



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

The Landscape Mosaic.

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

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1. Background

Land cover maps show the spatial locations of different land cover classes. The spatial and thematic information in these maps can be used to analyze a wide variety of research and landscape planning questions. A temporal comparison of land cover maps may highlight locations of changes in land cover types, for example urban sprawl, parcellation, deforestation and/or desertification processes. An increasing number and amount of individual land cover classes leads to a higher degree of landscape heterogeneity, which may even be seen as a measure for landscape fragmentation. The typically used patch-based metrics describe only certain patch aspects of one land cover class and do not account for the interplay of different land cover classes. However, landscape planning, monitoring and risk assessment studies require a meaningful and holistic assessment of a given land cover context.

The [landscape mosaic model](#) quantifies and maps the spatial juxtaposition of different land uses. It provides a landscape perspective of anthropic threats posed by agriculture and urban development. The spatial-temporal shifting of the landscape mosaic indicates landscapes where anthropic intensity has changed.

Scope of this report:

Illustration of an analysis methodology, *Landscape Mosaic* (LM), to locate and measure dominant land cover and the degree of land cover heterogeneity on a given land cover map. The methodology outlined in this document has been developed with the goal to

- a) bypass typical limitations of existing patch-based metrics.
- b) be based on geometric concepts and providing a generic framework, which can be applied to any kind of data type and at any scale.
- c) be applicable to any kind of multi-class (land cover) raster maps.
- d) provide relative contributions [%] of the three prevalent land cover types Agriculture, Natural and Developed within a given neighborhood/observation area.
- e) provide a concise statistical summary chart (heatmap) highlighting the frequency and location of all pixel triplets in the ternary land cover domain.

The Landscape Mosaic and the heatmap summary can be used as a state variable to measure the degree of land cover heterogeneity, locate areas exhibiting dominant and/or highly intermixed land cover. Due to its setup for provision of a normalized measure, the Landscape Mosaic can also be used to directly quantify changes in land cover dominance over time as well as directly compare the degree of land cover heterogeneity and composition of different sites. The Landscape Mosaic may be a useful measure in questions of landscape planning, monitoring and biodiversity studies.

2. Landscape Mosaic

2.1 The methodology

The Landscape Mosaic is a tri-polar classification of a location accounting for the relative contributions of three prevalent land cover types, i.e., *Agriculture*, *Natural*, *Developed* in the window surrounding that location. The classification model is designed to identify anthropogenic activity (land cover classes falling in the categories Agriculture and Developed) in relation to natural land cover (application examples can be found in Wickham et al. (1994), Riitters et al. (1996, 2000, 2009, 2020), Maes et al. (2020), Vogt et al. (2024)).

The tri-polar classification scheme (Figure 1) uses the threshold values of 10%, 60%, and 100% along each axis to partition the tri-polar space into 19 mosaic classes. These threshold values are indicative for the presence (10%), dominance (60%), or uniqueness (100%) of each land cover type. A lower-case letter (*a-Agriculture*, *n-Natural*, or *d-Developed*) in a mosaic class name denotes a respective land cover type proportion of at least 10% but less than 60%; an upper-class letter (*A*, *N*, *D*) denotes a respective contribution of at least 60% but less than 100%; A letter does not appear if the respective land cover proportion is less than 10%. Locations being composed of a single land cover type only (100%) are found at the corner points of the Mosaic triangle and are labeled with *AA*, *NN*, and *DD*, respectively. With this notation, *Dominance* is indicated by upper-case letters, an *Interface Zone* by a combination of upper- and lower-case letters, and a *Mixture* is indicated by lower-case letters only. The Mosaic colors reflect the varying degree in color intensity with respect to the proportion of *blue-Agriculture*, *green-Natural*, and *red-Developed*.

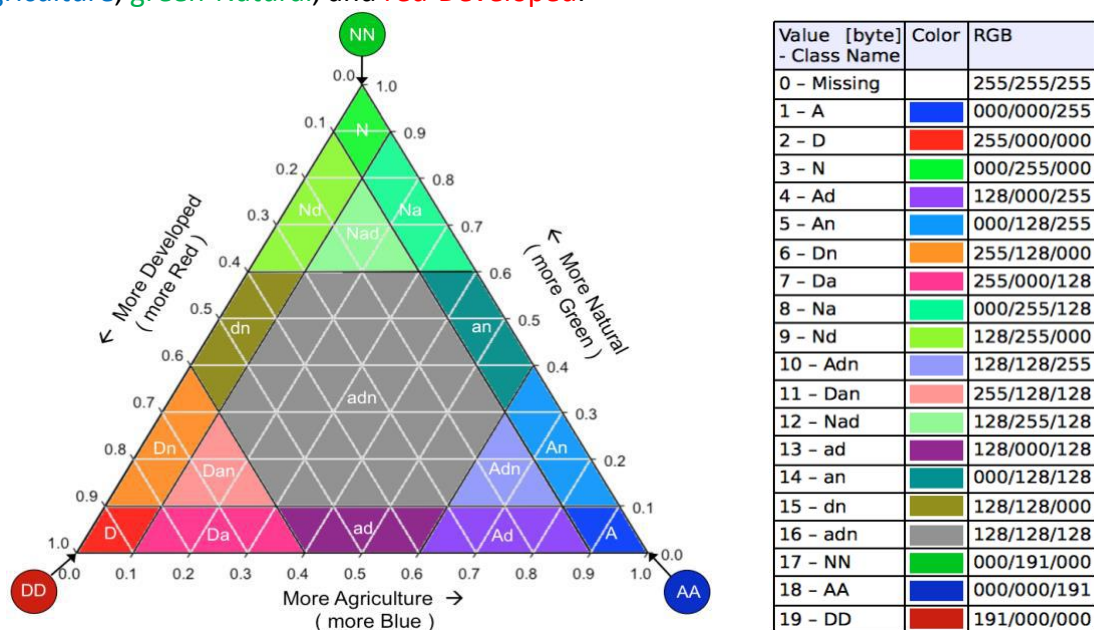


Figure 1: The Landscape Mosaic (LM) showing 19 mosaic classes and their proportions to the three land cover types Agriculture, Natural, and Developed.

In the resulting LM map, each pixel has a triplet of values showing the relative contribution to the 3 land cover types Agriculture, Natural, Developed. This implies that each pixel value triplet is positioned at a specific location within the triangular domain space shown in Figure 1. The 19 sub-sections of the triangle - representing presence, dominance and uniqueness - are color-coded into 19 mosaic classes, which are displayed in the resulting LM spatial maps and summarized in the legend at the right in Figure 1. Because each image pixel value triplet corresponds to a specific location in the triangle, the entire set of image pixels can be inserted in the triangle, resulting in a heatmap (point cloud distribution, Figure 2). To minimize computation time and facilitate the interpretation, this process is conducted for the 100 sub-triangles only, defined by the 10% intervals along each axis. The corner points of the triangle representing exclusive presence of one land cover type only form an additional 3 classes. With this setup, the heatmap consist of 103 occurrence classes, showing the relative pixel occurrence frequency in each sub-space. An empty sub-space denotes no occurrence, the maximum occurrence frequency is highlighted by a black background.

How to read the triangle:

Each image pixel has a relative proportion of the Blue, Green and Red classes (triplet of values), corresponding to a unique point in the triangular domain.

For example, the triplet at the arbitrary location * has the three values: $0.25 + 0.62 + 0.13 = 1.0$
 Locations along the outside boundary of the triangle have only two values/classes, the third value is zero. The triangle corners have a single value/class only. The white sub-triangles define sub-spaces with 10% intervals for each class.

The white circles show the percentage of all pixels occurring in a sub-space with respect to the total number of pixels in the image. The black circle shows the maximum occurrence:

Symbol	Pixel occurrence [%]
○	no occurrence
○ ₅	> 0% - 100%
● ₁₀	Max. occurrence %

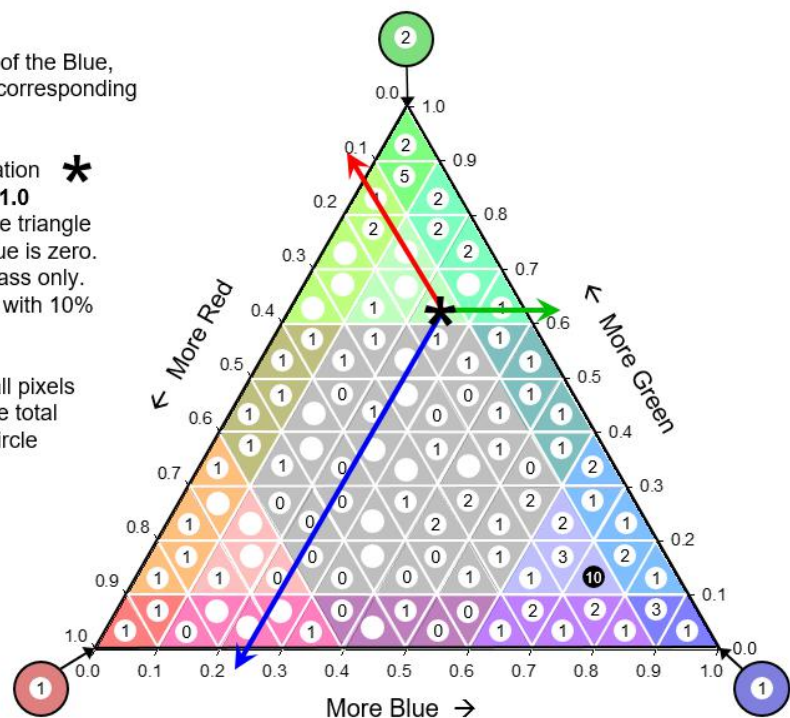


Figure 2: Explanation of reading out the triplet value for a given pixel in the Landscape Mosaic (LM) image. The values in the circles show the relative occurrence [%] of all pixels of the LM image.

2.2 The input data:

The input image for the Landscape Mosaic analysis must be a raster map with no more than 3 target classes having the assignment AND (1 Byte - Agriculture, 2 Byte - Natural, 3 Byte - Developed) plus an optional class value of 0 Byte which is reserved for masking missing/no-data pixels. The target classes must not necessary be Agriculture, Natural, Developed but could be any three prevalent land cover types in a given area.

2.3 The output data:

The result of the Landscape Mosaic analysis is a set of the following files:

1. LM-image.tif: (geo-)tiff image showing the 19 color-coded Mosaic classes (Figure 1) at the user-selected observation scale.
2. LM-image_103class.tif: (geo-)tiff image showing all 103 Mosaic classes (Figure 3) at the user-selected observation scale. Figure 4 shows a suggestion for thematic regrouping.
3. heatmap.png: Visual summary of occurrence frequency in the 103 sub-spaces.
4. heatmap.csv: same as 2 but with precise occurrence values in csv-format.
5. heatmap.sav: binary encoded summary data for potential change analysis.
6. Heatmap_legend.png: Explanatory image (Figure 2).

For visual clarity, occurrence numbers in the visual summary (heatmap.png) are displayed as rounded integers only and therefore not necessarily total to 100%. The precise occurrence values are listed in the csv-file.

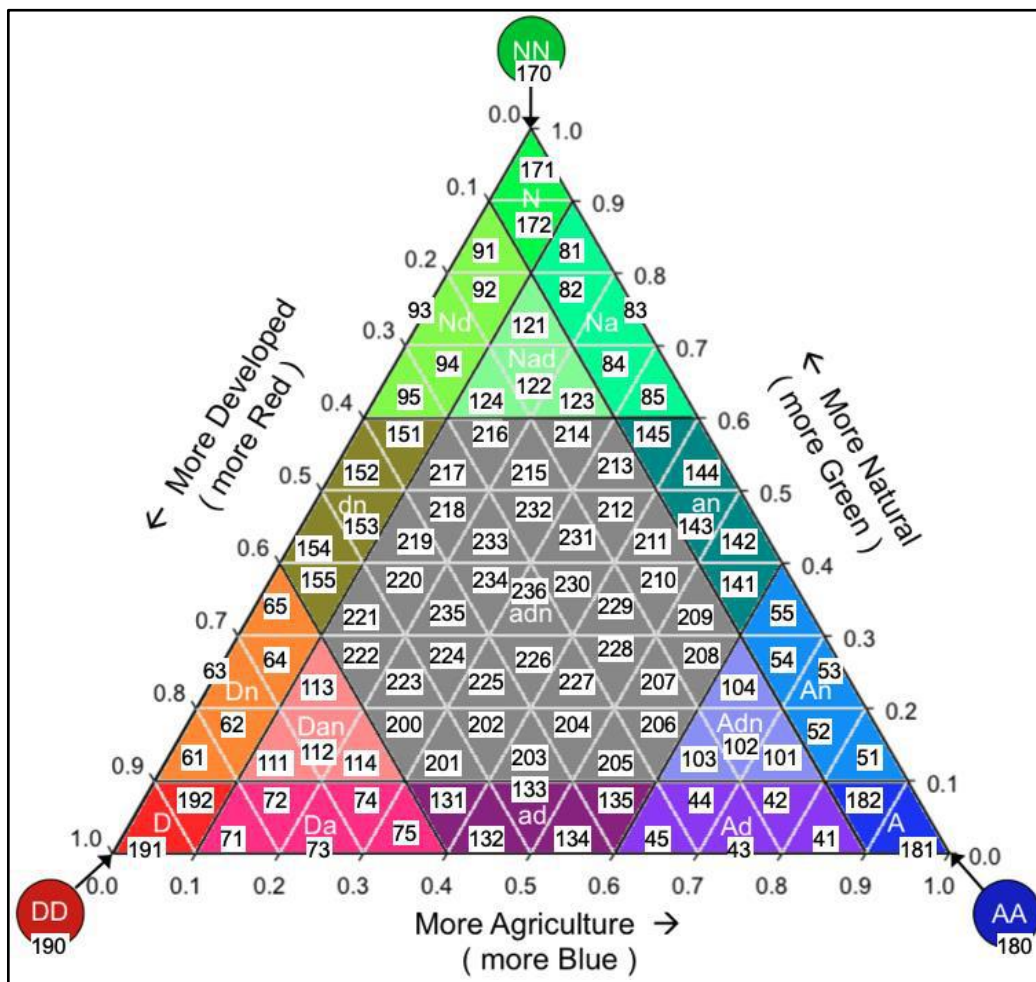


Figure 3: Image pixel value assignment of the 103 classes in the LM*_103class.tif image.

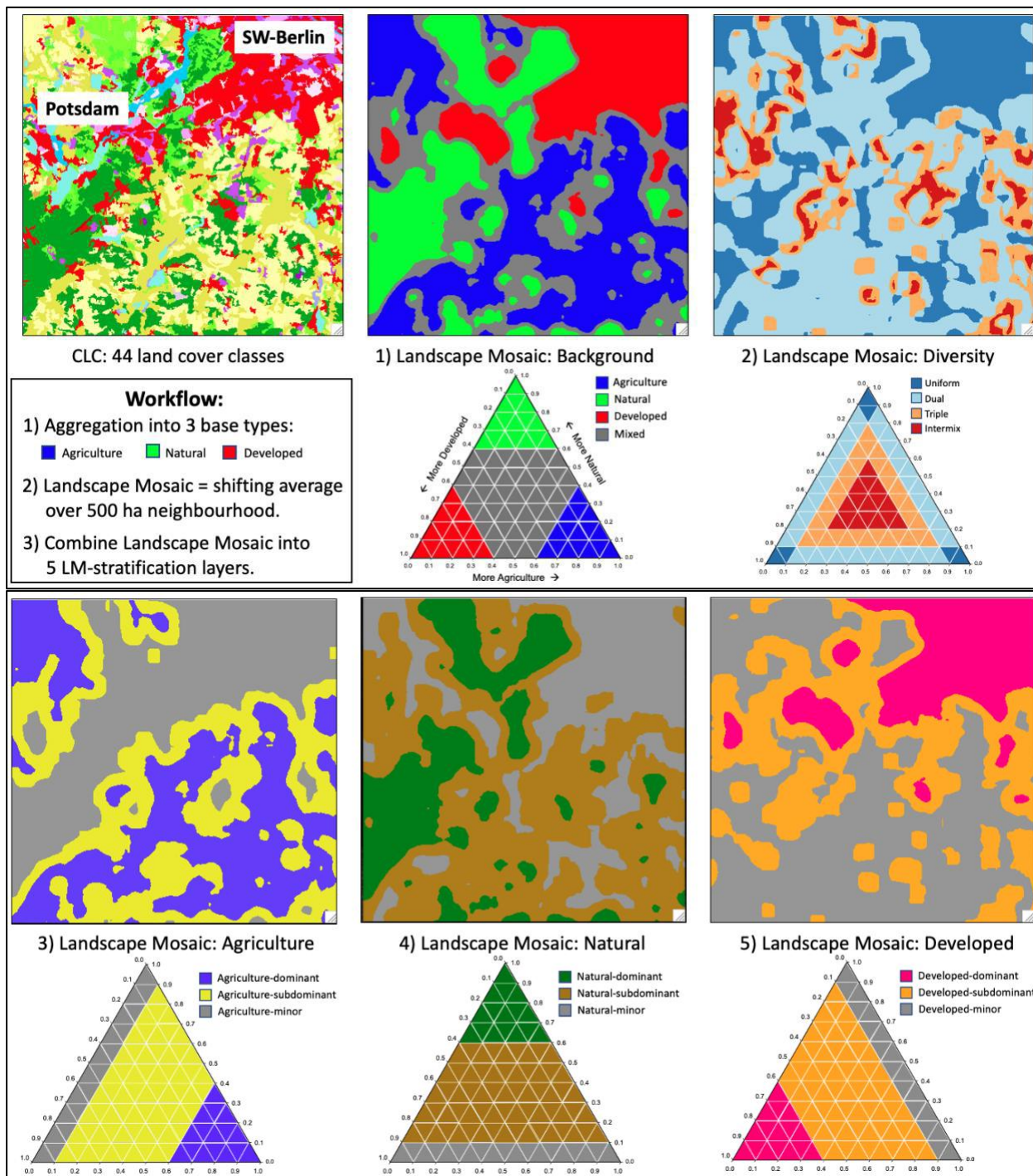


Figure 4: Example of color-coding the 103 classes of the Landscape Mosaic over the region of Potsdam/SW-Berlin, Germany. Top panel: Original landcover data, LM-Background (showing predominant land cover type), LM-Diversity (showing degree of heterogeneity). Bottom panel: LM-Agriculture, LM-Natural, LM-Developed showing dominance of agricultural, natural, and developed land cover, respectively.

[See Figure 4.3.1 and page 319-326 in the MAES report, (Maes, J. et al. (2020).]

3. Example application

This section provides examples illustrating the features and final results for the Landscape Mosaic analysis scheme. All image processing was done in GuidosToolbox. The following results can be reproduced by using the example data from the workshop material provided for GuidosToolbox.

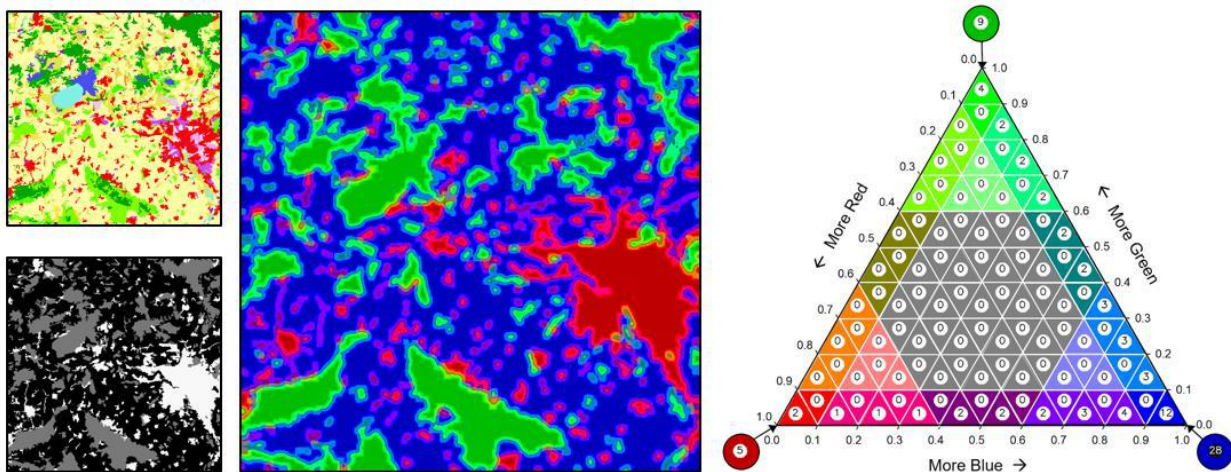


Figure 5: Landscape Mosaic example: a CORINE land cover class image (top-left) is re-mapped into the three land cover type image featuring Agriculture, Natural, Developed (bottom-left). The image in the center shows the 19-class LM-analysis at an observation scale of 27x27 pixels and the image on the right the corresponding heatmap.

Figure 5 shows the processing sequence of the Landscape Mosaic analysis. The top-left image shows a CORINE land cover image of dimension 2000^2 pixels having a total of 26 individual land cover classes. To comply with the LM-input requirements, this image is then re-mapped into the 3 land cover types Agriculture, Natural, Developed (gray-scale image in Figure 5 showing Agriculture-black, Natural-gray, Developed-white). The center image shows the LM-analysis at a user-selected observation window of 27x27 pixels. With the CORINE pixel resolution of 100 m this observation scale corresponds to 2.7 km x 2.7 km = 729 hectare.

Each pixel in the LM-image is derived by a moving window procedure in the following way: a) a fixed-area square window (here with edge-length 2.7km) is centered over a given pixel of the land cover type image; b) the composition of the three land cover types (the contribution triplet in A, N, D) is calculated from the pixels covered by the square window; c) the corresponding mosaic class is placed on the LM-image at the location of the investigated pixel. This implies that each pixel in the LM-image describes the land cover context within the surrounding square area of 27x27 pixels, here 729 hectare. The LM-image in Figure 5 shows predominantly agriculture (blue) in the background, some isolated smaller and one larger urban area (red) and a couple of extended natural areas (green).

Because each pixel has a contribution triplet in A, N, D, it will fall in one of the 103 sub-spaces of the LM-triangle. The heatmap (right image in Figure 5 or the tabular numbers in Figure 6) shows the relative occurrence frequency of all LM-image pixels. The highest occurrence (black circle) is found for the class featuring exclusively agriculture, or in other words: 28% of all pixels in the LM-image are in class AA. Similarly, 5% of all LM-pixels at this observation scale are found in purely Developed and 9% in purely Natural. Furthermore, the heatmap shows a predominance for mixed agriculture mosaic classes, which is in line with the visual perception of the LM-image. In this way, the heatmap provides a summary assessment for a given LM-image. Because occurrence frequencies are shown in percent, the heatmap can be used to a)

compare landscape composition for images of different extent, or b) investigate time series at the same observation scale, or c) investigate changes in land cover prevalence across different scales.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Landscape Mosaic using Window size (27x27)																				
2											9.405										
3											3.51										
4										0.23	0.067	2.047									
5									0.183	0.044	0.045	0.056	1.961								
6								0.161	0.038	0.037	0.04	0.049	0.058	2.055							
7							0.156	0.038	0.032	0.034	0.042	0.044	0.05	0.069	2.27						
8						0.157	0.032	0.033	0.033	0.037	0.041	0.04	0.051	0.062	0.081	2.425					
9					0.152	0.025	0.033	0.032	0.034	0.038	0.038	0.037	0.052	0.055	0.066	0.09	2.596				
10				0.148	0.026	0.027	0.028	0.028	0.034	0.042	0.047	0.051	0.054	0.061	0.065	0.079	0.113	2.869			
11			0.176	0.028	0.028	0.028	0.036	0.037	0.048	0.046	0.061	0.056	0.063	0.06	0.068	0.078	0.106	0.148	3.466		
12		1.597	0.025	1.106	0.032	1.184	0.044	1.341	0.069	1.581	0.072	1.91	0.088	2.324	0.103	2.943	0.129	3.657	0.228	12.038	
13	4.79																				27.561

Figure 6: Tabular output of the pixel occurrence frequency of the image in Figure 5.

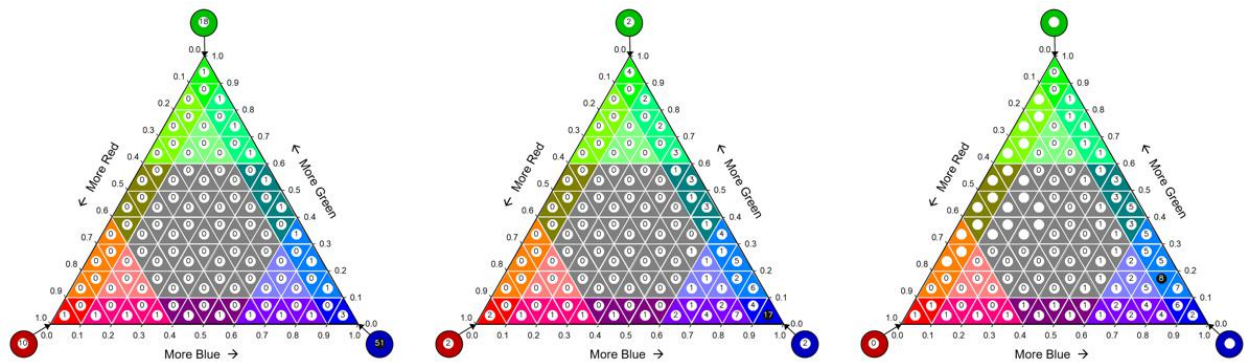


Figure 7: Heatmaps for the image of Figure 5 but at observation scales 7x7, 81x81, 243x243.

Multi-scale analysis: GuidosToolbox also includes the multi-scale assessment scheme *Dominance*. *Dominance* conducts a LM-analysis for the 5 fixed observation scales (7x7, 13x13, 27x27, 81x81, 243x243) as well as a summary across these 5 scales. These scales were selected to span a wide range of scales representing an approximately geometric progression of window area with scale. The idea of *Dominance* is to illustrate the change in land cover composition with changing observation scale. An increase in observation scale will increase the area of the surrounding neighborhood, which can be interpreted as looking at the same location from a different altitudes and having the effect that small objects will dissolve into the background. Such a multi-scale assessment may be of interest when looking for tipping points, exhibiting significant changes in the overall land cover characteristics. In general, the multi-scale assessment will show which mosaic class dominates at which observation scale. Figure 7 shows this effect in the heatmaps of the image used in Figure 5 but at observation scales 7x7, 81x81, 243x243: the most encountered mosaic class (black circle) changed from purely Agriculture (AA at 7x7) to Dominant Agriculture (A at 81x81) and Agriculture/natural (An at 243x243).

Change analysis: the saved Mosaic and heatmap information can be used in GuidosToolbox to investigate changes in Mosaic classes between two LM-images. This change analysis can be conducted for two different locations, or for the same spatial coverage but at different observation scales, or to investigate temporal changes over the same assessment area.

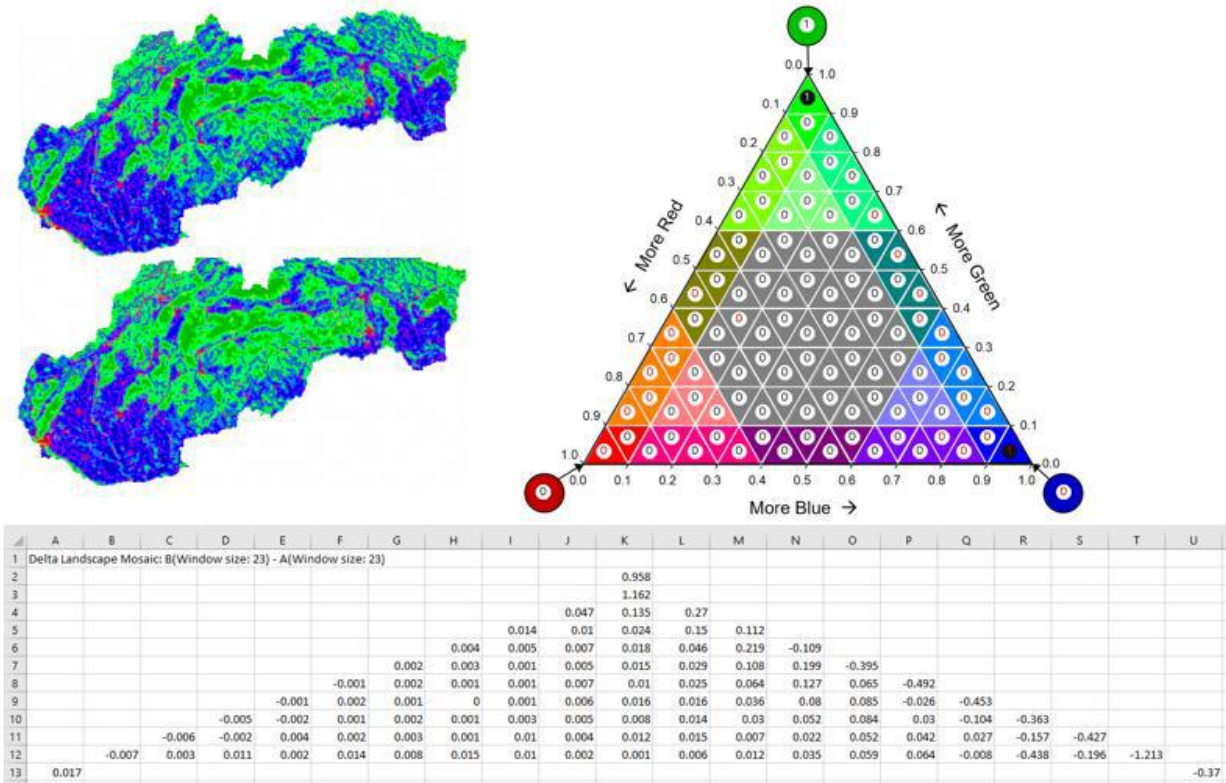


Figure 8: Landscape Mosaic maps for Slovakia based on CORINE 1990 and 2012 data (top-left) at an observation scale of 23x23 pixels ~ 529 hectare. The image on the top-right shows the delta heatmap where percent change increase is listed in black numbers and decrease in red numbers. The corresponding tabular data of the delta heatmap is shown in the bottom part of the figure.

For example, Figure 8 shows the LM-analysis for Slovakia using CORINE data for 1990 and 2012 at the observation scale of ~ 500 hectare (23x23 pixels). Comparing the heatmap summary from the year 1990 to the one from year 2012 leads to a new delta heatmap (top-right and bottom panel in Figure 8). The delta heatmap, and the corresponding csv-table, show the simple difference of heatmap 2012 minus heatmap 1990. Positive differences are shown in black and negative differences in red numbers and maximum differences are highlighted with black circles. In this example, we find a small increase for the dominant Natural classes (top of the triangle) and a slight decrease for the dominant Agriculture classes (bottom right of the triangle), while the remaining classes remain unchanged.

Comparative analysis: a comparison of landscape composition between different countries is feasible because the heatmap shows relative occurrence frequencies.

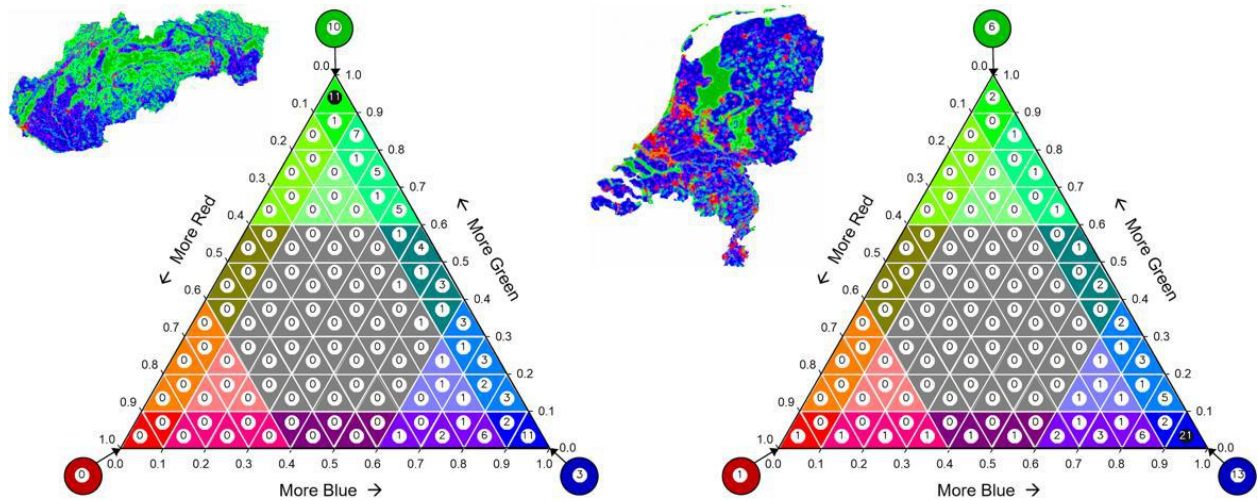


Figure 9: Landscape Mosaic and corresponding heatmap for Slovakia (left) and the Netherlands (right) based on CORINE 2012 data at an observation scale of 23x23 pixels ~ 529 hectare.

As can be seen from the maps and heatmaps in Figure 9, the Netherlands have a higher proportion of agricultural land cover compared to Slovakia. The heatmap also indicates a higher diversification of natural based land cover in Slovakia and a rather homogeneous agricultural land cover in the Netherlands.

Motivation/Purpose: A user or policy maker may be interested to detect geographic areas where anthropogenic activity has increased, for example areas used for agriculture or urban sprawl. In addition to detecting hotspots of heterogeneity, the Landscape Mosaic may be useful to investigate the interface of the remaining natural land cover. Both, the map product and the heatmap summary allow to locate and quantify interface zones of natural land cover with agriculture and/or urban/developed land cover. Biodiversity studies may be interested in examining the transition zone from a forest habitat. Here, a neighboring agricultural zone is often considered more favorable compared to the transition into developed land cover. On larger scales, the Landscape Mosaic could be used to detect remaining patches of *undisturbed* forest (class NN) showing no or very little anthropogenic influence. Mapping and measuring changes of prevalent land cover types is of interest in political directives targeted at ecosystem services, biological sustainability, landscape conservation and restoration of natural areas, or investigating the potential impact of land cover changes on and in the vicinity of protected natural parks. It may also help understanding cause-effect relationships; for example intersecting a map of forest loss with the Landscape Mosaic may reveal that forest loss predominantly occurs in the vicinity of a certain Mosaic class.

More generally, terms like human footprint, anthropogenic activity, population growth, urban sprawl, deforestation, degradation, etc. are all related to the conversion of natural land cover. The mapping and measurement of the type of conversion, its intensity and spatial extent are fundamental to understand the ecological and social impacts of human activity in our landscapes. Similar to fragmentation, landscape composition is observer-/scale-dependent. It is obvious that land cover patterns, or Mosaic classes, are different at different scales and there is a common agreement that patterns at local scale drive patterns at regional scale, etc. With most areas of the Globe being under human influence, there is a clear need for a general purpose, multi-scale reporting model to provide a clear message of mosaic classes across

different observation scales. The model described here may be used for either a user-selected specific scale or as a multi-scale assessment scheme. The three land cover types Agriculture, Natural, Developed could also be replaced with any other triplet of prevalent land cover types.

Anthropic intensity: The principal scope of the Landscape Mosaic is to detect and measure human impact on the originally unmodified natural land cover. A recent [paper](#) illustrates how anthropic intensity in terms of converting natural land to agriculture and developed land can be mapped and quantified by simply applying a dedicated color scheme to the 103-class LM map. In GuidosToolbox, the 103-class LM map can be displayed for various thematic aspects by applying the respective predefined color table. For example, the five color tables shown in Figure 4 or the color table Anthropic Intensity shown in Figure 10 and 11.

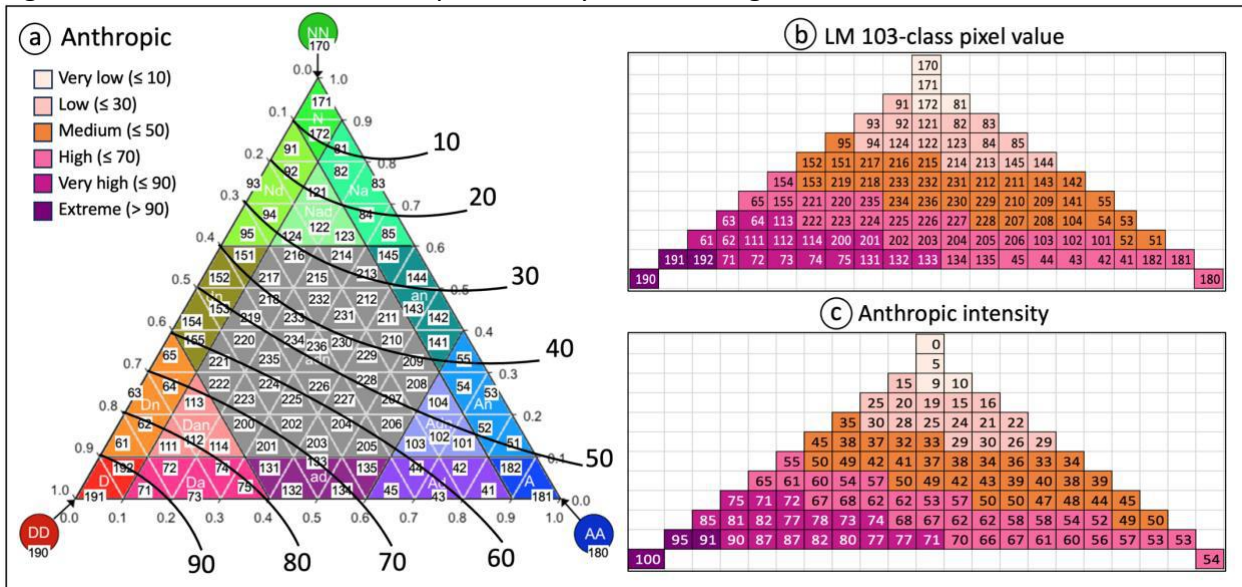


Figure 10: LM103-class mapping to the degree of anthropic intensity (a); associated 103-class pixel value (b); and respective anthropic intensity value (c).

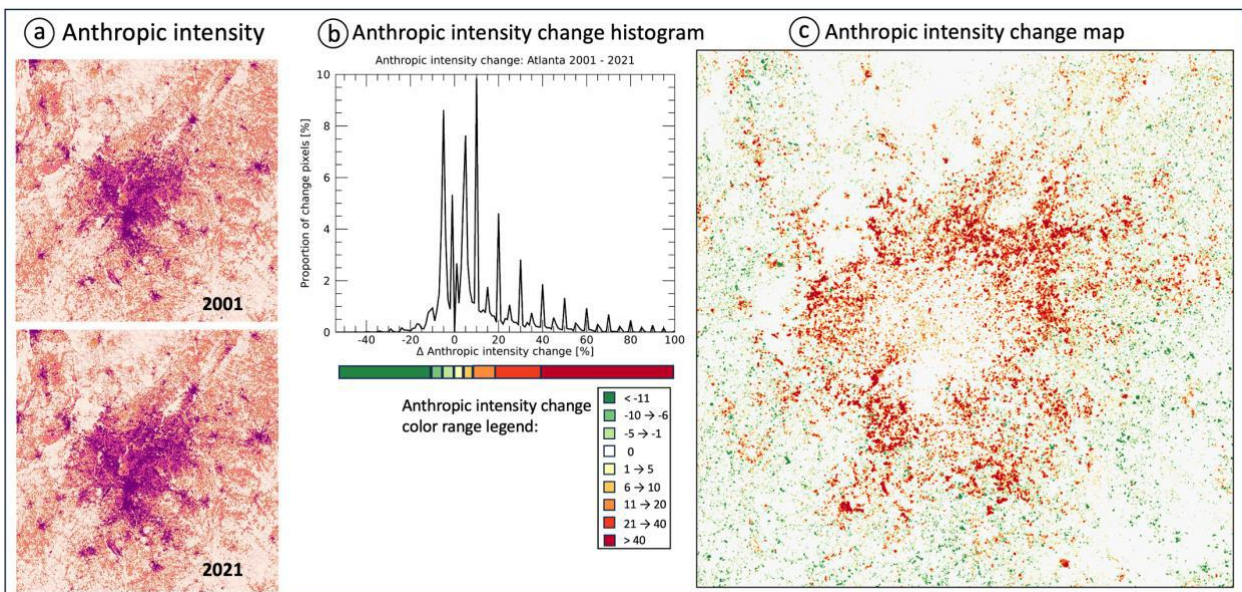


Figure 11: Anthropic intensity for Atlanta 2001 and 2021 (a); histogram of change pixels and anthropic intensity change color range legend (b); locations and degree of anthropic intensity change (c). Results based on 13-pixel window size, equivalent to ~ 15 ha local neighborhood.

4. Discussion

This document describes a methodology for the assessment of the heterogeneity and spatial composition of a land cover map. The approach is based on a moving window analysis measuring the relative contribution of three key land cover types in the neighborhood of a given pixel. The analysis provides a spatially detailed map product and a concise summary of all pixel triplets in a heatmap, highlighting the frequency and relative land cover contribution over each pixel in the image.

The Landscape Mosaic assessment scheme provides:

- **Generic concept:** The methodology is based on geometric principles only. As such, it can be applied to any kind of land cover raster maps, independent of the number of land cover classes and the spatial resolution of the map. The user can choose a specific observation/analysis scale or use a set of pre-defined scales. This document explains the concept using the three key land cover classes *Agriculture*, *Natural* and *Developed*. However, the same concept is applicable to any other triplet of key land cover classes, or any other kind of categorical multi-class raster data, which can be decomposed into three key classes generically denoted with Red, Green and Blue. The universal, yet flexible concept may provide a generic framework for interdisciplinary comparability across a wide range of application fields.
- **Land cover class statistics:** In contrast to many existing patch-based single value indices, the outlined methodology provides an assessment of the entire landscape configuration and detailed summary statistics (heatmap), including frequency of occurrence, and relative contribution to each land cover class at a given location and analysis scale.
- **Landscape Mosaic maps:** The spatial information of the map product may be of high importance for monitoring, planning and risk assessment, such as highlighting hotspots of highly fragmented areas or those areas dominated by undisturbed natural land cover. Locations of land cover changes over time can be easily detected on a map while they may not necessarily appear in typical summary statistics. Information on the locations of spatial features and changes is an essential requisite to measure progress or the overall effectiveness of political directives.
- **Communication:** The simple, yet intuitive assessment scheme is easy to communicate and can be related to a variety of land cover planning measures, change in time series of land cover and derived topics such as biodiversity or other environmental measures. The normalized measures of Landscape Mosaic and the heatmap summary also allow for direct comparisons with results from different regions. The Landscape Mosaic assessment scheme contributes to answering questions like:
 - **State Analysis/Dominance:** What is the degree of land cover diversity in different administrative units/counties or ecological regions of the country? Which land cover type is dominant at which observation scale? Can we find tipping points of dominant land cover across a series of observation scales?
 - **Trend Analysis:** How much forest cover was located in the vicinity of urban land cover? Which land cover type was dominant in the past? Where and how much has it changed over the past decades? How are the trends? Which kind of change can be expected for the future?

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

5. Conclusions

The Landscape Mosaic analysis is available in the free JRC software *GuidosToolbox*. The software can be downloaded and used by anybody and for any kind of analysis. All data analysis schemes in GuidosToolbox are based on geometric principles, which permits processing categorical maps of any kind and at any spatial resolution.

With the outlined setup, and the availability in a free software, each user can test the Landscape Mosaic and its settings on their own data. In addition to Landscape Mosaic, GuidosToolbox provides dedicated routines for spatial mapping and quantification of pattern, fragmentation, distance and other aspects derived from land cover maps. Further information is available in related product sheets available on the GuidosToolbox homepage.

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