis methodology (MSPA: Morphological Spatial Pattern Analysis) to describe and measure forest pattern attributes. The methodology outlined in this document has been developed by the JRC and is used by many public entities for the reporting on forests and/or other land cover types (i.e. USDA-Forest Service (USFS) for official national reporting on the state of forest and grasslands; Brazilian Agricultural Research Corporation (Embrapa); US-EPA: national green infrastructure assessment, EnviroAtlas). The methodology provides a map product together with a statistical summary for a series of forest pattern classes including different types of openings within the forest area and the detection of connecting pathways. The latter is a unique feature of MSPA, not available in any other image processing software, and of key importance in questions of landscape connectivity, restoration, risk assessment, habitat suitability and biodiversity studies.

2. Morphological Spatial Pattern Analysis (MSPA)

2.1 The methodology

Details on the methodology are described in [Soille & Vogt, 2009](#). In short, MSPA is a customized sequence of mathematical morphological operators targeted at the description of the geometry and connectivity of the image components. Based on geometric concepts only, this method can be applied at any scale and to any type of digital images in any application field.
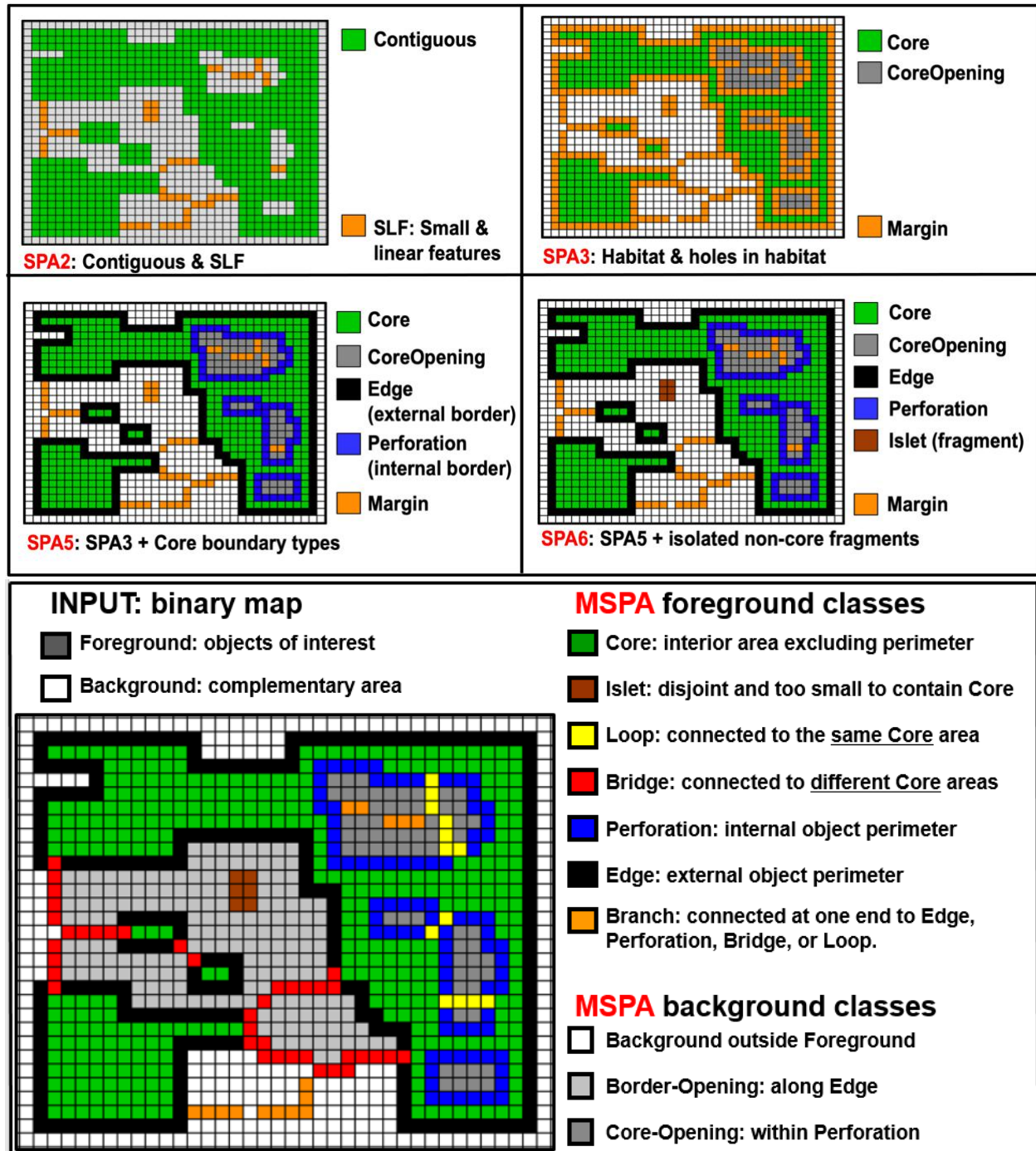

Figure 1: Top: Simplified Pattern Analysis (SPA2/SPA3/SPA5/SPA6) including detection of holes inside Core and providing a total of 2 up to 6 classes. SPA cannot detect connecting pathways and the EdgeWidth is fixed to 1 pixel.
Bottom: MSPA: Up to 25 foreground and background feature classes. MSPA detects connecting pathways and can be fine-tuned in many ways via the four MSPA processing parameters.

The top panel of Figure 1 shows the Simplified Pattern Analysis (SPA), a down-scaled version of the original MSPA, providing 2, 3, 5 or 6 MSPA-classes plus Core-Opening. The bottom panel shows a graphical summary of the full version of MSPA applied to a binary mask and visually resulting in 7 foreground and 3 background pattern classes. With this setup, the user can choose the appropriate (M)SPA version providing adequate amount of detail for a given application. While the SPAx versions can detect up to 6 different morphological classes the full MSPA is much more configurable: provision of up to 25 different classes, apply the 4- or 8-connectivity rule for the foreground pixels and define edge widths larger than 1 pixel.

For example, when applying the full MSPA version to a binary forest mask the foreground (forest) is divided into seven MSPA classes: Core, Islet, Perforation, Edge, Loop, Bridge, and Branch, while the Background (nonforest) is divided into three classes: Core-Opening (Background inside Core), Border-Opening (Background along Foreground boundary) and Background outside of Foreground. All morphological pattern analysis schemes conduct a segmentation of the input image pixels. The result are mutually exclusive pattern classes which, when merged, exactly correspond to the initial binary mask.

Many more features and application examples can be found on the MSPA-website and in the MSPA-Guide, which is included in the GuidosToolbox software. MSPA examples on European or Global scale can be browsed in GoogleEarth following the instructions at the bottom of the GuidosToolbox website here.
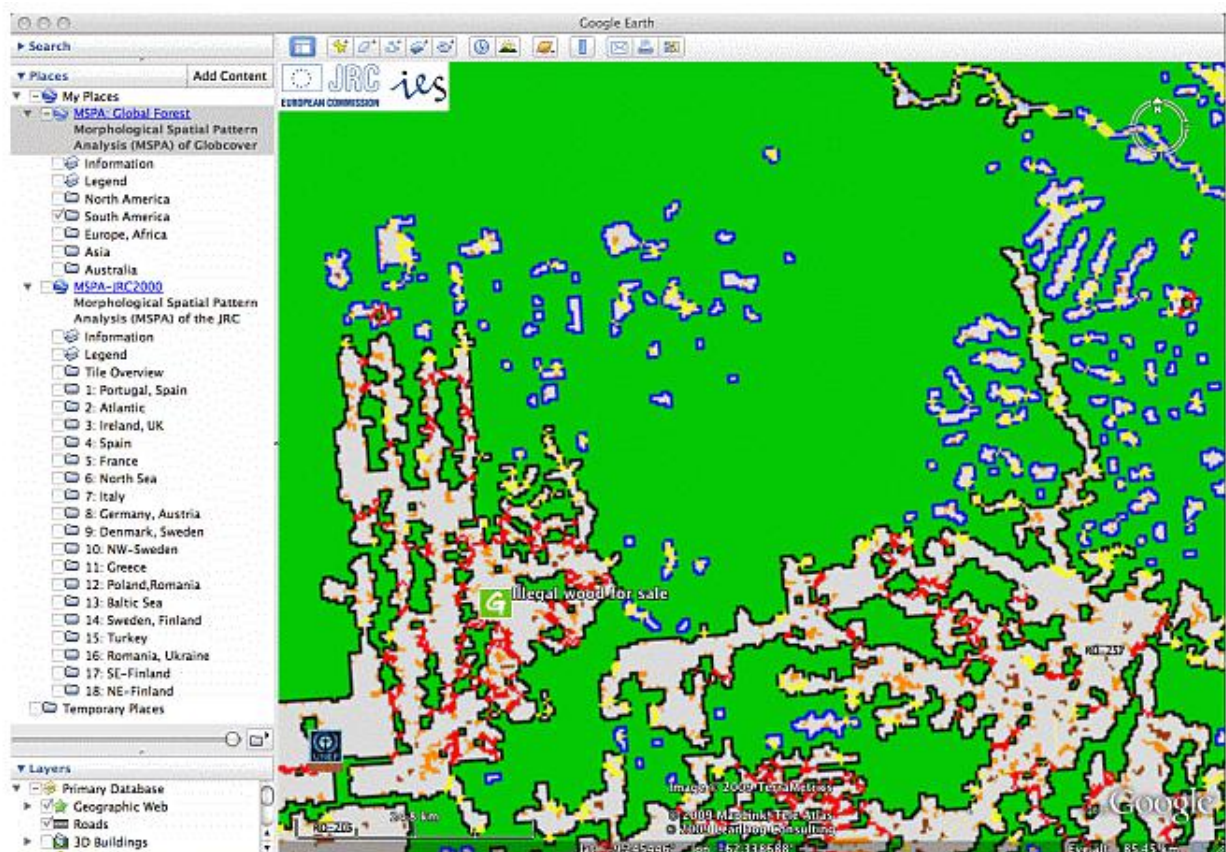

Figure 2: MSPA example overlay in GoogleEarth showing deforestation in forest patterns in the Amazon, Rondonia, Brazil. Additional MSPA examples are available on the website: https://forest.jrc.ec.europa.eu/en/activities/lpa/mspa/

The purpose of this document is to provide a short summary of MSPA-related output products for reporting on the state of forest. However, it can be equally applied to any other land cover type or in general, to any binary mask in digital image processing.

2.2 The input data:

The input image for the (M)SPA analysis must be a binary raster map. It must have the values 1 byte for background (nonforest), 2 byte for foreground (forest) and it may have the value 0 byte to mask missing data (i.e. clouds, ocean or no-data area).

2.3 The output data:

The result of the (M)SPA analysis is a graphical image and optional statistics featuring:
1. **Visual result:** (GeoTiff) image having the identical coverage as the input forest map and showing various forest pattern classes, background classes, and no-data (if present).
2. **Numerical result:** Depending on the chosen (M)SPA settings up to 25 unique classes describing forest pattern, connectivity and area of openings enclosed by forest.
3. **Statistical summary:** indices and proportions for the different (M)SPA classes.

The next section will illustrate the MSPA methodology on an example forest map located near Göttingen, Germany.

3. Example application

This section illustrates features and output examples of the MSPA analysis. The methodology can be applied in the same way for any other definition of a forest map and at local, regional, or national scale. The example below is just indicative to show the features of MSPA.
All image processing was done in GuidosToolbox. The following images are screen snapshots, they can be reproduced by using the image *input.tif* included within GuidosToolbox.

From the zoom-in of the MSPA image in Figure 3, one can see the different forest pattern types. Of specific interest could be the size, number and locations of Perforations within intact core-forest or the location of forested pathways (Bridges) providing connectivity between different Core forest areas. The option to divide Core forests into user-selected size classes of small/medium/large patches facilitates getting an overview about the location and the size distribution of the existing core forest patches.
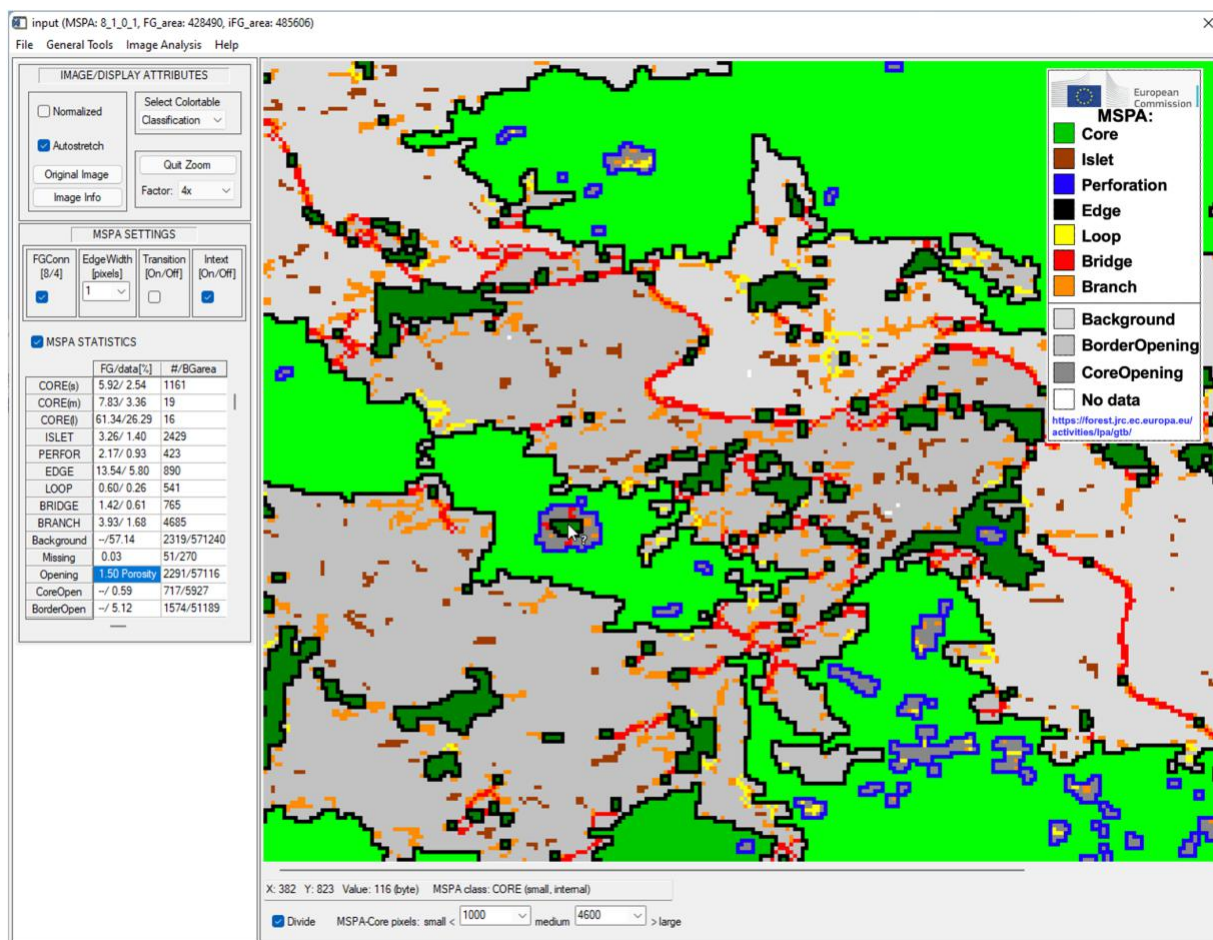
Figure 3: MSPA example of a forest map showing a zoom-in on connecting pathways (Bridge - red), Perforations (blue) and isolated forest fragments (Islets - brown). The left bottom panel shows the statistical summary for the entire image; the panel below the viewport allows setting user-driven thresholds for the division of Core-forests into small/medium/large sized Core-forest strata (3 green tones).

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MSPA results using:
input (MSPA: 8_1_0_1, FG_area: 428490, iFG_area: 485606)

CORE(s)  <  1000 CORE(m)  <  4600 CORE(l)
   MSPA-class [color]:  FG/data pixels [%]  #/BGarea
=================================================================
      CORE(s) [green]:        5.92/ 2.54      1161
      CORE(m) [green]:        7.83/ 3.36      19
      CORE(l) [green]:       61.34/26.29      16
        ISLET [brown]:        3.26/ 1.40      2429
  PERFORATION [blue]:         2.17/ 0.93      423
         EDGE [black]:       13.54/ 5.80      890
         LOOP [yellow]:       0.60/ 0.26      541
        BRIDGE [red]:         1.42/ 0.61      765
      BRANCH [orange]:        3.93/ 1.68      4685
   Background [grey]:          --/57.14      2319/571240
      Missing [white]:        0.03            51/270
      Opening [grey]:    1.50 Porosity        2291/57116
Core-Opening [darkgrey]:      --/ 0.59        717/5927
Border-Opening [grey]:        --/ 5.12        1574/51189
```

Table 1: Example of statistical summary from the full image in Figure 1.

Table 1 provides a statistical summary of the different pattern class types. In general, the image pixels can be divided into Data+Missing = (Forest+Nonforest)+Missing. From the second line we find that the total forest area amounts to 428,490 pixels and the integral forest area =

forest+openings is 485,606 pixels. The MSPA statistics shows simple statistics of the seven forest MSPA classes, like the percentage (central column: number of class pixels per foreground area and per data area) and its frequency (right column: number of unique objects of the given class) as well as statistics on forest openings. For example, statistics on isolated small forest fragments (Islets), which are too small to contain Core area:

ISLET: 3.26% of the forest area or 1.40% of the data area (= Forest+Nonforest) are Islet pixels. There are 2429 Islets (regardless of their individual size) in this image.

Large Core: There are 16 large Core patches (> 4600 pixels) accounting for 61.34% of the total forest area.

Perforation: 2.17% of the forest area are Perforation pixels. There are 423 Perforations in the image and the background area enclosed by Perforation pixels, the Core-Openings, is 5927 pixels.

Opening: There are 2291 openings in the forest area with a total area of 57116 pixels. 717 of the 2291 openings are Core-Openings within the Core area of the forest covering a total area of 5927 pixels (area inside of Perforations). The remaining 1574 openings are Border-Openings (see Figure 1, bottom panel) located along the outside forest boundary (Edge) and covering a total area of 51189 pixels.

Porosity: Measures the degree of core-openings inside contiguous forest area.

$Porosity = 100 - (\frac{Contiguos}{Internal} * 100)$, with Contiguous = Core+Edge+Perforation and Internal = Contiguous+Core-Openings. Porosity is 0 % if the forest has no core-openings at all.

The maximum image dimension for MSPA processing depends on the available memory. If the input image is larger than the supported dimensions an automated buffered tiling procedure (MSPA-Tiling) can be selected. It will cut and process buffered sub-tiles and reassemble them into the final full-dimension image.

Motivation/Purpose: A user or policy maker may be interested to detect geographic areas where larger Core-forest areas or many small-scale features are present. Or, in the case of risk assessment or restoration projects, locating areas having connecting pathways between existing larger Core-forests could be of importance because the conservation of these connecting pathways may be crucial to maintain an existing network structure. Alternatively, a fragmentation assessment may include locating and quantifying the number of perforations within intact core-area as well as detecting and measuring the total area of the different types of openings within the forest area.

Note: The full version of the MSPA analysis can be fine-tuned to provide an Edge-width larger than the default 1 pixel, apply the 4- or 8-connectivity rule for the forest pixels and many more settings, which are beyond the scope of this document. All processing details are outlined in the MSPA-Guide provided with the software. Within GuidosToolbox, the MSPA result can be further processed to rank the importance of each MSPA-detected connecting pathway for the network connectivity.

In general, morphometric information on forest coverage including perforations and especially connecting pathways (Bridges) provide essential information to any connectivity related study such as fire or pest-spread simulation models, impact assessments in simulated land cover changes, land cover planning, habitat suitability, conservation and restoration studies.

The explicit assessment of forest pattern is also needed for the monitoring and progress evaluation of policy programs.

4. Discussion

This document describes a methodology for reporting on spatial pattern. The approach is based on measuring morphometric attributes of image objects including detecting perforations and connecting pathways. The (M)SPA concept provides a concise summary of spatial and statistical information on forest cover attributes going beyond the typical forest information on forest area and single value patch indices. The additional information from (M)SPA can be crucial for the definition, monitoring and evaluation in policy making and land management.

The morphological pattern assessment scheme provides:
- **Generic concept:** The methodology is based on geometric principles only. As such, it can be applied to any kind of forest raster maps, independent of the definition of forest and the spatial resolution of the forest map. In contrast to many existing patch-based single value indices, the outlined methodology provides more statistics on patterns details and additionally a spatially explicit map product including connecting pathways.

- **Forest pattern classes:** The intuitive naming scheme (see Figure 1) can be easily communicated and has a direct relation to habitat and biodiversity related studies. Core forest may be directly assigned to habitat, Bridges to connectors, etc.

- **Forest pattern statistics:** The statistics provide a concise summary of the morphological pattern classes in a tabular format with details on area, percentage and frequency of occurrence for each pattern class.

- **Forest pattern maps:** The map product provides additional spatial information, which cannot be retrieved from indices and statistics: A geographic map of forest pattern classes is not only visually appealing but it permits localizing hotspots of fragmentation, which is a crucial information for planning and risk assessment. Moreover, comparing maps over time can show where and in which way forest patterns change, or how a given forest network has changed over time. This information is an essential requisite to measure progress or the overall effectiveness of political directives; for example, if a conservation policy aimed at improving connectivity between habitat areas in protected sites was successful or not.

- **5 MSPA versions:** By providing 5 versions of MSPA the user can chose the most appropriate (M)SPA version to best focus on the key pattern aspects for his application. It also allows the user understanding the methodology and the different pattern classes by starting with a simple analysis (SPA2), then adding additional features (SPA3/SPA5/SPA6), up to the full version of MSPA with all configuration and processing options.

- **Communication:** With clearly defined morphometric feature classes (M)SPA provides geographic as well as statistical summary information which is easy to communicate. The pattern assessment contributes to answering questions like:
  - **State Analysis:** Where are core areas of intact forests and where is forest sparse? What are the proportions of core and other feature classes in different administrative units/counties or ecological regions of the country?
  - **Trend Analysis:** Where and how much has the area coverage and its pattern components changed over the past decades? How are the trends, and what can

be expected for the future? Compared to previous decades, how much forest area do we have and what are its pattern class contributions today?

➢ **Connectivity:** Is the network of forest patches well connected? Where are core habitats less spatially intact and what is the overall degree of porosity? Do connecting pathways exist between major forest patches and if so, where are they exactly?

➢ **Monitoring & Assessment:** How strong was the impact of a specific political directive or planning program in the targeted area? How big is the change outside of the monitored region? Does the result of the directive merit the money spent? With these findings, what are the implications for future planning and which areas should be targeted first?

5. Conclusions

The (M)SPA pattern analysis is available in the free JRC software *GuidosToolbox*. The software can be downloaded and used by anybody and for any kind of analysis. All data analysis schemes in GuidosToolbox are based on geometric principles, which permits processing (forest) maps of any kind, independent of the definition of forest and/or the spatial data resolution.

With the outlined setup, and the availability in a free software, each user can test (M)SPA and its settings on their own data. Additional comments:

- A *forest - nonforest* raster map as described in this document is of generic nature. It can be derived from any source such as airborne or satellite or NFI data, rasterizing a vector map, or plot data.
- The definition of *Forest* can be based on land *use* or actual land *cover.* For example, non-stocked forested land can still be defined as Forest even if it appears as nonforest in satellite scenes.
- The user can customize the MSPA analysis to his requirements by modifying 4 dedicated processing parameters detailed in the [MSPA Guide](#).

In addition to the outlined pattern analysis schemes GuidosToolbox provides dedicated routines for spatial mapping and quantification of fragmentation, distance, naturalness, Landscape Parcellation and other aspects derived from land cover maps.
Further information is available in related product sheets available on the GuidosToolbox homepage.

References:

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Soille P, Vogt P, 2009. Morphological segmentation of binary patterns. Pattern Recognition Letters 30, 4:456-459, DOI: [10.1016/j.patrec.2008.10.015](#)