EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate D – Sustainable Resources
Land and Climate Unit

MSPA GUIDE

This document provides information on the usage of *Morphological Spatial Pattern Analysis* (MSPA); its implementation in the free GTB (GuidosToolbox) and GWB (GuidosToolbox Workbench) software package, the MSPA-standalone version, the MSPA input data requirements, the MSPA-Parameter settings, the resulting MSPA output data, and the Simplified Pattern Analysis (SPA). Additional information is available in the Morphology product sheet. This is a living document, please click here to access the latest version.

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1. MSPA input data

The input data must be a raster (grid) map. Vector (polygon) maps are not supported; please convert them to raster format first. The map does not have to be square, but it is necessary that both, the number of rows and columns, are at least 10 pixels.

- **GTB:** The maximum map dimensions (in pixels) depend on the amount of available RAM, for example: ~ 25,000 × 25,000 for 16 GB RAM or ~ 75,000 × 75,000 for 128 GB RAM for macOS and Linux, less under MS-Windows. **The maximum image size for MSPA-processing is calculated in real-time and displayed in the Help → About GTB window.**
- **GWB:** Images of any size can be processed, see page 8.

The input map must be of type BYTE ([0, 255] byte) and must contain the two data classes Foreground and Background. In addition, it may contain one data class Missing. The MSPA segmentation is performed for the data class Foreground only. The definitions of Foreground, Background, and Missing depend on your situation. For example, to classify forest patterns on a forest/non-forest map, the Foreground is forest and the Background is non-forest. To classify wetland patterns on a wetland map, the Foreground is wetland and the Background is non-wetland. In general, Foreground corresponds to the features which should be classified, Background is complementary to Foreground, and in addition there may be data which are neither Foreground nor Background or should be excluded, those belong in the class Missing. In GTB/GWB, please use *General Tools* → *Preprocessing* → *Recode Classes* to recode the pixels (cells) in your input map as follows:

0 byte = Missing (optional)
1 byte = Background (mandatory)
2 byte = Foreground (mandatory)

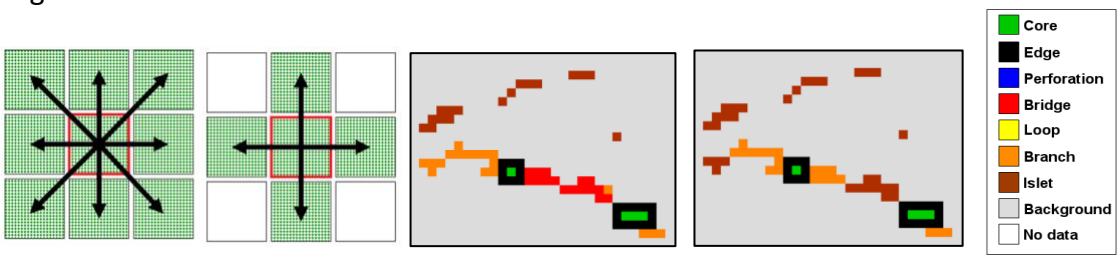
Further notes on the input map format:
No color code is needed. Export your (recoded) map as a signed 8-bit GeoTiff, or 8-bit Tiff. Please use either no compression or LZW compression. Please ensure that your exported map is an 8-bit (geo)-tif because some software may not automatically produce 8-bit for maps with cell values of {0,1,2}. It may be possible to process other image format types (png, gif, etc.) but we strongly suggest using the default image type tif, or when passing geo-information GeoTiff. You will only need the 8-bit tif/GeoTiff file, not any additional file created by your software like tfw, .hdr, etc. The input map must be a single-band image without potential overviews. To clean the image from overviews run the command: `gdaladdo -clean <input_map.tif>`

2. MSPA-Parameters

The result of the spatial pattern analysis depends on the settings of the four MSPA-Parameters described below:

MSPA-Parameter 1: Foreground Connectivity (Options: 8, 4)

For a set of 3×3 pixels the center pixel (surrounded in red below) is connected to its adjacent neighboring pixels by having either,
a) a pixel border and a pixel corner in common (8-connectivity) or,
b) a common pixel border only (4-connectivity).
The two sets of images below show 8- and 4-connectivity and its impact on the MSPA segmentation results.



8-connectivity ↔ 4-connectivity MSPA: 8100 ↔ MSPA: 4100

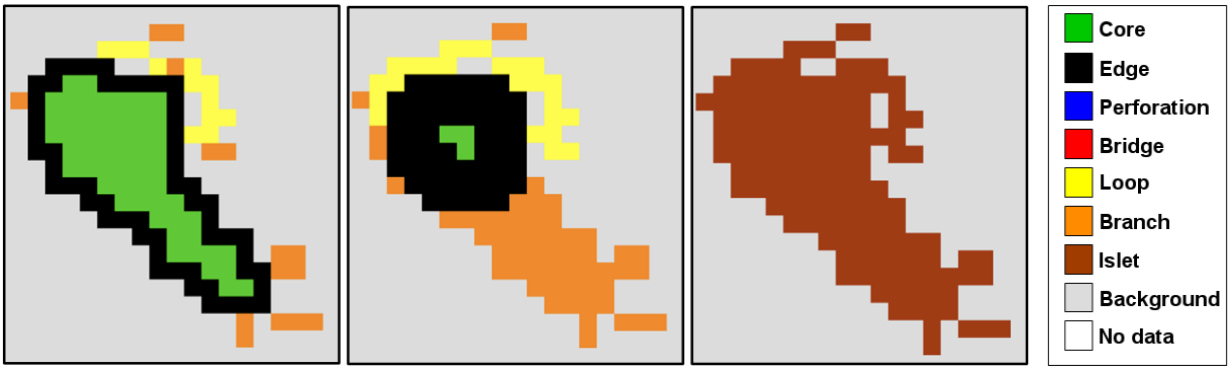
Parameter 1: *Foreground Connectivity* (<Foreground Connectivity>, 1, 0, 0).

The default value for MSPA-Parameter 1, Foreground Connectivity, is 8.

MSPA-Parameter 2: EdgeWidth (Options: 1, 2, 3, 4, ...)

The EdgeWidth parameter defines the width or thickness of the non-core classes in pixels. The actual distance corresponds to the number of edge pixels multiplied by the pixel resolution of the data. The EdgeWidth distance used in MSPA corresponds to the radius of a Euclidean disk. Imagine inserting a pin in the center point of this disk and drive the pin along the perimeter line of a Foreground object. Those Foreground pixels which are within the radius of this disk are boundary pixels (edge + perforation) and those with a distance from the pin larger than the radius of the disk are core pixels. For example, if the spatial resolution of your input data is 25m and you wish to get a 100m wide boundary in MSPA (4 pixels thick), then EdgeWidth = 4. Within GTB,

you can use a drop-down menu to select a predefined value or insert a custom value for EdgeWidth.
An increase of the width of the non-core classes has two effects:
a) the remaining core area will decrease and may even disappear,
b) relatively small image components may change their spatial pattern class.



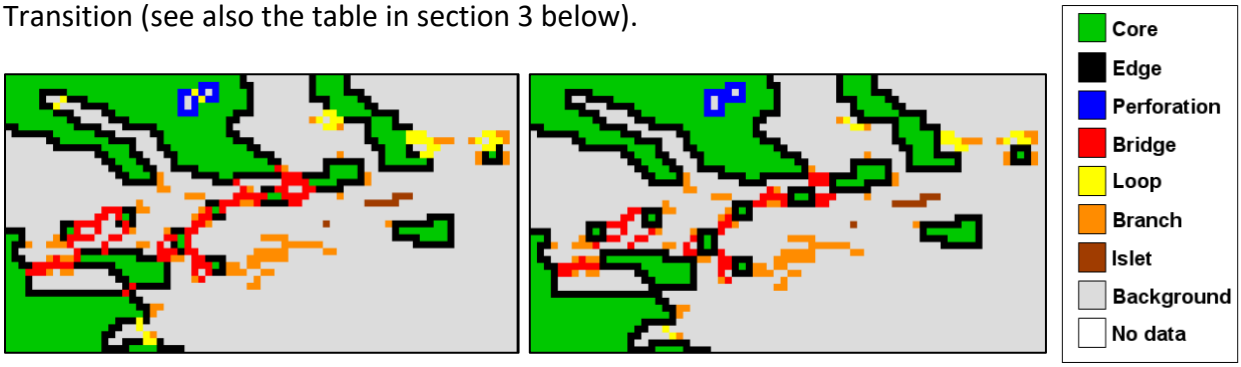
EdgeWidth: 1 EdgeWidth: 3 EdgeWidth: 9

Parameter 2: *EdgeWidth* (8, <EdgeWidth>, 0, 0).

The default value for MSPA-Parameter 2, EdgeWidth, is 1.

MSPA-Parameter 3: Transition (Options: 1, 0)

Transition pixels are loop or bridge pixels that traverse an edge or a perforation to connect to the core area. If Transition is set to 0 (↔ do not show transition pixels) then the perforation and the edges will show closed core boundaries. Note that a loop or a bridge of length 2 is not visible for Transition = 0 because it will be hidden under the edge/perforation pixels. The default is to show (Transition = 1) transition pixels to display all detected connections. For larger EdgeWidth parameters, the connectors as well as the area covered by transition pixels strongly increases. While the results are mathematically correct, they may look confusing for the unexperienced user. The figure below shows the impact of Transition on/off for the settings of Foreground Connectivity, EdgeWidth and Intext: 8110/8100. Note how for Transition = 0 the two yellow loop pixels in the upper left and upper central part of the image are hidden under the edge pixels (black, upper left part) and perforation pixels (blue, upper central part).
Note: Changing the value for Transition will use a different color table only. The actual pixel values of the MSPA segmentation are identical and independent of the selected setting for Transition (see also the table in section 3 below).



Transition: 1 (On) Transition: 0 (Off)

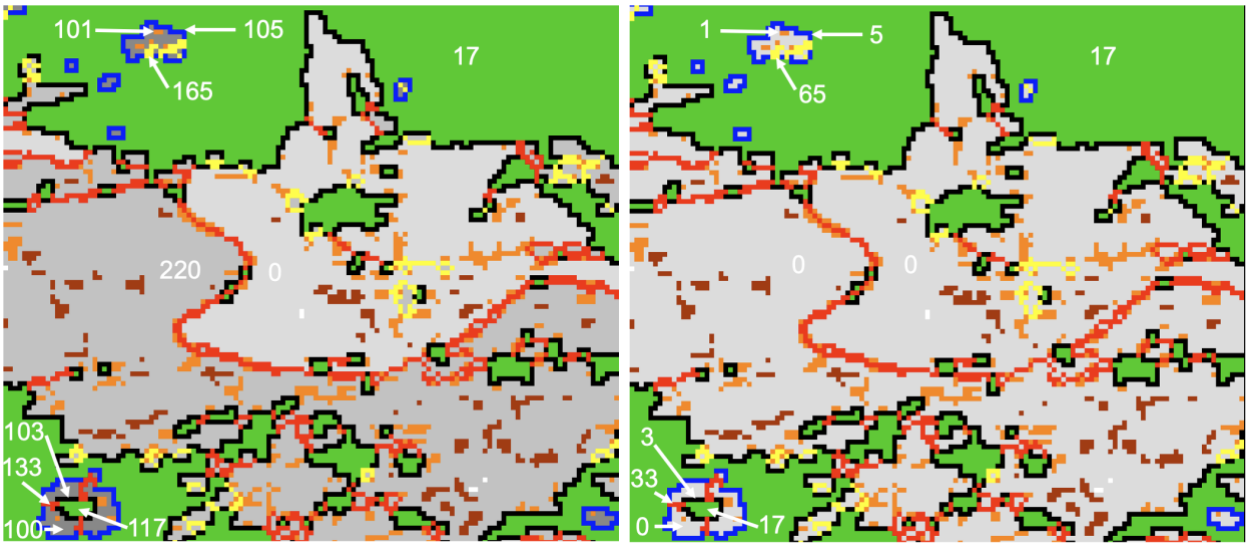
Parameter 3: *Transition* (8, 1, <Transition>, 0).

The default value for MSPA-Parameter 3, Transition, is 1.

MSPA-Parameter 4: Intext (Options: 1, 0)

The parameter Intext allows separating internal from external features, where internal features are defined as being enclosed by a Perforation. Pixels values of internal features are offset by 100 byte. All classes, except for Perforation, which by default is always internal (105b), can then appear as internal or external. The default is to enable this distinction, which will add a second layer of classes to the seven basic classes. The image below shows the difference in pixel values when Intext = 1 (default – left panel) versus Intext = 0 (right panel).

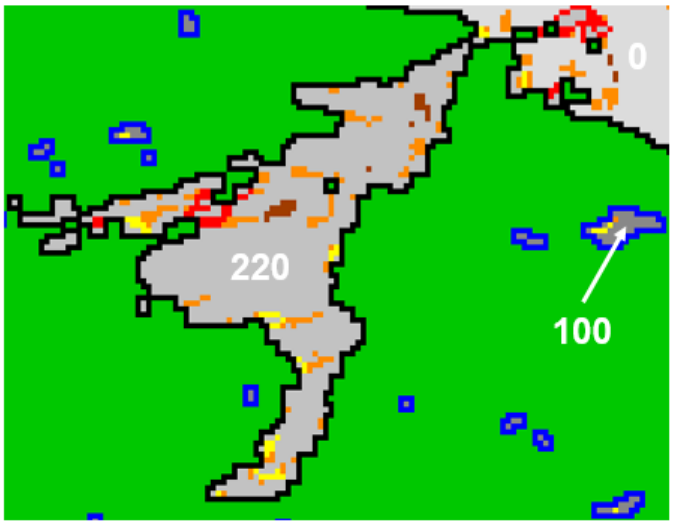
Note: When using the default Intext = 1, the internal Background is segmented into the two categories: Border-Opening and Core-Opening (bottom panel).



Intext: 1 (On)

Intext: 0 (Off)

Parameter 4: *Intext* (8, 1, 1, <*Intext*>).



Background: 0 byte outside Foreground

Border-Opening: 220 byte surrounded by FG-pixels (mainly Edge)

Core-Opening: 100 byte surrounded by blue Perforation pixels (inside Core)

The default value for MSPA-Parameter 4, Intext, is 1.

3. MSPA output data

MSPA conducts a segmentation of the input image Foreground objects. MSPA assigns each Foreground pixel into one of the mutually exclusive geometric feature classes. This principle implies that first, the spatial coverage of the initial Foreground and the resulting MSPA classes is identical, and second, MSPA is a true mathematical segmentation due to the assignment in mutually exclusive classes comprising the Foreground area. Please note that MSPA will only conduct a segmentation of the input data, it does not do magic and interpret the pattern, nor can it find user-desired features which are not available in the input data. It is up to the user to provide appropriate input data containing all features of interest, as well as doing the final interpretation of the pattern classes provided by MSPA.

The MSPA result is **visualized** using the following colors:
- 7 colors: corresponding to the pattern classes of Foreground,
- 3 gray tones: corresponding to external Background, Border-Opening, Core-Opening,
- 1 color white: corresponding to Missing, if this class was in the input map.

The legend for these 11 colors is listed in the table on page 6 below. Please note that:
- data area = Foreground area (class 1 → 7) + Background area (gray)
- image area = data area + Missing (white)

Naming scheme of the resulting MSPA classes:

The resulting spatial pattern classes have a generic naming scheme. The meaning of these classes depends on the nature of the input data and the class names should be amended by the user. For example, the class Perforation denotes Foreground pixels which form the outer perimeter of a 'hole' in a Foreground area: For a forest mask, the area enclosed by a perforation could be a 'clearing' while for a water mask such an area would be an 'island'.

Details on the resulting image:

The default colors and legend do not fully describe the actual byte values in the output image, because some of the byte values have been combined into one RGB/pattern class for visual simplicity. You can read out the actual pixel values either in GTB via the mouse pointer or after importing the output image into any other image processing software. The table below lists the spatial pattern classes, their colors, RGB-, and image byte values. Note that the boundary intersecting (transition) pixels of Loop and Bridge classes are each represented by three different byte values to distinguish between the Loops and Bridges and their intersections with Edge and Perforation.
The table below shows the color code for Transition = 1. For Transition = 0, the intersecting pixels of class 5b and 6b are color coded as Edge (black) and the pixels of class 5c and 6c are color coded as Perforation (blue).

Class	Color	RGB	Intext = 0	Intext = 1
1) Core		000/200/000	17	17 / 117
2) Islet		160/060/000	9	9 / 109
3) Perforation		000/000/255	5	105
4) Edge		000/000/000	3	3 / 103
5a) Loop		255/255/000	65	65 / 165
5b) Loop in Edge		255/255/000	67	67 / 167
5c) Loop in Perforation		255/255/000	69	169
6a) Bridge		255/000/000	33	33 / 133
6b) Bridge in Edge		255/000/000	35	35 / 135
6c) Bridge in Perforation		255/000/000	37	137
7) Branch		255/140/000	1	1 / 101
Background		220/220/220	0	0
Border-Opening		194/194/194	N/A	220
Core-Opening		136/136/136	N/A	100
No Data		255/255/255	129	129

Class names, color codes, and byte values for MSPA feature classes.

Important: Changing the setting for Transition changes the display color of the Transition pixels only, it has no impact on the actual pixel values. Regardless of the actual Transition setting, **the statistics in GTB/GWB are always calculated for closed boundaries (Transition = 0) to provide consistent results for the parameter Porosity**, see page 6 of the Morphology product sheet. In this way the pixels of class 5b) *Loop in Edge* and 6b) *Bridge in Edge* converge in the statistic of class 4) *Edge*; and the pixels of classes 5c) *Loop in Perforation* and 6c) *Bridge in Perforation* converge in the statistics of class 3) *Perforation*.

Intext = 0: the result does not address internal features and consequently provides no information on Openings.
Intext = 1 (default): all classes can appear as internal or external. This naturally excludes the pixels of the class Perforation, which are always internal. In addition, Background pixels are segmented into the three classes Background, Core-Opening and Border-Opening.

In summary:

- The **visual result** can have a total of up to 7 unique Foreground colors plus 3 gray tones for the Background area and the color white for Missing or no data areas.
- The **actual image pixel values** for Intext = 0 can be up to 13 (11 for Foreground + 1 for Background + 1 for Missing) and for the default Intext = 1 up to 23 (19 for Foreground + 3 for Background + 1 for Missing).

4. MSPA-standalone version

The command-line version of MSPA can be used as a standalone application. It is intended for advanced users only with a very clear understanding of the MSPA parameters and required input data. **Beginners should not use the standalone version but the one in GTB instead.**
GTB/GWB acts as a wrapper around the standalone version and in addition also addresses the **four limitations of the standalone version**:

1. No support for tiled tiff images and writing of geoheader (GeoTiff) information,
2. No verification if input data is MSPA-compliant,
3. No summary statistic,
4. No MSPA-Tiling.

This implies that certain tiff file-types, or input data that is not MSPA-compliant, will simply crash the standalone version.

Within GTB, the directory MSPAstandalone contains statically linked, operating system specific mspa-executables for 64bit Linux, macOS and MS-Windows. The Linux version is compiled for Linux distributions using glibc-version 2.31 or newer. Instructions on compiling MSPA or downloading pre-compiled MSPA executables for various target platforms are provided in the MSPAstandalone GitHub repo.

The directory MSPAstandalone is in the directory `GuidosToolbox/idl/save_add/` (Linux), `GuidosToolbox/GuidosToolbox.app/Contents/Resources/idl/save_add/` (macOS), and `GuidosToolbox` (MS-Windows). To use the standalone version, copy the operating system and CPU-architecture specific mspa-executable into the directory where you have your data and run it to get an overview of the processing options, i.e.:

```
peter$./mspa_mac
------------------------------------------------------------------------
      Morphological Spatial Pattern Analysis (MSPA)
        by {Pierre.Soille,Peter.Vogt}@ec.europa.eu
              Version 2.4, October 2026
     (c) European Commission, Joint Research Centre

 References:
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 P. Soille & P. Vogt, 2009: Morphological Segmentation of Binary
 Patterns. Pattern Recognition Letters,
 DOI: http://dx.doi.org/10.1016/j.patrec.2008.10.015

 P. Vogt & K. Riitters, 2017: GuidosToolbox: universal digital
 image object analysis. European Journal of Remote Sensing (TEJR),
 DOI: http://dx.doi.org/10.1080/22797254.2017.1330650

 P. Soille & P. Vogt, 2022: Morphological Spatial Pattern Analysis:
 Open Source Release. The International Archives of the Photogrammetry,
 Remote Sensing and Spatial Information Sciences, Volume XLVIII-4/W1-2022
 DOI: https://doi.org/10.5194/isprs-archives-XLVIII-4-W1-2022-427-2022

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   for non-commercial purposes. For commercial purposes please
   contact: Peter.Vogt@ec.europa.eu
2. The JRC, on behalf of the Commission does not accept any
```

```
   liability whatsoever for any error, or for any loss or damage
   arising from the use of the software of this interface.
3. If the results of this interface are passed on to third parties
   it has to be assured that the conditions of the disclaimer
   are agreed and fulfilled.
------------------------------------------------------------------------
Usage : ./mspa_mac
----------------
[-v] [-usage] [-help] [-i <input>] [-o <output>] [-eew <psize>] [-graphfg <pgraphfg>]
 [-internal <internal>] [-odir <output_dir>] [-transition <transition>]
 [-disk]
Parameters:
------------
 -v : Flag for verbose mode.
 -usage : Flag for displaying progam usage.
 -help : Flag for help.
 -i : Name of the input image.
 -o : Name of the output image; default: "out.tif".
 -eew : Effective Edge Width; default: 1.000000.
 -graphfg : Foreground connectivity; default: 8.
 -internal : Internal flag; default: 1.
 -odir : Name of the output directory; default: "./".
 -transition : Transition flag; default: 1.
 -disk : Flag for minimum RAM usage
```

For example, to process your image with the default MSPA-parameters the command would be:
`./mspa_mac -i input.tif -o output.tif -odir ./`
or to process your image with 3-pixel wide edges and not showing transition pixels (to show closed boundaries): `./mspa_mac -i input.tif -eew 3 -transition 0 -o output.tif -odir ./`
The terminal will show a progress bar during processing.

The maximum image size that can be processed in GTB depends on the amount of free RAM and the basic memory footprint of the operating system. In general, and especially on MS-Windows, please ensure to not run anything else in parallel to MSPA to ensure the maximum size of available RAM. **Within GTB, the maximum image size for MSPA-processing is calculated in real-time and displayed in the Help → About GTB window.** Indicative RAM requirements for memory-efficient operating systems (Linux or macOS) are:
~ 22 x uncompressed image size (with option "-disk")
~ 25 x uncompressed image size (without option "-disk")
Example: MSPA-compliant input image dimension is 75,000 × 75,000 pixels → 5.24 GB uncompressed image size → requiring ~ 100 GB of free RAM. If you have a PC with 128 GB RAM and Linux or macOS then you could process an image of that size. In general, the maximum size of a square image of dimension Z (ZxZ pixels) that can be processed is approximately: Z = sqrt(1024^3 / 25 * RAM). For example, on a laptop with 16 GB RAM and Linux or macOS: 2 GB for the operating system, 14 GB free RAM; then Z = sqrt(1024^3/25*14) = 24,500 pixels, meaning you can process an image of 24,500 × 24,500 pixels. Indicative processing times from such a laptop having these specs and for processing an image of 10,000 × 10,000 (0:52 mins), 20,000 × 20,000 (3:50 mins).

Note: GTB is an interactive desktop application, designed to get familiar with MSPA processing. **Operational processing and processing of large images should always be conducted in GWB.**

More details on the concepts of MSPA are provided in
Soille P. and Vogt P. (2009). Morphological segmentation of binary patterns.
Pattern Recognition Letters. DOI: 10.1016/j.patrec.2008.10.015

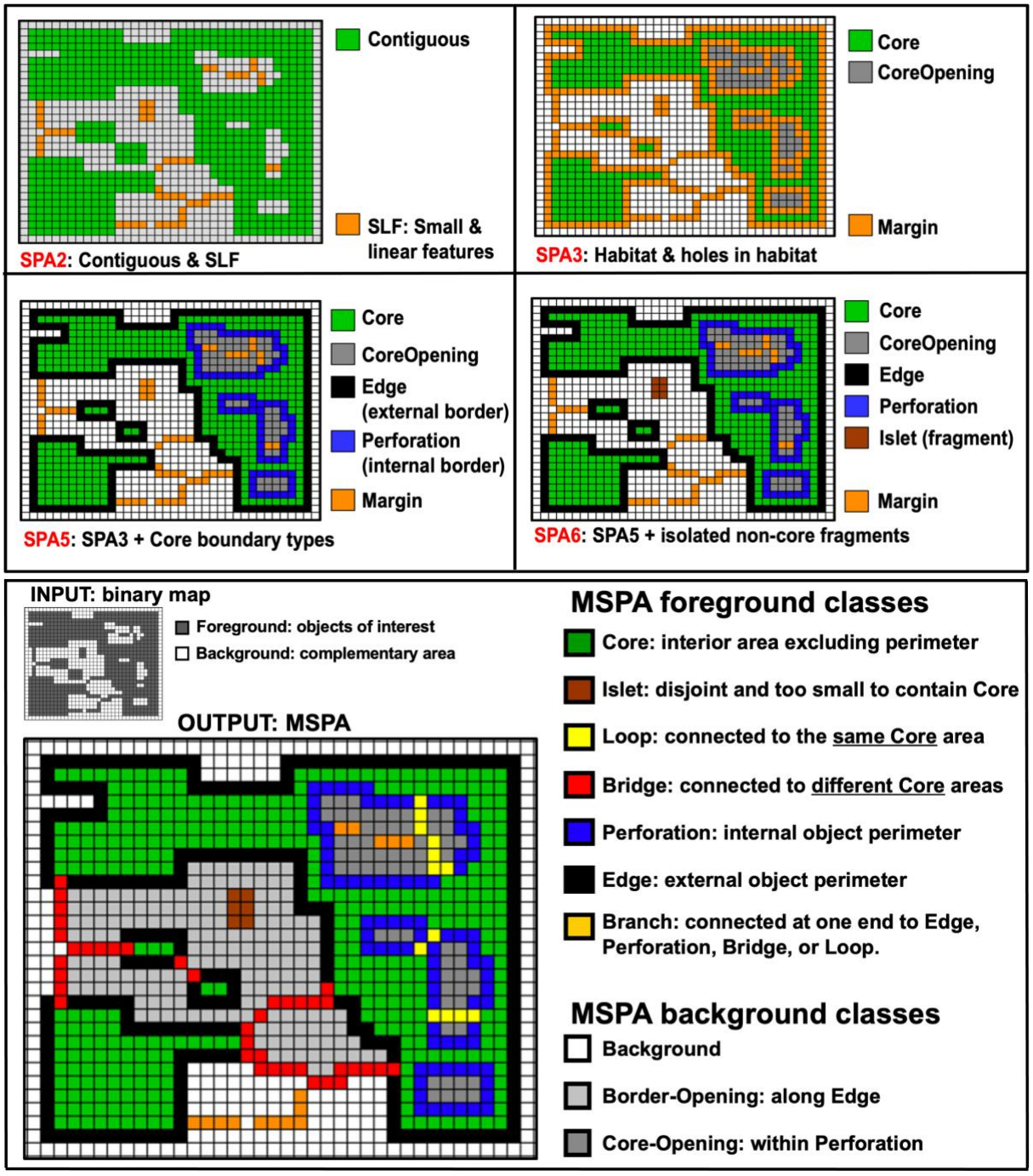
Soille P. and Vogt P. (2022). Morphological spatial pattern analysis: open source release. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-4/W1-2022 Free and Open Source Software for Geospatial (FOSS4G) 2022 – Academic Track, 22–28 August 2022, Florence, Italy. pp. 427-433, DOI: 10.5194/isprs-archives-XLVIII-4-W1-2022-427-2022.

Vogt P. and Riitters K. (2017). GuidosToolbox: universal digital image object analysis.
European Journal of Remote Sensing (TEJR), DOI: 10.1080/22797254.2017.1330650

Vogt P., Riitters K., Rambaud P., d'Annunzio R., Lindquist E., Pekkarinen A. (2022).
GuidosToolbox Workbench: spatial analysis of raster maps for ecological applications.
DOI: 10.1111/ecog.05864

5. Simplified Pattern Analysis (SPA)

In many occasions, the 25 classes of the MSPA are not needed and fewer classes are sufficient to describe specific morphological features of interest. The Simplified Pattern Analysis (SPA) is a downscaled version of MSPA, providing 2, 3, 5, or 6 classes only. Compared to MSPA, SPA is significantly faster but restricted to 8-connectivity, EdgeWidth = 1, and it cannot detect connecting pathways (Bridge or Loop):



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.

Note: Compared to MSPA, SPAx may provide different results along image boundaries due to a simplified treatment of image border pixels.