INTERACTIVE METRICS TOOL (IMT) – A DIDACTICAL SUITE FOR TEACHING AND APPLYING LANDSCAPE METRICS

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Abstract

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This article introduces a software suite called Interactive Metrics Tool (IMT). As a collection of commonly used landscape metrics for vector-based landscape structure analysis it has been designed for didactical purposes. Therefore it not only provides analytical functionality, but also gives insight into the calculation procedure and gives access to implemented formulas through its open structure. We describe the general structure of the tool and characterise the scope of its application. In an overview style we discuss the implemented metrics for structural landscape assessment.

Key words: landscape metrics, GIS, structural assessment, education

Introduction and motivation

The quantitative assessment of landscape structure is of increasing importance for a wide range of landscape-ecological applications (Turner, 1990; McGarigal, 2002). Landscape-ecological research has always been focussing on the relationships between pattern and process, i.e. how ecological processes are influenced or even driven by the spatial configuration of ecological units (Turner et al., 2001). As the landscape exhibits a specific pattern or mosaic of constituting elements (patches) this heterogeneity can be measured and quantified. As Forman (1995) and others point out, ecological processes and functions are strongly interlinked with the structural properties of the landscape. Analysis of the landscape pattern gives insight into these underlying potentials, processes and functions. Moreover it has been argued that the arrangement of ecological units (patch mosaic) rather than the mere quality of patches is crucial for the integrity of e.g. protected areas. Recent findings in habitat integrity assessment and suitability of habitat arrangements are based on the premise that ‘spatial context matters’ (Wiens, 1997). Originating from of the quantitative branch of North American landscape ecology, these ideas approach have also reached the European continent and are used throughout the various application of landscape-ecological research (Blaschke, 2000; Walz, 1999).

Landscape metrics – the toolbox for quantifying landscape structure

Landscape structure can be quantitatively investigated by the use of specific measures all belonging to a toolbox called ‘landscape metrics’. These measures describe basic geometric properties of patches like e.g. area, edge length and shape (*patch metrics*). On the level of classes any patch metric can, at first, be statistically aggregated (the mean, standard deviation, etc.). Furthermore, the spatial arrangement of patches can be measured on class level, based on e.g. area weighted distances. On the highest level (the level of the entire landscape) the overall spatial distribution of patches can be evaluated, either spatially implicit (*composition*, i.e. based on area percentages) or spatially explicit (*configuration*). For a concise overview of the levels of landscape structure assessment see McGarigal, 2002.

Selecting a set of metrics for special investigation purposes

Recent studies on mathematical behaviour and inter-correlation of landscape metrics revealed that many of them are statistically correlated (Riitters et al., 1995; Lausch, Herzog, 2002). It has often been tried to reduce the overwhelming amount of more than 150 metrics to a small set of statistically independent ones. However, these approaches neglect in some way the fact, that more advanced metrics were developed for particular ecological questions. As Lang et al. (2002) point out, the principle ideas of metrics should be extracted; thus measures can be grouped semantically. Those categories are supposed to address different structural and corresponding ecological questions can be formulated. In terms of specific parameterization and the definition of thresholds subsequent ‘fine-tuning’ is required with respect to the very situation of the landscape under investigation. To support this selection process, a documentation tool called IDEFIX (*Indicator database for scientific exchange*) is being established within the EU project SPIN (*Spatial Indicators for European Nature Conservation*). In general, within planning authorities or nature conservation agencies, there is little knowledge and experience in terms of the applicability of landscape metrics. IDEFIX therefore can support in extracting valuable information on published metrics. It also provides filters for different purposes (Klug et al., 2003).

Software for calculating landscape metrics

There is a multitude of software packages for landscape structure analysis available in the free software domain. Lang et al. (2003) give an overview of recent tools, plug-ins or extensions which can be downloaded from the internet. They range from descriptive tools over more advanced decision support software packages up to modelling tools that enables the user to create artificial landscape patterns modelling (neutral models) according to certain rules. The quasi-standard of implemented metrics has been set by the software FRAGSTATS 3 (McGarigal, Marks, 1995). The latter provides the 'entire' range of metrics. Yet most of them do not incorporate any didactical pre-selection or start-up mechanism for the beginner. Some of these tools (e.g. APACK) are still implemented in a DOS environment using on a command line, which is inconvenient for the student growing up in a windows environment. Moreover the handling of data and format is sometimes tricky and therefore repetitive use of the tool on various data sets is a tedious task. Finally students are often reluctant to use extra tools once they are familiar with larger software packages, like ArcView GIS.

Design and application of the Interactive Metrics Tool (IMT)

Implementation of the Interactive Metrics Tool (IMT) in standard software packages

IMT was designed to serve as a didactical suite to teach and understand landscape metrics and their mathematical conception, but of course it can be also used to apply the set of metrics for landscape structure assessment. The tool distinguishes itself from other software packages by being completely integrated in standard software environment. Therefore no additional installation or setup routines are required. It is built in a coupled ArcView GIS 3.x / Microsoft ® Office environment. Therefore the user or learner will find himself moving in a familiar setting. The suite comprises customized ESRI ArcView GIS 3.x projects along with pre-prepared MS Excel spreadsheets and a MS PowerPoint sequence for interactively control. IMT works on basic the functionality of the mentioned software packages. Therefore it is well suited for students to become acquainted with the metrics. Additionally the PowerPoint material can be used as teaching material to demonstrate the use of landscape metrics in a lecture.

Interactive training and learning

As the name indicates the IMT is an interactive tool. The general idea is that PowerPoint slides guide the user through different categories of analysis. 'Interactive' means that the user has to actively trigger several steps of calculations and therefore she or he can also control the pace to proceed. ArcView projects and Excel spreadsheets are directly accessed from the slides. Thus, with the different software packages open, the user will read through the steps in PowerPoint, while spatial analysis is performed in ArcView and final calculations are made in Excel. The actual user interface consists of a slide sequence with hyperlink buttons to navigate through the show. The different categories of analyses are introduced with an overview of the principles workflow of analysis (workflow slide) followed by one or more slides giving a step-by-step explanation of the steps to be performed (documentation slides). Workflow-slides have additional hyperlink buttons to trigger the respecting software. It is recommended to first open the software which is needed, and then continue with the documentation slides. Navigation buttons support jumping back and forth to revise contents (Fig. 1).

The different categories of analysis have associated ArcView 3.2 GIS projects and MS Excel spreadsheets. The ArcView projects are all customised with AVENUE scripts that are linked to buttons added to the user interface. For the sake of didactical aspects, both the ArcView projects and the Excel files are kept separately according to the categories. It is clearly distin-

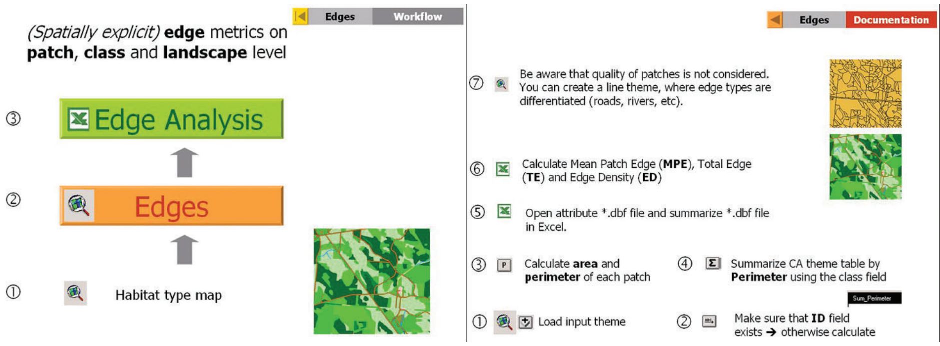

Fig. 1. User interface of the IMT with control buttons (example: ‘edges’). Overview of workflow (*left*) and detailed descriptions of steps to be performed (*right*).

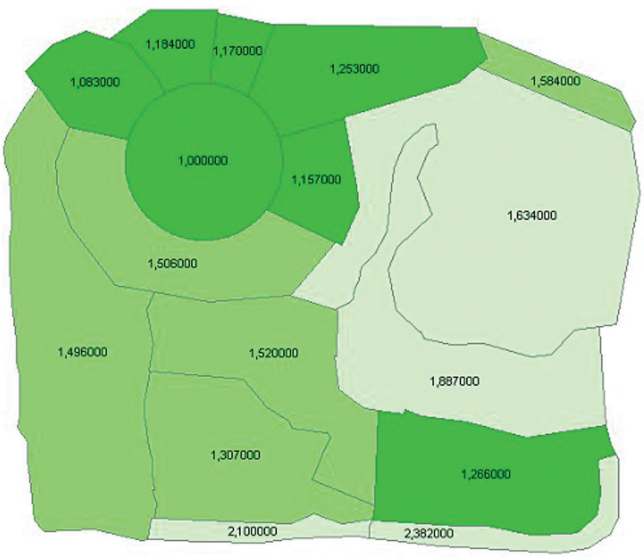

Fig. 2. Shape index for patches of various forms. The ranking shows values from 1 to 1.5 (dark shades), 1.5 to 2 (medium shades), beyond 2 (bright shades).

guished between spatial explicit computations using GIS functionalities and statistical aggregations or numeric calculations. Most final calculations are performed in Excel in order to show, that GIS functionality in a stricter sense is only required for spatial measurements.

The implemented set of metrics

After a short description of how IMT works we discuss the set of metrics being implemented. As mentioned above the IMT provides a bundle of the most common and profound metrics grouped in seven categories of analysis. These groups of metrics are considered to reflect main aspects of structural pattern analysis according to McGarigal, 2002; Turner et al., 2001; Perera et al., 1997; Lang et al., 2002). Most categories (*area*-, *form*-, *core area* [*interior*]-, *edge*-, *proximity* [*isolation*]-, and *subdivision* analysis) describe form and configuration of the landscape pattern on different levels of investigation (patch-, class and landscape level). Besides that metrics are included that address landscape composition on landscape level (diversity analysis).

Area analysis

The quantification of patch size is implemented as a basic functionality in any GIS software. Therefore it is widely used as a 'de facto indicator' (Lang et al., 2002). Many users are familiar with minimum habitat sizes and species data usually exist on minimum area requirements.

Metrics in IMT: Class area (CA) equals the sum of all patch areas belonging to one class. Mean patch size (MPS) is the average patch size within a class or the entire landscape. It is further specified by the number of patches (NP) and the standard deviation of patch size (PSSD).

Form analysis

Patch size does not provide information about the concrete shape of a patch. The latter can be measured in various ways. A possible categorization of patch shape and the respective ecological implications is given by Forman, 1995. The most common and intuitive measures are based on interior-to-edge ratios. Combining area and parameter provides metrics for form description. Since the measurement of a simple perimeter/area-ratio does not give standardized values, the application of the shape index (Fig. 2) is recommended, which relates area and perimeter to the respective ratio in a perfect circle. Patches of a rather compact shape have Shape Index values close to 1, whereas elongated patches yield higher values. This ratio can be standardized when comparing it to area/perimeter ratio of a circle. The shape index can be area-weighted.

Metrics in IMT: The shape index measures the circularity of a patch. In other words it calculates the form deviation of a circle. The mean shape index (MSI) is the average shape index of all patches belonging to one class. Contrarily to the shape index the perimeter-area ratio (MPAR) is not standardized.

Edge analysis

In general it is assumed that high structural richness in contrast to a monotonous landscape is of high ecological value. Several metrics exist to measure landscape heterogeneity through edge length and edge density occurring in the landscape. However – when not explicitly considering the quality of the linear elements we can easily obtain misleading results. For example, if the edges are mainly constituted by little roads, the landscape has to be considered as being rather fragmented.

Metrics in IMT: Total edge (TE) is the total length of patch boundaries within one class or the entire landscape. Its length per area unit is described by edge density (ED), whereas the average length of boundary per patch is given by mean patch edge (MPE). Note that in a shapefile format shared boundaries exist two times, whereas in a topological format (e.g. coverage) they are only considered once.

Core area analysis

Boundaries between habitats are often transition zones (ecotones) with a particular species mix (Forman, 1995). In general we can distinguish between species without any sensitivity for boundaries, or species that either prefer or avoid edges. When considering edge sensitive species that avoid boundaries, the effective area of a patch differs from its actual size corresponding to a specified core area distance. Methodologically core areas are constructed by negative buffers. In cases where the initial patch is very small, no core area remains. On the other hand elongated and complex shaped patches like alluvial forests along a river are split up in a large number of disjunct core areas.

Metrics in IMT: Total core area or (TCA; IMT: sum core area) is the total remaining core area per class. It consists of *n* remaining core areas being expressed in NCA (IMT: count). The core area index (CAI; IMT: decline) reflects the ratio between resulting core area and the original area. A new index called 'Cority' is proposed (Fig. 3). It is calculated by the difference between number of patches and number of patches that have no core area divided by number of resulting core areas. It therefore reflects both the amount of effective habitat loss (no remaining core areas) and the degree of disjunction of the remaining core areas. Note that resulting core area can also be zero (0).

Proximity analysis

The proximity of neighbouring patches may have strong ecological influence on the viability of meta-populations (Hanksi, Simberloff, 1997; Wiens, 1997) of key species, when functional exchange between suitable habitats through animal dispersal is guaranteed. The Proximity Index(es) measure "both the degree of patch isolation and the degree of fragmentation" (McGarigal, Marks, 1995). A specific search distance (*proximity buffer*) reflects the potential range of the respective species. It is assumed that larger neighbouring patches have more ecological importance for smaller patches vice versa. This results in higher Proximity Index values for smaller nearest-neighbour patches showing the same distance. A zero(0)-value is assigned to patches, which are situated outside the buffer distance.

Fig. 3. Cority of two classes under investigation (core area distance 10 m). All patches have exactly one core area ⟶ cority = 1.0 (left); cases of disjunct core areas and no core area occur ⟶ cority = 0.4 (right).

Metrics in IMT: The distance to the nearest neighbour patch of the same class is given by NNDIST, its ID is listed in the field NNID. Nearest neighbour distance is calculated as the shortest possible connection between the patches, effective distances (along networks or on cost surfaces) are not considered. Proximity is characterized by the area/distance ratio(s) to the nearest neighbouring patch(es). Possible variations of the Proximity Index (Gustafson, Parker, 1994; McGarigal, Marks, 1995) can be obtained when shifting the corresponding focal patch or modifying the underlying nearest neighbour concept (Fig. 4 and 5).

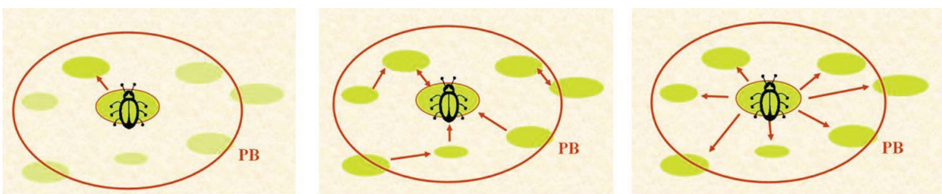

Fig. 4. Different concepts of nearest neighbouring patches. The nearest neighbour patch within PB (*left*), all nearest neighbour distances within PB (*middle*), all distances to neighbouring patches within PB (*right*).

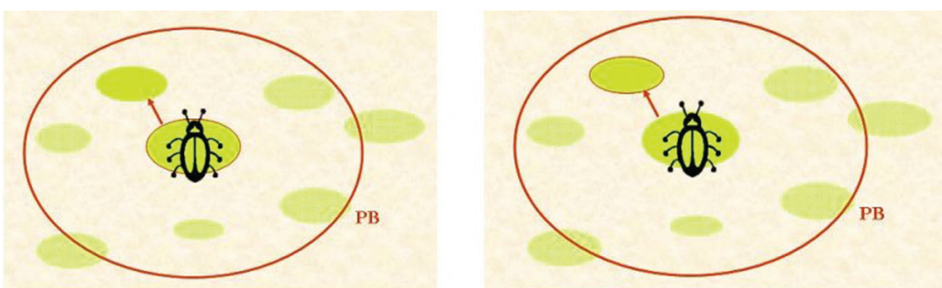

Fig. 5. Variations by changing the focal patch. Source patch as focal patch (*left*), target patch as focal patch (*right*).

Diversity analysis

This group of metrics is based on information theory (Shannon, Weaver, 1949) and quantifies landscape composition. The basic element of the formula is percentages of class areas. Diversity metrics are rarely useful for interpreting absolute values, and therefore they are more suitable for comparative studies. Due to the fact that the number of classes (increasing potential richness) influences diversity, this group of metrics strongly depends on the thematic resolution and class aggregation (Fig. 6).

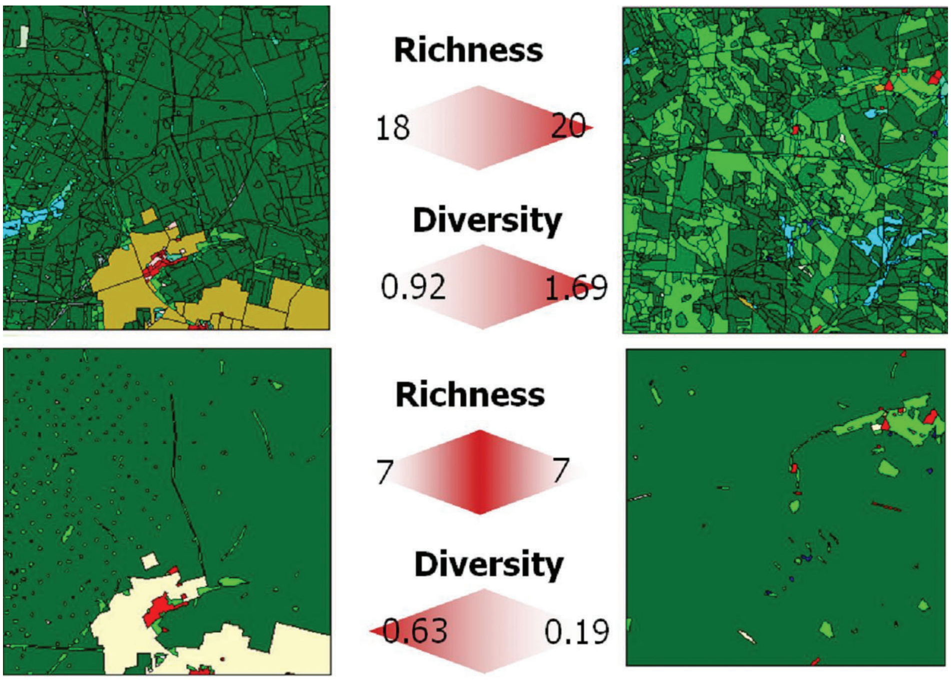

Fig. 6. Diversity values for the same landscape. Different classification schemes and levels of aggregation yield to contrary results (*above*: fine level; *below*: coarse, overview level).

Metrics in IMT: Proportion is the percentage of the landscape being covered by a class type. Relative richness corresponds to the ratio between the actual number of classes and the potential number of classes according to the classification scheme being applied. Shannon's diversity increases either by higher richness or increasing evenness (equal distribution). Dominance corresponds to the deviation of the actual diversity from the highest possible one. Shannon's evenness is equal to the actual diversity standardized by the maximum diversity. Thus mathematically dominance is not the complement of evenness.

Subdivision analysis

The group of subdivision metrics measure landscape dissection and fragmentation on the level of specified classes (Jaeger, 2000). Landscape dissection (e.g. by roads) does not lead to a significant loss of area, as the portion of land covered by the dissecting lineaments is comparatively small. But with an increasing number of dissected patches the squared area successively decreases compared to the original undissected area.

Metrics in IMT: The landscape division index (Division) is based on the degree of coherence and measures the probability that two randomly set points do not belong to the same undissected area. The splitting index (Split) is a measure for the regularity of division and indicates the (hypothetical) number of equaly sized areas at a given division. The effective mesh size (Mesh) is the average size of those areas.

Discussion and outlook

IMT is made for educational purposes and therefore maybe not suitable for very advanced applications. In this case, the combined use of different software products may then be a hindrance. The main scope is settled in the didactical context, in particular on an introductory level but with quite some potential for student applications from seminar works to master theses.

Many times it has been emphasized by several authors that the underlying classification scheme is a critical factor for further analysis (Turner et al., 2001). The IMT is not – and neither are other products similar to it – sensitive to the quality of input data, as long as being provided in the demanded form. So it remains the user's responsibility, which data she or he uses and what basic geometry is used for calculations. The underlying classification scheme is critical to the results. Moreover the tool does not provide any thresholds or critical values for any patch constellation. These can hardly be generalized and thus remain to be defined by the user.

Related products to IMT are the abovementioned database for structural metrics and indicators IDEFIX and the ArcGIS 8.* extension ^{v}LATE. The latter offers similar metrics as the IMT and can be used to perform landscape structure assessment on polygon datasets in an ArcMap environment (Lang,Tiede, 2003). All tools can be downloaded after simple registration on the website of LARG (www.geo.sbg.ac.at/larg).

Translated by the authors

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