Continuity, complexity and change: A hierarchical geoinformation-based approach to exploring patterns of change in a cultural landscape

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Abstract

Both terms, continuity and change, necessitate the exploration and interpretation of underlying spatial patterns at different spatial and temporal scales. Comprehensive fieldwork on fine spatial scales is necessary but the interpolation and upscaling of the results using existing geoinformation including remote sensing data and GIS-data is becoming more widespread. This paper introduces an approach for examining image characteristics at different scales simultaneously and it explores methodologies to describe change spatially explicit beyond a change in pixel characteristics. The example is taken from the Rhön Biosphere Reserve in central Germany and illustrates new ways of dealing with complex landscapes on the basis of image texture. Driven by socio-economic developments, some areas are becoming abundant and/or are used less intensively. The complexity in this case lies in the different textures and structures of pastures and grassland of the cultural landscape formed over centuries and the coexistence of nature and nature-compatible farming practices. A new approach, the hierarchical patch dynamics paradigm (HPDP) utilises some older theoretical ideas of breaking down complexity with a hierarchical scaling strategy and this research applies it in an object-oriented software environment based on multiscalar image segmentation and analysis.

1 Introduction

The measure of progress in landscape ecology and, more specifically, in descriptive-explorative landscape analysis is its ability reliably to explain and predict the behaviour of the objects under study. Consequently, the long-term scientific goals are the development of methods of predicting the response of ecosystems to changes in their physical, biological and chemical components. This leads to a need for a means to express and manipulate the data and theories that we have about the systems under study. Since, in general, these systems are complex and poorly understood we attempt to develop ways of distilling patterns and principles from empirical data and mathematics through the machinery of computation. The broad ecological issues to be addressed also relate to the central challenges of global change, biodiversity and sustainability, some of the most pressing scientific issues. Specifically, the cross-cutting conceptual themes involve the need to incorporate variation among components that are interacting non-linearly, to examine the interactions among processes operating at varying scales of time, space and organizational complexity, and to relate patterns to the processes that generate and maintain them. These topics hold the key to developing the mechanistic understanding fundamental to a predictive ecology, detail may be much less reliable than incorporating only "relevant" detail.

In this paper, a multiscalar landscape analysis is presented. It is based on an extension of the hierarchical patch dynamics paradigm (HPDP), suggested by Wu [50] to spatial and temporal changes. Measures of landscape patterns and patch-based measures of individual patch contributions to the landscape level heterogeneity are aggregated. I examine the sensitivity of segmentation-based pattern exploration to changes in landscape configuration, and I provide an outlook on the implications of the analysis for habitat preservation efforts with regard to a cultural heritage landscape of high conservation value. The problem of linking processes at the scale of the individual and local to processes at the community and regional scale raises issues regarding the sufficient characterization of the interactions between individuals, populations and the physical-chemical environment. The difficulty of translating theoretical models to real landscapes with potentially huge numbers of parameters to be incorporated from data collected at varying spatial and temporal scales poses both conceptual and practical problems.

Landscape pattern can act as a scale-dependent "filter" acting differentially on the movement of species with different degrees of agility, in much the same way as high- and low-pass filters remove high and low frequency components. In relatively continuous landscape mosaics, where habitat quality varies smoothly, it is likely that the filtering effect of landscape pattern will also be smooth, reducing the rate of movement of some species while enhancing that of others (Johnson et al./ [30]). In fragmented landscapes, the filter response might be much more abrupt; species that perceive the habitat distribution below a critical scale could be effectively isolated on individual habitat patches. Therefore, identification of critical scales associated with abrupt changes in landscape connectivity is an important consideration in quantifying habitat pattern and the influence of habitat pattern on species and populations.

Patches may be disturbance patches, remnant patches, environmental resource patches, introduced patches, or simply patchy entities on a map (Forman Godron / Forman [18, 17]). Patches may simply be landscape elements, such as roads, dwellings, forest patches, grassland patches, hedgerows or fields. Patches could also be types of forest in a forested landscape (e.g. deciduous forest, recently-burned forest, conifer forest), or types of grassland in a prairie landscape. Patches of different age occur in landscapes subject to disturbances (e.g. fires, floods), where the age of the patch represents the time since it was last disturbed. Patches could also be the types identified by completing a classification of spectral data in a Landsat image, or in a scanned aerial photograph as used in this paper. In general, patches are simply the result of grouping pieces of the landscape into units whose members share a common set of attributes. But the delineation is not always intrinsically evident. Figure 1 illustrates a computer-generated image of texture and although any other image signature and texture is removed, there are many solutions to the problem of grouping single bushes or shrubs to patches.

An important question is how important a particular patch is for the regional persistence of a set of interacting species. For real species on real landscapes, the location of patches is not so easy to define as in a model. It is difficult to define the landscape and its relative suitability grid-cell by grid-cell in the surroundings of any particular species. The relevance of the landscape analysis approach or its applicability, respectively, relate to the importance of model flexibility, so that questions not imagined can be addressed: the importance of transients, ecotones, and phase transitions, and the importance of non-linear phenomena such as chaos and multiple domains of attraction. The latter is known to be important for example in understanding evolutionary processes, and is also central to our management ability to react to environmental changes and/or changes in the economic system. The changes addressed in this paper are manifestations of changing economic conditions due to European Union agricultural policy. Questions to be adressed in this paper are: Do the changes in agricultural practices, namely the decreasing grazing activities and the shifts from pastoral grazing systems to unattended cattle grazing result already in changes to the cultural landscape which can be explored through image analysis? Can we delineate areas of change and areas of relatively continuous yet dynamic conditions?

Additionally, ecologists are further exploring the behaviour of cattle when unattended and are investigating their movement pattern (Conrade Plachter / [14]), but the latter goes beyond the objectives of this paper, which concentrates on the differentiation of pastures with relative continuous conditions and pastures with changing conditions, expressed mainly by bush encroachment. It introduces an alternative approach to pixel-based image analysis and measurements of texture.

2 Methods

2.1 Putting into practice the patch-matrix concept

A basic part of landscape analysis is characterizing the elements (i.e., patches) within a landscape. Numerous landscape metrics are used to evaluate structure, too many to cover in detail in this paper. Descriptions of landscape metrics as well as software packages that calculate these metrics can be found in McGarigal and Marks [36], Baker and Cai [5] or Rempel [41]. For simplicity, metrics can be categorized into four main groups - Patch Shape, Patch Size & Extent, Patch Connectivity, and Patch Dispersion (Gustafson / Farina /[23, 16]).

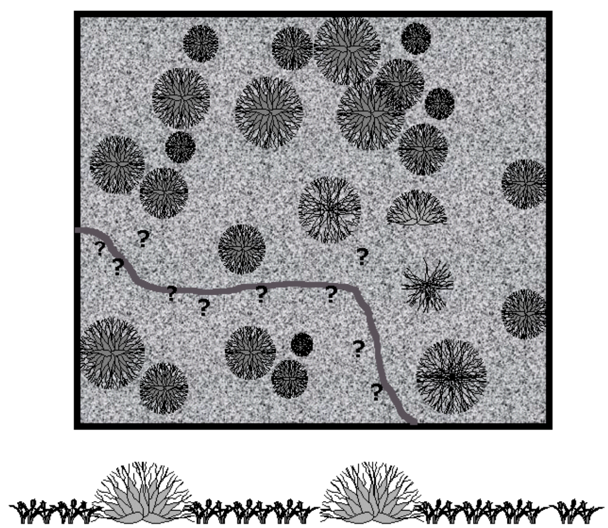

Figure 1: Illustration of one empirical problem studied in this paper: bush encroachment (schematic, vertical and horizontal view).

The variety of landscape metrics and indices has led to a discussion of their actual significance (Fry / Haines-Young / Blaschke Petch [21, 25, 9]), although many examples have illustrated their usefulness in various applications, if carefully chosen and tested against hypotheses (Haines-Young / Dramstad et al. /Burnside et al. / Lausch Biedermann / Luoto [24, 15, 12, 31, 32]). It is concluded that the need for a regionalisation and quantification of patterns and their changes is increasing.

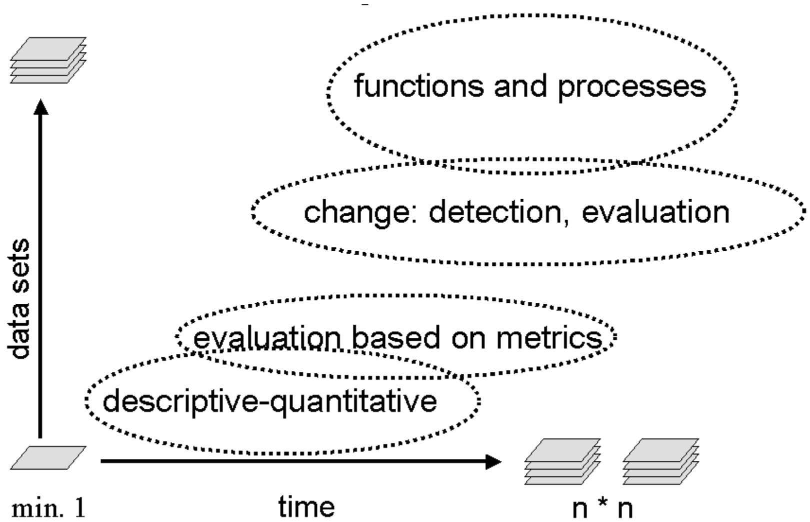

Figure 2: Categorisation of landscape metrics applications in relation to data necessary.

The purpose of quantitative landscape indices is twofold: (1) to be additional attributes for classification of landscape types or regions, and (2) to be indicators of landscape changes and disturbances. However, the potential for such quantitative analyses depends fundamentally on the availability of geographical data, especially from maps (Antrop van Eetvelde [3]). Recently, Haines-Young [25] criticised the patch-matrix concept of Forman [17] and Forman and Godron [18]. He doubts that for planning practices an optimal patch configuration exists, and claims to focus on the dynamic qualities of a system. This view asserts that we have to examine how the different changes of land cover and the different landscape transformations, including quality changes within the same land cover class affect quantities and qualities of transition types.

A consequent way of examining this approach may be the fractal dimension, D, which is used to express the irregularity of the borders of the patches (Milne / Farina [37, 16]). The fractal dimension D was determined as the slope of the regression of log (patch perimeter) on log (patch area). An alternative which can be used is the Shannon entropy (Antrop van Eetvelde [3]).

Simple measures of landscape structure and patterning provide only limited insight into the functional aspects of a landscape. Associations between habitat suitability and patch size and shape are established to a limited degree for only certain well-studied species. This is partially due to the amount of data needed (see Fig. 2). The association between landscape patterning and disturbance propagation, and degree of connectivity necessary to support a range of processes are topical issues requiring detailed field and simulation studies. Making the causal connection between pattern and processes such as biodiversity requires extensive evaluation and goes beyond this paper.

2.2 Geographic information

Remote sensing is not just a required tool for landscape analysis but aerial photography and its interpretation was a starting point for Carl Troll to coin the term landscape ecology (Troll [46]). Today, the use of digital information extends our analysis capabilities. Satellite remote sensing started digitally but also aerial photography is more and more done digitally and both domains, the air photography and the satellite data sets are growing together. Higher resolution satellite imagery and other forms of remotely sensed data can be processed and interpreted by new types of software to produce maps that allow us to visualize ecological variables across huge spatial scales. At the same time there have been technological advancements that make it easier to collect, manipulate, and visualize. It has been found in many studies that the number of pixels containing more than one land cover type is a function of both the complexity of the scene and the spatial resolution of the sensor. Therefore spatial resolution is among other factors important to classification. The relationship is very much based on the simple fact that higher resolution images contain a smaller percentage of pixels regarded as 'boundary pixels'; that means, falling into two or more different land use classes. But with increasing spatial resolution the need for advanced classification methods occurs.

The term 'Geographic Information' bridges GIS data and remotely sensed data and refers more to the scientific foundations of 'GI Science' (Goodchild [22]). Geographic Information Systems or GIS have emerged as powerful tools for managing, analysing and displaying spatially structured data. GIS makes feasible detailed map analyses that would otherwise be too labour intensive and too expensive to contemplate. Older generations of GIS software were limited to storing and manipulating static, two-dimensional data. For many years, an objective of the research community was to make GIS more dynamic by creating linkages between simulation models and GIS databases, and we see a convergence today. For landscape ecology, these considerations might be regarded as technical discussion but the author believes that recent developments create an enormous potential for a comprehensive analysis of complex environments. More specifically, it will be demonstrated that new approaches allow for the use of hierarchies of complex relationships by technically supporting and transferring the ideas of multiple levels of organisation of ecological systems or domains of scales (Simon [44, 45]).

2.3 The multi-level segmentation approach

Following the concept of Forman and Godron [18], each landscape element at a certain scale can be recognized as either a patch with a significant width, a narrow corridor, or a background matrix. Determining these spatial distributions is to understand landscape structure. Ecological objects, however, continually move or flow between landscape elements, and nearly all ecological systems are complex in that their structures contain many components of different kinds, both living and non-living.

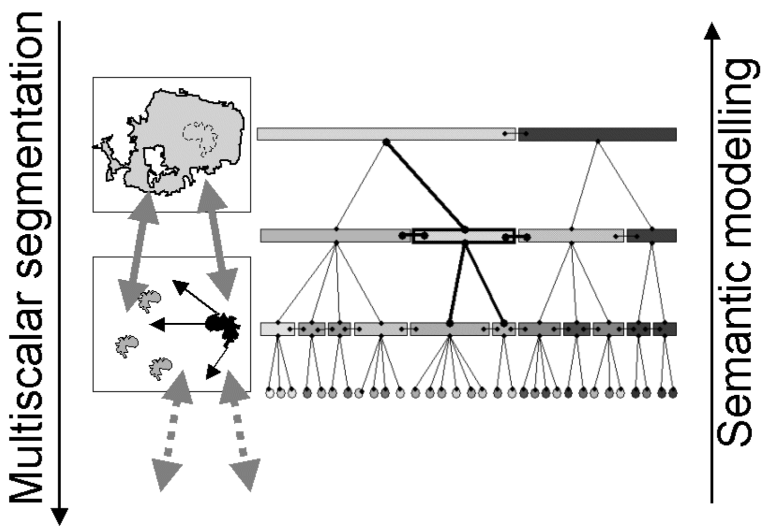

Figure 3: The concept of an hierarchical approach in pattern exploration applied to the HPDP theory from Wu [50].

These entities interact with each other in the context of a varying external environment. One possible solution to this inherent dichotomy is a delineation of patches “on demand” rather than one fixed system of patches. In this paper, the ‘fractal net evolution approach’ (Baatz Schäpe [4]) is used to extract the objects of interest at the scale of interest by segmenting images simultaneously at finer and at larger scales and building image semantics between levels and between their elements (Baatz Schäpe / Blaschke et al. / Blaschke [4, 11, 7]). This way, some concepts of hierarchy (Simon [44, 45]) and some ideas to breaking down complexity into operational units of modularity through a 'scaling ladder' (Wu [50]) are utilised in an object-oriented software environment (sections 2.4. and 4).

The key issue in this fractal-based segmentation approach is homogeneity and heterogeneity. Two main sets of definitions for the evaluation of the merging of two regions are distinguished by (Baatz Schäpe [4]). Both types describe the degree of mutual fitting and are therefore applied to the optimisation procedure to get the lowest possible overall heterogeneity across an image. Both types of definition actually describe the degree of difference between two regions. As this difference decreases, the fit of two regions can be said to be closer. These differences are optimised in an heuristic process (Baatz Schäpe [4]) by comparing the attributes of the regions. Given a certain feature space, two image objects are considered similar when they are near to each other in this feature space. For a d-dimensional feature space the heterogeneity h is described by equation 1

$$h = \sqrt{\sum_d (f_{1d} - f_{2d})^2} \quad . \tag{1}$$

Examples for appropriate object features are, for instance, mean spectral values or texture features, such as the variance of spectral values. The distances can be furthermore standardized by the standard deviation of the feature in each dimension using equation 2.

$$h = \sqrt{\sum_d \left(\frac{f_{1d} - f_{2d}}{\sigma_{fd}} \right)^2} \quad . \tag{2}$$

Equation 3 defines the homogeneity of two adjacent regions by describing the difference of heterogeneity h of the two regions before ($h1$ and $h2$) and after a virtual merge (hm). Given an appropriate definition of heterogeneity for a single region the growth of heterogeneity in a merge should be minimized. There are different possibilities for describing the change of heterogeneity $hdiff$ before and after a virtual merge.

$$hdiff = hm - (h1 + h2)/2 \quad . \tag{3}$$

2.4 Study

As spatial heterogeneity becomes a major theme in a wide range of ecological studies (Hay et al. [28]), the concepts of scale, scaling, and hierarchy become increasingly important in ecology in general. The remote sensing community discusses scale and scaling very much in terms of pixel resampling techniques while in ecology scale is a dominant topic and theory is well developed (for a comprehensive review see Withers and Meentemeyer [48]). Only recently, theoretical frameworks and sound methodologies are developed to detect "critical" or "significant" scales within images (Marceau Hay / Hay et al. / Blaschke Hay [33, 28, 10]). The main problem is to identify "the patch level" in the landscape with relevance to the phenomenon under investigation and consequently to identify hierarchical relationships between the focal level and the necessary mechanistic levels of image segmentation and object definition.

Patch dynamics provides a powerful way of dealing explicitly with spatial heterogeneity, and has emerged as a unifying concept across different fields of earth sciences. Wu [50] suggested the integration between hierarchy theory and patch dynamics through the emergence of the hierarchical patch dynamics paradigm (HPD) and laid a theoretical framework for a theory-driven breaking down of ecological complexity through a hierarchical scaling strategy. Most of the systems we examine in ecology (Wu [50]) and environmental science are characterized by organized complexity (Allen Star [1]). On one hand, these systems have more components than analytical mathematics can handle; on the other hand, the use of traditional statistical methods can not be justified because of the inadequate number, and the non-random behaviour, of components. Wu [50], drawing on the concept of flux rates in hierarchy, suggests that ecological systems are nearly completely decomposable (or nearly decomposable) systems because of their loose vertical and horizontal coupling in structure and function.

In the following chapter, the multiscalar segmentation approach is applied to quantify heterogeneity by utilising "*mean spectral difference between all subobjects*" as one (among other) manifestation of heterogeneity. Note that this attribute allows us to distinguish between two types of pastures with similar mean reflectance values but different "within-patch heterogeneity" (Blaschke [6, 7]). Image information is basically of a fractal nature. Ecological structures of a range of scales are present in an image simultaneously. Speaking about extraction of meaningful image regions, therefore, obviously needs to take into account the scale of the research problem that is to be solved. Hierarchy theory suggests that in order to understand phenomena at a particular level (the focal level), the 'mechanistic understanding' must be based on the next lower level (Level –1) whereas the significance of that phenomenon can be revealed only at the next higher level (Level +1) (Wu [50]). Taking the example of the pastures of Central Germany, I refer to the pasture as the focal level: single bushes, islands of intensively grazed grass and other visually relatively homogeneous areas (for the human observer) as the –1 or reductionist level: and at Level +1, the landscape, consisting of a mosaic of pastures and meadows.

2.5 Change detection and exploration

In landscape ecology the role of land-use changes and their implications on functions and processes play a fundamental role. In general and simplified, landscape change principles coincide in the insights that undisturbed horizontal landscape structure tends progressively toward homogeneity; moderate disturbance rapidly increases heterogeneity, and severe disturbance may increase or decrease heterogeneity (Forman Godron [18]). In the case study this theory is taken as an hypothesis. The heterogeneity in images is explored and it is hypothesised that the decrease of cattle grazing intensity and/or abandonment of land initially increases spatial heterogeneity and consequently diversity while on the long run diversity will decrease in line with the disappearance of the traditional pastures. In this paper, only the first part is examined, namely the change of spatial pattern and of spatial heterogeneity, while the consequences for species and biodiversity is currently studied comprehensively and it is too early to evaluate the changes.

In many vegetation studies the ratios, commonly known as vegetation indices, have been developed for the enhancement of spectral difference on the basis of strong vegetation absorbance in the red and strong reflectance in the near-infrared part of the spectrum. It has been shown that a ratio of a near-infrared band and a red band is significantly correlated with the amount of green leaf biomass (Price [40]). Numerous vegetation indices have been developed to make use of this difference. Still, these indices are centred on pixels and treat them statistically. In order to explore the texture in images and to utilise them for a differentiation of patches of pastures or grasslands which have roughly the same amount of biomass but exhibit different textures due to different farming/grazing systems, the multi-level segmentation approach is used.

2.6 Case study

The Rhön Biosphere Reserve is a highland region in central Germany. It is formed mainly by tertiary vulcanism and the influence of ancient and modern human land use. Due to the partition of Germany, the Rhön was situated in a pronounced peripheral situation. For this reason expansion and consolidation of the infrastructure was hampered, and agriculture remained of economic importance up to today. Under the unfavourable conditions (wet, steep and stony), intensive land use was restricted to the flood plains whereas the plateau and the slopes were grazed or cut more extensively. This practice maintained a diverse, small-structured landscape with a high proportion of open area. We can regard it as a “multi-scale” landscape. On the broad scale, forest and “open area” are the main classes. They are extensively mixed and their boundaries seem to be sharp and distinct at this scale. On a finer scale, pastures und meadows show an obvious different inner structure formed by trees, shrubs, basalt stone walls, and wet and fallow areas (Conradi Plachter [14]). Current changes in agricultural policy are leading to the increase of bush encroachment and woody plants (Fig. 4).

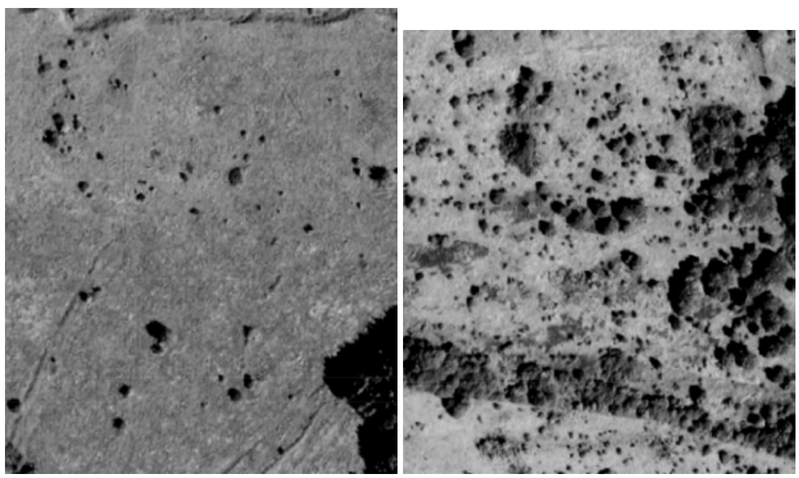

Figure 4: Different status of change of the pastoral systems from minor changes (left) to severe changes (right).

Aerial photographs are scanned and orthorectified in an Erdas Orthobase software environment and finally aggregated to 40 cm pixels. This source of information allows the identification of single bushes and encroachments within the pastures and at the same time modern equipment permits the researcher to look at a large proportion of a landscape simultaneously.

3. Results

Several image segmentation steps are performed resulting in various candidate layers ranging from thousands of very small objects (groups of shrubs, single trees) to a couple of hundred objects comprising “landscape level elements” (meadows, forest stands). Object layers of different mean size with best relations to the objects of interest are selected. These layers and their respective objects automatically obtain topological and hierarchical relationships (contain subobjects, are contained within superobject x, are bordering object y). Different structures of the landscape appear – continuous within a certain range, but then leaping to a higher level and forming new objects based on former ones.

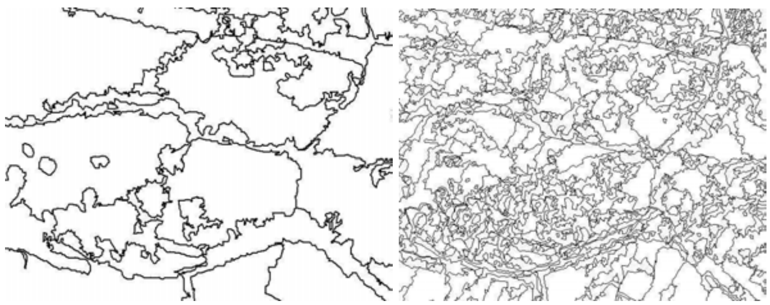

Figure 5: Different segmentation levels in their vector representations.

In Fig. 6, the differentiation of different statuses of change is illustrated for two neighbouring patches of pastures. The semantics used are "mean spectral distance of all subobjects" (of a super object at the level +1). This means that once an appropriate segmentation level for "the meadow patch level" is defined, the patches of this respective level serve as "super objects". In Fig. 6, the vertically striped patch (left) exhibits medium intensive shrub encroachment and gains a value of 28.3 which is the mean spectral difference of all three spectral bands of all subelements (one level below, right hand side in Fig. 6) within this (super)object. The neighbouring patch to the right (vertically striped) gets a value of 45.4. This value results from a combination of the fact that there are many small island patches which are much "darker" (in the black and white figure here) or exhibit higher reflectance values in the red and infrared band.

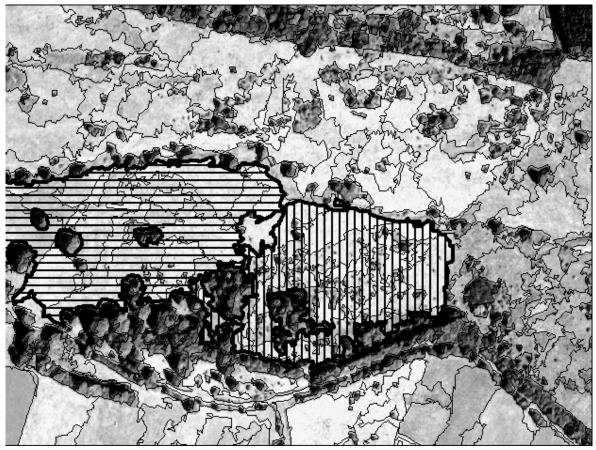

Figure 6: Differentiating status of change utilising multiscalar object-based texture exploration (see text for explanation).

The resulting figures for the status of different meadows are evaluated with external ground truth material and in the field. The different texture values are grouped in qualities from 1 to 5 (undisturbed to totally changed). The horizontally striped patches (see Fig. 6) fall in class 2 (slightly disturbed) and the vertically striped patches fall in class disturbed. These ordinal values only refer to the encroachment and not to nature conservation values since an altered environment can exhibit quite high species values.

4 Discussion

4.1 Exploration of patterns: flexible discretisation of heterogeneity

While some ecologists were focusing on heterogeneity, others were building spatial variation into theory in the form of patches. Much of this work focused on population genetics and population dynamics, although patch theory also developed in studies of foraging behaviour. Some ecologists studying succession adopted a patch perspective in their focus on gap dynamics (Wiens [49]). To retain analytical tractability, the patches were usually assumed to be internally homogeneous and equivalent in size and quality. The results here proved that with new algorithms in image analysis it is possible to analyse texture beyond the pixel and its restrictions and allow for a differentiation of patches based on various texture and internal heterogeneity measures. Wiens [49] points out that heterogeneity is generally greatest at intermediate levels of disturbance, when diversity is also high. Heterogeneity here simply refers to variation in space and its manifestation in the texture of an image. In a statistical sense, heterogeneity (spatial variance > 0) contrasts with homogeneity (spatial variance = 0). The idea of a 'within-patch diversity' (Blaschke [6]) was briefly discussed in section 2.3. and serves as a framework for the differentiation of different statuses of change as described above and illustrated in Fig. 6.

One application of the hierarchical approach is concisely described in this paper. It needs further study involving the benefits of modularity or encapsulation of model components. These include improved image semantics and flexibility with the aim that the rules can be inserted into simulation systems. With recent advances in computer technologies, the ability to create high dimensional graphical representations of data, modelling and subsequent results are available to ecologists. We can use visualizations to explore the nature of data, discover patterns of behaviour or anomalies in the data, and patterns or anomalies of models used to analyse the data sets. In order to support a diverse set of analytical capabilities in a manner that is accessible to users, an appropriate metaphor must be used. One possibility which is readily understandable is the hierarchical patch dynamics paradigm proposed by Wu [50] and the metaphor of a scaling ladder. By this the author means that ecological processes would be rendered to enable ease of interpretation. Users must be able to change quickly between temporal and spatial scales of analysis depending on the context of the analysis. In certain circumstances the landscape level view might be appropriate; yet this view may need to be changed quickly to an individual view as a dynamic process unfolds.

An assessment of landscape context is required to assess the ecological viability of the area of interest. Landscape context means the nature of the surrounding landscape, and the patterns and conditions therein. Is the landscape composed of clear cuts and plantations, or a mosaic of pastures and agricultural fields? Does the surrounding landscape improve or decrease the likelihood that the particular area of interest will continue to survive? How does the landscape affect the type and number of plant and animal species? Factors such as these determine, to a great extent, the characteristics and viability of the biotic community of the area and, consequently, its biodiversity. Still, empirical relationships between measures of heterogeneity and relevant ecological features must be derived in further studies.

The approach described can also address the rationalisation or technical implementation of some holistic concepts. Holism is a bio-philosophical theory that originated with naturalists during the early 19th century. It was also important for Gestaltpsychology and in particular as a theory to explain how our perception works. The perceptive dimension in landscape is fundamental as the concept 'landscape' embraces both a piece of land with all the objects it contains and also its appearance (Antrop [2]). The multi-level segmentation approach utilizes the possibilities of an object-oriented software environment and allows a flexible, semantics-based classification and exploration procedure.

4.2 The role of technology

The increasing complexity of environmental data requires that we assess the suitability of existing data models. For example, will newer object-oriented data models be better suited than the widely used relational data model to represent the complexity of environmental data? Is the traditional layer concept in GIS an obstacle to its further development? Or is an "associative" data model required which can store and retrieve data based on association between observations (e.g., spatial, temporal, thematic and taxonomic domains) instead of explicitly defined relationships? Irrespective of the form of the data model, ecological data acquisition, management and integration require that there be a common, logical representation of the entities (objects) that comprise an ecological observation, and the relationships among those entities. In addition to the primary quantitative observations (raw data), data models should represent supporting information such as location, date, methods, quality assessment, audit trails and other information that is generally associated with the metadata. Computer pattern capabilities have far to go, however, before they can rival those of the human eye (Hay et al. [27]). Thus, land use / land cover classifications using aerial photographs have mainly relied on visual interpretation (Hudak Wessmann [29]). Textural approaches of land cover classification have been in the still somewhat experimental arena of pattern recognition and knowledge-based systems. Studies have exploited image texture as an additional source of land cover type information besides spectral information (Franklin Peddle / Musick Grover / Peddle Franklin / Hay et al. / Ryherd Woodcock [19, 20, 38, 39, 27, 43]). Hudak and Wessmann [29] have demonstrated a simple textural analysis s ecologically applicable even when used alone. Greater use of textural indices could increase our capability to measure and monitor canopy structure at landscape scales.

4.3 The need for an advanced landscape change detection methodology

Change detection is useful in such diverse applications as landuuse change analysis, monitoring of agricultural practices, assessment of deforestation or studies of changes in a dynamic environment. Although change detection is an increasingly popular application for remotely sensed data, there is no comprehensive theoretical framework and no standardised methodology (Mas / Blaschke [35, 8]). Technically, it is a process of identifying differences in the state of an object or phenomenon by observing it at different times. However, most remote sensing approaches focus solely on pixels. Per pixel, it seems (technically) relatively straightforward to quantify the likelihood of a change in the land cover. But there are two general types of land cover change: land cover conversion and land cover modification (Turner Meyer [47]). The distinction between land cover conversion and land cover modification has important implications for image analyses. Land cover conversion entails a shift in the relative proportions of land cover classes within a given area, such as urban expansion into formerly agricultural land, or clear-cutting of forests for conversion into croplands or pastures. Land cover conversion generally attracts more attention, as it tends to be more localized and immediate in impact. Land cover modification is more subtle and involves a shift within a particular land cover class, such as tree thinning on forested land. Land cover modification tends to occur more gradually and over a wider area, making it more difficult to perceive, but no less important over the long term or over alarge area.

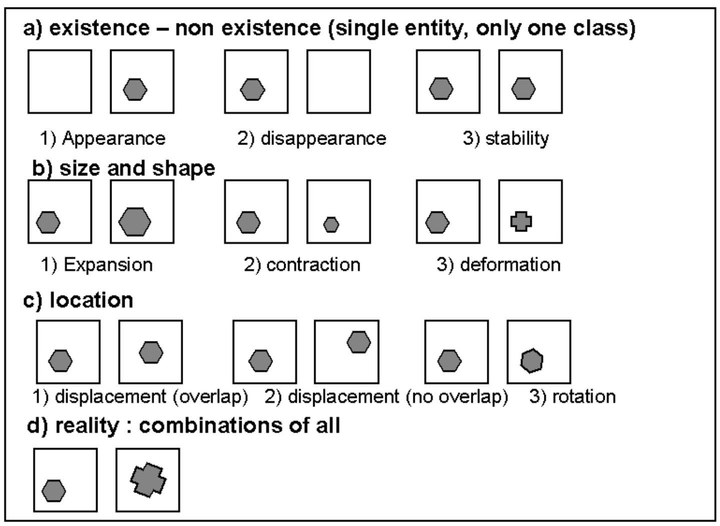

Figure 7: A simplified object-based change detection methodology. The abridged illustration of the complex issue 'change' point up the need for a comprehensive methodological framework for landscape objects and their geometric and thematic changes (from Blaschke [8]).

The example occurring in the cultural landscape of the Rhön Biosphere Reserve, which is the focus of this chapter, is the encroachment of mostly unpalatable woody plants at the expense of desirable grasses. This bush encroachment reduces the grazing capacity of the pastures and can lead to a "paradox overgrazing" on remaining, attractive grass areas, as found in a comprehensive study on the alpine dairy farming system in the Austrian Alps within the UNESCO Man and Biosphere Programme (Riedl [42]). The consequences are very different. While in the alpine area erosion processes are developing, in the Rhön a loss of a cultural heritage and a characteristic species assemblage associated with the less intensive farming practices will be initiated.

To conclude, in many environmental applications it is necessary to identify the nature of change and the spatial pattern of change including, for instance, geometric aspects of shape and compactness. This is a great challenge, not to technology in a narrow sense but to the establishment of a comprehensive framework of a) land cover change, b) land cover conditions, c) spatial changes in the geometry and position of the objects. Figure 7 illustrates how even one aspect out of these three would open many possible options; a three-dimensional matrix would be extremely complex.

5. Conclusions

It has been shown, how difficult scale-independent and transferable measures of structural indicators are to achieve. Consequently, it is even more difficult to adequately describe changes in structural patterns. Inappropriate techniques may imply an image of continuity. But continuity at a landscape level is much more than relatively stable patterns. Continuity in landscape is a holistic characteristic which refers to the overall dynamics of a region (see Antrop in this book). Although most attention goes to the study of land cover change, this is only one highly dynamical aspect that rarely causes an overall transformation of the landscape character or identity. Changes in landscape components and their internal structure are in many cases linked. More research is needed into a comprehensive and transferable exploration methodology of structure. Although structure has in this paper been restricted mainly to a combination of land use and texture utilising between-patch and within-patch heterogeneity, much work is needed on the integration of biotic and abiotic properties within landscape analysis and change analysis. Researchers from the University of Marburg, Germany, are working intensively on the relationships between image analysis results and vegetation structural parameters measured on the ground (Conradi Plachter [14]). When we have gained a better understanding of descriptive landscape metrics, consequent indicators and ecological processes and functions, we still have to investigate landscape compositions concerning an "ideal" patch configuration (Forman Godron [18]). In landscape planning, current discussion tends toward the more holistic concept of landscape coherence (Mander Murka [34]) and leads to discussion of "sustainable landscapes" (Haines-Young / Buttimer [26, 13]), but from a conceptual point of view it is still unclear to the author how the anthropocentric concept of multifunctional landscapes can add another dimension to the outlined n-dimensional feature space of landscape change analysis.

6 Acknowledgements

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