User Guide of GuidosToolbox (GTB)

Release 3.4, Revision 4, November 2026

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GTB, a collection of geometric analysis tools following three principles:

1. **Spatial information:** *Where* are hotspots/changes? Provide spatially explicit information, which is crucial for monitoring progress and spatial planning. Statistical summaries can always be derived from a map, but they do not capture the spatial variability of the spatial map product.
2. **Quantitative indicators:** *How much?* Provide intuitive, ideally normalized, indicators for effective reporting. Quantify the status and measure trends.
3. **Generic and flexible:** *How?* Make exclusive use of geometric concepts resulting in a generic reference framework that can be equally applied to any kind of raster data and at any scale; parameterize the analysis setup allowing to fine-tune the analysis to end-user requirements.

GTB is free and open-source software. This document describes the various menus and features of GTB:



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GTB requires a PC or a Mac with Intel/Apple Silicon M CPU and at least 4 GB of system memory, the more the better. This 64-bit application has been tested on a variety of Linux distributions, macOS, and Microsoft Windows 11 platforms. The latest GTB version can be downloaded from the GTB homepage.

Support will be provided for the most recent GTB version only, downloaded from the official homepage and following the GTB installation instructions.

GWB, the GuidosToolbox Workbench, contains the most popular GTB image analysis modules as a command-line application for Linux 64bit servers, desktop, or workstations. GWB is available for a variety of Linux distributions and can be installed system-wide or used as a standalone application on systems, where users do not have root privileges. GWB is also available on the FAO SEPAL and the JRC BDAP JEO-desk cloud computing platform. Finally, pyGuidos is a Python implementation of the main GWB modules.

License information: using the compiled version of GTB or GWB requires accepting the respective End User License Agreement for GTB or GWB. The open-source code of GTB and GWB and all dependencies is released under GPL version 3 on GitHub for GTB and GWB.

Citation reference:

Vogt P., Riitters, K., 2017. GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing 50:1, 352-361, DOI: 10.1080/22797254.2017.1330650. Software available for free at: https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/

Vogt P., Riitters, K., Rambaud P., d'Annunzio R., Lindquist E., Pekkarinen A. 2022. GuidosToolbox Workbench: spatial analysis of raster maps for ecological applications. Ecography, Volume 2022, Issue 3, Software note, 1-7, DOI: 10.1111/ecog.05864. Software available for free at: https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/

Please add the following reference if you use MSPA in your work:
Soille P., Vogt P., 2008. Morphological segmentation of binary patterns. Pattern Recognition Letters 30, 4:456-459. DOI: 10.1016/j.patrec.2008.10.015

MSPA open-source reference paper:
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: doi.org/10.5194/isprs-archives-XLVIII-4-W1-2022-427-2022

Windows and menus

The following graphical elements can be used to interact with GTB:

- a horizontal menu bar (top panel)
- a window to set different attributes of the image and its graphical display (top left panel)
- a window to set MSPA parameters and statistics (bottom left panel)
- a viewport (right panel)
- a window for image coordinates & values (bottom right panel)

1. The menu bar of GTB

The top menu bar offers four pull-down menus:

- File
- General Tools
- Image Analysis
- Help

1.1. The File pull-down menu

The File pull-down menu offers the following options:

- Read Image
- Save Image
- Batch Process
- Change
- Set Data Directory
- Tif-Compression
- Exit

1.1.1 Read Image

This menu is used to read your input data:

- **GeoTIFF: the default image type is GeoTIFF** (a **.tif**-formatted file having a geoheader - information on projection, etc.). GeoTIFF can be read or pre/post-processed by *any* image processing (IP) software.

- **Generic:** images of formats like **tif**, **png**, **bmp**, **jpeg**, etc.

- **IP Software:** image processing (IP) software (ESRI, ARC, IDRISI, etc.) raster image formats like **img**, **bil**, etc. The included GDAL library will try to convert these formats into GeoTIFF. Alternatively, go back into your IP software and export the image to GeoTIFF.

- **ENVI:** an image from an ENVI session (file extension: **.hdr**). GTB will not use the geo-information of the ENVI-data. If you want to maintain the geo-information you should export the data in ENVI to GeoTIFF and then read this format in GTB.

1.1.2 Save Image

This menu is used to save your processed data. The options are similar as in the Read menu. Additional options are:

- **Display Snapshot:** this option will save a snapshot of the current viewport in GTB. This may be useful when working with a large image and a quick look of the processed image is sufficient. When saving a MSPA result, the filenames will include the settings of the 4 MSPA parameters. If MSPA statistics were enabled, an additional file containing these statistics will be saved with the same notation and the file extension **.txt**.

- **GoogleEarth KML:** this option will export to kml-format for visualization in Google Earth, requiring an image in the projection EPSG:4326 (WGS 84). To re-project either use **Reproject for GoogleEarth** or start the **GTB Terminal** and use the command gdalwarp and the appropriate EPSG reference codes. The result is stored in a zip-archive. Extract this zip-archive at any location and load the included kml-file into Google Earth. When exporting a MSPA or a FAD image, a customized header plus legend is added automatically.

The default data directory is the subdirectory **data** located in the main GTB directory. Please use the default GeoTIFF format for maximum compatibility.

1.1.3 Batch Process

This option allows for automatic processing of multiple files in batch mode. Please put all batch input files into a dedicated empty subdirectory within the directory **GuidosToolbox/data** and avoid empty spaces in file names or directory path names. Input files must be in the default format (Geo-)Tiff. GTB will save the output files in batch-processing specific directories located next to the batch-input directory, i.e., batch-input files directory: **GuidosToolbox/data/batch-input/** and resulting output files (for example for Accounting) are in the directory: **GuidosToolbox/data/batch-ACC**/. Batch-processing options are like the respective options in the Image Analysis menu.

Objects:

- **Accounting:** batch processing of **Accounting**.

- **Parcellation:** batch processing of **Parcellation.**

Pattern:

- **Morphological:** this option will process the user-selected files using the following options:
  - **SPA2/3/5/6:** this option calculates the Simplified Pattern Analysis, a down-scaled version of MSPA, resulting in 2/3/5/6 classes and saves the resulting maps and statistics in the input directory.
  - **MSPA:** this option will open a window to select the MSPA parameters and a switch for statistical output. The resulting filenames will include the settings of the 4 MSPA parameters and, if selected, separate statistics.

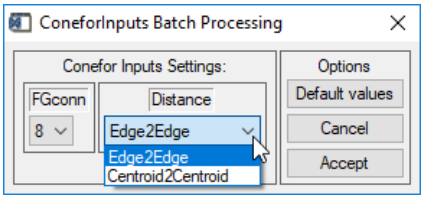
- **Moving Window:** this menu provides options for batch processing of several moving window algorithms. The dimension of the moving window can be specified via a popup window (**Figure 6**).
- **GraySpatCon:** Batch process images for ***GraySpatCon*** .

Network:

- **MSPA-based:** this menu provides options for batch processing of several network analysis algorithms featured in the Image Analysis – **Graph Theory Network (GTN)** section. All options require MSPA input images, non-MSPA input images are ignored and cannot be processed.

- **ConeforInputs:** this option will generate the node file (area per object) and the connection file (pairwise distance between objects) in the format required by Conefor. Object area and distance will be calculated for objects of value 2 only (if needed, use *Recode* to reassign object values). The distances can be calculated as Euclidean edge-to-edge distance (8/4-connected) or centroid-to-centroid distance between all foreground objects of the raster image.

Figure 1: *ConeforInputs*: Select 8/4-connectivity and distance measure.



When using the option ***ConeforInputs*** the connectivity is defined via the *pairwise distance* between image objects. This is different to the option **MSPA ConeforInputs,** where the connectivity is defined via the MSPA-detected *structural connectors* (Bridges).

Fragmentation:

This menu provides options for batch processing of several fragmentation analysis algorithms featured in the Image Analysis – **Fragmentation** section.

Distance:

- **Euclidean Distance:** batch process images for Euclidean Distance resulting in maps and a summary of the distance histogram properties.

Restoration Status:

Batch process images for **Restoration Status**.

Recode Classes:

Batch recoding for a series of images. Batch-recoding requires a recoding table with 256 entries to deal with all kinds of class allocations. A recoding table can be set up from scratch or saved and restored later. Here, please use the naming scheme **GTBbatchrecode_*.sav**, and replace the placeholder * with a meaningful name. After the recoding table has been defined, select a series of images to which this recoding table should be applied.

1.1.4 Change

This menu provides the following options for change analysis. A popup window allows for selecting the two input images, which are then processed:

- **FOS:** this option will calculate changes in fragmentation classes between two **FOS** images. The change map, histogram, and summary statistics for the fixed, user-selected observation scale are saved in csv-format.

- **FAD Multiscale:** this option will compare two **FAD Multiscale** image sets and calculate changes in fragmentation classes over all observation scales as well as the multiscale image. All changes are summarized in a bar-plot image and further detailed in observation-scale specific summary statistics provided in txt and csv-format. The output files are:
  a) **fadchange_barplot.png**: FAD-bar chart summary
  b) **fadchange_{7,13,27,81,243,mscale}.txt**: FAD summary statistics.
  c) **fadchange_{7,13,27,81,243,mscale}.csv**: FAD change summary statistics by scale in comma-separated value format for import into a spreadsheet application

  The first table shows the number of pixels in each FAD-class or in the background at time A and B. If the area of a pixel is known and constant throughout the image (equal-area projection) then the number of pixels times the pixel-area corresponds to actual area measures. Gross area gain equals to the number of pixels changing from background at time A to any foreground class at time B. Similarly, gross area loss equals the number of pixels changing from any foreground class at time A to background at time B. The net area change is the sum of gross area gain and gross area loss.

  The second table shows relative changes within the foreground only. Entries along the diagonal of the matrix are zero because these entries correspond to pixels being in the same class at time A and B. Matrix entries below the diagonal represent fragmentation increase (+), and Fragmentation decrease (-) is found above the matrix diagonal.

- **Landscape Mosaic heatmap:** this option will calculate the difference of the occurrence frequency [%] in the heatmaps of image *B* minus image *A*. The resulting delta heatmap image and the corresponding csv-table are saved into the **GTB/data** directory.

- **Simple Change:** this option will calculate a by-pixel difference of image *B* minus image *A* with the same input and output notation as described for the following Morphological Change.

- **Morphological Change:** this option will conduct a Morphological Change Detection (MCD), described in Seebach et al. (2013). MCD will remove unwanted spurious changes caused by misregistration between classified maps and their thematic accuracies. MCD requires that both input images are binary and MSPA-compliant maps (2b – FG, 1b – BG, 0b – Missing (optional)) **in GeoTIFF format**, having the same projection, pixel-resolution, location, and area in common. The resulting GeoTIFF image will show the essential changes in the common area of input image *A* and *B*. The output values have the following assignment: 11b – BG/BG, 12b – BG/FG (gain), 21b – FG/BG (loss), 22b – FG/FG, 176b – neglected, spurious changes, 255b – undetermined (missing data in either input image). The title bar lists net percent change values for FG (Foreground) and FG_i (Foreground interior area: 1-pixel eroded FG), with negative values indicating a net loss. Finally, *Elasticity* (Riitters et al., 2015) is the ratio of FG_i to FG. For example, in case of forest loss higher elasticity values indicate higher fragmenting effects on the remaining forests.

1.1.5 Set Data Directory

Use this option to define the default data directory, preset as **GuidosToolbox/data**. GTB will read input images from and write output into this directory. The default data directory location can only be set after starting GTB and is reused after restarting GTB.

1.1.6 Tif-Compression

While GTB-output is always compressed, Tif-files generated by other GIS applications (i.e., ArcGIS) are often uncompressed and hence occupy a significant amount of disk space. Use this option to select one, or more Tif-files to be tested for file compression. If a selected Tif-file is found to be uncompressed, the Tif-Compression tool will a) backup the uncompressed Tif-file to ***filename_orig.tif*** and b) LZW-compress the image maintaining the original filename. After verifying the compressed Tif-files, the uncompressed backup copies (***_orig.tif**) can be deleted to free up disk space. Because file compression is conducted directly on disk with **gdal_translate**, Tif-images of *any* file size can be compressed.

1.1.7 Exit

Quit the program and return to the operating system.

1.2. The General Tools pull-down menu

The General Tools pull-down menu provides generic image processing utilities, which may be useful for a variety of purposes. The following options are available:

- Preprocessing
- Convolution
- Equalization
- Thresholding
- Edge Enhance
- Morphological
- GIS Software
- Switch Cursor
- Undo/Redo

1.2.1 Preprocessing

The Preprocessing menu provides several generic image-processing routines targeted to reassign image pixel values. These routines can also be used for setting up MSPA-compliant input images. The following options are available:

- **Convert → Byte/Integer/Long:** convert the map data to the selected data type.

- **RGB → Single Band:** convert an RGB-image into a single-band image.

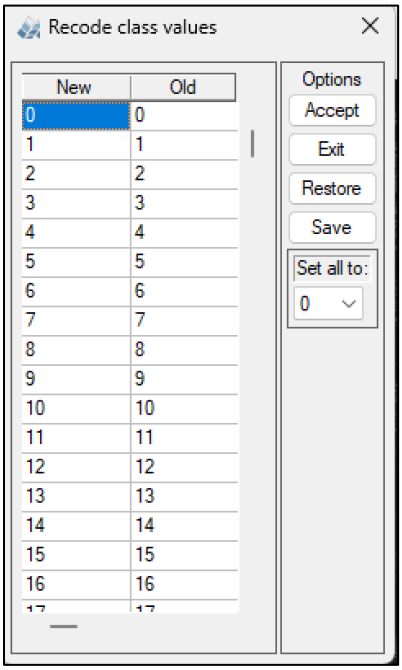
- **Reproject for GoogleEarth:** if the geo-header information of the currently loaded GeoTIFF file has a EPSG code and it is different to 4326 then this option can be used to reproject the image to EPSG:4326 (WGS 84).

- **Setup Batch Recode Table:** define a recoding table from scratch or restore and modify an existing recoding table for later use. The recoding table shows the full Byte range of 256 values in [0, 255] with the new values in the left column and the old values to be recoded in the right column. Please note that any new value in the cell of the left column will only be active after **pressing the Enter key** or after switching to a different cell of the left column. Once done, click the *Save* button to write the recode table to disk. Please use the naming convention **GTBbatchrecode_*.sav** (keep the prefix ***GTBbatchrecode_*** and the file extension ***.sav*** and only modify the placeholder *).

- **Recode Classes:** a table showing new and current unique pixel values is displayed. The new value entries in the left column can be reassigned to match the desired

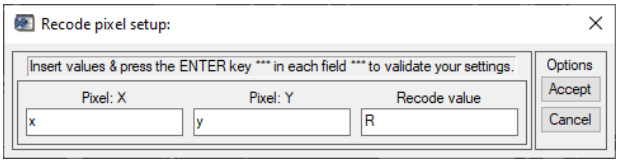
recoding of image class values. The *Set all to* dropdown menu can be used to assign all classes to a single value. The *Save* button can be used to save a new recode table to a file **GTBrecode_*.sav** (please keep the prefix ***GTBrecode_*** and the file extension ***.sav*** and only modify the placeholder *). Any previously saved recoding table **GTBrecode_*.sav** can be restored via the *Restore* button. Here, only those entries that match the current class values will be restored. This option is only available for images of data type Byte. Please note that any new value in the cell of the left column will only be taken over after **pressing the Enter key** or after switching to a different cell of the left column.

Figure 2: *Recode Classes* GUI showing existing class values in the right column (Old) and new assignments in the left column (New).



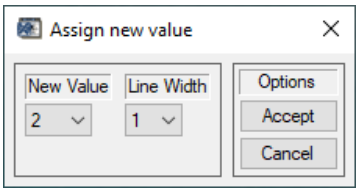
- **Recode Pixel:** this window allows assigning a new value to a specific pixel location. Please press the Enter key in each field to validate your input settings.

Figure 3: *Recode Pixel* GUI



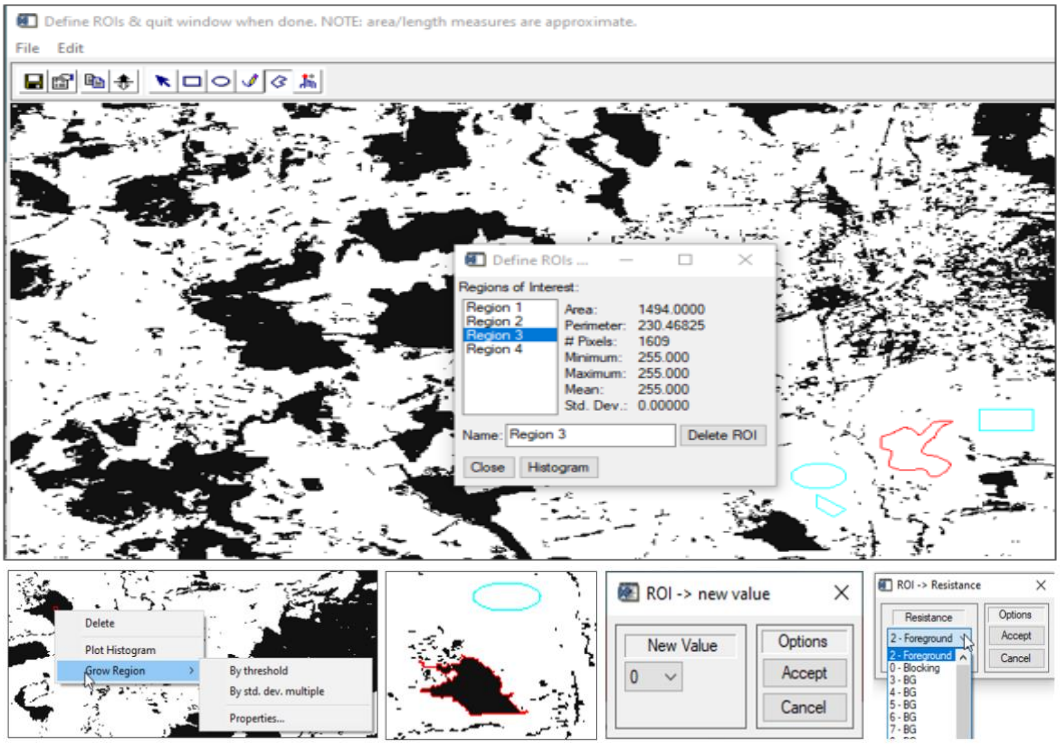
- **Recode Line:** click on MSPA parameter 1 *FGconn* to activate the Recode Line option. It provides the ability to interactively draw a freehand (left mouse button) or straight line (right mouse button) as long as the mouse button is pressed. Upon releasing the mouse button, a new window allows assigning a specific value and the width of the line from a dropdown menu.

Figure 4: *Recode Line* GUI



- **Recode Region Of Interest (ROI):** this option will open the full image in a new window: click the icons in the menu bar to draw, move or warp custom ROIs. A small popup window lists all custom ROIs shown in cyan color in the image with the currently selected ROI highlighted in red color. Please note that the ROI statistics are indicative, they will only be correct on very small images. Once all ROIs have been inserted, close the Define ROI interface, and assign the new value for all ROIs via the final popup window. The same procedure is applied to assign resistance values within the **Restoration Planner**.

Figure 5: *Recode ROI* window showing various tools to draw custom ROIs (top) and region growing to select a given object outline (bottom left). Once defined, exit the window, and assign the new value for all ROIs (bottom right).



- **Threshold: FG/BG:** apply a threshold to a gray-scale image to obtain a MSPA-compliant binary image with foreground and background (FG and BG) values assigned to 1 and 2 byte, respectively.

- **Group: FG/BG/Missing:** group a sequence of gray-scale image values into FG/BG/Missing.

- **X → FG/BG/Missing:** assign an individual pixel value to FG/BG/Missing.

- **Invert:** exchange the current assignment of FG/BG/Missing.

- **Add 1b:** add 1 byte to all current image pixel values.

- **Subtract 1b:** subtract 1 byte of all current image pixel values.

The *Image Info* box in the main window can be used to control the output of the Preprocessing functions or to query image properties. The box *Original Image* in the main window can be used to restore the originally loaded image.

1.2.2 Convolution

The Convolution menu offers the choice for one of the following image convolution filters:

- **Median:** median filtering is effective in removing salt and pepper noise, (isolated high or low values). The median is the middle value of a given data array, which should not be confused with the average value. A set of predefined median filter box sizes is available in the submenu.

- **Boxcar:** like Median, this filter computes the average value instead.

- **Lee:** Lee filtering (Lee, 1986) will smooth additive image noise by generating statistics in a local neighborhood and comparing them to the expected values. A set of predefined box sizes for the Lee filter is available in the submenu.

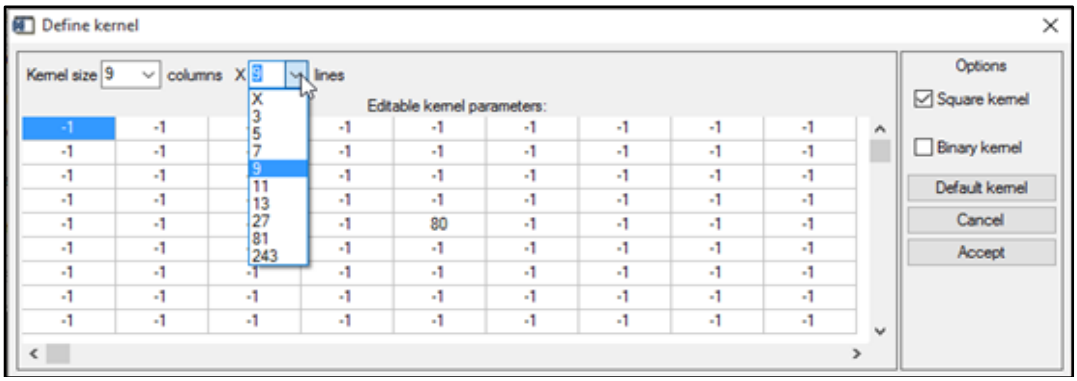
- **Sigma:** this filter computes the mean and standard deviation of pixels in a box centered at each pixel of the image but excluding the center pixel. If the center pixel value exceeds one standard deviation from the mean, it is replaced by the mean in the 5×5 box overlaying the pixel of investigation.

- **Hilbert:** the Hilbert function outputs a series that has all periodic terms phase-shifted by 90 degrees. This transform has the interesting property that the correlation between a series and its own Hilbert transform is mathematically zero.

- **User-Defined:** a popup window allows the user to select or customize a kernel within dimensions within [3, 501] to be applied to the current image. The kernel size (*ks*) is an uneven number because it is measured with respect to the center pixel; for example, *ks=5* corresponds to a moving window with x/y-dimensions of 5 pixels (the center pixel ± 2 pixels in x/y-direction). Some predefined kernel sizes can be selected to analyze typical area measures *A* in [m^2] at spatial resolution *res* in [m], in general: $ks = \frac{\sqrt{A}}{res}$
  For example, if we have satellite data with a spatial resolution of *25m* and want to apply an analysis window area of *1,000 acres* (4,046,856 m^2) we need *ks=81*

($\frac{\sqrt{4046856}}{25} = 80.47$, closest uneven number is 81), or you insert your custom size, i.e., an analysis window of 1km^2 on satellite data having 30m resolution: *ks=33* ($\frac{\sqrt{1000000}}{30} = 33.33$, closest uneven number is 33).

Figure 6: *Define Kernel* interface showing options to define the kernel dimension within the range [3, 501], select a square and/or a binary kernel and a reset option to go back to the default kernel for the current application.

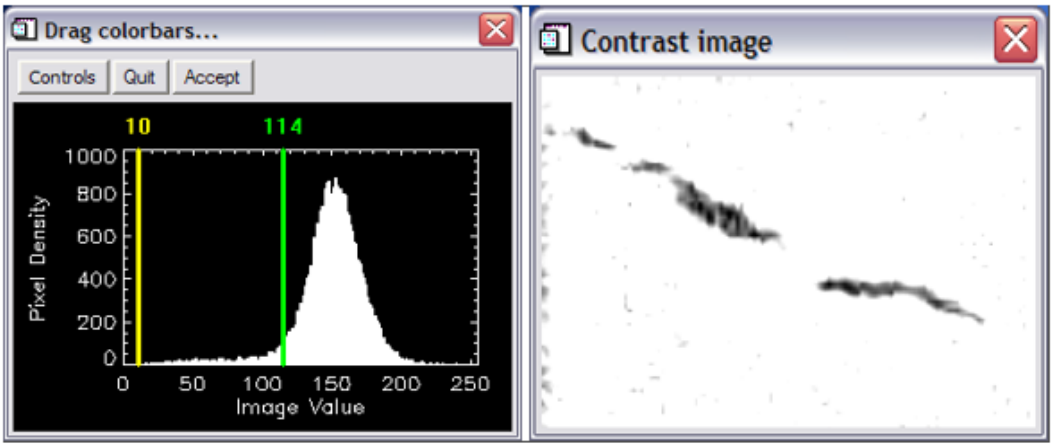


1.2.3 Equalization

The Equalization menu offers the choice for one of the following image processing algorithms:

- **Contrast:** the image contrast can be adjusted in an interactive mode. This option will close the main window and open a new, dual window interface (**Figure 7**). The window on the left displays the histogram of the brightness values of the image and two color-bars, which can be dragged with the mouse to set a lower and upper limit for the intensity range into which the image will be rescaled. The result of this procedure is shown in the preview window on the right, which can be saved in a variety of image formats from the *Controls* → *Save image as* menu. Furthermore, the maximum pixel density may be reset from the *Controls* → *Max pixel density* menu to display the histogram in an adequate way. Finally, choosing *Quit/Accept* will close this interface, return to the main interface, and cancel/apply the selected settings to the current image.

Figure 7: *Contrast* interface showing on the left the histogram of the brightness values including the two color-bars to define the contrast range; and on the right the preview of the selected contrast range applied to the current image.



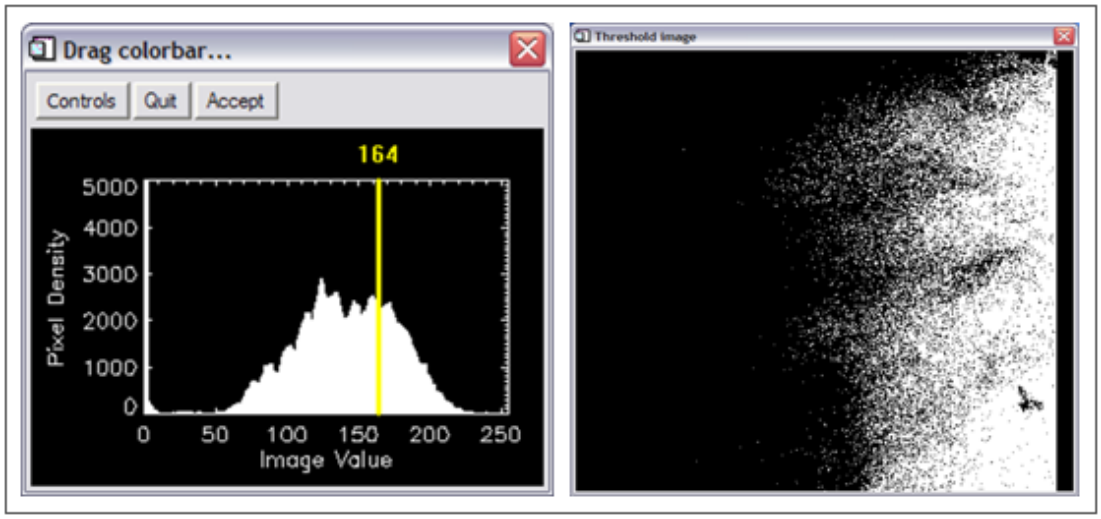
- **Histogram Equalization:** this function is used to obtain the density distribution of the input array. The histogram is integrated to obtain the cumulative density-probability function and a histogram-equalized image is returned.

- **Adaptive Histogram Equalization:** this function applies contrast enhancement based on the local region surrounding each pixel. Each pixel is mapped to an intensity value, which is proportional to its rank within the surrounding neighborhood.

1.2.4 Thresholding

This option will open a dual window (**Figure 8**). The left window displays a histogram of the brightness values from the current image. A color bar indicating the current threshold value can be moved with the mouse to set a new threshold value, which is displayed in the right window of this interface. The *Controls* menu provides the option to save the current preview to an image in a variety of image formats and to redefine the maximum pixel density to best display the brightness value distribution of the histogram. Finally, the *Quit* or *Accept* buttons are used to cancel/apply the selected threshold. Please note that this process results in a binary image and can therefore only be applied once.

Figure 8: *Thresholding* interface with a color bar to set and preview a brightness threshold value on the current image.



The result of using this interface is a binary image having foreground and background (FG/BG) values assigned to 0/1 byte, respectively. This is different to the option in *Preprocessing* → *Threshold* where the resulting binary image is MSPA-compliant having foreground and background (FG/BG) values assigned to 1/2 byte.

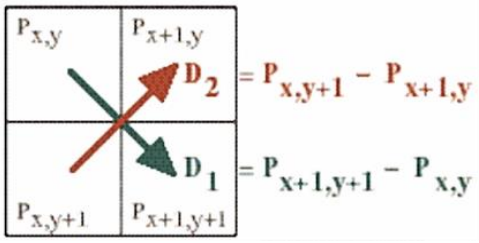
1.2.5 Edge Enhance

This Edge Enhance menu provides a series of edge enhance filters, which are described in the following:

- **Canny:** this filter produces results like the Sobel operator, but is separable (Canny, 1986). This means that it can be performed in two passes, computing the derivative in the horizontal and the vertical direction. They are then combined to calculate the gradient or the difference of the two components.
- **Laplace:** the image is convolved with the kernel:

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

- **Roberts:** the diagram below shows the principle of the Roberts operator (1965) where two differences in orthogonal directions are combined to determine the gradient.



$$\text{Result} = \sqrt{D_1^2 + D_2^2}$$

- **Sobel:** like the Roberts filter, the Sobel filter computes the derivatives in two orthogonal directions, which are combined as the square root of the sums of their squares to obtain a result independent of orientation.

- **Sharpen:** this filter adds the Laplace filter of the image to the image itself. The *Define Kernel* window (**Figure 6**) offers the option to use a different user-defined filter.

- **Unsharp masking:** this filter subtracts the original image from a smoothed version of the original image. Different smoothing box sizes are selectable from the submenu.

- **Skeleton:** this filter combines thresholding with the Sobel filter.

1.2.6 Morphological

Mathematical morphology is a methodology of analyzing digital image objects based on their shape attributes. A discussion of this topic is beyond the scope of this manual. A suggested reference is Soille, 2004; In short, a user-selectable object of a given size and shape (structuring element) is defined and the image is scanned for the presence or absence of this shape of interest (some examples in **Table 1**). This option will open a new window (**Figure 9**) providing a series of morphological filters (Dilate, Erode, Open, Close, Tophat, Gradient), structuring element types (horizontal, vertical, diagonal up, diagonal down, circular) and sizes (1-10). Any combination of filter and structure type and size can be selected and tested by pressing the *Test* button in the upper panel. The *Define kernel* window (**Figure 6**) allows for selection of the default or user-defined kernel to be applied to the previously selected settings. The result of this process is displayed in the graphical display of this window. Other combinations may be tested at any time after restoring the original state in the display via the *Reset* button. When using the *Tophat*-filter, the contrast of the resulting image can be

adjusted with the sliders in the horizontal panel above the display. Finally, the *Quit/Accept* button will close this window and cancel/apply the selected filter settings to the current image in the main window.

Figure 9: *Morphological filter* interface showing a preview for a variety of combinations of filters with structuring element type and sizes.

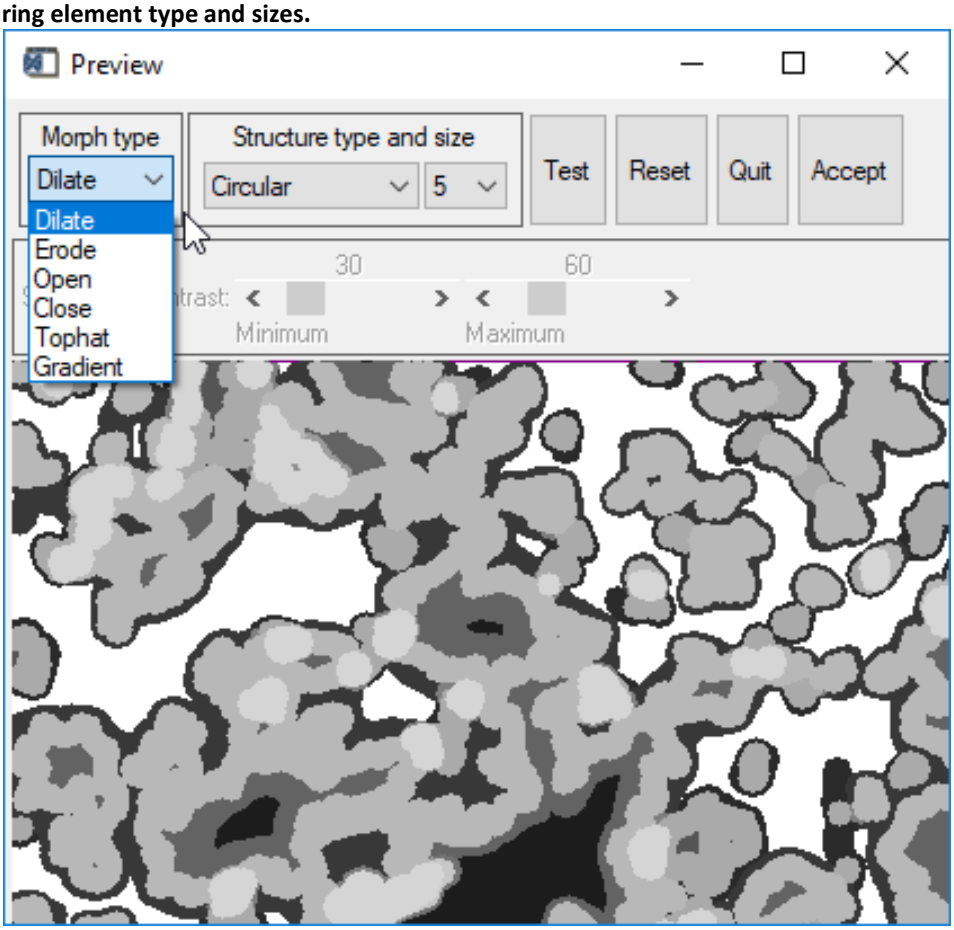


Table 1: Description of some basic morphological filters.

Filter	Description
Dilate	fills holes of size equal to or smaller the structuring element.
Erode	removes islands smaller than the structuring element
Open	an erosion followed by a dilation; pixels are removed
Close	a dilation followed by an erosion; pixels are added
Tophat	= image–open(image): Shows brightness peaks on inverted image
Gradient	= dilate(image)–erode(image): Highlight structure boundaries

1.2.7 GIS Software

The GIS Software menu provides access to the following GIS related software packages on the host PC running GTB:

- **GTB Terminal:** this option will open a separate terminal to access all GDAL-commands. Use this terminal to work on your data, for example to reproject (**gdalwarp**), format conversion (**gdal_translate**), get information (**gdalinfo**), and much more.

- **OpenEV Viewer:** this option will open a separate window with the image viewer OpenEV, which is only available in the MS-Windows version of GTB.

- **Conefor:** this option will open the Conefor 2.6 GUI and related documents and sample data in a dedicated subdirectory within the GTB-Data directory. The Conefor software package is only available in the MS-Windows version of GTB.

- **QGIS**: this option will open QGIS if it is found in the operating system.

1.2.8 Switch Cursor

This option can be used to change the appearance of the mouse cursor within the GTB viewport.

1.2.9 Undo/Redo

GTB stores the settings of one (1) processing step only. The *Undo* button may be used to undo the last processing step. If selected, this button will change to *Redo* allowing reverting to the previous step.

1.3. The Image Analysis pull-down menu

All image analysis modules under this section are grouped into dedicated thematic containers and have been developed to address specific questions. The section itself as well as each container are briefly summarized with an introduction named **Overview**. Please have a look at this overview, the respective sections in this manual, and the mentioned product sheets to better understand the scope and usage of each image analysis module.
The Image Analysis pull-down menu provides the following thematic containers:

- Objects
- Pattern
- Network(MSPA)
- Fragmentation
- Distance
- Restoration Planner

1.3.1 Objects

This menu provides several options for the analysis of individual image object attributes.

1.3.1.1 Accounting

The Accounting option will label and calculate the area of all foreground objects (coded with 2 byte) according to user-specified area thresholds:

Figure 10: *Accounting* interface showing user-selectable fields for Foreground Connectivity, Pixel Resolution, Big3pink and up to six foreground-object size classes.

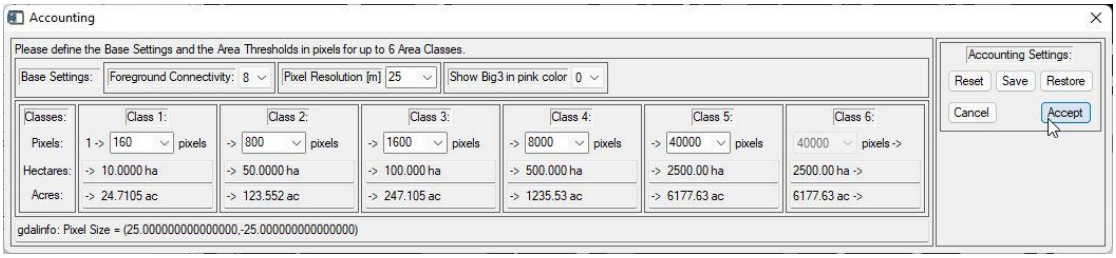
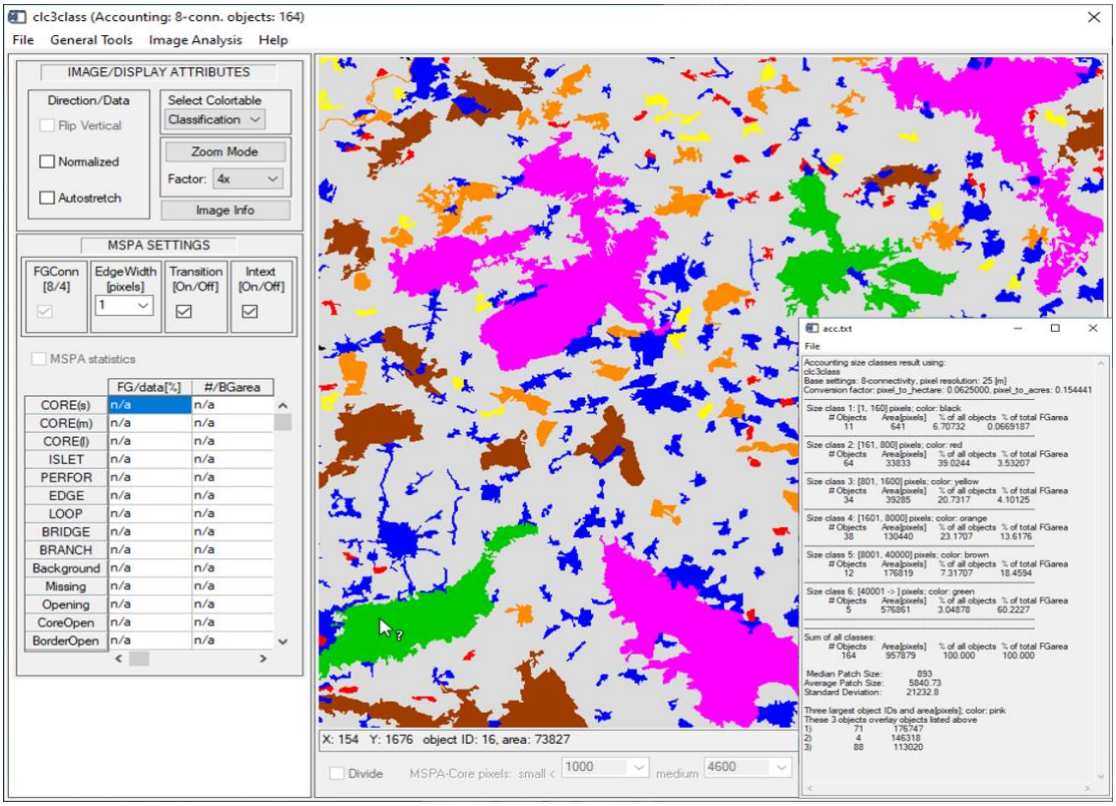


Figure 10 shows the *Accounting* interface where in the top row, the user should specify the Base Settings (Foreground Connectivity, Pixel Resolution, Big3pink: show the largest three objects in pink – no/yes). In the center row, select or insert custom values to define the area thresholds (in pixels) of up to six object size categories. The bottom row shows the spatial pixel resolution retrieved via the ***gdalinfo*** command. Depending on the geoheader, it might be in meters, degrees, any other unit, or not

available at all and for this reason should be considered for information only. The initial 5 area thresholds are derived by GTB by calculating the range from the smallest to the largest object area and scaling the range into 5 sections starting from the smallest object area + [0.001, 0.01, 0.1, 0.5, 0.9]*range. Use the *Reset* button to re-assign the initial automatic scaling thresholds. The *Save* and *Restore* button saves or restores custom user settings. The area interval of Class 1 starts with the smallest object area up to and including the area threshold specified by the user. The following Classes start at the area threshold of the previous Class + 1 pixel up to the Class threshold. Class 6 accounts for all objects larger than the area threshold of Class 5. The interface will automatically adjust the thresholds to ensure a positive progression of the threshold settings. Neighboring classes can be collapsed into a single class by assigning the same area threshold value. Combined with the pixel resolution, the two bottom rows show the upper area limit of each class in hectares and/or acres. Please note that this information is only valid when using an image having an equal area projection and a properly specified information on the pixel resolution.
Via the *Accounting* interface, the user can set each area threshold to define specific area classes in pixel, hectare, or acre. To apply the user-defined settings press the *Accept* button.

Figure 11: *Accounting* result showing different area categories in different colors and a statistical summary for the number of objects, their area, and proportions in up to six different area classes and highlighting the 3 largest objects in pink color, if the switch Big3pink was set to 1.



The result is an image showing all objects in up to six different area classes, each with its own color, background in grey and potential missing data in white. In addition, the three largest objects are highlighted in pink color, if the switch Big3pink was set to 1.

Moving the mouse cursor over an object will show the object ID and its area in the information panel below the viewport. For example, in **Figure 11** the mouse cursor is over the green object at the position 154/1676, the unique object ID is 16 and the area of object 16 is 73,827 pixels, thus falling into size class 6, shown in green color.

Saving an Accounting image will produce a directory with files having the prefix <name>_acc:
a) **prefix.tif**: same graphics as displayed in GTB
b) **prefix.txt** (only when saving the entire image): a table listing the number and area [in pixels] for the objects per size class (see **Figure 11**).

In batch mode, the user can select to add the following optional two files:
c) **prefix_ids.tif**: the unique identifiers of the objects in positive integer values and pixel values for Background (0), Missing (-1), Water (-3 in input data, Special Background 1), SpecialBG (-4 in input data, Special Background 2).
d) **prefix_pixels.tif**: the area in pixels for each object plus the following fixed values for Background (0), Missing (-1), Water (-3 in input data, Special Background 1), SpecialBG (-4 in input data, Special Background 2).
More information is available in the Accounting Product Sheet.

When running Accounting in batch-mode, no automatic scaling settings are calculated, and the user-selected settings are applied to all input images regardless of their actual object area range and/or pixel resolution.

1.3.1.2 Parcellation

On a given categorical map, Parcellation provides a summary of number, area, and some simple metrics for each class as well as the entire image (see **Table 2** below) with:
$a_{i,j}$ = area of object *i* in class *j*
n = number of unique objects in each class
A_j = total area of a given landcover class *j*
A = image data area: all classes in the image = image – missing pixels

Parcellation provides a statistical summary file (txt/csv-format) with details for each unique class found in the image: class value, total number of objects, total area plus the full image summary, (see **Table 2** below):

- Class: sequential number of individual landcover classes
- Value: landcover class value in the image
- Count: total number of patches in the given landcover class j
- Area: total area of a given landcover class j:
  A_j (Unit: area, measured in pixels)
- APS: Average Patch Size of a given landcover class j:

$\mathrm{APS} = \frac{1}{n} * \sum_{i=1}^{n} a_{i,j}$ (Unit: area, measured in pixels)

- AWAPS: Area Weighted APS of a given landcover class j:
  $\mathrm{AWAPS} = \frac{1}{A_j} * \sum_1^n a_{i,j}^2$ (Unit: area, measured in pixels)
- AWAPS/data: AWAPS with respect to the entire data area A:
  $\mathrm{AWAPS} = \frac{1}{A} * \sum_1^n a_{i,j}^2$ (Unit: area, measured in pixels)
- DIVISION: degree of division of a given landcover class j:
  $\mathrm{DIVISION} = 1 - S = 1 - \sum_1^n \left(\frac{a_{i,j}}{A_j}\right)^2$ (Unit: index in [0, 1])
- PARC: a logarithmic conversion and normalization of the Division complement $S = \sum_1^n (\frac{a_{i,j}}{A_j})^2$:
  a) convert/constrain S into the range $R = [-\ln(1.0e^{-6}) \leq -\ln(S)]$
  b) normalize: $Parc = \frac{100}{-\ln(1.0e^{-6})} * R$ (Unit: index in [0, 100]%)

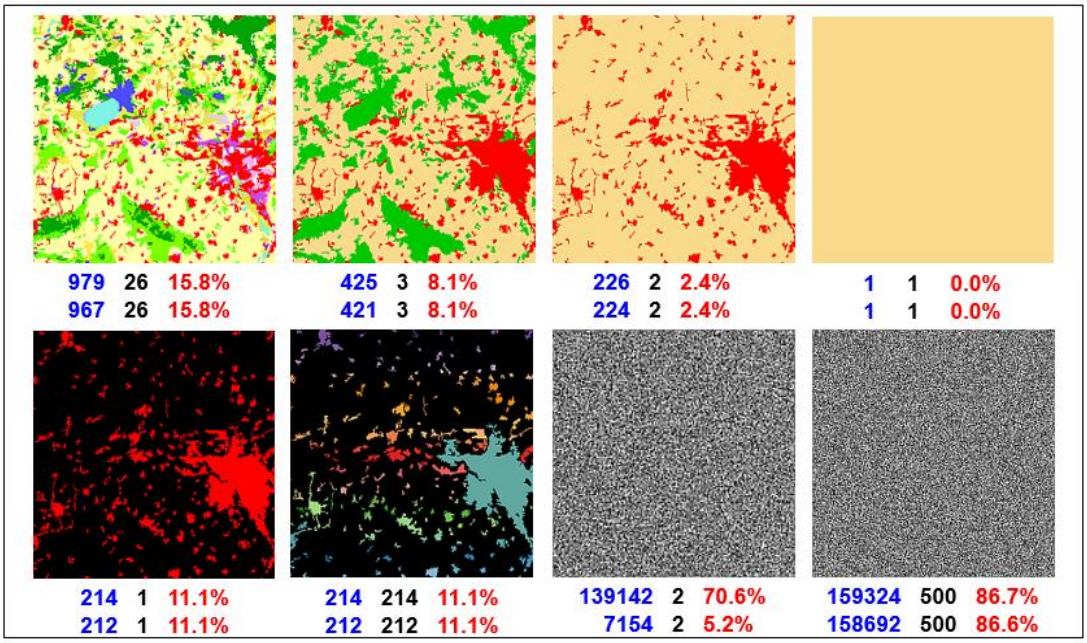
The final line (**Table 2**) provides the overall summary for the entire image, top-left image in **Figure 12**: the parcels were investigated using the 8-connectivity rule: there are 26 individual classes and 967 individual objects. The total area of all objects (= data area) is 4,000,000 pixels, the Average Patch Size (APS) is 4,136 pixels, the Area Weighted Average Patch Size (AWAPS) is 450,657 pixels, and the degree of division is 0.8873 corresponding to a Parcellation (PARC) for the entire image of 15.8%.

Table 2: Example for tabular statistics of Parcellation.

Class	Value	Count	Area[pixels]	APS	AWAPS	AWAPS/data	DIVISION	PARC[%]
1	1	2	2792	1396.0000	1998.3600	1.3948	0.2843	2.4207
2	2	201	432930	2153.8800	24287.2000	2628.6600	0.9439	20.8507
3	3	35	56446	1612.7400	3655.9400	51.5909	0.9352	19.8106
4	4	5	6131	1226.2000	1335.9000	2.0476	0.7821	11.0293
5	5	1	418	418.0000	418.0000	0.0437	0.0000	0.0000
6	6	2	14708	7354.0000	7779.0500	28.6036	0.4711	4.6105
7	7	14	10134	723.8570	783.5970	1.9852	0.9227	18.5281
8	8	3	1779	593.0000	701.8210	0.3121	0.6055	6.7325
9	9	6	6687	1114.5000	1979.0300	3.3084	0.7040	8.8130
10	10	15	25139	1675.9300	4503.9000	28.3059	0.8208	12.4460
11	11	28	36026	1286.6400	1773.8400	15.9761	0.9508	21.7950
12	12	61	2013006	33000.1000	875187.0000	440439.0000	0.5652	6.0291
13	18	139	278701	2005.0400	7531.4400	524.7550	0.9730	26.1377
14	20	48	80188	1670.5800	2995.8400	60.0575	0.9626	23.7932
15	21	53	77036	1453.5100	2042.6800	39.3399	0.9735	26.2749
16	23	108	308382	2855.3900	38797.6000	2991.1200	0.8742	15.0047
17	24	111	398163	3587.0500	29455.4000	2932.0100	0.9260	18.8483
18	25	93	118067	1269.5400	2976.5900	87.8591	0.9748	26.6402
19	26	4	6717	1679.2500	2505.7000	4.2077	0.6270	7.1374
20	27	1	675	675.0000	675.0000	0.1139	0.0000	0.0000
21	29	1	3828	3828.0000	3828.0000	3.6634	0.0000	0.0000
22	32	1	1022	1022.0000	1022.0000	0.2611	0.0000	0.0000
23	35	2	1577	788.5000	941.6470	0.3712	0.4029	3.7324
24	36	14	57507	4107.6400	22376.6000	321.7020	0.6109	6.8321
25	40	1	2092	2092.0000	2092.0000	1.0941	0.0000	0.0000
26	41	18	59849	3324.9400	32760.4000	490.1690	0.4526	4.3618
8-conn. Parcels:		967	4000000	4136.5049		450657.9072	0.8873	15.8036

The MSPA parameter 1 *FGconn* can be used to set the 4 or 8-connectivity rule for the image objects. The input image for the Parcellation analysis must be a raster map with at least two landcover classes. A class value of 0 (zero) is reserved for masking no-data pixels.
In general, the value of Parcellation will increase with increasing number of feature classes, number of objects per class, and decreasing object areas.

Figure 12: Example images showing: the number of image objects (blue), the number of individual classes (black) and the value of Parcellation (red). Results of the top (bottom) row below each image correspond to using the 4- (8-) connectivity rule for the image objects.



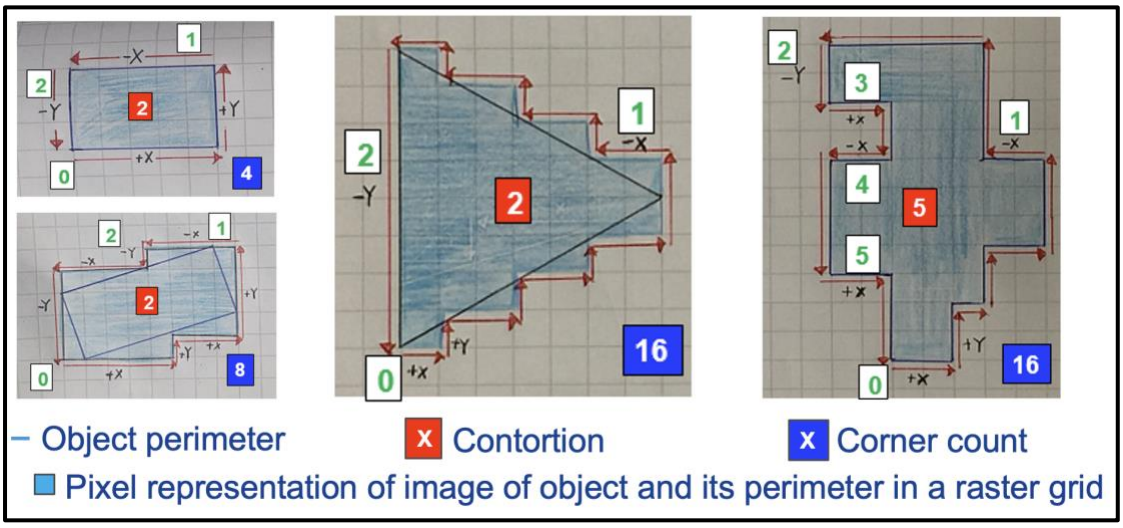
The left image of the top row in **Figure 12** shows a CORINE landcover image of dimension $2{,}000^2$ pixels having a total of 26 individual landcover classes. When using the 4-connectivity rule the image is composed of 979 parcels. When adding the diagonal direction of the 8-connectivity rule some neighboring parcels of the same landcover type become combined resulting in a lower total of 967 individual parcels. **Table 2** provides further details for the latter case on the relative Parcellation of each landcover class. The next three examples in the top row of **Figure 12** show the effect of joining the existing 26 landcover classes into 3, 2 and finally a single landcover class: the decrease of the total number of parcels and classes is directly related to the value of Parcellation and reaching the minimum at the lower boundary condition represented by a fully homogeneous landcover. However, this expected behavior is different when a substantial number of missing pixels or no-data areas are present in the image, represented in the black color in the first two images of the bottom row in **Figure 12**: assigning all parcels into a single landcover class or each parcel into a different one should not, and in fact it does not change the Parcellation value of the image data area. This behavior is also evident from the Parcellation formula, which is simply building the sum of the relative contribution of each parcel over each landcover class. The third image in the bottom row of **Figure 12** shows a random distribution of two landcover classes generated for an image size of dimension 1024^2 pixels. The purpose of this image is to illustrate the potentially strong impact of applying the 4- or 8-connectivity rule, here resulting in a drastic difference in the total number of parcels and the Parcellation itself. Obviously, this behavior is very pronounced when only 2 classes are present, resulting in a high probability of the same landcover class being present in a diagonal neighborhood. The probability to encounter the same landcover class in the direct neighborhood is far less with more classes present in the image. The final image in **Figure 12** confirms this thought showing a very similar number of parcels and Parcellation on an image of dimension 400^2 pixels and being

composed of 500 individual classes in a random distribution. A further increase in the number of individual classes will obviously increase the value of Parcellation up to the boundary condition of 100% when each pixel has its own individual class value.
More information can be found in the Parcellation Product Sheet.

1.3.1.3 Contortion

Contortion describes the degree of regularity of a foreground object perimeter. Its value corresponds to the number of times a given object perimeter direction changes its sign.

Figure 13: Contortion: measuring the number of directional changes in x-/y-direction.



Contortion can be used for shape description to distinguish random shapes from regular shapes. This is achieved by following the entire perimeter line, which includes the final angle at the starting point. **Figure 13** shows a sketch of the raster representation for a series of simple objects. Starting at the lower left border point, and following the entire perimeter outline of the object, the number of the directional changes in the X-/Y-direction are shown in white boxes. The final Contortion value for each object is shown in a red box while the number of perimeter corner counts is shown in a blue box. For example, when following the perimeter of a rectangle the direction changes one time in the horizontal and one time in the vertical direction: the contortion of a rectangle is 2, regardless of the orientation of the rectangle in the rectangular grid representation (see left part of **Figure 13**). Similarly, the contortion of the letter E is 6. An important feature of contortion is the invariance with respect to the length of diagonal lines. For example, two triangles oriented in the same direction but of different size will have a different number of pixel corners points due to the staircase representation along the diagonal lines. However, they both have the same contortion value of 2. The same is true for circles of different size. In satellite images, regularly shaped objects such as buildings and agricultural fields will have low

contortion values while natural objects are more likely to be non-regular and hence have higher contortion values.
Since contortion investigates the object perimeter, contortion will be calculated only on objects having a core area. In addition, the user can define a minimum object area to be considered for the calculation via the MSPA parameter 2 *EdgeWidth* drop-down menu. Either select a pre-defined value or specify a custom value in the first entry of the drop-down menu. Pressing the Enter key will then apply the new custom minimum area value and recalculate the contortion. In the resulting image, small, neglected objects are denoted as *omitted* and displayed in black color. The title bar shows the fraction of calculated versus total number of foreground objects in the image. The Divide Range panel below the GTB viewport can be used to group the contortion value range into small/medium/large using either pre-defined or custom values in the respective threshold drop-down menu.

1.3.2 Pattern

This menu provides access to the following pattern analysis tools:

1.3.2.1 Morphological

This option will process the user-selected file using the following options:

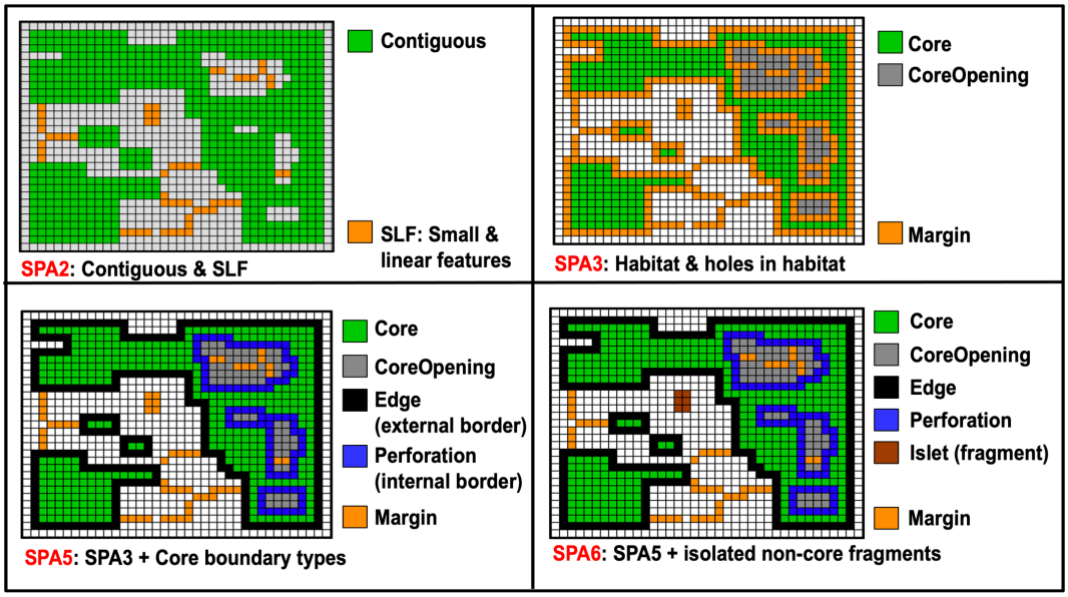
- **SPA2:** this option will process a binary input image resulting in a simplified version of the full MSPA with a map and statistics for two (2) morphological classes: Contiguous areas and small/linear features (SLF), see **Figure 14**. SPA2 input images are *not* subject to the MSPA input image size limitations.
  *The main purpose of **SPA2** is to delineate small/linear features from contiguous foreground objects*.

- **SPA3:** this option will process a binary input image resulting in a simplified version of the full MSPA with a map and statistics for three (3) morphological classes: The two foreground classes *Core* and *Margin* plus the background class *Core-Opening*, see **Figure 14**. SPA3 input images are *not* subject to the MSPA input image size limitations.
  *The main purpose of **SPA3** is to focus on Core, non-Core and Core-Openings only*.

- **SPA5:** this option will process a binary input image resulting in a simplified version of the full MSPA with a map and statistics for five (5) morphological classes: The four foreground classes *Core, Edge, Perforation, Margin* plus the background class *Core-Opening*, see **Figure 14**. SPA5 input images are *not* subject to the MSPA input image size limitations.
  *The main purpose of **SPA5** is to provide more details compared to SPA3 by adding information on the internal and external Core-boundaries.*

- **SPA6:** this option will process a binary input image resulting in a simplified version of the full MSPA with a map and statistics for six (6) morphological classes: The five foreground classes *Core, Edge, Perforation, Islet, Margin* plus the background class *Core-Opening*, see **Figure 14**. SPA6 input images are *not* subject to the MSPA input image size limitations.
  *The main purpose of **SPA6** is to provide more details compared to SPA5 by adding information on isolated small fragments, which are too small to contain Core area.*

Figure 14: Simplified Pattern Analysis (SPA) including coherent areas and small/linear features (top-left), detection of holes inside Core and providing a total of 3-classes (top-right), 5-classes (bottom left) and 6-classes (bottom-right).



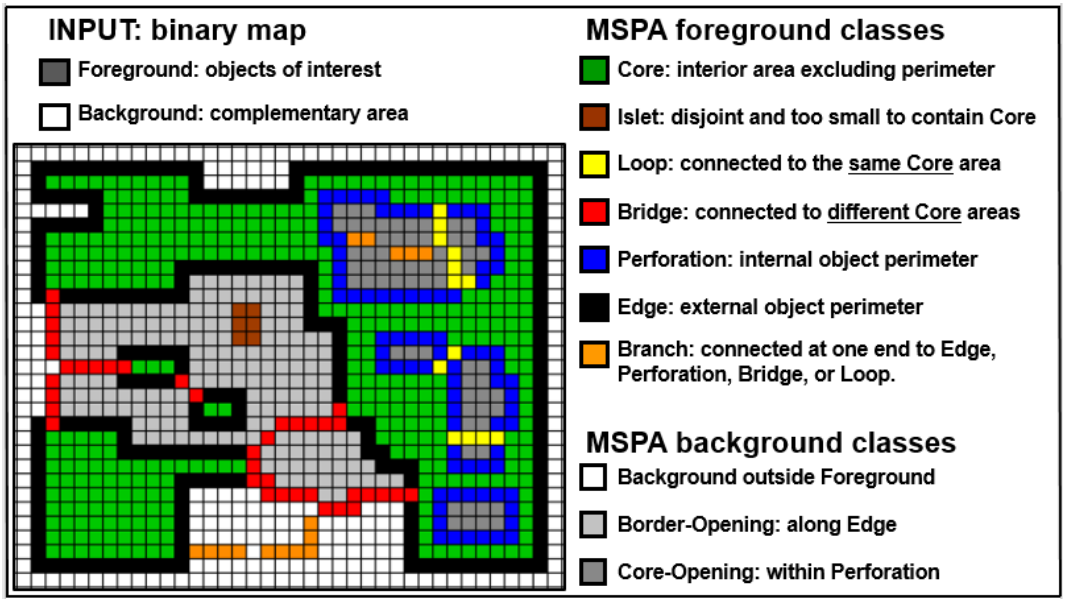
Compared to MSPA, SPAx may provide different results along image boundaries due to a simplified treatment of image border pixels. More information can be found in the Morphology Product Sheet.

- **MSPA:** this option will process a binary input image using the mathematical morphology algorithm described in Soille & Vogt, 2009 and Soille & Vogt, 2022. Compared to SPA2/3/5/6 the full version of MSPA provides many more morphometric details of the foreground patches as well as detecting holes along foreground boundaries. The 10 classes shown in **Figure 15** are only the visual result while the numeric result can provide details on up to 23 different morphometric classes. The full MSPA version has many additional features to fine-tune the analysis, for example, using the 4- or 8-connectivty rule for the foreground pixels, using an EdgeWidth larger than 1 pixel, showing transition pixels of connecting pathways and distinguishing background within from background at the boundary of foreground. Further details on input requirements, processing options, resulting pixel values and morphological classes are summarized in the dedicated **MSPA Guide** or Online. This document provides information on the operating system specific MSPA input image file size limitations, also available in the Help → **About GTB** menu.

Selecting MSPA statistics will conduct summary statistics for the foreground pixels and the openings within foreground, more details can be found in the section **MSPA Statistics**.

Standalone MSPA-plugins with documentation and installers are also available for ArcGIS, R, and QGIS from the MSPA-website.
The main purpose of MSPA is to provide additional details on connecting pathways, branches, and internal features and a user-selectable, scale-specific spatial pattern analysis.

Figure 15: MSPA: overview of the various foreground and background MSPA pattern classes derived from a binary input mask (9 → 23 classes, connecting pathways, variable edge width, and additional fine-tuning options).



1.3.2.2 Moving Window

This menu provides access to several moving window (convolution) algorithms, implemented via the generic image-convolution program *spatcon.c* (K. Riitters, personal communication, 2015; and demonstrated in earlier papers: Riitters et al. 1997, 2000, 2002, 2009). *SpatCon* metrics conduct focal statistics within a user-defined neighborhood area over each pixel of the input image.

Image convolution (Gonzalez and Woods, 1992), also known as moving window, is a general process that can be used for various types of smoothing, signal processing, shifting, differentiation, edge detection, etc. It places a window (kernel) on each pixel of the input map, calculates the pattern metric within the window, and puts the result on a new map at the same location. The value of the resulting index is driven by the dimension and the individual weights assigned to the window elements.

Think of it as opening an umbrella over a foreground pixel, do the assessment for the area covered under the umbrella (local neighborhood), and assign the result to the center pixel of the umbrella in the output map. The process is repeated over each foreground pixel, hence the term *moving window*, and illustrated at four example locations using a 3x3 neighborhood (umbrella) in the following chart:

Figure 16: Moving window analysis: a moving window of size *n* x *n* (here, 3x3) is centered over a given foreground pixel, the metric is calculated, and the resulting value is assigned to the same location in the output map. The central panel shows four example locations to illustrate the process.

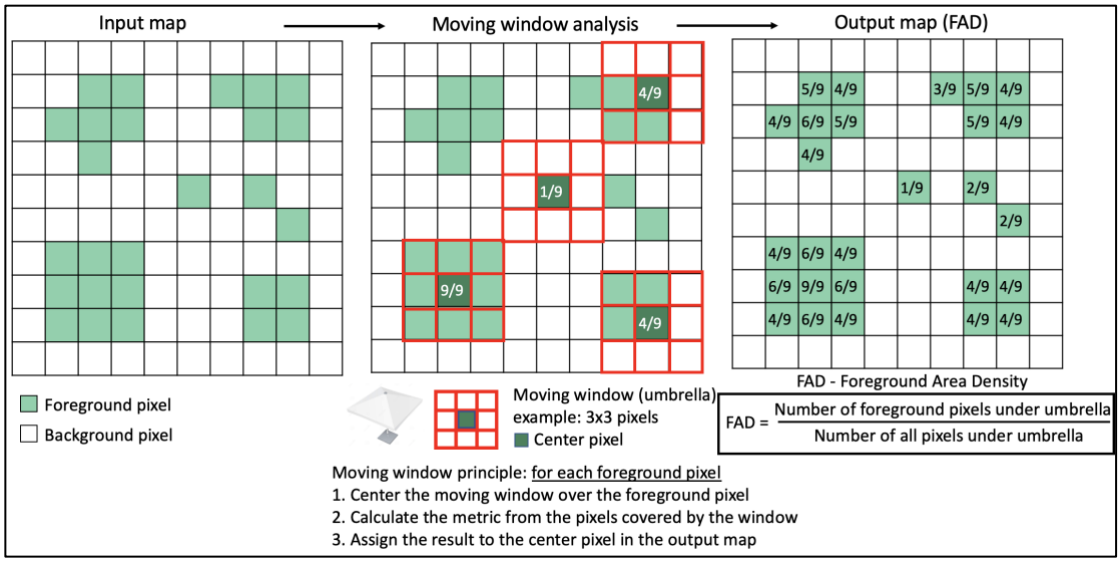


Figure 16 shows an example of a map of 10x10 pixels with foreground pixels in green color. The central panel shows the application of a moving window analysis using a 3x3 window/umbrella. For the area covered by the umbrella, the metric Foreground Area Density (FAD), equivalent to the amount of foreground area relative to the moving window area, is assigned to the central location of the umbrella in the output map. After repeating these steps for all foreground pixels, the result of the computation is shown on the right panel, having identical pixel coverage as in the input map but now showing the degree of FAD for each foreground pixel and considering a local neighborhood of 3x3 pixels. Increasing the dimension, or size of the moving

window, implies accounting for a larger local neighborhood area or using a larger analysis/observation/reporting scale.

Via an initial pop-up window, the user can specify the size of a square (kernel) window, which is then overlaid over each pixel of the input image, the selected metric is calculated for the area of the window, and the result is re-assigned to the center pixel of the overlaid window in the output image. All texture metrics are derived from analyzing the attribute adjacency table (Musick and Grover 1991), where Fij (i, j = 1 to t) is the frequency of adjacent pixel pairs with land-cover types {i, j}. When forming the attribute adjacency table, adjacency is evaluated in the four cardinal (horizontal and vertical) directions, each adjacency is counted once, the order of pixels in pairs is not preserved, and pairs involving a missing pixel are not included (Riitters et al. 1996b).

Figure 17: Illustration of moving window metrics (as implemented in *SpatCon*).

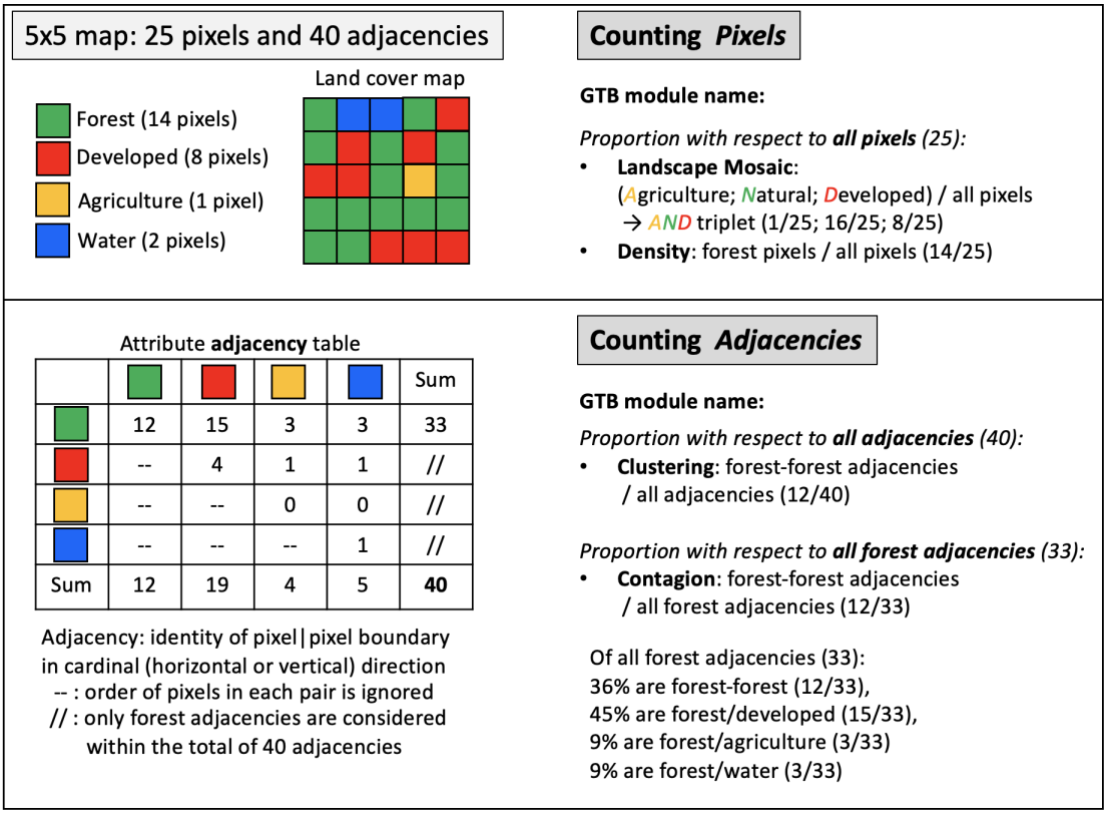


Figure 17 shows a sample landcover map with four landcover classes (top left) and the associated attribute adjacency table (bottom left), which is derived from counting the landcover classes in cardinal directions of each pixel boundary. For example, a 5x5 map has a total of 40 adjacencies and we consider foreground (forest) adjacencies only. The top line of the attribute adjacency table in Figure 17 shows that we have a total of 33 adjacencies having forest on at least one side of the pixel boundary. From those 33, 12 adjacencies have forest on both sides of the pixel boundary, 15 adjacencies have forest on one side and developed on the other side of the pixel boundary, 3 adjacencies have forest on one side and agriculture on the other side of the pixel boundary, and 3 adjacencies have forest on one side and water on the other side of the pixel boundary.

The image-convolution program *spatcon.c* offers a series of moving window metrics. Note: GWB includes all 21 *SpatCon* metrics in the dedicated module *GWB_SC*. GTB offers access to four *SpatCon* moving window metrics only, which can be grouped in two categories:

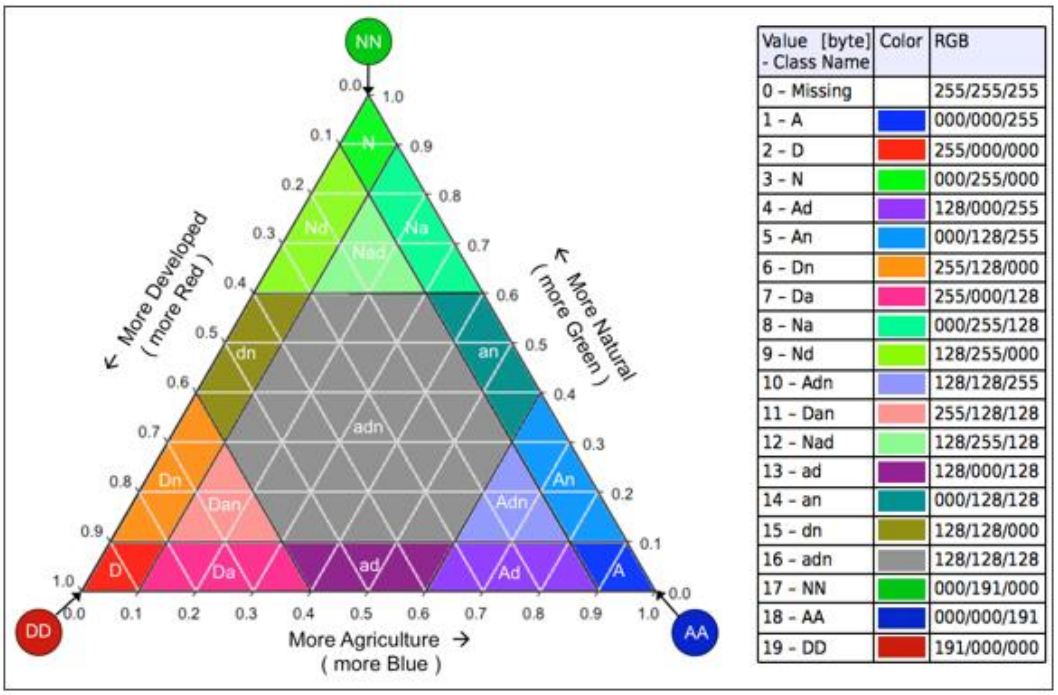
- Pixel counting metrics (measuring density): the density metrics *Landscape Mosaic* and *Density* are calculated from the proportions of pixel values in the window. For those metrics, missing pixel values are not included in the calculation, and the calculation result is missing if all pixels in the window are missing.

- Adjacency counting metrics: all adjacency metrics are calculated from the pixel|pixel adjacency values in the window. We define *N* as the total number of adjacencies between all pixels in cardinal directions, and the subset *n* as the number of adjacencies that have foreground on one side or the other. All adjacencies (N-n) that do not have foreground on either side are excluded in the metric calculation. If there are missing pixels in the (kernel) window, the adjacencies involving missing pixels are not included. As a result, the total number of adjacencies is less than *N* and the total number of adjacencies involving foreground may be less than *n*, if missing pixels are adjacent to foreground pixels. *Clustering* is *landscape-level* contagion, the denominator is the number of all adjacencies of the moving window. *Contagion* is *class-level* contagion (one row of the attribute adjacency table), the denominator is the number of foreground adjacencies only.

The following moving-window processing options are available in GTB:

- **Landscape Mosaic** (**Figure 18**): a tri-polar classification of a location accounting for the relative proportions of three classes in the window surrounding that location. The classification model uses the critical values of 10%, 60%, and 100% along each axis to partition the tri-polar space into 19 mosaic classes. More details on the concept of Landscape Mosaic and application examples can be found in Wickham et al. (1994) and Riitters et al. (1996a, 2000, 2009).
  The result of the moving window analysis is a geographic map showing the 19 landscape Mosaic classes for each pixel at the user-selected observation scale (**Figure 19**, left). A second output shows a statistical summary as a heatmap (image and csv-file). The statistical summary is for an expanded, 103-class version of LM with the LM image pixel value assignment detailed in **Figure 20**. In this expanded version, each of the 100 sub-triangles in **Figure 19** is a separate class, and three additional classes correspond to the external circles (AA, DD, NN in **Figure 19**). The heatmap image (**Figure 19**, right) shows the relative frequencies of pixels in each of the 103 categories (see also **Figure 21**). The accompanying csv-file contains the numeric values from the heatmap image.

Figure 18: Landscape Mosaic (LM) tri-polar classification scheme showing 19 mosaic classes and their proportions of the 3 landcover categories *Natural*, *Agriculture*, and *Developed*. A capital letter denotes more than 60% and a small letter a contribution in the range of [10-60]% of a given landcover category.



Value [byte] - Class Name	Color	RGB
0 - Missing		255/255/255
1 - A		000/000/255
2 - D		255/000/000
3 - N		000/255/000
4 - Ad		128/000/255
5 - An		000/128/255
6 - Dn		255/128/000
7 - Da		255/000/128
8 - Na		000/255/128
9 - Nd		128/255/000
10 - Adn		128/128/255
11 - Dan		255/128/128
12 - Nad		128/255/128
13 - ad		128/000/128
14 - an		000/128/128
15 - dn		128/128/000
16 - adn		128/128/128
17 - NN		000/191/000
18 - AA		000/000/191
19 - DD		191/000/000

Figure 19: Landscape Mosaic (LM) image (left) and corresponding heatmap (right) showing LM-pixel occurrence frequencies. The maximum frequency is highlighted in a black circle. In this example, 21% (i.e., 17% plus 4%) of all LM-pixels are in the Mosaic class A (Agriculture).

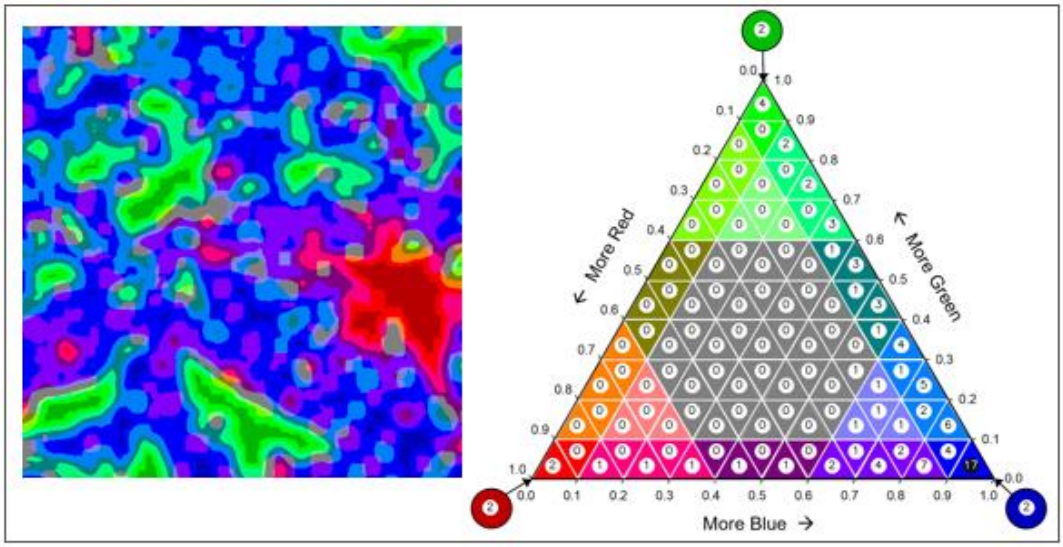


Figure 20: Image pixel value assignment of the 103 LM-classes.

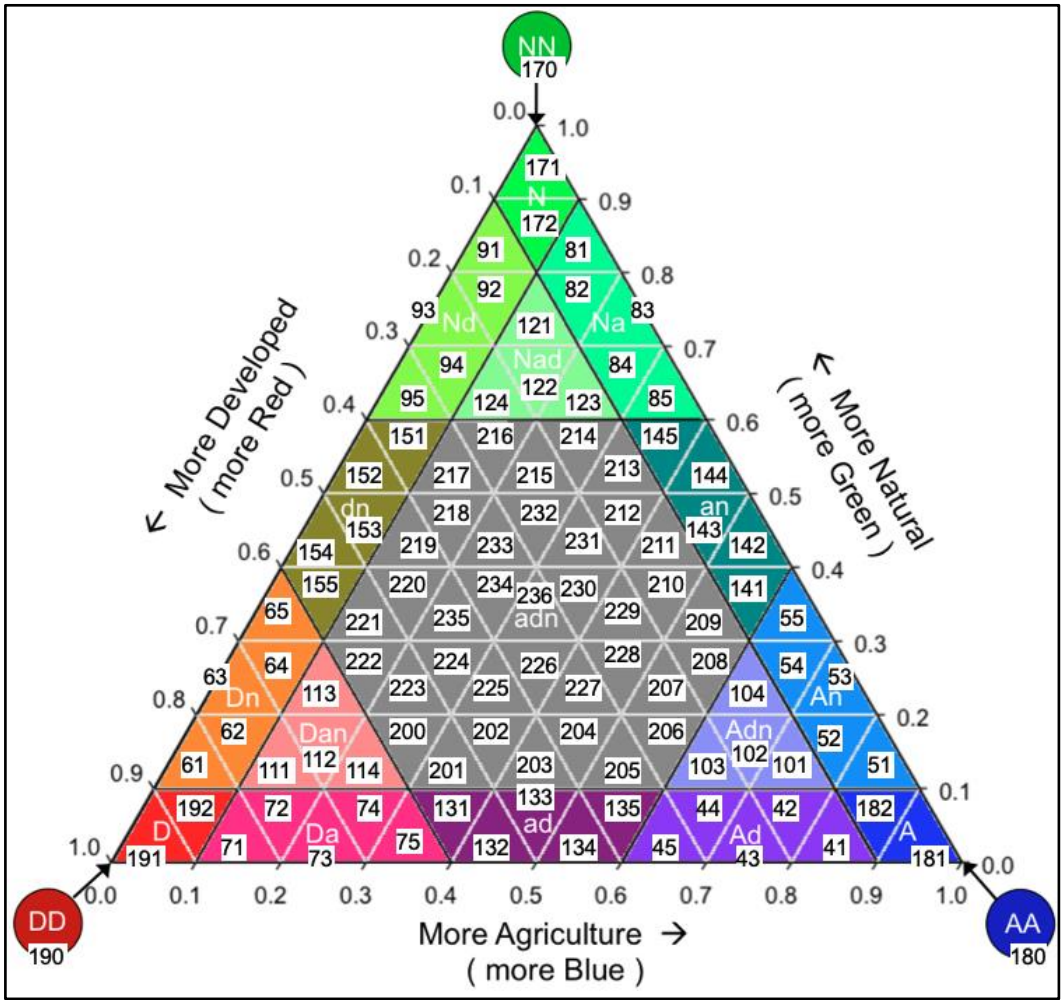


Figure 21: Explanatory chart to read out Landscape Mosaic pixel value triplets and to locate these triplets in the ternary domain space.

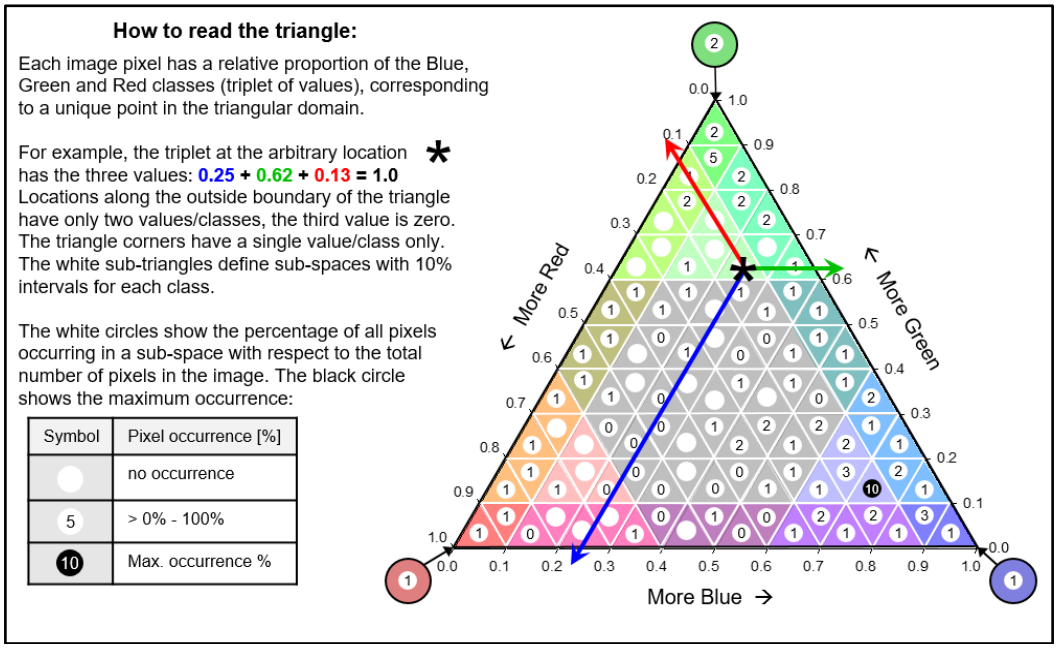
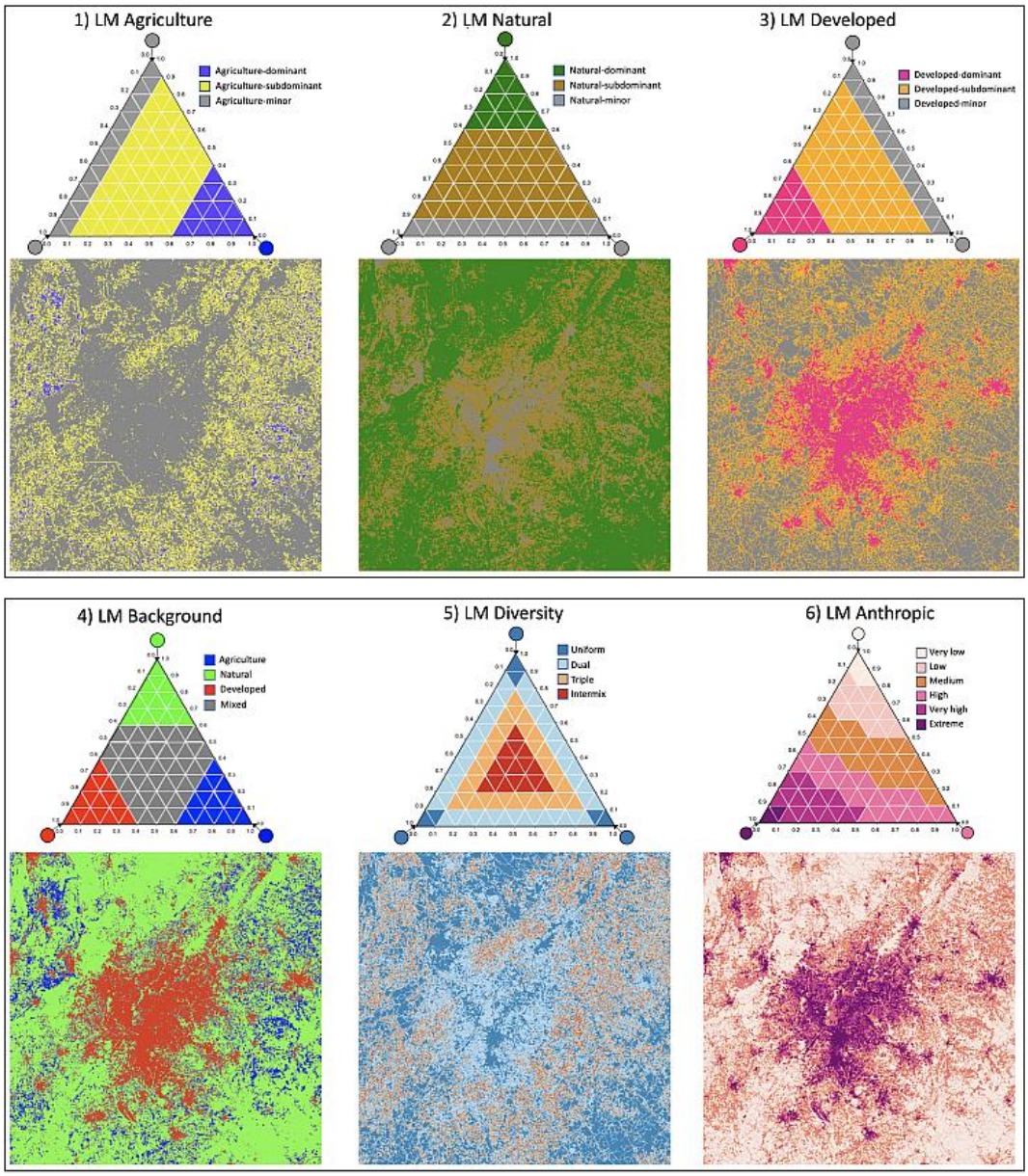


Figure 22 shows how the 103-class LM image can be displayed with different predefined color tables to focus on a specific thematic topic of interest. Simply load the 103-class LM image and select the color table of your choice from the **Select Colortable** dropdown menu: *LM_AGR, LM_NAT, LM_DEV, LM_BGR, LM_DIV,* or *LM_ANT*. Alternatively, define a custom color table to highlight a particular section of the ternary LM-chart.

Figure 22: Example of color-coding the 103 classes of the Landscape Mosaic over Atlanta, GA, USA. LM-Agriculture, LM-Natural, LM-Developed showing dominance of agricultural, natural, and developed land cover, respectively. LM-Background (predominant land cover type), LM-Diversity (degree of heterogeneity), LM Anthropic (anthropogenic intensity).



The input image for Landscape Mosaic must be a Byte array with no more than 3 target classes with the assignment **AND** (1-**A**griculture, 2-**N**atural, 3-**D**eveloped) plus an optional class for missing values (0 Byte).

More information can be found in the LM Product Sheet and/or the LM paper.

- **Density (or Foreground Area Density - FAD):** the proportion of foreground pixels (2b) in the moving window. More details on the concept of *Density* and *Contagion* (see below) and application examples can be found in Riitters et al. (1997, 2002, where Density=P_f and Contagion=P_{ff}). Click *Intext* for FG-masking and *Divide* for range grouping. The input image for Density must be *MSPA-compliant*: A Byte array having 0b – missing (optional), 1b – background, 2b – foreground. The output map is a byte image showing the proportion of foreground density within [0, 100]% and masked by foreground, background (101 byte) and missing pixels assigned to 102 byte.

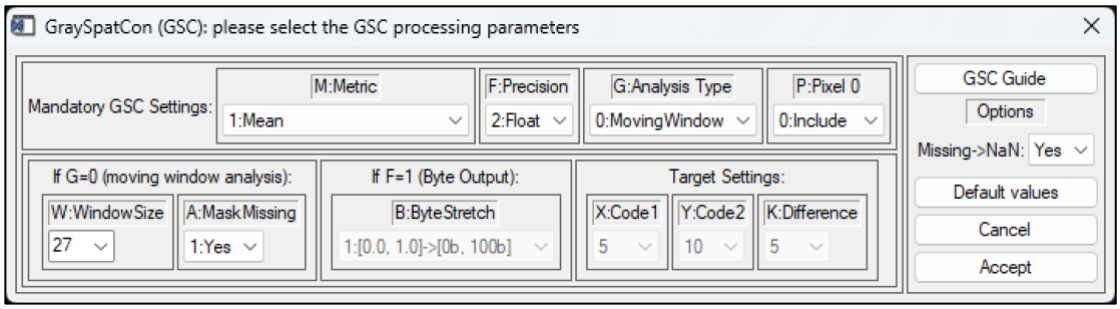
- **Clustering (or Foreground Area Clustering - FAC):** foreground clumpiness at landscape level. The reference level for Clustering are all adjacencies within the area covered by the moving window/umbrella. Clustering measures the proportion of adjacencies in cardinal directions for which both pixels are foreground (2b|2b) with respect to all adjacencies in the moving window. Click Intext for FG-masking and Divide for range grouping. The input image for Clustering must be *MSPA-compliant*: A Byte array having 0b – missing (optional), 1b – background, 2b – foreground. The output map is a byte image showing the normalized degree in foreground clustering within [0, 100]% and masked by foreground, background (101 byte) and missing pixels assigned to 102 byte.

- **Contagion:** foreground clumpiness at class level. The reference level for Contagion is limited to all forest adjacencies within the moving window/umbrella. Contagion measures the proportion of adjacent pixel pairs in cardinal directions that include at least one foreground pixel, for which both pixels are foreground (2b|2b). Contagion estimates the conditional probability that, given a foreground pixel, its neighbor is also foreground. Click Intext for FG-masking and Divide for range grouping. The input image for Contagion must be *MSPA-compliant*: A Byte array having 0b – missing (optional), 1b – background, 2b – foreground. The output map is a byte image showing the normalized degree in foreground contagion in [0, 100]% and masked by foreground, background (101 byte) and missing pixels assigned to 102 byte.

1.3.2.3 GraySpatCon

The image-convolution program *GraySpatCon* (GSC) offers a wide variety of texture metrics for the analysis of dichotomous (binary), nominal, and ordinal raster data. The metrics are based on the frequency of pixel values and/or the frequency of pixel value adjacencies in a moving window and measure either the attraction or the dispersion of numerical pixel values on a map. The input map requirements, GSC metrics, parameters, processing options, and output specifications are summarized in the GSC Guide (Help → GTB Documentation → GSC Guide) and can be configured in a dedicated popup window:

Figure 23: GraySpatCon popup window



For a global analysis, the result is a plain text file listing the GSC-parameters used and the global metric value. For a moving window (non-global) analysis, the result is a set of two files: a) a plain text file with the GSC-parameters used, and b) a (Geo)TIFF formatted image showing the selected metric value at pixel level and in the format specified by the GSC processing parameters. The GSC-metrics are calculated as integer, nominal, or floating-point values. For the metrics which are floating-point values, *GraySpatCon* rounds the calculated value to 5 decimal digits (0.00005) for output of either float values or rescaled byte values.

For 8-bit (byte) output the missing value is always 255. For 32-bit (float) output, the missing value is -0.01, except for metrics 44, 45, and 50 that may take on a negative value, in which case the missing value is -9000000.0. The switch *Missing → NaN*, see right panel in **Figure 23**, provides the following two options:

- Yes: will assign all NODATA pixels the value of NaN. This step will resolve output display issues and show consistent results across all image viewers. When saving a *GraySpatCon* image, GTB will write out the original *GraySpatCon* value for those pixels that were manually assigned to NaN via the GTB popup window.
- No: will use the unmodified *GraySpatCon* output image. When saving a *GraySpatCon* image, GTB will add the respective NODATA information in the GeoTIFF header.

With either of these options, any user can then make necessary adjustments to amend the missing data value to either, the original *GraySpatCon* value or any other value that is suitable for the image viewer software application.

1.3.3 Graph Theory Network: GTN(MSPA)

The MSPA-analysis can be converted into a Graph Theory Network (GTN) setup for further analysis in a graph theory application, here *Conefor* (Saura, 2009a). A **Graph Theory Network (GTN) is composed of *Nodes*** (↔ MSPA class: **Core**) **and *Links*** (↔ MSPA class: **Bridge** = connectors between different Cores) and **the remaining MSPA classes are neglected**. A connected set of Nodes and Links is called a ***Component***.

Figure 24: Relation between MSPA and Graph Theory

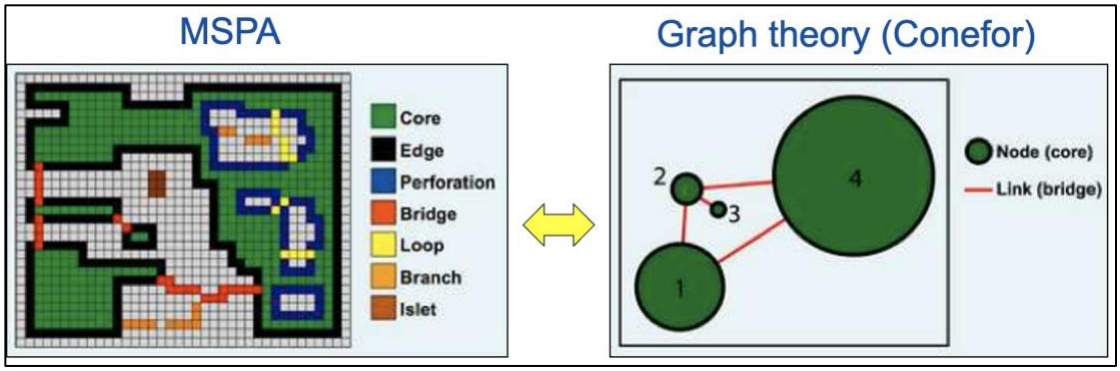


Figure 24 shows the relation between MSPA and graph theory. The network illustrated above has one component, which is composed of four Nodes and four Links. The Nodes correspond to the MSPA class Core and the Links to the MSPA class Bridge. All other MSPA classes are neglected for graph theory analysis, for example the MSPA features Edge, Perforation, Loop, Branch, and Islet are removed when transitioning to a graph theory network. In addition, a graph theory Link (MSPA Bridge) is a feature without area.

The following GTN options are available **after a MSPA-analysis**:

1.3.3.1 GTN Components

Individual components of the graph theory network are displayed in alternating colors. The color black is used for node-only components having no links. The **ECA**, *Equivalent Connected (Node/Core) Area*, (Saura et al. 2011) is the square root of PCnum= $\sum_{i=1}^{N}(node\ area\ of component_i)^2$, the overall network connectivity. ECA is measured in units of area, i.e., hectare, or in the generic case in units of pixels. **ECA_rel** is the normalized or relative ECA with respect to ECA_max= $\sum_{i=1}^{N}(node\ area\ of component_i)$, when all components are fully connected. When looking at landscape habitats, ECA_rel is also known as *ARH* (amount of reachable habitat) or *PRH* (percentage of reachable habitat). ECA_rel is equivalent to the Degree of network Connectivity (**DOC**) of the NW Components in the image.

The information window below the main display shows the unique component identifier, the total area of the component, and the contribution of links. Saving the result will produce the following three files:
a) **<name>_nw.tif**: same graphics as displayed in GTB
b) **<name>_nw_nwdata.tif**: image with component IDs
c) **<name>_nw.txt** (only when saving the entire image): statistics for each component, total area, and contributed area of links, ECA, DOC.

1.3.3.2 GTN Node/Link Importance

This option will show the connectivity importance for each node and each link of the graph-theory network. The connectivity importance is calculated according to equation 4 in Saura (2009b) and having the following three contributions: $dPC = dPCintra + dPCflux + dPCconnector$, where the importance corresponds to the term dPCconnector only. The information window below the main display shows the node/link ID, and its absolute and relative connectivity importance. The importance of all Nodes is normalized such that the highest Node importance is assigned to 100%. The same normalization procedure is applied for the Links. After the normalization, each individual Link or Node will have a relative importance within [0, 100]%, with allows finding the most important Links and/or Nodes.
With respect to the maximum importance of Nodes/Links we then assign a decreasing intensity of green color for Nodes: dark green (highest importance: 99-100%), medium green (importance 95-> 99%), light green (90->95%) and with a decreasing intensity of red for Links: dark red (highest importance: 99-100%), medium red (importance 95-> 99%), light red (90->95%). Objects with a lower importance are color-coded with light purple color to mark Nodes (having a negative ID), while the black color denotes Links (having a positive ID to distinguish them from the Nodes).
Saving the result will produce the following four files:
a) **<name>_cs.tif**: same graphics as displayed in GTB
b) **<name>_cs_conn.tif**: connectivity importance for each node and link.
c) **<name>_cs_ids.tif**: unique identifier of each node and link where nodes have a negative sign to distinguish them from links.
d) **<name>_cs.txt** (only when saving the entire image): statistics for each component, its nodes and links, area, and connectivity importance.

1.3.3.3 MSPA ConeforInputs

The option MSPA ConeforInputs will setup and save the two input files ***nodes_mspa_<input>.txt*** and ***links_mspa_<input>.txt*** for further analysis in Conefor (Saura, 2009a). Use this option for detailed graph-theory analysis, which is beyond the network connectivity importance provided within GTB. When using this option **MSPA ConeforInputs** the **connectivity is defined via** the *MSPA-detected structural connectors (**MSPA-Bridges**)*. This is different to the option **ConeforInputs**, where the **connectivity is defined via the *pairwise distance*** of image objects.

1.3.4 Fragmentation

Fragmentation can be seen as the spatial heterogeneity, or the spatial composition and arrangement of foreground objects in an image. It accounts for the number of objects and the distance between them, hence addressing foreground and background characteristics at the same time. Due to its holistic nature the description of fragmentation is rather complex and, in the case of landscapes, usually defined for a given species of interest and as such species-specific. Moreover, current fragmentation definitions are only descriptive and for this reason do not allow *quantifying* the degree or changes of fragmentation for a given image. In GTB, all fragmentation assessment schemes are designed to quantify fragmentation into the minimum-maximum range of [0 – 100]%. To further facilitate communication of the result the Divide Range panel below the viewport can be used to group the fragmentation values into the three categories small/medium/large. The GTB title bar provides additional summary information of the selected fragmentation assessment scheme.
The aim in GTB is to *describe* fragmentation by using different concepts, each emphasizing a specific aspect of the very generic term fragmentation. Based on the nature of the selected approach, each concept will provide a focused result, which best matches the user-selected aspect of fragmentation. An additional benefit of *quantifying* the state of fragmentation in percent on a given map, all measures permit the comparison of the degree of fragmentation of different sites, the *quantification of changes* in fragmentation over time, and *monitoring* as well as *measuring progress* in planning programs and political directives.

1.3.4.1 Fixed Observation Scale (FOS)

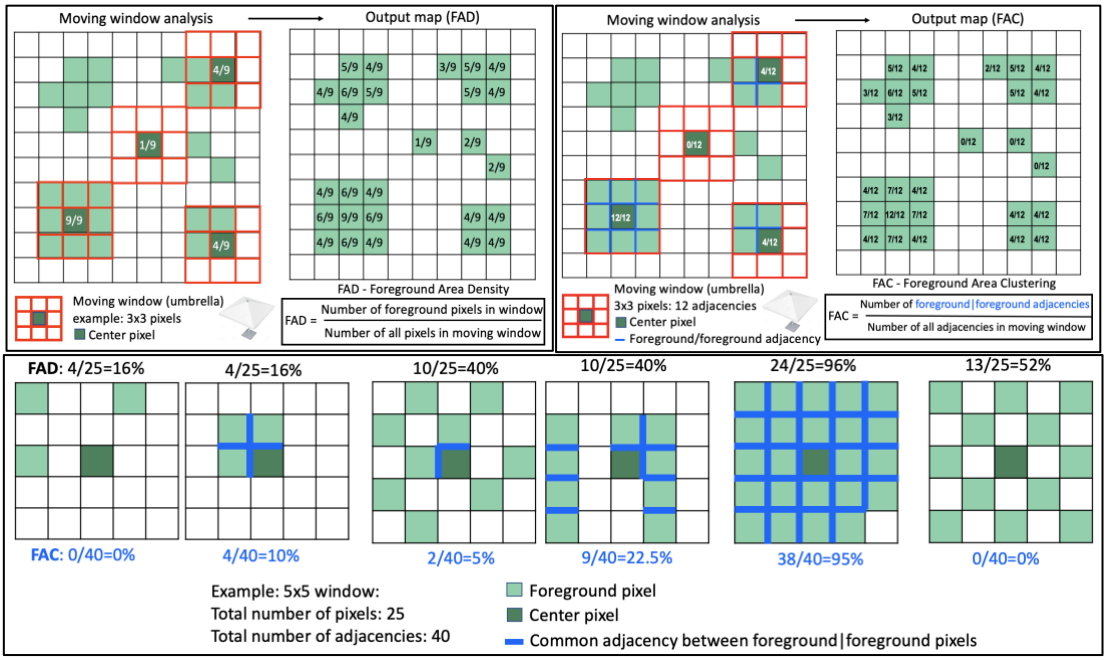
This section provides methodologies to conduct a fragmentation analysis at a user-selected specific Fixed Observation Scale (FOS). The user can choose between three moving window metrics and four reporting schemes.

The three moving window metrics: FAD, FED, and FAC

The concept of a moving window was introduced earlier and exemplified for FAD in **Figure 16.** A FOS-analysis can be conducted with measuring either the *Foreground Area Density* (FAD), *Foreground Edge Density* (FED),or the *Foreground Area Clustering* (FAC) metric. FAD measures the proportion of foreground pixels with respect to the total number of pixels in the local neighborhood. FAC measures the proportion of foreground|foreground adjacencies with respect to the total number of adjacencies in the local neighborhood. **Figure 25** illustrates the difference between FAD and FAC at four example locations and using a 3x3 neighborhood (umbrella) in the top panel, and for three amounts of foreground coverage in a 5x5 neighborhood in the bottom panel. Both metrics measure the degree of local connectivity, or its complement

fragmentation. FAD is driven by the amount of foreground while FAC is driven by the local clustering or direct adjacency of foreground (for example forest pixels) in the local neighborhood (area under the umbrella) over each foreground pixel. Note the difference on the checkerboard.

Figure 25: Fragmentation metric FAD and FAC



The third assessment option FED, or Foreground Edge Density, calculates the average value along all foreground edges, where foreground pixels are assigned full coverage (100%) and background pixels have no coverage (0%). With this assignment, FAD and FED can then also be applied to grayscale input maps, i.e., tree cover density maps in [0, 100]% (Vogt et al., 2024). When using grayscale maps, a grayscale threshold value must be specified to define background cover, which is needed to delineate foreground cover patches. Because FAC counts the same values along common foreground edges, FAC is not applicable for grayscale input maps. A comparison of FAD, FED, and FAC is exemplified in **Figure 26** for a 5x5 window with binary or grayscale pixel coverage.

Since FAD only counts the number of foreground pixels, it is not sensitive to their spatial configuration within the moving window. But FED and FAC will change when the spatial configuration of the foreground pixels is changed, see **Figure 27**.

If sensitivity to spatial configuration is of interest then the user may opt for using the methodology FED or FAC. However, differences to FAD-derived values may only appear for very small moving windows or when the foreground coverage is medium. FED calculations, especially on grayscale data, will require more calculation time.

Figure 26: Comparison of FAD, FED, and FAC

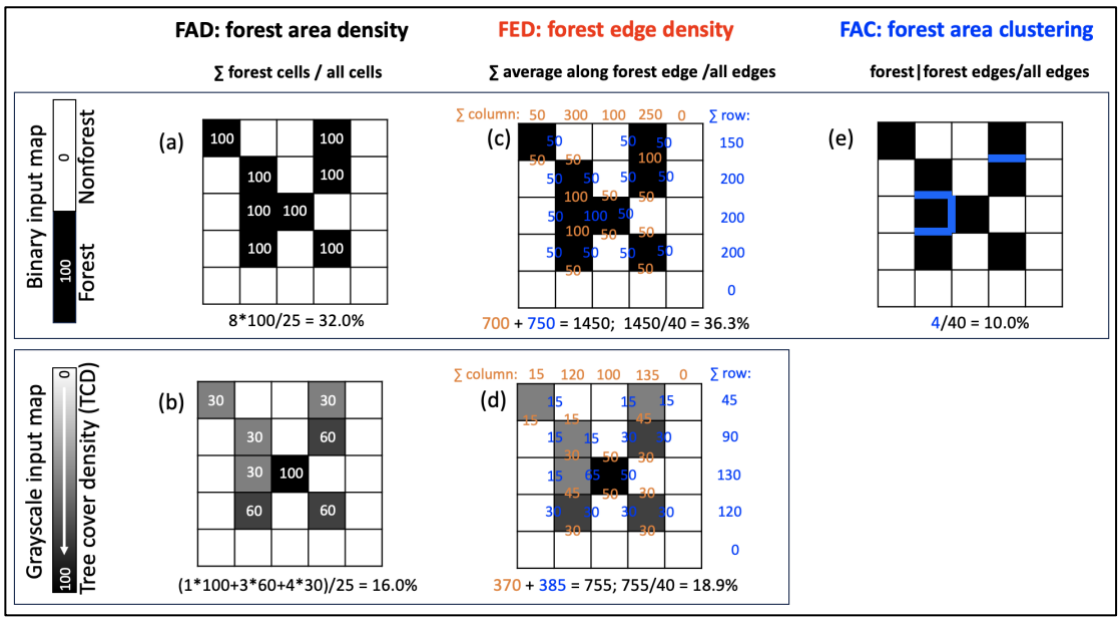
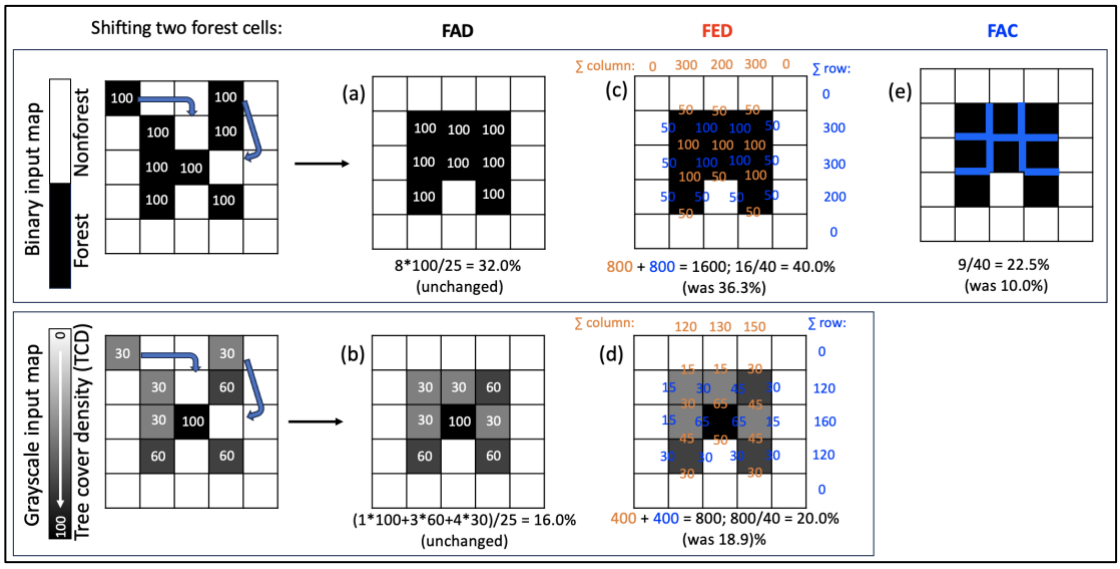


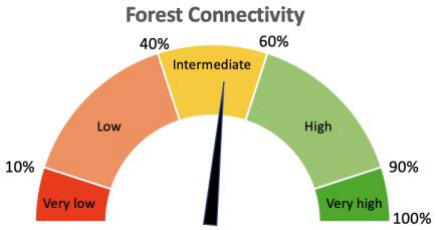
Figure 27: Comparison of shifting two foreground pixel locations for FAD, FED, and FAC



The two reporting schemes: 5class, 6class.

The resulting map shows the degree of connectivity, or fragmentation in percent within the user-specified neighborhood (under the umbrella) over each foreground pixel. This pixel-level result is then color-coded into several categories of connectivity/fragmentation to facilitate communication. Moreover, the per-pixel values can be aggregated into either, a single average value at foreground or reporting unit level.

Figure 28: Example for reporting connectivity/fragmentation using the default 5-class scheme.



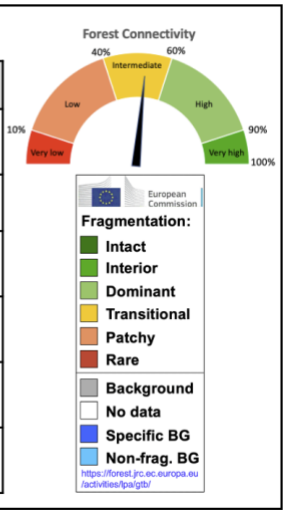
Foreground cover	Color	FAD/FED/FAC	Connectivity	Fragmentation
1-Rare		0% ≤ x < 10%	Very low	Very high
2-Patchy		10% ≤ x < 40%	Low	High
3-Transitional		40% ≤ x < 60%	Intermediate	Intermediate
4-Dominant		60% ≤ x < 90%	High	Low
5-Interior		90% ≤ x ≤ 100%	Very high	Very low

Figure 28 shows the default 5-class reporting scheme where the full range of the metric FAD/FED, or FAC in [0, 100]% is divided into 5 reporting classes and their reference with respect to foreground cover, connectivity, and fragmentation. The map product is simply color-coded into these 5 categories to facilitate communication. The statistical summary provides the proportion of the total foreground area in each category and the average across all foreground pixels. For example, in class 4 the foreground cover within the neighborhood is *dominant*, which is equivalent to FAD/FED, or FAC being within the range [60, 90]%, the degree in connectivity is *high*, and the degree in fragmentation is *low*. The 6-class reporting scheme is similar but with a separate class 6, named *Intact*, where FAD/FED, or FAC = 100%. The two pixel-level reporting schemes are summarised in **Figure 29**:

Figure 29: Summary of FOS reporting options.

Range Pixel level reporting

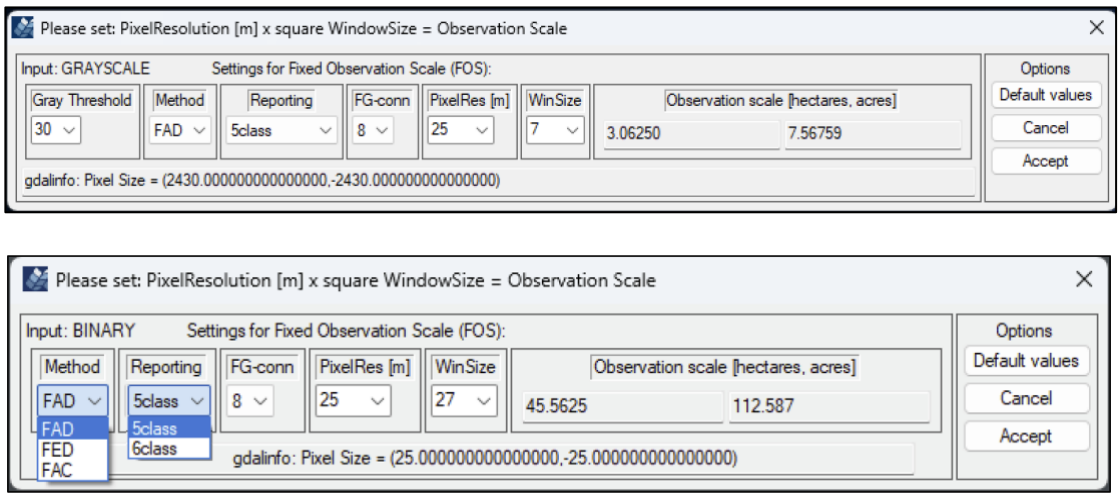
Indicator [%]	6class	5class	Connectivity	Fragmentation
0 ≤ x < 10	1-Rare	1-Rare	Very low	Very high
10 ≤ x < 40	2-Patchy	2-Patchy	Low	High
40 ≤ x < 60	3-Transitional	3-Transitional	Intermediate	Intermediate
60 ≤ x < 90	4-Dominant	4-Dominant	High	Low
90 ≤ x < 100	5-Interior	5-Interior	Very high	Very low
100	6-Intact		Intact	None



Examples of per-pixel FAD reporting are *FAO* (Vogt 2019b), *MAES* (Maes 2020), *EUROSTAT* (Vogt 2022b), and EUFO (Vogt 2022c) to measure forest fragmentation (see **References**). More information is available in the Fragmentation Product Sheet.

In a dedicated popup window, the user can choose the FOS type and reporting scheme, and define the observation scale by specifying the pixel resolution (in meters) and the side length (in pixels) of the square moving window in a GUI:

Figure 30: FOS interface: select the reporting scheme and set the spatial resolution of the data and the moving window size to define a Fixed Observation Scale for the fragmentation analysis. FOS reporting options for grayscale input maps (top) and binary input maps (bottom).



The selected settings are then used to calculate the area of the moving window (observation scale), which is displayed in hectares and acres. The bottom panel of the GUI provides information on the pixel size retrieved via the *gdalinfo* command. Please note that this information is not automatically used for calculating the observation scale but displayed only as a guide for the user. The GDAL-reported pixel size may be in meters or degrees and can only be retrieved from properly formatted GeoTIFF headers. The image above shows a combination of pixel resolution and window size resulting in an observation scale of ~45 hectares (window side length = 27 pixels x 25m = 675m; window area = 675m x 675m = 455.625m^2 = 45.5625 hectares). The user can choose settings from the drop-down menu or insert custom values, followed by the Enter key. After the definition of the analysis type and the user-selected observation scale, click on *Accept* to apply this scale for the fragmentation analysis.

The input map for the FOS analysis must have the following values:

Binary input map (i.e. forest-nonforest map):
- 0 byte: missing (optional). These pixels will show in white color in the output image.
- 1 byte: background.
- 2 byte: foreground.
- 3 byte: specific background. These background pixels (e.g., water) will show in dark blue color in the output image.
- 4 byte: non-fragmenting background. In contrast to all other background pixels, these background pixels will not have a fragmenting effect on the foreground. These pixels will show in light blue color in the output image.

Grayscale input map (i.e. tree cover density map):
- [0, grayt-1] byte: background.
- [grayt, 100] byte: foreground.
- 103 byte: specific background. These background pixels (e.g., water) will show in dark blue color in the output image.

- 104 byte: non-fragmenting background. In contrast to all other background pixels, these background pixels will not have a fragmenting effect on the foreground. These pixels will show in light blue color in the output image.
- 255 byte: missing (optional). These pixels will show in white color in the output image.

When using grayscale maps, a grayscale threshold value (grayt) must be specified to define background cover, which is needed to delineate foreground cover patches. For example, when using a tree cover density map, and specifying grayt=30, Background pixels are defined where tree cover density is less than 30% and foreground pixels where tree cover density is in [30, 100]%.

Because input data pixels with 4 (104) byte do not have a fragmenting effect, changing background to non-fragmenting background will lead to a reduction of foreground fragmentation and consequently change the fragmentation statistics.

Saving a FOS analysis will create a new directory with the naming convention **<input name>_<FOS_type>_<windowsize>** and the four files:

a) **<name>.tif**: FOS output map

b) **<name>.txt**: FOS summary statistics

c) **<name>.csv**: FOS summary statistics in comma-separated value format for import into a spreadsheet application

d) **<name>.sav**: FOS summary settings for change analysis

The resulting images have the following dedicated value assignments:

1-100 byte: Foreground area density (FAD), edge density (FED), or clustering (FAC) value in percent

101 byte: Background pixels (gray color)

102 byte: Missing pixels (white color)

105 byte: Specific background pixels (dark blue)

106 byte: Non-fragmenting background pixels (light blue)

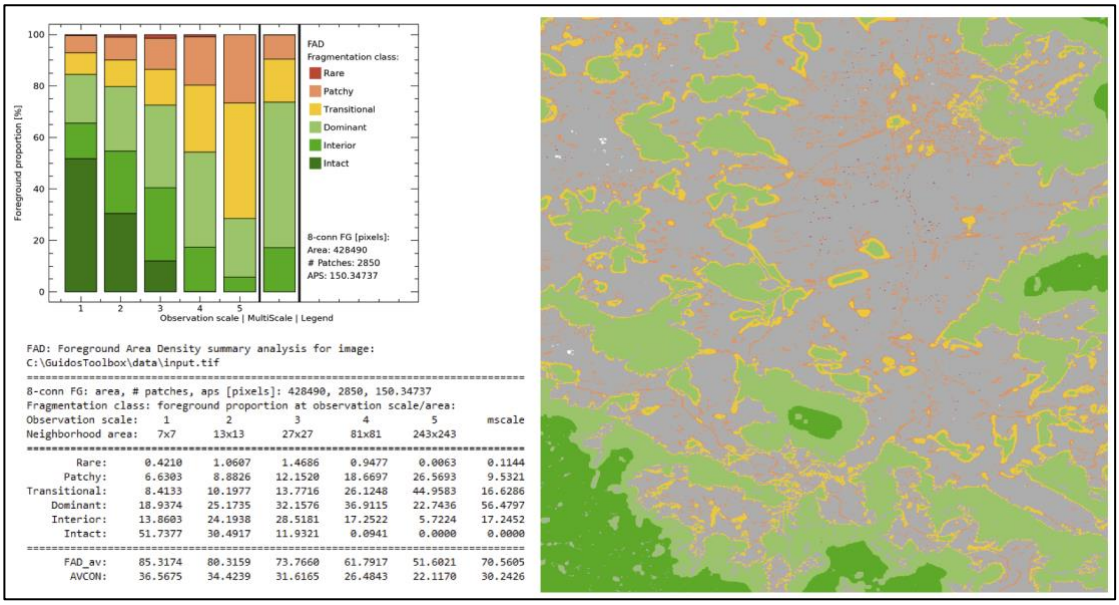
Saving a zoomed area is disabled, or if needed use the *Display Snapshot* option from the *Save Image* menu but the statistics will always refer to the entire map area. When saving a FOS analysis all saved files refer to the entire extent of the original input map.

1.3.4.2 Multiple Observation Scale

This section provides methodologies conducting a fragmentation analysis for a series of five fixed observation scales with window/umbrella dimension 7x7, 13x13, 27x27, 81x81, 243x243 pixels. These neighborhood areas were selected to span a wide range of scales representing an approximately geometric progression of window area with observation scale. An additional sixth map and related statistics show a summary across all five observation scales.

- **FAD**: the Foreground Area Density is measured at five observation scales (FAD Multiscale) and masked for foreground (Riitters et al., 2002, 2012a, 2012b). The result is a set of six maps (one for each observation scale plus a multiscale summary) showing the FAD value for each foreground pixel. The resulting maps list the FAD values at pixel level using the FAD 6-class reporting scheme.
  The statistical summary (**Figure 31**) lists the proportion of foreground in each fragmentation class and for each of the 5 observation scales. The column *mscale* lists the MultiScale summary, which is built on a per-pixel basis across all 5 observation scales. The map legend and the aggregated results for the entire image are displayed as a cumulative bar chart. The observation scales 1, 2, 3, 4, 5 correspond to the window lengths 7, 13, 27, 81, 243 pixels.

Figure 31: Statistical summary table and bar-plot example for FAD 6-class multiscale analysis.




```
FAD: Foreground Area Density summary analysis for image:
C:\GuidosToolbox\data\input.tif
================================================================================
8-conn FG: area, # patches, aps [pixels]: 428490, 2850, 150.34737
Fragmentation class: foreground proportion at observation scale/area:
Observation scale:    1        2        3        4        5        mscale
Neighborhood area:    7x7      13x13    27x27    81x81    243x243
================================================================================
            Rare:    0.4210   1.0607   1.4686   0.9477   0.0063   0.1144
           Patchy:   6.6303   8.8826   12.1520  18.6697  26.5693  9.5321
    Transitional:    8.4133   10.1977  13.7716  26.1248  44.9583  16.6286
        Dominant:    18.9374  25.1735  32.1576  36.9115  22.7436  56.4797
        Interior:    13.8603  24.1938  28.5181  17.2522  5.7224   17.2452
           Intact:   51.7377  30.4917  11.9321  0.0941   0.0000   0.0000
================================================================================
          FAD_av:    85.3174  80.3159  73.7660  61.7917  51.6021  70.5605
           AVCON:    36.5675  34.4239  31.6165  26.4843  22.1170  30.2426
```

The viewport image in GTB shows the multiscale FAD assessment: the average FAD value across all five observation scales, which is displayed color-coded into the user-selected fragmentation classes. When moving the mouse cursor into the viewport, the information panel below the viewport will display the cursor coordinates followed by the multiscale FAD value and the sequence of FAD values across the five observation scales.

The input map for the FAD multiscale analysis must have the same specifications as for the FOS analysis.

The FAD multiscale analysis can be saved as a single multiscale image when using the option Display Snapshot or KML. When using the option GeoTIFF or Generic the full result is saved into a new directory and the following files:

a) **<name>_FAD_{7/13/27/81/243}.tif**: FAD-values at 5 observation scales
b) **<name>_FAD_barplot.png**: FAD-bar chart summary

c) **<name>_FAD_mscale.txt**: FAD summary statistics
d) **<name>_FAD_mscale.csv**: FAD summary statistics in comma-separated value format for import into a spreadsheet application
e) **<name>_FAD_mscale.tif**: FAD summary multiscale image

The resulting images have the following dedicated value assignments:
1-100 byte: Foreground density
101 byte: Background pixels (gray color)
102 byte: Missing pixels (white color)
105 byte: Specific background pixels (dark blue)
106 byte: Non-fragmenting background pixels (light blue)
Saving a zoomed area is disabled, or if needed use the *Display Snapshot* option from the *Save Image* menu but the statistics will always refer to the entire map area. When saving a FAD multiscale analysis all saved files refer to the entire extent of the original input image.

Note:
1. The five observation scales are arbitrary; they were selected to span a wide range of scales (window area) and to approximate a geometric progression of window areas with scale.
2. Please use the FOS scheme to conduct a single-scale FAD fragmentation analysis at a user-specified scale.
3. The results displayed in the viewport could suggest that FAD may also be useful for labeling different morphological parts of the foreground patches (Riitters 2005). However, such labeling is better accomplished by using the MSPA algorithm.

1.3.4.3 Legacy

This section provides various fragmentation assessment schemes that have been used in the past. They are provided here for historic reasons and for the curious reader, who may be interested in alternative assessment schemes.

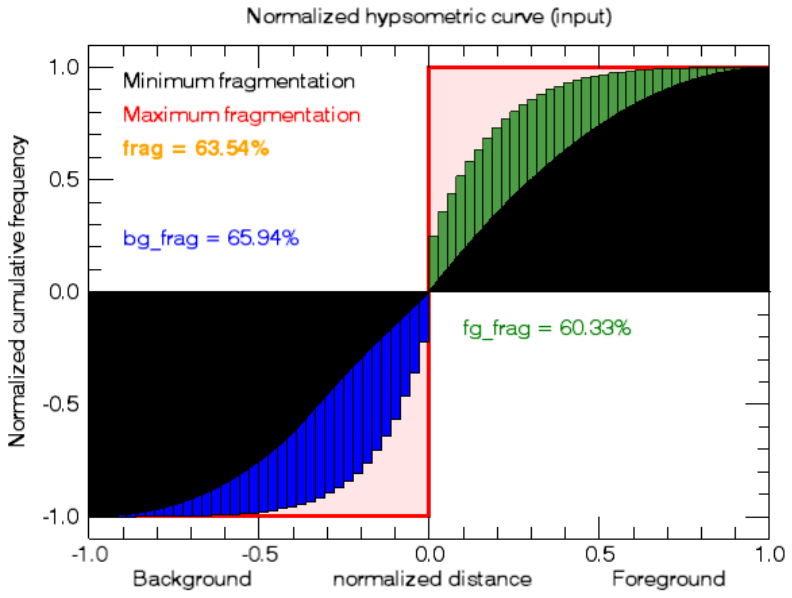
Index

The Fragmentation submenu ***Index*** provides methodologies resulting in a normalized fragmentation value (index) for the entire image.

- **Entropy:** this option will calculate the **Entropy** of the entire image and the input map dimension must be at least 500 pixels in x- and y-direction.

- **Hypsometry:** the *Normalized Hypsometric Curve* (NHMC, **Figure 32**) is the Hypsometric Curve (**Figure 33**) scaled by the maximum distance in the foreground and in the background. **Figure 32** shows the NHMC for three images and the following three conditions:
  - Minimum fragmentation (black): NHMC of an image with maximum foreground aggregation: All foreground pixels accumulated to a circle.
  - Actual image (blue/green): NHMC of the actual image
  - Maximum fragmentation (red): NHMC of a checkerboard image of the same size as the actual image and with 50% coverage. This theoretical maximum condition for fragmentation is characterized by all foreground as well as all background pixels having 1 pixel and thus resulting in the step-function outlined in red in **Figure 32**.

Figure 32: Normalized Hypsometric Curve for minimum (black), maximum (red), and actual fragmentation state in the foreground (green) and in the background (blue).



For a given image, the degree of fragmentation (Kozak et al. (2018)) corresponds to the area covered between minimum fragmentation (black) and maximum fragmentation (red). In **Figure 32**, this area is highlighted in blue for the background and in green for the foreground. Accounting for the dual nature of fragmentation (foreground is fragmented by background and vice versa) the degree of fragmentation for a given image is defined by the weighted sum of fragmentation in the foreground and the background:

Frag (hypso) = (bg_area/100.0 * bg_frag) + (fg_area/100.0 * fg_frag)

The so-defined fragmentation provides values in the range of [0, 100]%, accounting for and summarizing key fragmentation aspects: duality, perforations, amount, division, and dispersion of image objects.

Map

This section provides methodologies resulting in spatial distribution of normalized fragmentation values.

- **Entropy**: in thermodynamics, Entropy describes the degree of disorder in a system. Transferring this concept into spatial geometry (raster images), we can use entropy as a descriptor for spatial fragmentation. Starting from the classical definition of entropy in information theory $H = -\sum Pi * \log(Pi)$ (Shannon, 1948) we define the discrete set of probabilities *Pi* as the probability that the difference between 2 adjacent pixels is equal to *i* and log is the base 2 logarithm. The original entropy definition has been implemented in many ways and it is important to distinguish the above definition of Pi from other commonly used indicators such as Shannon's diversity index or the Evenness index (where Pi is the proportion of *species*) and variations of contagion indices (where Pi is the proportion of different type of pixel edges). In short, in Shannon's original concept Pi refers to percentages of species classes in categorical maps, as defined in the species diversity literature. In contrast, here we investigate differences between cell values in all 8 directions (that is, the values of i), which is meaningful because raster images are continuous variables where their magnitude has meaning. While the entropy in the edge-type evenness is derived from the attribute adjacency table, the spatial entropy here is calculated on spatial tiles and assuming 8-connectivity for the foreground pixels.
  For a given amount of foreground area, an image with a single compact foreground object has minimum entropy while the entropy reaches its maximum value when the given area is split into the maximum number and dispersed equally over the entire image. Maximum entropy is thus found for a checkerboard distribution. These two boundary conditions define the possible range of fragmentation in the image. The spatial entropy is calculated by averaging calculations using box size tiles of 50 and 33 starting from the center of the image. This approach replaces the precise but much slower performing moving window computation. Finally, a smoothing filter is applied to return a spatial contiguous per pixel distribution. The result shows the normalized fragmentation as a function of spatial entropy.

- **Contagion**: contagion describes the degree of clumpiness of image objects. With this definition, fragmentation can be defined as the complement of contagion (1 – contagion); an image region with high contagion is equivalent to having low fragmentation. The contagion of foreground objects is calculated via the moving window metric Contagion and the window size of 49 pixels, providing a statistically meaningful data sample. The result shows the normalized fragmentation as a function of spatial contagion.

  Both, Entropy and Contagion are local aggregation measures but with an important difference: while Contagion will consider the Foreground objects only, the Entropy based fragmentation assessment is based on the *simultaneous* evaluation of Foreground and Background together (duality). For example, an image with predominant Background cover (i.e., 95%) and a few isolated Foreground objects (5%) will result in high fragmentation values for Contagion. For Entropy, this image will have low fragmentation values because the dominant area coverage (Background) is only slightly fragmented by the Foreground. In fact, we will get the same low fragmentation value for Entropy when using the inverted image with 95% Foreground cover and 5% background; in this case, the dominant area coverage is now *Foreground*, which is only slightly fragmented by the *Background*. In short, Entropy derives Fragmentation for the interplay of Fore- and Background while Contagion will focus on the Foreground only.

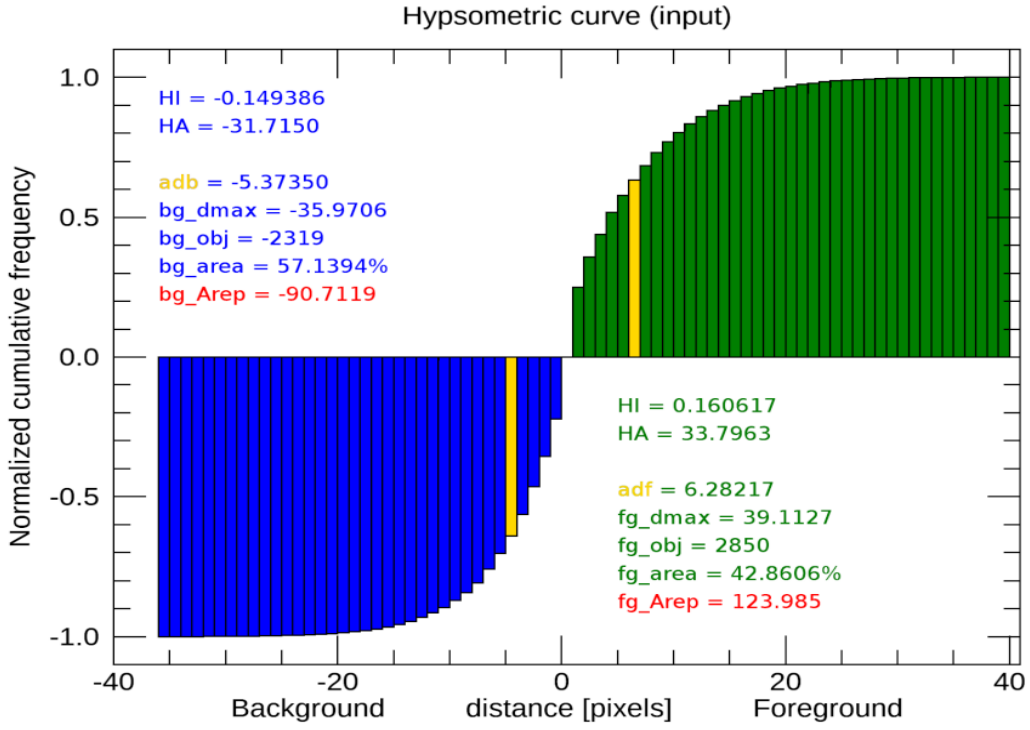
1.3.5 Distance

This menu provides several options for Distance analysis.
When using GeoTIFF data the distance value in pixels is only meaningful for images having **equal-area projection**!

1.3.5.1 Euclidean Distance

This option calculates the approximate Euclidean Distance map for both, the background, and the foreground. If the Divide button below the viewport is not active, a click on the Intext button will trigger the display of two summary graphs:
a) Distance histogram: including foreground and background specific information on average distance (adf/adb), total number of objects (fgo/bgo), and maximum distance found in the image. Here, Background data have a negative sign to distinguish them from foreground data.
b) The Hypsometric Curve: the normalized cumulative frequency of the Euclidean distance histogram:

Figure 33: Hypsometric Curve for the Euclidean distance distribution in the foreground and in the background and related distance measures.



When viewing the image distance distribution as a pseudo-elevation map the Hypsometric Curve summarizes the relief or contour lines in the foreground, the same process is known as bathymetry in the background. **Figure 33** shows the normalized cumulative frequencies of Euclidean distances as well as the following related statistics for the background and the foreground:
- *Hypsometric Index (HI)*: adb/bg_max or adf/fg_max

- *Hypsometric Area (HA)*: integral area under the curve

- *Average distance (adb/adf)*

- *Maximum distance (bg_max/fg_max)*

- *Number of objects (bg_obj/fg_obj)*

- *Total area of objects (bg_area/fg_area)*

- *Representative area (bg_Arep/fg_Arep)*

The *Representative Area* is calculated for a vicarious object of circular shape with a radius of adf/adb. In a similar way, a representative square object could be defined having the edge length $\sqrt{Arep}$. As with the *Average Distance* (adf/adb), changes in the *Representative Area* are indicative for fragmentation processes.

The GTB title bar shows adf/adb and the spatial distance distribution is displayed in the viewport. For each pixel, this map shows the shortest distance to the nearest foreground/ background boundary. The distance is provided in pixel units since the actual spatial pixel resolution is unknown. The color code is designed to mimic a pseudo elevation map: blue colors represent ocean (background), yellow/red/green colors represent land or mountains (foreground), and a value of zero is assigned to the coastline (intersection of foreground/background). Saving a Euclidean distance image will save the actual distance image as well as the histogram and the HMC bar plot images. As in any other image, the zoom function can be used to retrieve more detailed pixel information via the mouse cursor.
More information can be found in the Distance Product Sheet.

1.3.5.2 Influence Zones

The influence zone is defined as the outside equal distance delimiter line (iso-distances) separating selected foreground objects. The boundary of an influence zone is derived by applying a morphological watershed operator to the Euclidean distance map of the background area in the image. Considering the gray scale (8-connected Euclidean distance) image as a surface, each local minimum can then be thought of as the point to which water falling on the surrounding region drains. The boundaries of the watersheds lie on the tops of the ridges. Small objects in the original image can produce spurious minima in the gradients, which leads to over-segmentation. For this reason, the default minimum object size is set to 5,000 pixels. Omitted objects smaller than the minimum object size are displayed in pale blue color. Objects for which influence zones are calculated are displayed in alternating colors. Potential missing data is displayed in white and the influence zone boundaries (watershed lines) in black color. The information panel below the viewport allows setting buffer zones for both, foreground, and background. In summary, the influence zones provide a segmentation of the background and buffer zones can be added to define *core areas* as well as *outreach zones* of any size.

Influence zones are driven by the following 3 parameters:

1. Minimum area: influence zones are calculated for foreground objects larger or equal to the specified minimum area in pixels. The threshold of small objects to be excluded from the calculation can be set to any value via the MSPA parameter 2 *EdgeWidth* drop-down menu. You can either select a pre-defined value or specify a custom value in the first entry of the drop-down menu. A new custom value will only be assigned after the Enter key has been pressed.

2. FG Buffer zone: a non-zero value for the foreground buffer zone corresponds to the perimeter width of the foreground objects to be excluded from the calculation. Consequently, this parameter can be used to define core-foreground objects. In this case the title-bar will show, and the calculation will be conducted for foreground *core* objects having the minimum area specified via the MSPA parameter 2 *EdgeWidth.*

3. BG Buffer zone: a non-zero value for the background buffer zone will add a dark grey colored buffer zone of the specified width around, and if sufficiently large holes are present, inside the selected core or foreground objects. The boundary of the background buffer zone is depicted in pink color. Background buffer zones will terminate at the boundary of the influence zones.
After changing any of the three influence zones parameters the *Divide* box under the viewport is changed to Off. Check the *Divide* box to On to apply any new influence zone settings. Clicking the *Divide* box switch to Off will reset both, the foreground and background settings to their default value of zero, omitting buffer zones and showing influence zones only.

A minimum object area value of one (1) will calculate influence zones for *all* foreground objects. Since influence zones are defined to describe the **outer** region of objects, they are calculated for **filled foreground objects***.* For this reason, objects insides holes of surrounding objects will have the same object ID and hence, the total number of objects when calculating influence zones may be smaller compared to the total number for object labeling. Saving an influence zone image will produce the following two files with the prefix <name>_influence_<Y>_<b1>_<b2>_<zoom>, where Y stands for the selected minimum object size in pixels, b1 and b2 stand for the selected foreground and background buffer zone width, respectively, and the suffix *zoom* will be added if a subregion of the image is saved:
a) prefix.tif: same graphics as displayed in GTB
b) prefix_ids.tif: image showing the unique identifiers of the objects, buffer zones and watersheds, etc. using negative values for specific data and positive values for the individual objects with the following notation:
- 6: buffer zone
- 5: buffer zone boundary
- 4: missing data
- 3: watershed
- 2: omitted Foreground pixel
- 1: hole in Foreground
- 0: background
1-x: unique object identifier

1.3.5.3 Proximity

This option will measure the vicinity between neighboring objects. As with the Influence Zones, the objects of interest are defined with 8-connectivity and a minimum area, which can be set via the MSPA parameter 2 *EdgeWidth*. Objects smaller than the minimum size are displayed in light blue and the watershed line in black. When browsing with the mouse pointer through the image, the information panel below the viewport will list the component ID and the associated area in pixels, if we are in the background, or over an omitted foreground object.

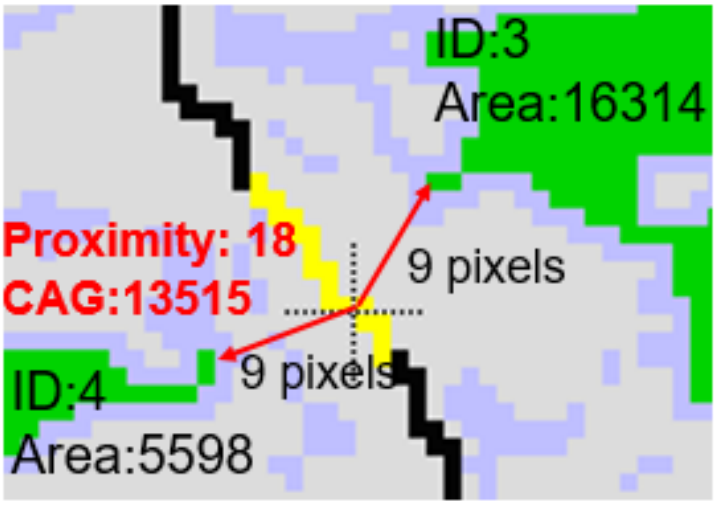
Placing the mouse pointer over the watershed line will list the x/y-coordinates of the watershed location and the following three measures (**Figure 34** below illustrates a sample situation):

1. Proximity: the proximity value is equivalent to the shortest distance, measured in pixels, needed to connect neighboring objects. Along the watershed line, this will be two objects. At watershed intersection points, the proximity value corresponds to the shortest distance needed to connect all neighboring objects.

2. CAG: the **C**onnected **A**rea **G**ain (CAG) is a measure of how much area is gained when establishing a connection between disjoint components at a given location. In general, and when combining two objects with area *a* and *b* the combined *reachable* area becomes $\sqrt{(a+b)^2} = \sqrt{a^2 + 2ab + b^2}$. Here, the area gained through the establishment of the new connection is $\sqrt{2ab}$ when connecting 2 components, $\sqrt{2ab + 2ac + 2bc}$ when connecting 3 components, etc. For example, in **Figure 34** the proximity between the two components with ID 4 and ID 3 is 18 pixels. The connected area gain at this location would be:
$CAG = \sqrt{2ab} = \sqrt{2 * 5598 * 16314} = 13515.$

3. CAG_rel [%]: the relative CAG [%] is defined as the ratio of CAG to the total area of all components. Larger percentage values imply that a larger amount of area will be connected and hence indicate a higher efficiency of a connection established at this given location.

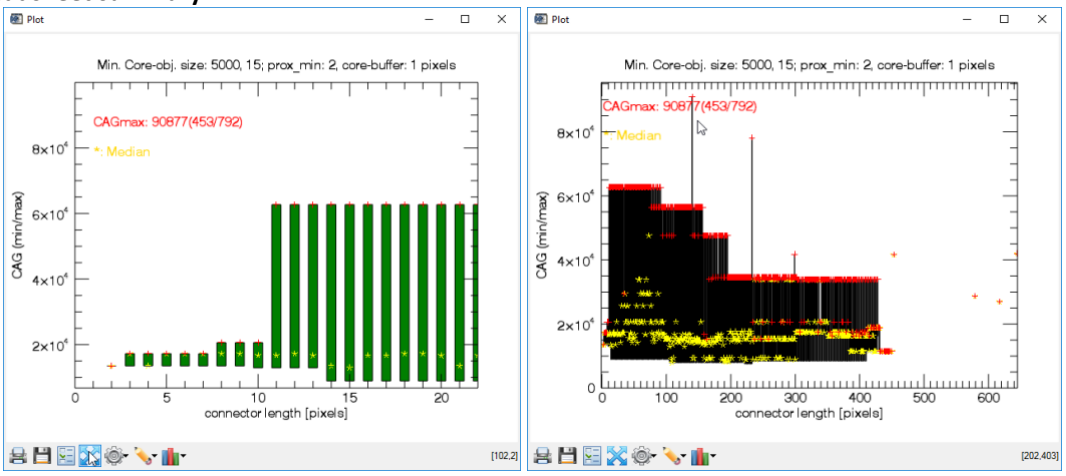
Figure 34: Example showing *Proximity* and *CAG* (connected area gain) between two components.

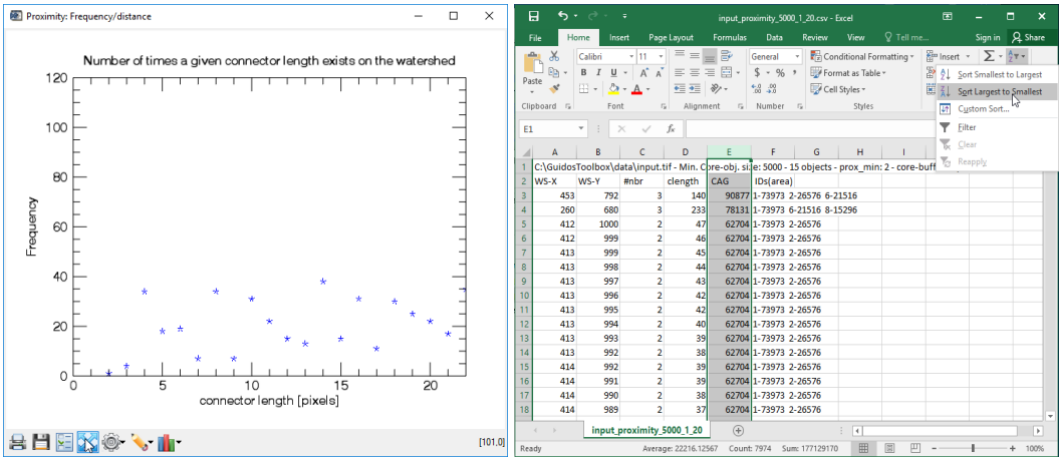


The left dropdown menu in the panel below the viewport, *CoreZone,* can be used to neglect branches by defining core zones of the objects. The dropdown menu on the right, *Prox_max,* can be used to define a maximum proximity value of interest. Proximity values equal to or smaller than *Prox_max* will be highlighted in yellow on the watershed line. The minimum proximity value is shown in red color and the total number of pixels having this minimum value is listed in the title bar description above the viewport. A mouse-click on the *Divide* button will reset the *CoreZone* and *Prox_max* fields to their default values of zero. The Proximity module can be used to examine the vicinity of neighboring objects while the CAG measures the (relative) importance for any proximity value. In combination, these tools may be useful to locate and evaluate restoration pathways of dissected landscape patches.

Proximity statistics for the entire image may be obtained by clicking on MSPA-parameter 4 **Intext**, providing the following three actions (**Figure 35**):

Figure 35: Example showing *Proximity* and *CAG* statistic summaries for the entire image. Top: CAG range for each Proximity (connector length) value (to expand to the full proximity range click the blue cross in the bar plot – top right). Bottom left: Proximity frequency along the watershed. Bottom right: spreadsheet summary.





a) CAG histogram: a new graphic window plot (**Figure 35** top left) showing the range of CAG values (minimum, median, maximum) encountered for each proximity value encountered along the watershed. The default proximity range is [0, prox_max]. Click the blue cross icon in the bar-plot image to display the full proximity range (**Figure 35** top right). In addition, the maximum CAG found in the image and its x/y-location is printed out in red color in the bar plot image.

b) Frequency histogram: a new graphic window showing the number of times a given proximity value was found along the watershed. The default proximity range is [0, prox_max]. Click the blue cross icon in the bar-plot image to display the full proximity range.

c) Spreadsheet summary: a summary spreadsheet is written to disk providing comma separated information on location; proximity; CAG; number, ID, and area of objects for each watershed location. This csv-file can be imported into a spreadsheet application and then sorted to the property of interest; for example, to find the x/y-location providing the highest CAG or to list all CAG values and spatial locations for a given connector length (proximity).

Saving the proximity analysis will produce the following five files with the prefix <name>_proximity_<Y>_<b1>_<b2>_<zoom>, where Y stands for the selected minimum object size in pixels, b1 and b2 stand for the selected values in the *CoreZone* and *Prox_max* fields, respectively, and the suffix *zoom* will be added if a subregion of the image is saved:

a) **prefix_CAG.tif**: image showing CAG values along the watershed.
b) **prefix_viewport.tif**: same graphics as displayed in GTB.
c) **prefix.csv**: proximity/CAG statistic summary spreadsheet file (csv).
d) **prefix_ws.tif**: image showing the proximity values on the watershed.
e) **prefix_ids.tif**: image having positive values for the unique identifiers of the objects and negative values for specific data with the following notation:

- 4: missing data
- 3: watershed
- 2: omitted Foreground pixel
- 1: hole in Foreground
  0: background
1-x: unique object identifier

1.3.6 Restoration Planner

The scope of the Restoration Planner is to provide tools tailored to reduce habitat fragmentation by increasing the area of reachable habitat and to provide answers to the following key questions:
- What is the current restoration status of the existing network?
- Where and how much has the restoration status changed over time?
- How efficient is a specific restoration measure?
- What is the most efficient restoration measure?
- How can we simulate and evaluate various restoration measures?

The tools are designed to measure coverage, connected extent and degree of coherence of an existing network of objects. Here, the generic term *object* refers to a landcover parcel, species habitat, or any other homogeneous area outline. A set of quantitative indicators is used to summarize the restoration status (**Table 3**) and/or evaluate the cost and efficiency of a restoration planning event (**Table 4**). The tabular summary statistics are derived from spatially explicit maps, allowing to detect hotspots of changes as well as locating positions where restoration planning is most efficient. The combination of spatially explicit maps and quantitative indicators has been designed as a framework to investigate planning scenarios in landscape planning as well as to provide concise and intuitive information to program managers, policy makers and the public. More details and examples are summarized in the Restoration Planner Product Sheet.
All indicators are measured in pixels, which is only meaningful for images having **equal-area projection**!

1.3.6.1 The restoration status indicators

The Restoration Status indicators are based on the area of the network objects, attributing a higher importance to larger objects. The two key restoration status indicators, ECA (Saura et al. 2011) and Coherence are defined in **Figure 36** and illustrated in **Figure 37**.

Table 3: Summary of restoration status indicators.

Acronym	Name	Description	Unit
ECA	Equivalent Connected Area	Area of a fictive single object providing the same amount of *reachable area* as the current set of objects	pixels
COH	Coherence	Degree of network coherence/connectedness	[%]
REST_POT	Restoration Potential	Network restoration potential (100% - COH)	[%]
RAC	Reference Area Coverage	Network area proportion with respect to map data area	[%]
CNOA	Critical New Object Area	Area of a single additional object resulting in the same network coherence as found in the original network.	pixels

Figure 36: Definition of the two restoration status indicators ECA and Coherence

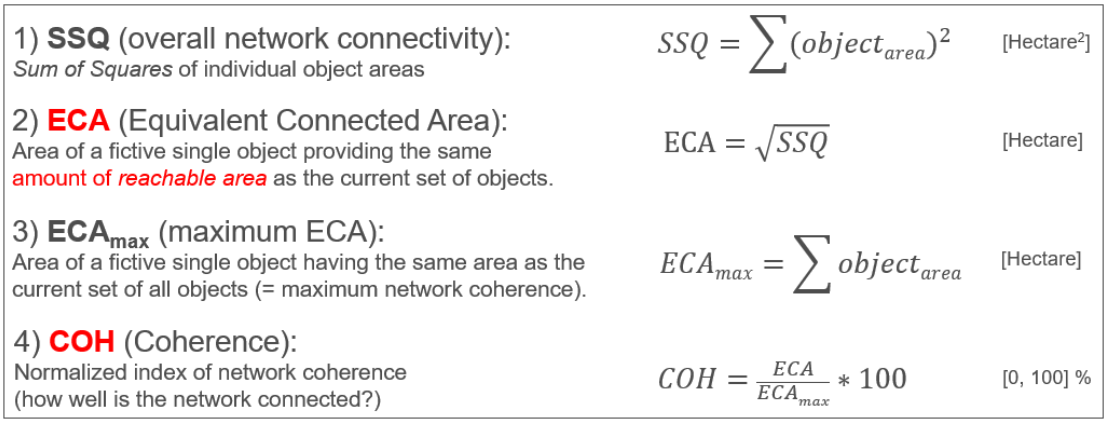
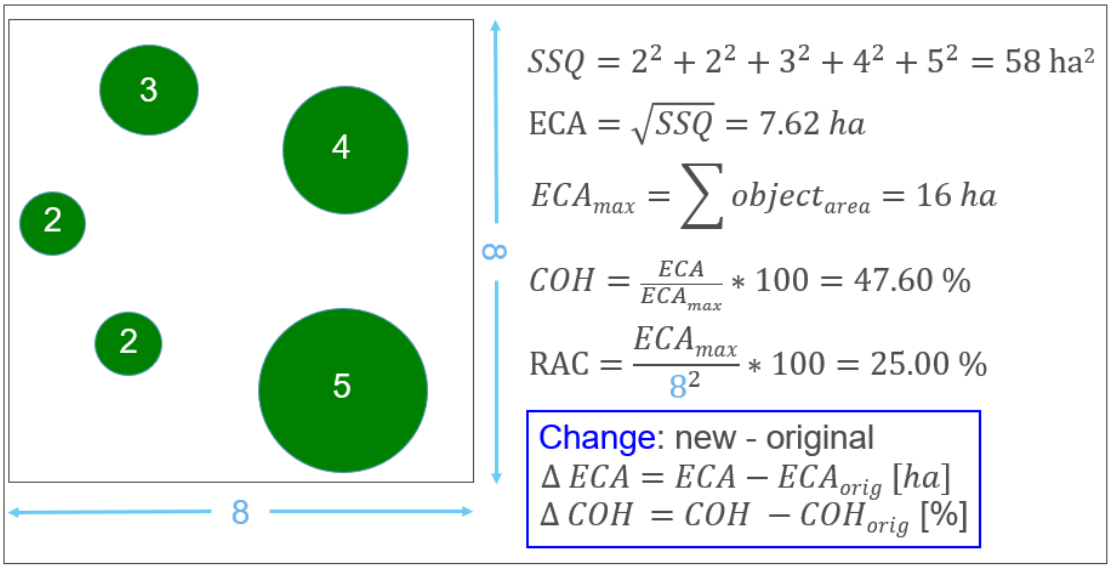


Figure 37: Example for restoration status indicator calculation for a network with five objects.



In principle, any kind of restoration planning will add new area to an existing network. Here, the key question is: which of the following is most efficient?

Reconnect objects? *Add area to an existing object?* *Add a new object?*

Because both, ECA and Coherence are driven by large object areas (Sum Of Squares – SSQ), it is evident that connecting large objects is most efficient, followed by adding area to preferably large objects. Adding a new disjoint object will typically increase fragmentation and consequently decrease network Coherence. The Critical New Object Area (CNOA) is the area of a new object, which is large enough to compensate the fragmentation effect and will result in the same network coherence as found in the original network.

$$CNOA = (2bc^2)/(b^2 - c^2) \quad \text{with } b = ECA_{max} \text{ and } c = ECA$$

New object areas larger (smaller) than CNOA will result in coherence increase (decrease). Further details are beyond the scope of this manual but can be found in the Restoration Planner Product Sheet.

1.3.6.2 The restoration planning indicators

The restoration planning indicators (**Table 4**) are designed to summarize and quantify the expense and efficiency of a given restoration measure.

Table 4: Summary of restoration planning indicators.

Acronym	Name	Description	Unit
RP	Restore Pixels	Length (in pixels) of a given restoration path	[-]
RESIST	Resistance	Difficulty to traverse a given pixel [3 – 100 (max)]	[-]
EXP	Expense	Effort to establish a restoration path (∑(RP*RESIST))	[-]
EFFIC	Efficiency	Proportion: ECA gained per unit of Expense	pixels
AVDIST	Remoteness	Average distance of RP away from existing network	pixels

The effort to implement a given restoration measure is modelled via the narrative *resistance*, defined as the relative difficulty to traverse a given location. For a raster image, each pixel is assigned to a specific resistance value of either:
- 0: pixel that can never be traversed (blocking = infinite resistance)
- 2: pixels of foreground object, having minimum resistance
- [3, 100] background pixel, having a larger resistance than foreground of at least 3 and maximum 100.

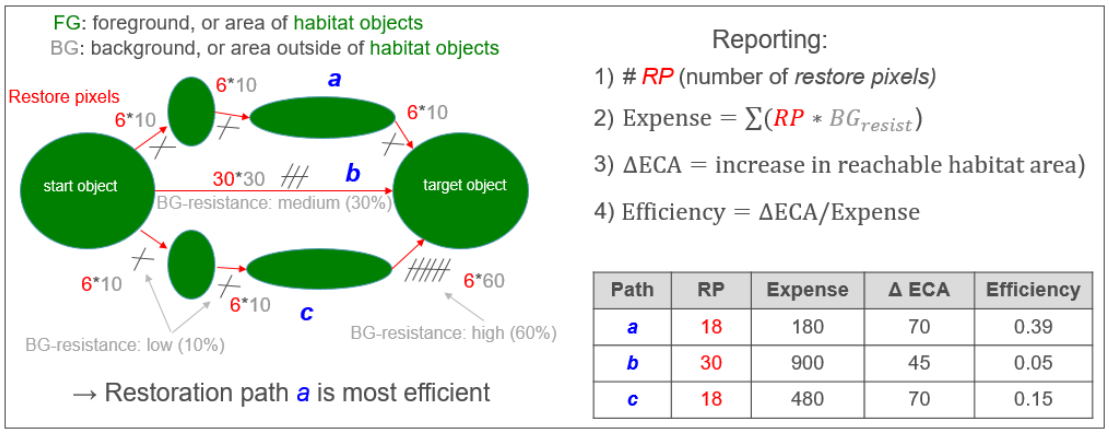
Because movement outside of foreground (FG) is more difficult, the background (BG) resistance must always be higher than the foreground resistance. BG-resistance starts at 3 to maintain compatibility and input data notation with all other GTB routines where FG is assigned a value of 2 byte. BG-resistance values are not simply sequential but can cover the entire range from minimum to maximum resistance [3, 100]. For example, assume you are interested in woodland species and you have 5 landcovers with different perceived resistances: woodland, natural grassland, intensive grassland, cropland, water: woodland equals target habitat (resistance=2), natural grassland is favorable to woodland species (Resistance=5), intensive grassland is 3 times more resistant than natural grassland (Resistance=15), cropland is 10 times more resistant than natural grassland (Resistance=50), water bodies cannot be traversed by the woodland species (Resistance = 0). Assigning different relative resistance values will result in different restoration expense, pathways, etc.

Setting the BG-resistance values is crucial, requiring a good deal of thought and rationale!

The generic narrative *resistance* allows the user to finetune the image to specific application setups: BG-pixels can be assigned to have a fixed resistance, or a variable landcover-specific resistance, or a resistance that is proportional to the distance away from FG-objects (i.e., for birds or flying insects). Other custom resistance assignments could be to assign country roads a lower resistance than motorways, or privately-

owned farmland a higher resistance than public farmland, or forest in protected areas a lower resistance than state-owned forest. You could block areas from being traversed by assigning them a resistance value of zero, or favor areas to be used for restoration by assigning them a low resistance value.
Once an application-specific BG-resistance is assigned, one can then select a start and target object that should be reconnected, exemplified in **Figure 38**.

Figure 38: Sketch of restoration path evaluation between start and target object.

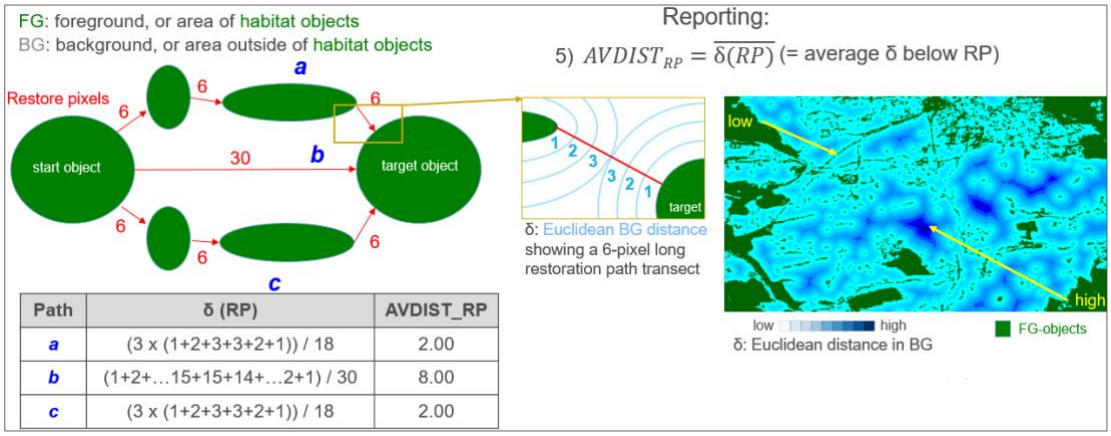


Path	RP	Expense	Δ ECA	Efficiency
a	18	180	70	0.39
b	30	900	45	0.05
c	18	480	70	0.15

Figure 38 shows an example comparing three potential restoration pathways (a, b, c) between a start and a target object. Along the individual path segments the number of restoration pixels is shown in red color and the respective BG-resistance in gray color. The right part of the figure illustrates the calculation of the restoration planning indicators concluding in restoration path *a* being the most efficient of the three options.
Restoration pathways may be inserted manually, or the optimum pathway can be automatically detected using the Generalized Geodesic Distance (GGEO) function (Soille 1994). GGEO calculates the fastest travel time (minimum of accumulated Background-resistance = Least Cost Path) between two objects, trying to take advantage of steppingstones along the pathway to reduce travel time and to minimize restoration expense. An increase in BG-resistance enforces stronger optimization by including more intermediate objects, resulting in less expense and a higher coherence gain.

The restoration pixels of a given path are located at a certain distance away from existing FG-objects. $AVDIST_{RP}$ (**Figure 39**) provides an indication of the average "remoteness" of the restoration pixels. When finding an optimum path via GGEO, $AVDIST_{RP}$ will be smaller due to the inclusion of steppingstones, hence a low value of $AVDIST_{RP}$ will be indicative for an efficient restoration effort.

Figure 39: Illustration of $AVDIST_{RP}$, indicating the average remoteness of a given restoration pathway.



Path	δ (RP)	AVDIST_RP
a	(3 x (1+2+3+3+2+1)) / 18	2.00
b	(1+2+…15+15+14+…2+1) / 30	8.00
c	(3 x (1+2+3+3+2+1)) / 18	2.00

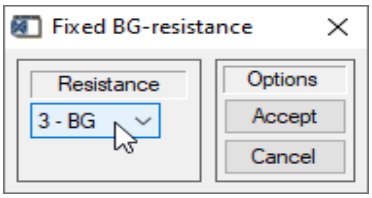
The **Restoration Planner** provides various modules for restoration planning and assessment grouped into the following two sections: *Setup Tools* and *Assessment*.

1.3.6.3 Setup Tools

The submenu ***Setup Tools*** provides interactive methods and guided help to setup an application-specific resistance map and/or to define the input map for a travel time analysis.

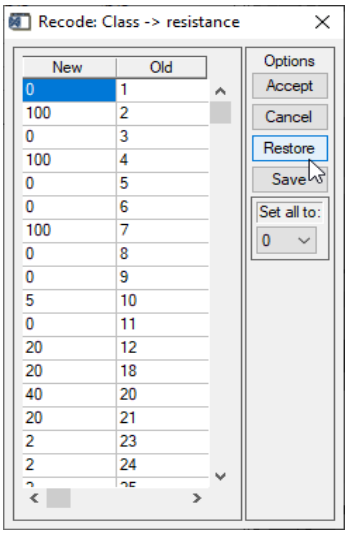
- **Fixed BG-Resistance**: from a new popup-window (**Figure 40**), select a resistance value from a dropdown menu that will be assigned to all BG-pixels of the current image. Missing data (pixel value = 0) are assigned a resistance value of zero (blocking).

Figure 40: Example to assign a fixed BG-resistance for all BG-pixels.



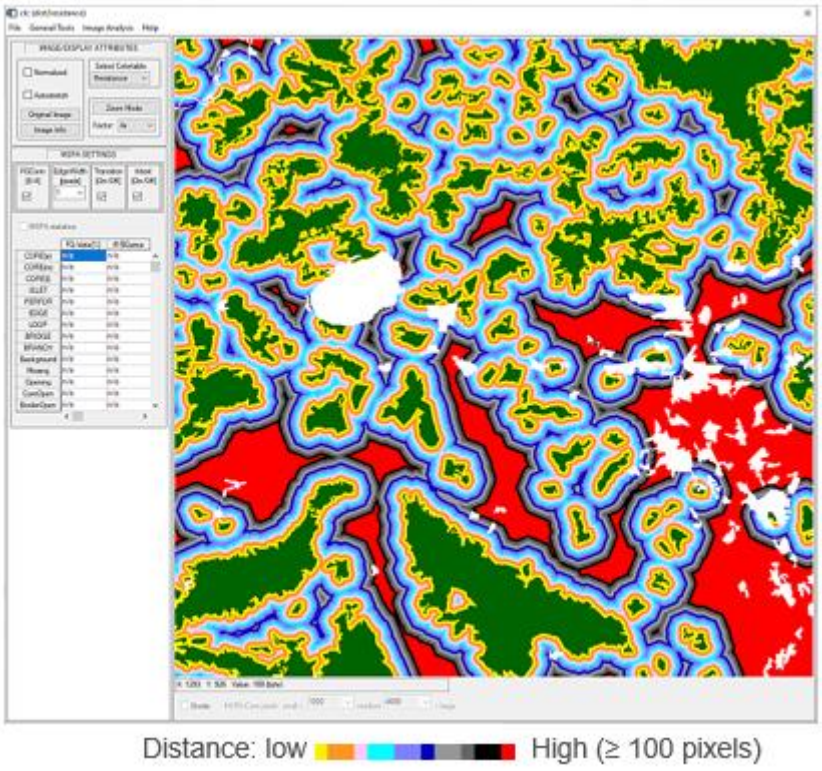
- **Landcover → Resistance**: a new popup-window (**Figure 41**, similar to the **Recode** option) provides a recoding table showing the existing landcover classes in the right column which should be assigned to landcover class specific resistance values [0, 2, 3-100] in the left column. The *Save* button may be used to save a custom resistance mapping table to disk, which can be restored via the *Restore* button in a future session.

Figure 41: Example to assign a landcover specific resistance value.



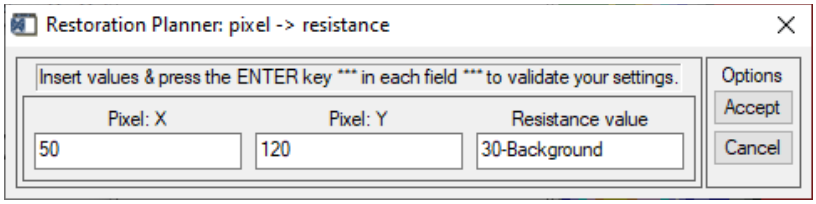
- **Distance → Resistance**: after calculating the Euclidean Distance in the Background, the distance (measured in pixels) away from FG-objects is assigned to the BG-pixels (**Figure 42**) starting with a resistance value of 3 and constrained to a maximum resistance value of 100. The resistance values are shown in the information panel below the viewport for the current location of the mouse pointer in the image.

Figure 42: Example to assign a distance-based resistance map.



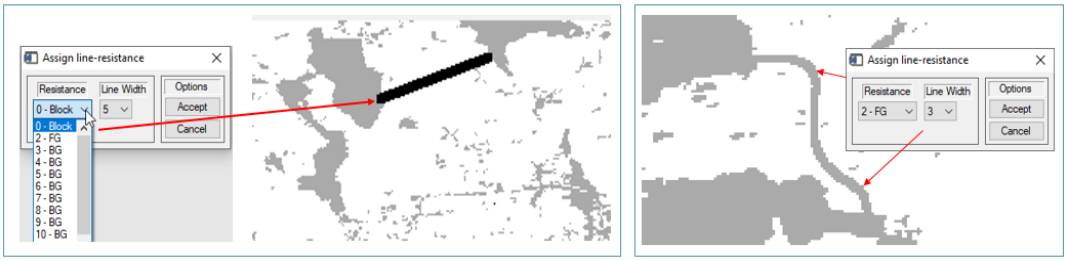
- **Pixel → Resistance**: in a new popup-window (**Figure 43**), insert the x- and y-coordinate and the new resistance value of your choice. Please press the *Enter* key in each field to validate your settings.

Figure 43: Example to assign a pixel-based resistance value.



- **Line → Resistance**: this option allows to interactively draw a custom path with a custom resistance into the image. First, click on MSPA-Parameter 1 *FGConn* to activate the process. Next, draw a straight line (left mouse button) or a freehand line (right mouse button) while keeping the mouse button pressed. Release the mouse button to finish the drawing process. In the final popup-window (**Figure 44**), select the resistance value and linewidth that should be assigned to the line drawn.

Figure 44: Example of Line → Resistance interface: insert a straight line of width 5 pixels (i.e., a motorway, blocking resistance – left panel); insert a freehand line of width 3 pixels (i.e., a hedge row, FG-object – right panel).



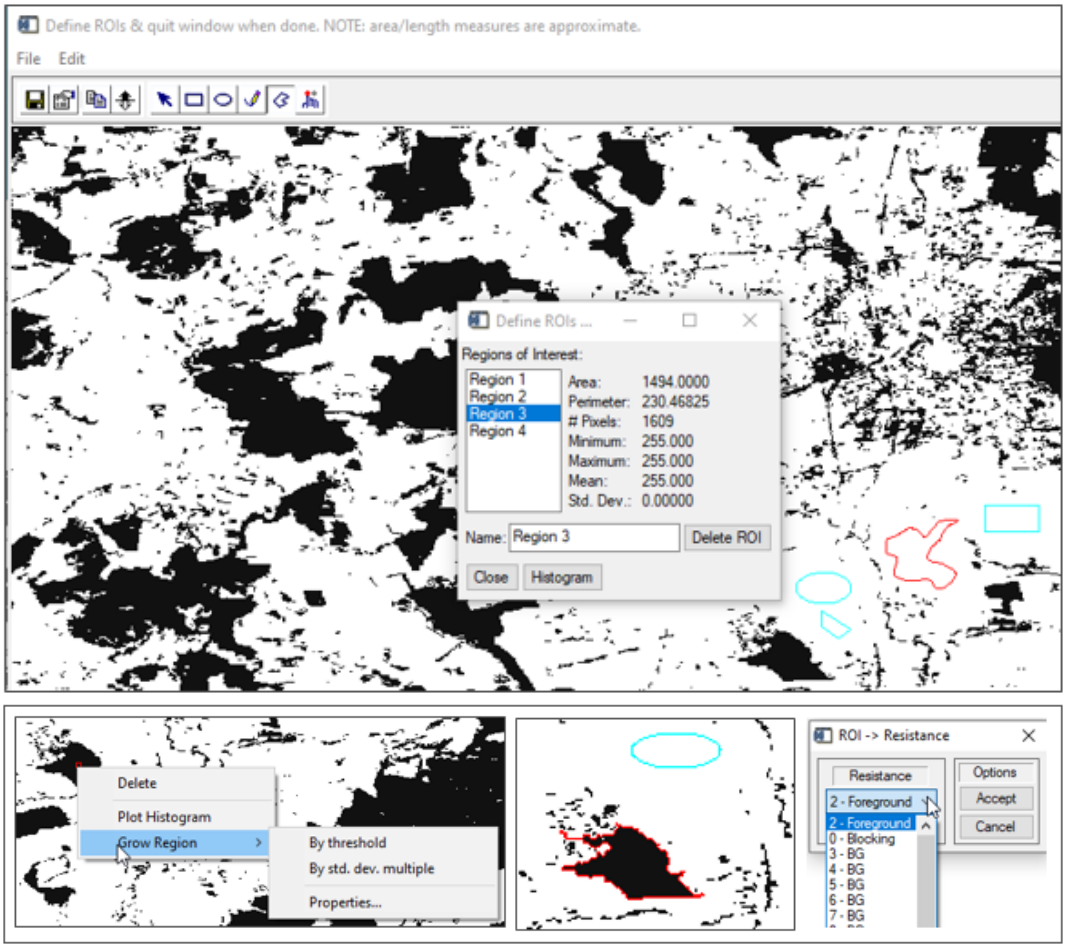
- **Region Of Interest → Resistance**: this option allows to interactively draw a custom area with a custom resistance into the image. First, click on MSPA-Parameter 1 *FGConn* to activate the process, opening the entire image in a new popup-window. Next, use the appropriate menu button (**Figure 45**, top panel) to add a new Region Of Interest (ROI), which can be rectangular, oval, freehand, or a polygon. A second small popup-window will provide an overview of all added ROIs. Please note that area and length readings within the ROI window are approximate only. All added ROIs are shown in cyan color, while the currently selected ROI is marked with red color. The Pointer and Hand tool from the menu bar can be used to shift or warp a selected ROI.

  The ROI interface will show the current GTB viewport image in full resolution. If the image is larger than the screen display window, scroll bars in x- and y-dimension are added automatically. If the current GTB viewport image is displayed in zoom mode, the ROI interface will show the zoomed sub-image extent in full resolution, which should facilitate adding custom ROIs at specific locations.

Due to image rescaling, the area/length measures displayed within the ROI interface are approximate or indicative only. Correct area readings may be retrieved on the final image using **Accounting** or other GTB assessment tools.

The ROI interface can also be used to select an existing irregular shaped object (**Figure 45**, bottom panel), for example to assign it to a new resistance value: start with placing a small ROI inside the target object. With the mouse pointer on the small ROI, make a right-click and choose *Grow Region*, which will automatically select the perimeter of the irregular shaped object. Select the *Properties* option to finetune the region growing settings. Once all ROIs are defined, simply exit the ROI window, and assign the desired resistance value to all ROIs in the final popup window.

Figure 45: The ROI interface to define custom regions (top), example to select irregular shaped objects through region growing (bottom left and center), and final ROI resistance assignment window (bottom – right).

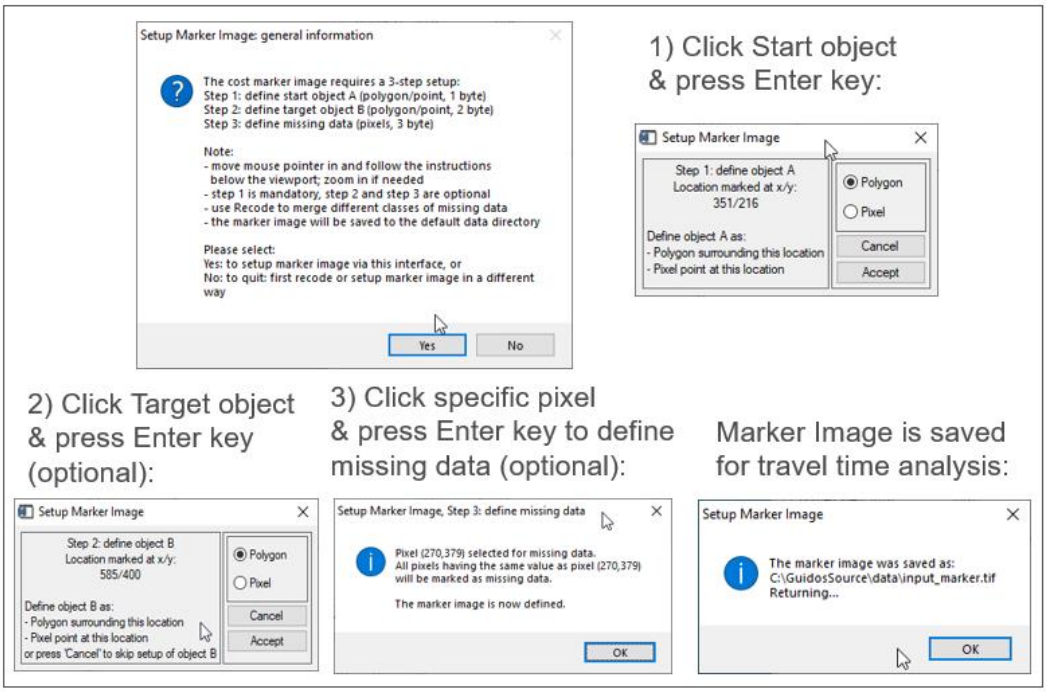


- **Isochrone Map Marker Image**: this option provides guided steps to setup a marker image, specifying the start object (mandatory) and the optional target object and missing data (**Figure 46**). The marker image is a single-band image of datatype Byte with the same dimensions as the resistance map and having the following values:
  0b: background

1b: start object A (either a single pixel or the area of an object)
2b: target object B (optional, only needed for Isochrone Map AB)
3b: no or missing data, or areas that should be neglected (optional)

The start/target objects A and B must be unique and must not intersect. The final marker image is written to disk and can then be applied to a suitable resistance map for travel time analysis using the Generalized Geodesic Distance function (GGEO, Soille 1994), see Isochrone Map A or Isochrone Map AB below.

Figure 46: Three step setup to define a marker image for travel time analysis.



The Setup Tools allow to simulate any type of landcover change or spatial restoration scenario. Once defined, the new setup can then be quantitatively evaluated via the Assessment menu to retrieve either, a new status summary and/or to quantify the efficiency of a simulated restoration measure.

1.3.6.4 Assessment

The submenu ***Assessment*** provides the following interactive methods and guided help to conduct restoration status-, change-, planning- and travel time analysis.

- **Status Summary:** this option will calculate and summarize the key restoration status descriptors of the network (**Figure 47**): area, coverage (RAC), # of network objects, area of largest object, average object/patch size (APS), CNOA, reachable area (ECA), degree of coherence (COH) and its complement restoration potential (REST_POT).

Figure 47: Example of restoration status summary assessment.

	A	B	C	D	E	F	G	H	I	J
1	REP_UNIT	AREA	RAC[%]	NR_OBJ	LARG_OBJ	APS	CNOA	ECA	COH[%]	REST_POT[%]
2	input.tif	428,490	42.86	2,850	214,811	150.35	311,712	221,292.76	51.64	48.36

Please use the **Restoration Status** batch module to derive a tabular restoration status summary for a series of input files.
*The main purpose of **Status Summary** is to get a quick overview on the current restoration status of a given network.*

- **Change Summary:** this option will calculate and summarize the key restoration planning descriptors (**Figure 48**), which are derived by building the difference between the original network and the modified network including the restoration features. The Restoration Change summary requires that both images must have identical geospatial coverage. This option is applicable to any kind of restoration scenario, such as a single new pathway or any custom setup via Setup Tools. The result permits to quantify restoration effort and benefit expressed via the number of restore pixels, remoteness, expense, efficiency, change in ECA/COH.

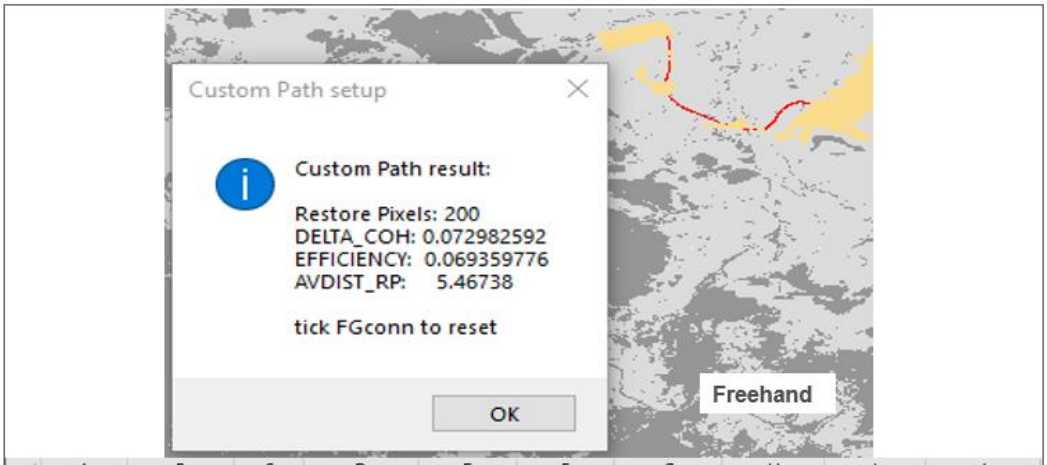
Figure 48: Example of restoration change summary assessment.

	A	B	C	D	E	F	G	H	I	J
1	REST_PIX	AVDIST_RP	EXP_3	EFFIC	ECA_ORIG	ECA_NEW	DELTA_ECA	COH_ORIG	COH_NEW	DELTA_COH
2	359	8.293	1077	23.46145	221292.76	246560.74	25267.982	51.644789	57.493603	5.8488133

*The main purpose of **Change Summary** is to quantify cost, efficiency, and impact of a restoration event on the restoration status of the network.*

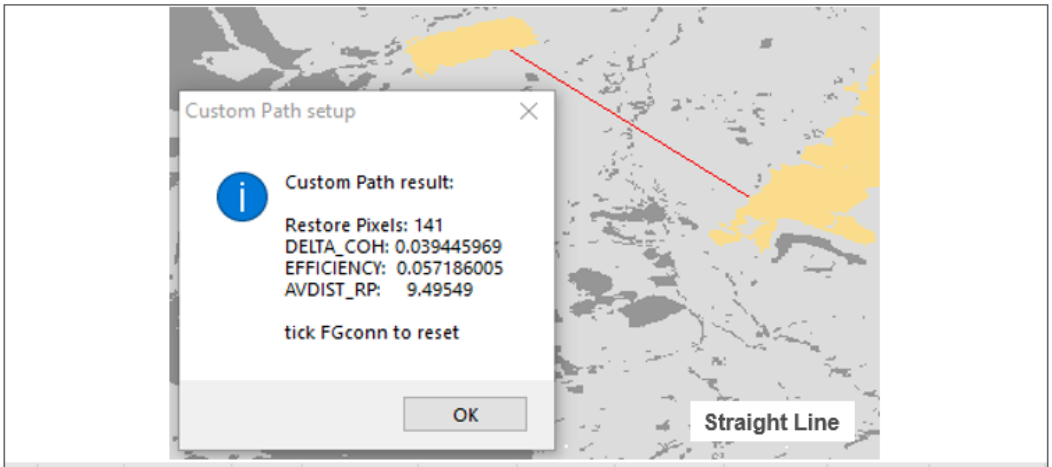
- **Add Custom Path**: this option allows to interactively draw a custom, 1-pixel wide restoration pathway into a restoration-compliant resistance image (0: missing, 2: FG, 3→100: BG). First, click on MSPA-Parameter 1 *FGConn* to activate the process. Next, draw a straight line (left mouse button) or a freehand line (right mouse button) while keeping the mouse button pressed. Release the mouse button to finish the drawing process. A new popup window lists key indicators of the restoration path, highlighted as a red line in the viewport. Start-, target- as well as any intermediate encountered network objects are shown in beige color (**Figure 49**). Tabular summary statistics are saved to disk when saving the image. Click on MSPA-Parameter 1 *FGConn* to reset the analysis for additional testing. **Figure 50** shows, on a slightly zoomed subregion, a straight-line reconnecting pathway between the same two start/target object as shown in **Figure 49**. Please note the differences in restoration planning indicators: while the freehand line path entails more restore pixels, the gain in coherence and the efficiency is higher compared to the straight line due to the inclusion of intermediate steppingstones, which will reconnect more habitat area. The beneficial effect of reconnecting intermediate habitat is even more pronounced when detecting the optimum reconnecting pathway, see next section and **Figure 51**.

Figure 49: Example for Freehand Custom Path restoration assessment.



	A	B	C	D	E	F	G	H	I	J
1	REST_PIX	AVDIST_RP	EXP_30	EFFIC	ECA_ORIG	ECA_NEW	DELTA_ECA	COH_ORIG	COH_NEW	DELTA_COH
2	200	5.46738	6000	0.069359776	221292.76	221708.92	416.15865	51.644789	51.717772	0.072982592

Figure 50: Example for Straight Line Custom Path restoration assessment.



	A	B	C	D	E	F	G	H	I	J
1	REST_PIX	AVDIST_RP	EXP_30	EFFIC	ECA_ORIG	ECA_NEW	DELTA_ECA	COH_ORIG	COH_NEW	DELTA_COH
2	141	9.49549	4230	0.057186005	221292.76	221534.65	241.8968	51.644789	51.684235	0.039445969

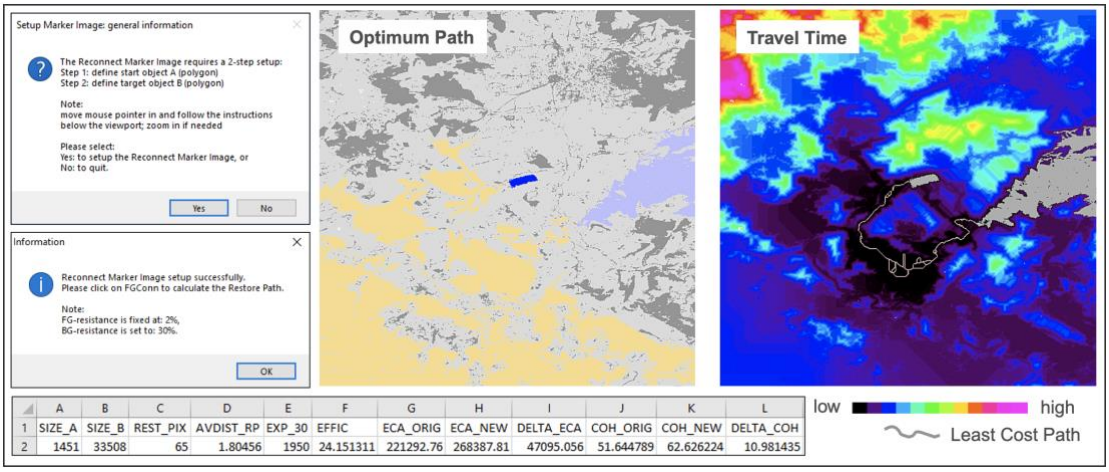
*The main purpose of **Add Custom Path** is to assess the impact of an already defined restoration pathway or to quickly simulate and evaluate various options of restoration pathways.*

- **Find Optimum Path**: this option will calculate and display the optimum restoration pathway between two user-selected objects on a restoration-compliant resistance image (0: missing, 2: FG, 3→100: BG). First, click on MSPA-Parameter 1 *FGConn* to activate the process. Follow the on-screen instructions to define the start object and the target object, then click on MSPA-Parameter 1 *FGConn* again to start the detection. The optimum path (minimum travel time and expense) depends on the BG-resistance. It is calculated via GGEO, which tries to take advantage of steppingstones along the pathway to reduce travel time and to minimize restoration expense (**Figure 51**). An increase in BG-resistance enforces stronger optimization by including more intermediate objects, resulting in less expense and

a higher coherence gain. The left panel of **Figure 51** shows the setup instructions, the center panel the optimum path between the start object (dark-blue) and the target object (light blue) with restore pixels highlighted in red color, and the right panel the travel time map with the least cost path outlined in grey color. The optimum path may include alternative, parallel pathways and/or bifurcations in the background having the same isochrone value. While alternative pathways are important for planning restoration pathways, these features may lead to an increased number of restore pixels and expense resulting in a decrease in efficiency. This implies, that the actual efficiency will be higher, if alternative pathways are neglected.

Please note the difference in parameters, esp. efficiency in **Figure 51** compared to **Figure 49** and **Figure 50** connecting the same two objects. In this example with a constant BG-resistance of 30%, the optimum path takes advantage of intermediate objects. To establish this path, only 65 restore pixels are needed with an expense of 65*30 = 1950, while coherence will increase by 11%.

Figure 51: Example for Optimum Path restoration assessment.



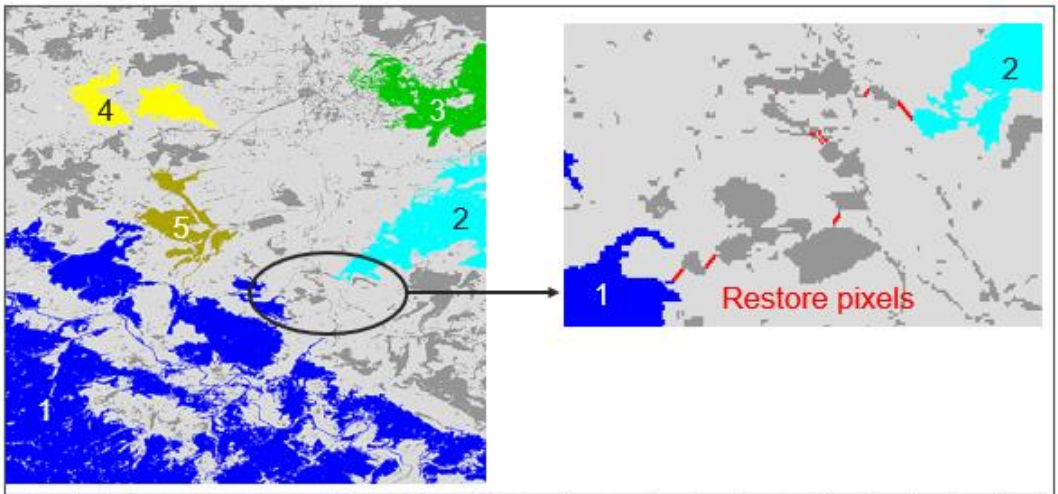
	A	B	C	D	E	F	G	H	I	J	K	L
1	SIZE_A	SIZE_B	REST_PIX	AVDIST_RP	EXP_30	EFFIC	ECA_ORIG	ECA_NEW	DELTA_ECA	COH_ORIG	COH_NEW	DELTA_COH
2	1451	33508	65	1.80456	1950	24.151311	221292.76	268387.81	47095.056	51.644789	62.626224	10.981435

*The main purpose of **Find Optimum Path** is to detect the optimum restoration pathway between two given objects. The drawback is slow processing time.*

- **Show Optimum Big 5**: this option will calculate the pairwise optimum pathway between the five largest objects on a restoration-compliant resistance image (0: missing, 2: FG, 3→100: BG). The result shows the restoration pixels in red between the five largest objects color-coded in decreasing size from the largest object in blue, cyan, green, yellow, and brown. The image is accompanied by a summary table (**Figure 52**) listing the size of the objects and the related restoration planning indicators. This table can then be sorted for the topic of interest. In this example, the most efficient restoration pathway (EFFIC=217) is found for connecting the largest object with the fifth-largest object (1 ↔ 5), requiring 2 restore pixels only to achieve the highest efficiency (ratio of ΔECA/EXPENSE). If the focus is on coherence increase, then the connection between the second and fourth biggest component (2 ↔ 4) should be considered.

Saving the result will create a new directory with the aggregated map and summary table as well as 10 individual maps of restoration and travel time pathways between each of the 5 largest objects.

Figure 52: Example for Optimum Big 5 restoration assessment.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	RESTORE	SIZE_A	SIZE_B	REST_PIX	AVDIST_RP	EXP_30	EFFIC	ECA_ORIG	ECA_NEW	DELTA_ECA	COH_ORIG	COH_NEW	DELTA_COH
2	1 <-> 2	214811	33508	18	2.14992	540	90.476013	221292.76	270149.8	48857.047	51.644789	63.044285	11.3995
3	1 <-> 3	214811	26366	43	1.24715	1290	34.731307	221292.76	266096.14	44803.386	51.644789	62.094668	10.4499
4	1 <-> 4	214811	14983	8	1.20711	240	131.13431	221292.76	252764.99	31472.233	51.644789	58.988605	7.34382
5	1 <-> 5	214811	13850	2	1.41421	60	217.68263	221292.76	234353.72	13060.958	51.644789	54.69267	3.04788
6	2 <-> 3	33508	26366	23	4.66506	690	5.8013699	221292.76	225295.7	4002.9452	51.644789	52.576165	0.931376
7	2 <-> 4	33508	14983	61	1.79058	1830	35.133502	221292.76	285587.07	64294.309	51.644789	66.640159	14.9954
8	2 <-> 5	33508	13850	56	1.85377	1680	27.135228	221292.76	266879.94	45587.183	51.644789	62.275681	10.6309
9	3 <-> 4	26366	14983	41	1.239	1230	2.6203955	221292.76	224515.84	3223.0865	51.644789	52.391973	0.747183
10	3 <-> 5	26366	13850	40	1.23462	1200	2.5434958	221292.76	224344.95	3052.195	51.644789	52.352216	0.707427
11	4 <-> 5	14983	13850	5	1.08284	150	9.9899756	221292.76	222791.25	1498.4963	51.644789	51.993898	0.349109

*The main purpose of **Optimum Big 5** is to detect the optimum restoration pathway within the entire image. The drawback is very slow processing time.*

- **Isochrone Map A:** this option will calculate and display the travel time map starting from object A. The input map must be a restoration-compliant resistance image (0: missing, 2: FG, 3→100: BG). The **marker image** should be setup via the *Isochrone Map Marker Image* from the *Setup Tools* menu.
  *The main purpose of **Isochrone Map A** is to display the travel time distance from a selected object, which might be of interest for restoration planning starting from that object. The drawback is slow processing time.*

- **Isochrone Map AB:** this option will calculate a travel time map starting from object A and a second one starting from object B, which are then combined into the final travel time map AB. The input map must be a restoration-compliant resistance image (0: missing, 2: FG, 3→100: BG). The **marker image** should be setup via the *Isochrone Map Marker Image* from the *Setup Tools* menu.
  Pixels having the minimum value of this map correspond to the shortest travel time and their skeleton is the *Least Cost Path* between start object A and target object B. The title bar shows the minimum and maximum travel time values encountered in the image. Travel time inside a start/target object is set to zero.

The division panel below the viewport can be used to group the normalized travel time surface into the ranges small/medium/large using either pre-defined or custom threshold values in the respective drop-down menu. This option may be of interest to highlight travel time corridors between A and B with a slightly increased minimum travel time (i.e., 1.1 x least cost) to visualize and/or investigate potential alternative connecting pathways. Values in [0, 100] show the normalized travel time while the following values are reserved for specific assignments:
101: start/target object A/B
102: missing data
103: Least Cost Path
104: pixels that cannot be reached from the start/target object

*The main purpose of **Isochrone Map AB** is to display the travel time surface between two selected objects. This information may guide finding suitable restoration pathways or evaluating additional restoration expense when deviating from the optimum pathway. The drawback is slow processing time.*

1.4. The Quick Access pull-down menu

This section and each entry within are briefly summarized with an introduction named **Overview**. Please have a look at this overview, the respective sections in this manual, and the mentioned product sheets to better understand the scope and usage of each menu entry. The Quick Access pull-down menu offers shortcuts to the following essential tools:

- Recode Classes (Shortcut to: General Tools → Preprocessing → Recode Classes)
- Setup Batch Recode Table (Shortcut to: General Tools → Preprocessing → Setup Batch Recode Table)
- Accounting (Shortcut to: Image Analysis → Objects → Accounting)
- Pattern (Shortcut to: Image Analysis → Pattern → Morphological → MSPA)
- Fragmentation (Shortcut to: Image Analysis → Fragmentation →Fixed Observation Scale (FOS))
- Landscape Mosaic (Shortcut to: Image Analysis → Pattern → Moving Window → Counting Pixels → Landscape Mosaic)

1.5. The Help pull-down menu

The Help pull-down menu offers the following options:

- GTB Documentation
- GTB Training
- GTB Online
- Related Resources
- Bug Report
- About GTB

1.5.1 GTB Documentation

- **GTB Manual:** this option will open the GTB Manual in a separate window. The manual provides general information on the graphical elements and the nature and functionality of the various GTB menus and options.

- **MSPA Guide:** this option will open the MSPA Guide in a separate window. The guide contains important, detailed information on the input data requirements for the processing of MSPA, the MSPA parameters, the resulting MSPA image output,

and on the use of the MSPA-standalone version. Please read this document carefully. It contains all MSPA related information, GTB is only a graphical interface, designed to facilitate MSPA processing.

- **GSC Guide:** this option will open the GraySpatCon Guide in a separate window. The guide contains important, detailed information on the input data requirements for GSC processing, the GSC parameters, the resulting GSC image output, and on the use of the GSC-standalone version. Please read this document carefully. It contains all GSC related information, GTB is only a graphical interface, designed to facilitate GSC processing.

- **Changelog:** this option displays recent changes and feature additions of the current GTB version.

- **EULA:** this option will display the terms of the End User License Agreement (EULA). Using GTB requires acceptance of these terms.

1.5.2 GTB Training

- **Accounting:** this section provides information on concepts, the product sheet, and the option to install or upgrade a dedicated tutorial for conducting Accounting analysis using NLCD sample data.

- **Pattern:** this section provides information on concepts, the product sheet, and the option to install or upgrade a dedicated tutorial for conducting Morphological Spatial Pattern Analysis (MSPA) using NLCD sample data.

- **Fragmentation:** this section provides information on concepts, the product sheet, and the option to install or upgrade a dedicated tutorial for conducting Fragmentation analysis using NLCD sample data.

- **Landscape Mosaic:** this section provides information on concepts, the product sheet, and the option to install or upgrade a dedicated tutorial for conducting Landscape Mosaic analysis using NLCD sample data.

- **GWS (GTB Workshop):** use this option to install or upgrade the complete GTB Workshop material. This material contains presentations with many details on the motivation, design, functioning, and application fields of the different methodologies available in GTB. It is complemented by key reference publications, as well as sample data sets and instructions to illustrate using these tools. This package is used during the GTB training courses, but it can also be easily followed by the interested GTB user. The workshop material can be installed automatically into an existing installation.

1.5.3 GTB Online

- **GTB News:** displays current ongoing activities and upcoming changes to be included in a future version or revision of GTB.

- **GTB Homepage:** will open the GTB homepage in a web browser providing current information on the GTB software.

- **Check for Updates:** check for & install GTB upgrades:
  - **Program release**: includes major changes within the libraries of the IDL programing framework requiring a new installation of GTB.
  - **Revision release**: a small patch, which will either fix issues found in the previous program release and/or add new features. A revision release can be installed automatically into the existing installation.

- **GTB Product Sheets:** open the GTB homepage at the section Product Sheets providing links to pdf-files having further documentation, explanation and application examples of dedicated GTB products.

- **GWB (GTB Workbench):** open the GWB homepage in a web browser. GWB provides the most popular GTB analysis modules as command-line modules on 64bit Linux workstations and servers. Command-line instructions, valid for any GWB installation and exemplified with the two included sample images, are detailed in the GWB online manual.

- **pyGuidos:** open the pyGuidos homepage in a web browser. pyGuidos is a Python-only implementation of the main GWB modules.

1.5.4 Related Resources

- **GIS Introduction**: an introduction into the Geographical Information System (GIS) provided by members of the QGIS project.

- **GDAL**: a translator library for raster and vector geospatial data formats providing a variety of useful command line utilities for data translation and processing.

- **CCRS Tutorial**: an introduction into the fundamentals of Remote Sensing provided by the Canada Centre for Mapping and Earth Observation.

- **OpenForis**: OpenForis is a set of free and open-source software tools that facilitates flexible and efficient data collection, analysis, and reporting.

- **SEPAL**: the FAO cloud computing platform provides a variety of tools for geospatial analysis in a browser-based online portal. SEPAL includes the GuidosToolbox

Workbench (GWB), providing easy access to the most popular GTB analysis modules, via either the command-line interface or a GUI.

- **EUFO**: the EU Observatory on Deforestation and Forest Degradation, exemplifying forest attribute layers (Fragmentation, Accounting, Pattern) derived with GWB.

- **TreeAtlas**: a link to the free European Atlas of Forest Tree Species.

- **IMPACT Toolbox**: this software collection offers a combination of remote sensing techniques, photo interpretation, and processing technologies in a portable and stand-alone GIS environment allowing users to accomplish all necessary pre-processing steps to produce a landcover map from Earth observation data.

- **Conefor**: this software permits quantifying the importance of habitat patches and links for landscape connectivity. In GTB, you may use **ConeforInputs** or **MSPA ConeforInputs** to setup input files for further graph-theory analysis in Conefor.

1.5.5 Bug Report

This option will setup a text file for bug reporting, including date and program version, installation details, and a log of processing steps. If you find a problem, please add precise and concise information allowing to duplicate your issue, which will facilitate detecting and fixing the problem in a future update. Finally, email the bug report to the developer.

1.5.6 About GTB

This option provides information on the currently installed program/revision version of GTB, homepage and contact information, the operating system dependent additional software, and the maximum image dimensions for various processing routines supported in GTB. On Linux and macOS the maximum supported image dimension for MSPA is recalculated dynamically accounting for the actual amount of available free RAM in the operating system.

2. The Image/Display Attributes window (top left panel)

This panel allows changing the image and display attributes of the image shown in the viewport in the right panel.

The left side provides:

- Normalized: display the image values using either their apparent values (default) or normalizing them into the range [0, 100].

- Autostretch: this switch will scale the present image values into [min, max]. This feature can be used to visualize images with small contrast range when using s spanning the entire range of [0, 255] byte.

- Original Image: selecting this button will restore the initially loaded image.

- Image Info: a separate window will display details of the currently loaded image, such as data type, number of bands, unique pixel values, and, if a GeoTIFF image was loaded, the geoheader information including projection name and EPSG-code.

The right side provides:

- Select Colortable: a series of predefined color tables and the option to setup a user-defined color table adjustable via a dedicated window interface. The option *Save/Restore* allows for saving or restoring any GTB-generated color table.

- Zoom Mode/Factor: these settings are used to specify a rectangular *Region Of Interest* (ROI), a sub region of the image: prior to the definition of the ROI, a zoom factor in the range of [1, 10] should be selected from the *Factor* drop-down menu. Next, a rectangular ROI is defined by holding down the left mouse button and dragging the mouse inside the graphic display. The selected region is outlined in green color and constantly updated until the mouse button is released. The selected zoom factor is then applied to the selected area and displayed in the viewport. The *Zoom Mode* button changes to *Quit Zoom*, providing the option to return to the display showing the entire image extent.

3. The MSPA window (bottom left panel)

This window is divided into the following two segments:

3.1. MSPA Settings

This window allows changing the settings of the four MSPA parameters (more details can be found in **Help → GTB Documentation → MSPA Guide**):

1. **FGConn:** the default setting for the connectivity of the foreground pixels is 8-connectivity (cardinal and diagonal directions) but may also be constrained to 4-connectivity (cardinal directions only).

2. **EdgeWidth:** the MSPA analysis scale driving the distance of the non-Core boundary classes (default: 1); the selected value is equivalent to the resulting boundary width in pixels. The x-entry in the drop-down menu can be used to insert a custom value within [0, 100]. A new custom value will only be assigned after the Enter key has been pressed.

3. **Transition:** Transition pixels are those pixels of an Edge or a Perforation where the Core area intersects with a Loop or a Bridge. The default value (1: checkmark set) is to show transition pixels as Loop or Bridge pixels connecting to the Core area. However, doing so will interrupt the visual integrity of a closed Edge or Perforation perimeter. The closed perimeter display can be maintained by switching transition to off (0: checkmark unset). Please note that when transition is off, short Bridges of 2 pixels will not be visible since they are hidden under the Edge/Perforation pixels.
   Changing the Transition setting will change the visual appearance only but not the actual pixel values or statistics of the MSPA image!

4. **Intext:** this parameter allows distinguishing internal from external background, where internal background is defined as being surrounded by blue Perforation pixels. The default is to enable this distinction, which will add a second layer of classes to the seven basic classes. All classes, except for Perforation, which by default is always internal (105 byte), can then appear in internal or external background.
   Setting Intext=1 is needed to retrieve information on ***Openings*** in the Foreground.
   Please read the **Help → GTB Documentation → MSPA Guide** for further details.

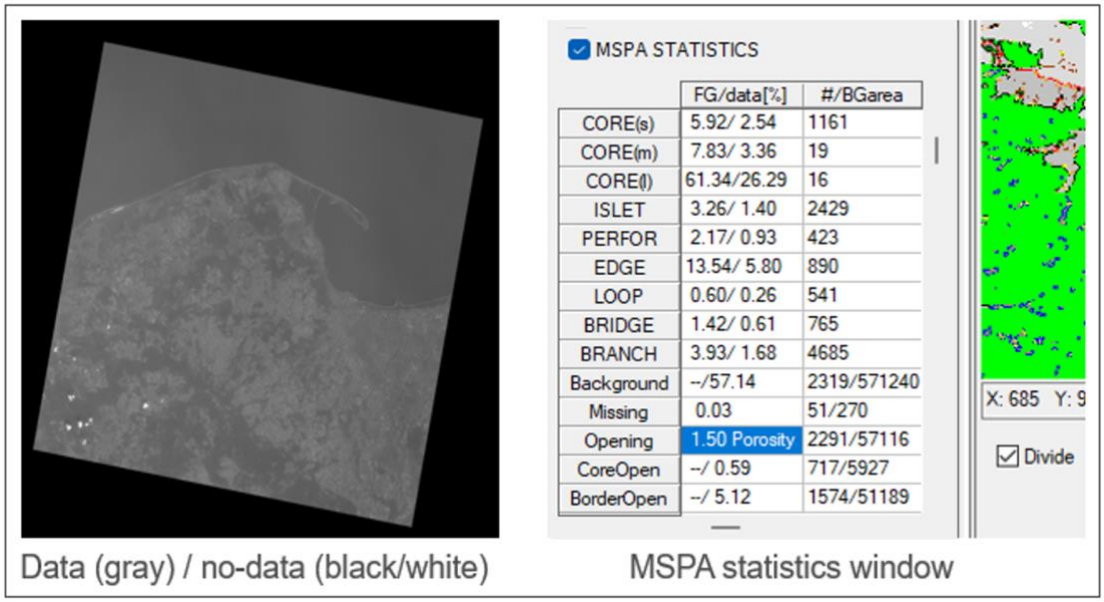
The 4-parameter fields are also used for non-MSPA purposes (**marker image**, **Recode Line**, **Restoration Planner**, and **Distance** analysis), please consult the respective section for further information.

3.2. MSPA Statistics

The MSPA analysis requires a (pseudo-) binary input image. In general, the rectangular image area is composed of the following two parts:
1) Data area (required): pixels with information and assigned to be either background or foreground.
2) Missing area (optional): pixels without information.

In the left image below, the data-area corresponds to pixels where information is available (the rectangular area composed of grey-scale pixels). The no-data area, where pixel information is not available, are the cloud pixels (white pixels at the bottom left of the data area) and the boundary segments (black) between the image boundaries and the grey data area. Please note that a particular landcover type could be defined as 'Missing' to exclude it from the MSPA analysis.

Figure 53: Left: the rectangular image area is composed of data and no-data area.
Right: example of entries in the MSPA statistics window.



We have: **Image = Data + Missing = (Foreground + Background) + Missing**
The MSPA statistics window shows simple statistics of the seven basic MSPA Foreground classes plus Missing, Background and Openings:
Left column: shows the percentage = number of class pixels per foreground area and per data area.
Right column: shows its frequency = number of unique objects of the given class and, where applicable, the area = number of background pixels covered.
In the example above and exemplified for the class ISLET we find:
- 3.26% of the *Foreground* area are Islet pixels
- 1.40% of the *Data* area (= Foreground + Background) are Islet pixels
- 2429: there are 2,429 Islets (regardless of their individual size) in this image.

Similarly, for the class PERFORATION the statistics show that the image has a total of 423 perforations, and all perforation pixels together make up 2.17% of the Foreground area, or 0.93% of the Data area (foreground area + background area). The total

Background area enclosed by Perforation pixels (Core-Openings) amounts to 5,927 pixels.
Important: changing the setting for Transition only changes the display color of the Transition pixels, 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 below or page 6 of the Morphology product sheet. In this way, page 6 of the MSPA Guide, 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.

Openings: a given foreground cover may contain openings, which can be divided into *Core-openings* (dark-gray, 100 byte; completely inside Core and surrounded by blue Perforation pixels) and *Border-openings* (medium-gray, 220 byte; next to foreground boundaries and *not* completely inside Core). Statistics for both type of openings are displayed in the MSPA statistics window and opening pixels are assigned with the values 100/220 byte, **if Internal = 1**. If Internal = 0 no distinction is made between regular background and Openings. Finally, the *integral Foregound* (iFG) is defined as the sum of foreground + all openings. There are 2,291 openings in the Foreground area with a total area of 57116 pixels. 717 of the 2,291 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 bottom panel in MSPA statistics in **Figure 53**) located along the outside forest boundary (Edge) and covering a total area of 51,189 pixels.

Porosity measures the degree of Core-Openings inside the contiguous foreground area. $Porosity = 100 - (\frac{Contiguous}{Internal} * 100)$, Contiguous = Core+Edge+Perforation and Internal = Contiguous+Core-Openings. Forest porosity is 0% if the forest has no openings at all.

If the *Divide* checkbox below the viewport is checked, the statistics for the MSPA class Core will be provided individually for small/medium/large Core areas.
Please note that the purpose of these basic statistics is to provide a quick summary only. For example, the statistics do not account for the distinction of internal/external Core classes. The statistics will be reset in case of changing a MSPA parameter affecting the statistics. More details on the MSPA classes are available in **Help → GTB Documentation → MSPA Guide**.

MSPA-plugins with documentation and installers are available for ArcGIS, R, and QGIS. They can be downloaded from the MSPA-website.
MSPA is also available as a standalone executable for inclusion into custom scripts. More details on the use and settings of the standalone version can be found on the last page of the **Help → GTB Documentation → MSPA Guide**.

Additional information is summarized in the MSPA Guide and Product Sheet.

4. The Viewport window (top right panel)

This window displays the original, processed or the zoomed area of the image. The image is either displayed in its original size or automatically downsized to fit into the GTB viewport. Any processing is performed on the original non-zoomed image. The icon of the mouse pointer inside the viewport can be changed via the General Tools → Switch Cursor option.

5. The Pixel Locator/Value panel (below the viewport)

This panel below the viewport shows the pixel coordinates, value, and type for the current location of the mouse pointer in the viewport. This feature works in full display as well as in Zoom Mode. It will also list related specific class names when investigating certain image types in the viewport, i.e., MSPA, FAD or MCD.

6. The Divide Range panel (below the viewport)

This panel below the Pixel Locator/Value panel allows dividing the data range of the following image types into the 3 groups: small/medium/large. The two thresholds defining these groups are defined via two drop-down menus. The user can either select predefined settings or enter custom thresholds to define threshold values for the 3 groups. A new custom value will only be assigned after the Enter key has been pressed.

- MSPA: divide the MSPA core area [pixels],
- Fragmentation: divide the Fragmentation range [%],
- Contortion: divide the Contortion range,
- Isochrone Map: divide the travel time range,
- Distance: Divide the distance range [pixels] for foreground and background.
- Influence Zones: define the width of buffer zones into the Foreground (to define Core-objects) and into the Background (buffer zones ranging outside of Foreground or Core objects),
- Proximity: define CoreZones and maximum proximity values of interest.

7. Limitations, known issues and tweaks.

The following list summarizes known limitations and provides suggestions for potential issues arising when using GTB:

1. **Proxy:** GTB includes an automatic proxy-detection, which can be disabled by placing an empty file **noproxycheck.txt** into the **GuidosToolbox\data** folder.
2. **GTB image dimensions:** the module-specific maximum dimensions measured in pixels in x and y are listed under Help → **About GTB**. By default, GTB can load images up to 30,000 x 30,000 pixels. This limitation can be disabled by placing an empty file **nolimits.txt** into the **GuidosToolbox\data** folder. **Warning:** using this tweak is **unsupported** and may result in system hangs or program crashes! For processing of large images use GWB, which has no size limitations.
3. **Restoration Planner:** analysis schemes based on GGEO may be very slow.
4. **GTB window size:** the size of the application window is driven by the currently loaded image dimensions and cannot be maximized to fit the entire screen.
5. **Save Image → kml:** on certain 64-bit versions of MS-Windows, the option to save an image in kml-format may not work due to a conflict with other GIS-software installed in the system. A patch to address this issue is available in the folder **C:\GuidosToolbox\guidos_progs**. Double-click the file **fix_saveaskml.bat** and provide the administrator password to apply the patch.
6. **GDAL:** the GTB MS-Windows included version is 1.11.3. Newer versions with additional features can be obtained from the GDAL Binaries website.
7. **Data folder on network drive:** the full path to the image filename must not contain any empty spaces, special or non-Latin characters (diacritics, ligatures).
8. **Concurrent use of external software:** simultaneous opening/processing of the same raster file in GTB and another software (QGIS, ArcGIS) should be avoided.
9. **Concurrent use of GTB:** running multiple instances of GTB from the *same* installation directory may cause overwriting temporary files within the program directory, resulting in program crashes or erroneous results. Multiple instances of GTB on the same machine can be run but must be executed from *different* installation directories.
10. **Batch processing under MS-Windows:** a MS-Windows system-inherent problem will limit the number of files for batch processing (maximum 32,000 bytes of string can be read). Either shorten the length for the full path to the image files, use the Linux/macOS version of GTB, or even better use GWB.
11. **Undo/Redo:** this step may not always work reliably. Since only one processing step is saved, the user is advised to save intermediate results to the hard drive.
12. **GTB for MS-Windows 32-bit has been discontinued.** The latest, **unsupported** version 2.702 can be downloaded from the GTB homepage.

8. Acknowledgments

The author would like to thank all those for the help and suggestions during the design phase of GTB. Parts of this software package are based on conceptual ideas, which can be found in the excellent IDL programs of David Fanning. I am deeply grateful to Pierre Soille for sharing in-depth knowledge into the beautiful world of mathematical morphology and especially for all his time and effort in writing the MSPA code. Sincere thanks go to Kurt Riitters for his invaluable advice on the pattern algorithms; Santiago Saura for providing details and help when implementing the network analysis routines; Frank Warmerdam for permitting to include the excellent FWTools package in the MS-Windows version of GTB; Bernd Eckhardt, Giovanni Caudullo, and Julien Carlier for advice and constructive suggestions improving the overall user-experience. Bill Reynolds, lead of the superb PCLinuxOS distribution, for providing deep insights into the world of Linux and application packaging. Finally, a big thank you to Dario Simonetti for his guidance and help with getting GDAL to work on MS-Windows.

This software package includes research products designed and developed within the context of the Collaborative Research Arrangement between the United States Department of Agriculture, United States Forest Service (Forest Service Agreement No. 14-MU-11330110-001) and the Joint Research Centre of the European Commission (Collaborative Research Arrangement No. JRC 33385).

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