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Foot of the Lilienstein (Elbe Sandstone Mountains) – fig. 3.16 (photograph by Wei Hou)

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Methodical basis for landscape structure analysis and monitoring: inclusion of ecotones and small landscape elements

Wei Hou

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Foreword

The now printed thesis of Mr. Wei Hou, which originated in the period of his stay at the Leibniz Institute of Ecological and Regional Development, deals with advanced methods of landscape structure analysis and remote sensing for landscape monitoring. Background is a widespread approach in landscape ecology, according to which the landscape structure or, in other words, the "pattern" or "mosaic" of a landscape arises from the composition and arrangement of discrete patches, e.g. Individual land use units.

These spatial patterns can be quantified using "landscape metrics". The goal is to capture the structure of a landscape, to document it for the purpose of monitoring, or to provide it as input parameters for landscape ecological simulation models. Up to now, however, landscape metrics have mostly deviated from concrete landscape elements. Ecologically important transitional areas between such elements, e.g. height differences, have so far been not or hardly included. In addition, small-scale elements such as individual trees, shrubs, hedges, etc. are also important for a landscape monitoring, but these often do not show up in existing data. The work begins on these two points. The objectives of the work were:

- Development of a model and corresponding methods for the detection of small landscape elements or biotopes as well as transitional areas between different land uses (ecotones) from remote sensing data and a high-resolution digital surface model.
- Integration of the small-scale landscape elements and ecotones into the methods of landscape structure analysis by adapting or extending existing methods and indices of landscape structure analysis.

For his work, he used data from the satellite “RapidEye” and high-resolution elevation data from airborne laser scanning. He subsequently developed a multi-level approach in which small-scale landscape elements can be detected using common image processing and GIS software. Furthermore, transitional areas between different land use classes, here mainly between forest and open land, can be characterized. Afterwards, methods for analyzing the landscape structure are presented on this basis. Specially developed indices allow the analysis of landscape diversity, fragmentation, landscape contrasts and biotope networks. Both for complex methods for the detection of small-scale elements and ecotones, as well as for the methods of landscape structure analysis, own algorithms and indices were developed. The developed methods were tested in study areas in Germany and China and their behavior in different landscapes and with different data bases were examined.

Mr. Hou has made a significant contribution to the progress of this research area - even in the international context - with the doctoral thesis he has presented. The innovative approaches, which he developed and exemplarily prepared, testify to this. Beyond that, the work also shows the necessity and also possibilities for application in landscape monitoring. We are confident, that the methods developed by him will find interest and application in science and practice.

Ulrich Walz

Editorial

When the term *landscape* emerged in the 16th century it was coined by the perception of nature in its holistic appearance, i.e. of the wholeness of the visible nature more or less shaped by a location- and time-dependent mixture of anthropozoogenic impact. The “scenery” comprising all the visible elements of a landscape was understood as an aesthetic impression of ostensibly harmonious patterns of a composition of organic and anorganic objects. Accordingly, it was through the fine arts, that by the painting of landscapes the term *per se* was invented during the late Renaissance (Gombrich 1966). Only during the late 18th and early 19th century the term was scientified by natural scientists such as Alexander von Humboldt, who nevertheless still relied to the (aesthetic) holistic concept of landscape, but at the same time tried to set up a categorisation of the types of elements which “construct” it (Humboldt 1849). Efforts were made to define landscape as a quantifiable multi-layer and multi-scale structure which is solely characterised by specific landscape elements which form ecotopes (“landscape cells”). The mosaic-like concinnity of ecotopes creates the landscape which is experienced as a consistent entity (Troll 1939).

Modern landscape ecology understands landscape as a heterogeneous area, which is coined by an aggregate of land forms or an association of habitats and which may comprise an area from some hectares up to hundreds of square kilometres (Turner et Gardner 1991). Three characteristics describing the typology of landscape are generally stressed, explicitly structure, function and change. Structure refers to relations of ecosystems in terms of shape, extent, abundance and configuration of components. Function relies to interactions of elements in space and time, i.e. flows of energy, material or organisms. Change describes the dynamics of structures and functions in a spatio-temporal context (Forman et Godron 1986).

Referring to structural characteristics it is obvious that the well-introduced patch-corridor-matrix-model is of limited reliability when extending the approach towards relief information, i.e. the third dimension in terrain description (digital surface/terrain models) as well as when integrating transition zones or gradients between patches. These ecotones have a significant temporal dimension in terms of dynamics of change and have thus a strong influence on parameters describing interrelated ecosystems. Improved approaches to a three-dimensional assessment and analysis of ecological gradients have to take into account that transition between ecological, geographical and environmental entities is generally non-discrete, often fuzzy. This aspect does not only concern relations between landscape elements and land use and land cover categories (describable by fuzzy logics) but also variations of approaches of analysis at multi-scale levels up to the dispersion of populations in respective areas of distribution. An ecological gradient can be described statistically by the fact that the variance of the relevant parameter increases with growing distance from the reference area (landscape element, habitat). It has nonetheless to be asked what would happen if that proportion were affected by diffuse impacts, which cannot be expressed by discontinuities in relief (e.g. in terms of canopy surface gradients from forest edges to adjacent copses and to grassland or agricultural land), such as environmental (human) impact varying locally both in time as well as in space, e.g. imission via air pollution or disturbances by tourism. Advanced technologies of 3D-topographic data acquisition such as Airborne Laser Scanning (ALS) as well as object-oriented approaches of remotely sensed image analysis (OBIA) allow for detection and mapping at very high geometric (spatial) accuracies. Thus, both relief gradients related to ecotones and also to small landscape elements (biotopes inside habitats) can be described in much more detailedness (e.g. Stumberg et al. 2014). It is worthwhile to take advantage of these data qualities and to focus on research into the integration of 3D-structural characteristics of ecotones via enhancing indices such as landscape diversity, fragmentation/connectivity and contrast.

One of the core problems in quantitative landscape ecology refers to the question to what extent landscape metrics are capable to assess information which supports the description of species richness (biodiversity?). Obviously, the integration of fine-scale landscape elements (small biotopes) and of ecotones into enhanced landscape metrics paves a way towards a better understanding and a more reliable interpretability and assessability of diversity, connectivity and contrast in landscapes. Gradient analysis along vegetation boundaries (edges) carries a load of further potential of information which needs to be integrated with more sophisticated landscape models to be developed. The extended potential of integration of any kind of gradient-type spatio-temporal information of environmental variables such as temperature, humidity and similar can be investigated.

Wei Hou has provided a very important contribution to pushing forward efforts of enhancing the real-world validity of landscape metrics by considering multi-scale characteristics of extent and distribution as well as of (canopy surface) gradients of small biotopes and (small) ecotones - smallness being a variable strongly depending on the scale of observation - based on the capability of spatial data to extract fine-scale elements of the landscape.

Elmar Csaplovics

References not appearing in the thesis

Gombrich EH (1966) The Renaissance theory of art and the rise of landscape, in: Gombrich EH (ed) Norm and form - studies in the art of the Renaissance, Phaidon, London, pp 107-121

Humboldt A v (1849) Ansichten der Natur mit wissenschaftlichen Erläuterungen, dritte verbesserte und vermehrte Auflage, 2 Bde. Cotta, Stuttgart Tübingen

Stumberg N, Hauglin M, Bollandsås OM, Gobakken T, Næsset E (2014) Improving classification of airborne laser scanning echoes in the forest-tundra ecotone using geostatistical and statistical measures. Remote Sensing 6(5): 4582-4599

Turner M, Gardner RH (1991) Quantitative methods in landscape ecology - an introduction, in: Turner MG, Gardner RH (eds) Quantitative methods in landscape ecology, Springer, New York Berlin

References appearing in the thesis

Forman RT, Godron M (1986) Landscape ecology. Wiley, New York

Troll C (1939) Luftbildplan und ökologische Bodenforschung, in: Zeitschrift der Gesellschaft für Erdkunde, Berlin 1939, Heft 7/8: 241-298

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Dresden, October 2016

Wei Hou

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List of Acronyms

2D	Two-dimensional – two dimensions
3D	Three-dimensional – three dimensions
ATKIS	Authoritative Topographic Cartographic Information System (German: Amtiches Topographisch-Kartographisches Informationssystem)
AWEC	Area-Weighted Edge Contrast
BfN	Federal Office for Nature Conservation (German: Bundesamt für Naturschutz)
BKG	German Federal Agency for Cartography and Geodesy (German: Bundesamt für Kartographie und Geodäsie)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (German: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
CAPE	Corridor Area Percentage of Econet
CBD	Convention on Biological Diversity
CIR	Color Infrared
CORINE	Coordination of Information on the Environment
CLC	CORINE Land Cover
DEM	Digital Elevation Model
dCAPE	Change rate of CAPE between two dispersal distances
DTM	Digital Terrain Model
DLM	Digital Landscape Model

DLM-DE	Digital Landscape Model for Germany (German: Digitales Landbedeckungsmodell für Deutschland)
DLR	German Aerospace Center (German: Forschungszentrum der Bundesrepublik Deutschland für Luft- und Raumfahrt)
DSM	Digital Surface Model
ECMS	Effective Connected Mesh Size
Econets	Ecological networks
ECON	Edge Contrast Index
EU	European Union
ESP	Estimation of Scale Parameters
GIS	Geographic Information System
HNV	High Nature Value
IIC	Integral Index of Connectivity
KIS	Environmental Key Indicator System (German: Umwelt-Kernindikatorensystem)
Lidar	Light detection and ranging
LIKI	State Initiative on Core Indicators (German: Länderinitiative Kernindikatoren)
MESH	Effective Mesh Size
MLR	Ministry of Land and Resources
MMU	Minimum Mapping Unit
MRIS	Multi-Resolution Image Segmentation
MS	Multispectral bands
NCAs	Nature Conservation Areas
NDSM	Normalized Digital Surface Model

NHS	Indicator System for National Sustainable Development (German: Indikatorenberichte zur Nationalen Nachhaltigkeitsstrategie)
NLPs	National Parks
NDVI	Normalized Difference Vegetation Index
NDVI-RE	Normalized Difference Vegetation Index-Red Edge
NIR	Near Infrared
OBIA	Object-Based Image Analysis
Pan	Panchromatic band
PBIA	Pixel-Based Image Analysis
PC	Probability of Connectivity
RE	Red Edge
REVI	Red Edge Vegetation Index
SEBI	Streamlining European Biodiversity Indicators
SHDI	Shannon’s Diversity Index
SIDI	Simpson’s Diversity Index
SWIR	Short Wave Infrared
SRTM	Shuttle Radar Topography Mission
TECI	Total Edge Contrast Index
TIR	Thermal Infrared
UBA	Federal Environmental Agency (German: Umweltbundesamt)
ULTA	Undissected, Low-Traffic Areas

1 Introduction

The motivation of this research is awareness of the linkage between biodiversity and landscape structure. A crucial key to the problem of biodiversity loss is consideration of changes in land use and in landscape structure. On a higher organizational level of landscapes or ecosystems, biodiversity can be evaluated by habitat diversity. The first chapter of this work is to illustrate the general relationship between landscape structure and biodiversity, and the current issues for methods used in landscape structure analysis. Detecting and analyzing the landscape structure from the perspective of conservation on biodiversity serve as guideline throughout this text.

1.1 Starting point of this work: biodiversity on landscape level

The rate of biodiversity loss, as a global issue, has been considered as one of the nine planetary boundaries that could help prevent human activities from causing unacceptable environmental change (Rockstrom et al., 2009). Recent research shows that climate change and human-driven land cover change, e.g. urban sprawl, increasing of transport infrastructures, the intensification of agriculture, and forest logging, are the main causes of the increasing species extinction (Giam et al., 2010); in fact changes in land use and landscape fragmentation by infrastructure development are expected to have the most significant effect on biodiversity (Sala et al., 2000). Although biodiversity loss occurs at the local to regional scale, it can have pervasive effects from continental to global level. For example, declining diversity of plants and algae will decrease the biomass of plants in natural ecosystems, and degrade their ability to use biologically essential nutrients from soil and water, moreover reduce the ability of natural ecosystems to produce oxygen, and to remove carbon dioxide from the atmosphere (Cardinale et al., 2011). According to the estimation of Rockstrom et al. (2009), the rate of biodiversity loss has already transgressed its boundaries that Earth can sustain. In order to reduce the rate of extinction and the loss of habitats, biodiversity considerations have to be integrated into spatial development planning (Walz and Syrbe, 2013). However, little is known quantitatively about how much and what kinds of biodiversity should be considered to maintain the resilience of the local ecosystem. This is particularly true at a higher level of large-extent scale.

The 1992 United Nations Earth Summit in Rio de Janeiro defined “biological diversity” as “the variability among living organisms from all sources including, inter alia, marine and other aquatic ecosystems and the ecological complexes of which they are a part of: this includes diversity within species and of ecosystems”(United Nations, 1992, page 146). This means the concept of biodiversity should not be limited to stand only for the species diversity, but in a broad sense, cover three levels: genetic, species, and of ecosystems and landscapes (Figure 1.1). The different levels of biodiversity are built upon one another, and at all levels biodiversity is influenced by temporal and spatial processes (Gaines et al., 1999). More and more ecologists (Blab et al., 1995; Duelli, 1997; Gaines et al., 1999; Noss, 1990; Otte et al., 2007) argue that biodiversity should be surveyed at different organizational levels: regional landscape, community-ecosystem, species-population, and genetic level (Gaines et al., 1999; Gosz, 1993). Since many species depend strongly on specific habitat conditions such as food, shelter, climate etc., it can be assumed that species diversity is determined by landscape structure as an expression of natural conditions and land use (Walz and Syrbe, 2013). As a consequence, the protection of high landscape heterogeneity is important for preserving the greatest possible biodiversity.

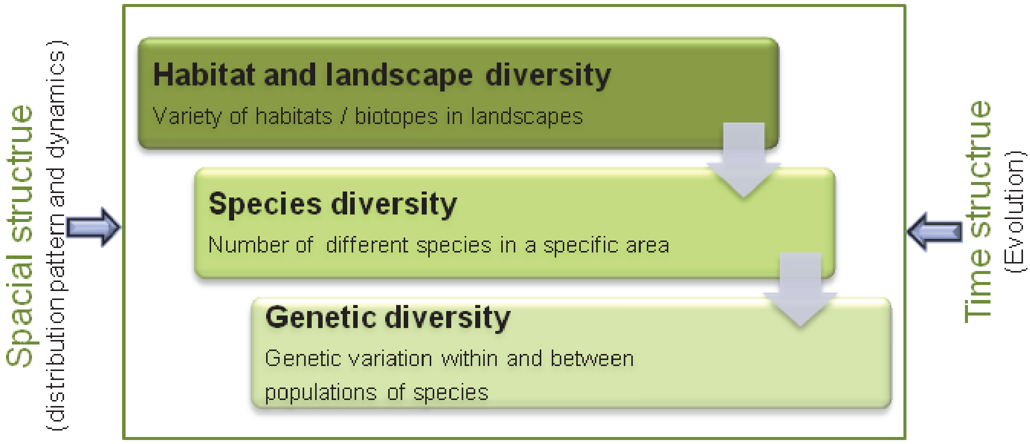

Figure 1.1: Levels of biological diversity (adapted from Blab et al., 1995; Walz, 2011).

1.2 Modern landscape ecology and its shortcomings

Landscapes are complex systems composed of a large number of heterogeneous components which are spatially correlated and scale-dependent (Hay et al., 2003; Wu, 2004). Spatial heterogeneity is considered ubiquitous across all scales and forms the basis for the structure and functioning of landscape (Wu, 2004). The goal of landscape ecology is to determine where and when spatial and temporal heterogeneity matter, and how they influence ecological processes (Turner, 1989). A fundamental issue is how to depict and measure heterogeneity. Spatial heterogeneity occurs in two forms: discrete patches and continuous gradients (Forman, 1995). A gradient works like a continuous surface including the underlying heterogeneity, but without boundaries, e.g. the different height structure of trees in a forest patch. However, the gradient landscape is considered as a rare situation in cultural landscapes and the mosaic pattern has been recognized as a universal form at all spatial scales, including landscapes, regions, and continents. Therefore, the patch-corridor-matrix model and their characterization by means of landscape metrics have been largely adopted to describe and analyze the ground surface. In addition, a variety of software (Baker and Cai, 1992; McGarigal and Marks, 1995; Rempel, 2008) based on this model has emerged and facilitated the knowledge transfer from theoretical model to practice. Indeed, the mosaic pattern is an effective and well conceptualized model that facilitates experimental design, analysis, and management and it has the advantage of computer simulation, calculation, and visualization. There is also criticism (Li and Wu, 2004) that the categorical model poorly represents the true heterogeneity of the landscape, which often consists of continuous multi-dimensional gradients (McGarigal and Cushman, 2005); and it is an oversimplification of realistic conditions without the consideration of the relief (Hoechstetter et al., 2006).

Many studies have drawn attention to the ecological value of small and linear vegetation patches (Lindenmayer and Hobbs, 2008; Lumsden and Bennett, 2005b; Manning et al.,

2006) and ecological gradient (di Castri and Hansen, 1992; Hufkens et al., 2009; Risser, 1993). These small landscape patches, such as hedgerows, tree rows and groves, are important for species migration and dispersal on a small scale and are closely related to species richness, e.g. birds (Schifferli, 2000) or arthropods (Duelli and Obrist, 2003). Ecological gradients are often recognized as "ecotones" to indicate the zone of transition between adjacent ecological systems, having a set of characteristics uniquely defined by the strength of interaction between adjacent ecosystems (di Castri and Hansen, 1992). The ecotones which have "functional combination" of habitats in the landscape mosaic are vital to animals that utilize multiple habitat types and have a profound influence on adjacent ecosystems (Cadenasso et al., 1997; Fagan et al., 2003; Senft, 2009; Strayer et al., 2003), for example, ecotones control the flux of materials and energy between ecosystems (Fortin et al., 2000), harboring a rich, specialized fauna and flora (Duelli, 1997; Hoffmann and Greef, 2003; Kumar et al., 2006).

Efforts have been made for using remote sensing images to quantify fine-scale landscape heterogeneity for biodiversity evaluation (Levin et al., 2009; Rocchini, 2007). However, small biotopes and transition zones (or "ecotones") are often ignored in the mosaic model for landscape monitoring. Commonly, map products offer either extensive geographic coverage at the expense of detail, or are comprehensive in detail but cover only small areas (Farmer et al., 2011). The biotope maps (scale 1:10,000) contain most detail small landscape elements, which are manually delineated based on high resolution imageries. In Germany, the biotope maps are not available for all federal states and they are not regularly updated. For example, the latest biotope map for the state of Saxon is from 2005.

It is stressed that the monitoring scale of landscape depends strongly on the purpose of analysis. In order to fully understand the spatial dimension of ecological patterns and processes with respect to biodiversity, it is necessary to consider the whole landscape matrix, including both larger patches and small biotopes (Walz, 2011).

1.3 Research objectives and key questions

Despite the limitations of the mosaic model, landscape metrics are widely used and useful (Turner, 2005). The question is which degree of simplification can be regarded as acceptable and how detailed information about the landscape structure this model appears not enough to represent. In the following the research objectives and key questions will be given in the background of complementing the mosaic model.

1.3.1 Research objectives

The main objective of this work is to develop methods for data analysis as a basis for regular monitoring of landscape structure. The focus is on data evaluation and extraction of small-scale landscape elements from remote sensing images and elevation models; and integration of these elements into landscape structure analysis in three-dimensional space. In line with the main objective of this work three sub-objectives are settled:

- Research objective 1: Establishing a model for detecting small biotopes and ecotones on the basis of the spectral and spatial features from remote sensing data and the high resolution Normalized Digital Surface Model (NDSM). Because some of these habitats are not only spectrally but also spatially similar, this gives a big challenge for a standard approach to habitat pattern detection for a regular landscape monitoring.

- Research objective 2: Incorporating these fine-scale biotopes into landscape structure analysis. The question is that these small biotopes cannot be treated simply as patches in the mosaic model, but as inner heterogeneity of patches that may affect the whole landscape. Not only the ecological function of every single small biotopes should be considered, but also the network connected by them.
- Research objective 3: Ecotones or transitional areas between adjacent patches are another part of information which should be integrated in the landscape mosaic model. The ecological functions of ecotones have been studied extensively by many authors. However, quantification and evaluation of ecological functions of ecotone by landscape metrics remains a question to be clarified.

1.3.2 Key questions

In this context, the main challenge of this research is to analyze the landscape structure and habitat pattern in a detailed level integrating small biotopes and ecotones with the existing methods. Under this challenge the following questions are raised and need to be answered:

- What roles do ecotones and small biotopes play in maintaining the ecological functions of the landscape? And how to define them across scales in heterogeneous landscape?
- How can these landscape elements, which are not contained in official / regularly updated land use data, be detected / selected?
- How to incorporate small biotopes and ecotones in existing evaluation methods of landscape structure based on the patch-corridor-matrix model?

The importance of functional roles of ecotones and small biotopes in landscape has been partly explained in this chapter and the detailed features of these landscape elements are given in chapter 2, since it serves as both the motivation and theoretical background for the work. A detail examination of the ecological roles of these landscape elements is necessary to support the argument of integrating them in landscape structure analysis. Question 2 and question 3 are mainly concerning the methodical work which is presented in chapter 3. It is the main innovative part of this work. The attempt is to develop a general approach for landscape monitoring at fine-scale level where the ecological functions of small biotopes and ecotones will be represented by quantitive indicators. After answering these three key questions, two real-world examples are used for testing the proposed methods in chapter 4. The results in two different study areas show whether these small biotopes and ecotones can be effectively detected and more meaningful and precise measurements can be obtained for landscape heterogeneity. Chapter 5 evaluates the applicability of the respective methods for their intended use and gives some additional possible fields for further applications. The main findings are summed up in chapter 6 and the answers to these three questions are finally reconciled and given.

2 Theoretical basis and background

The emphasis of this work is the integration of small biotopes and ecotones for landscape monitoring. This chapter firstly provides in detail about the ecological functions of small biotopes and ecotones, and the important terms are explained. Then, the landscape monitoring situation in Germany and China is presented to give a general impression about different monitoring systems in the context of biodiversity.

2.1 Small biotopes and ecotones as components of landscape pattern

A number of small landscape elements (e.g. hedges, tree rows, etc.) and ecotones have been recognized with high conservation values for biotope connectivity and as important habitats of a diverse and heterogeneous landscape (Driscoll, 2005; Jaeger, 2000; Walz, 2011). Habitat loss, in particular, is a serious consequence of fragmentation processes and has become an important field in conservation biology (Turner, 2005). On the other hand, fragmentation effects on biodiversity may not always be negative (Fahrig, 2003). What is decisive is, whether fragmentation describes the dissection of landscapes by barriers like roads or if it simply characterizes the degree of segmentation of a landscape into small components (Walz and Schumacher, 2005). In the following sections the characteristics of small biotopes and ecotones are reviewed as components of landscape mosaic.

2.1.1 Landscape fragmentation as a result of disappearing small biotopes

Fragmentation is a very manifold concept in ecology. It is comprised of several broad themes of work: biological organization, land cover and habitat, and connectivity (Lindenmayer and Fischer, 2007). 'Biological organization' refers to which perspective is used, either a perception of the landscape by a single species or a human perspective for multiple species. 'Land cover and habitat' corresponds to the landscape pattern and habitat loss (e.g. amount and configuration of vegetation). 'Connectivity' is a highly controversial topic that can be interpreted differently. It can be broken down into 'structural connectivity' and 'functional connectivity' (Baguette and Dyck, 2007). Structural connectivity refers to the physical connectedness among landscape elements, which is related to the landscape pattern or habitat configuration. Functional connectivity is a combination of both landscape structure and the response of organisms and processes to this structure. It reflects the connectedness of habitat patches for a given taxon or of ecological process (e.g. seed dispersal). Fragmentation and connectivity represent the same characteristic of landscape pattern from two different perspectives. They can be measured in the same way as fragmentation is on the opposite of connectivity. The structural connectivity also relates to the small biotopes which offer potential stepping stones for species movement. These interpatch connections are dependent on some local factors such as vegetation type and dispersal distance (Di Giulio et al., 2009). Jongman (2004) stated further that fragmentation is caused not only by barriers such as roads, urban areas and inaccessible agricultural land, but also by the continuing decrease of landscape elements (small forests, hedgerows, riparian zones).

Since different species require different types of habitat, and different amounts of habitat for persistence, a suitable configuration of landscape is having the required habitat amounts, with interspersed different habitat types as much as possible. A schematic example (Figure 2.1) from Schifferli (1987) shows the number of birds' species declines as the landscape pattern becomes simplified. In other words, large-scale intensively land utilization and removal of small biotopes make the landscape monofunctional and homogenized. Losing small biotopes can significantly influence the ecological functions of a whole landscape (Norderhaug et al., 2000; Oliver et al., 2006; Walz, 2011). Several studies have shown that small biotopes as important spatial elements need to be incorporated in landscape pattern for providing information on the effects of fragmentation and assessing ecological sustainability (Löfvenhaft et al., 2002; Peterseil et al., 2004; Renetzeder et al., 2010). For a holistic understanding of the dynamics of landscape processes, a land-cover map with the smallest distinguishable functional and structural homogenous elements is needed (Farmer et al., 2011). For this purpose, four types of small biotopes (area < 1 ha) including scattered trees, tree rows, hedges, and copses will be detected and incorporated in the landscape structure analysis in this work.

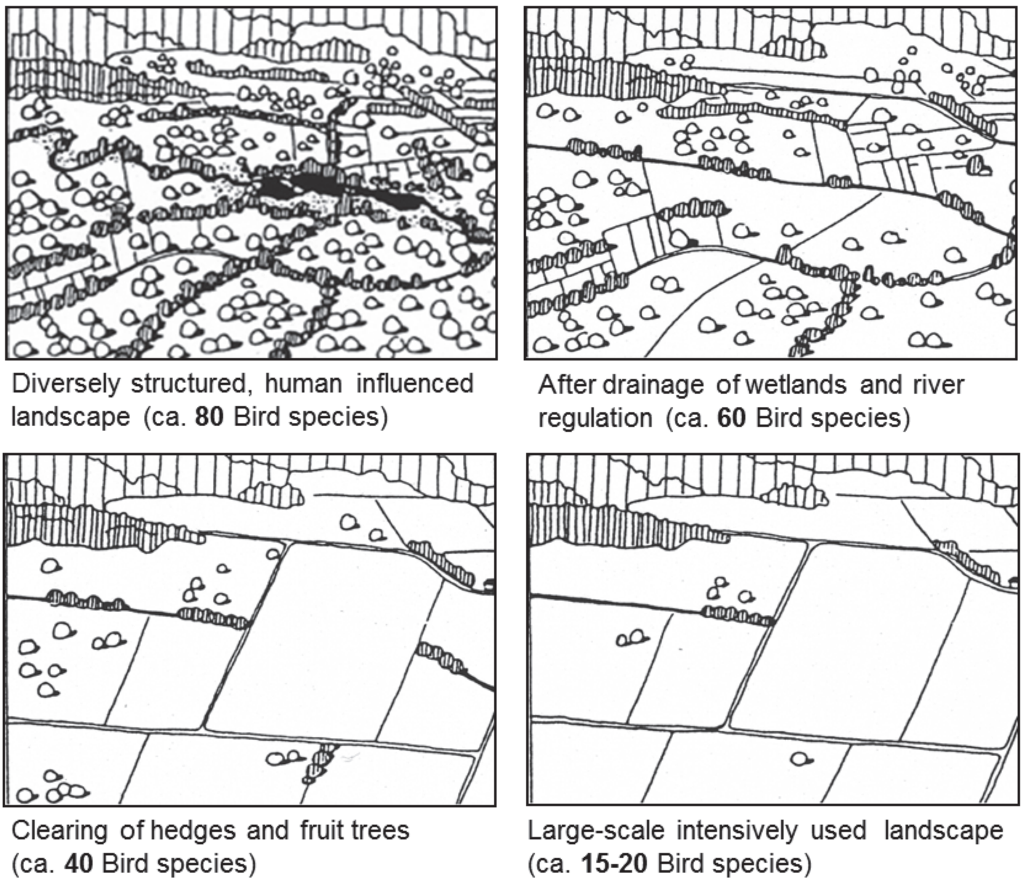

Figure 2.1: An example of effects of landscape structure change on biodiversity (Source: Schifferli, 1987).

2.1.2 A "soft" boundary: ecotones as transitional area between habitats

If the term "fragmentation" is only limited to "the breaking apart of habitat" (Fahrig, 2003), a more fragmented landscape (more, smaller patches and edges) will enhance the interactivity among different habitat types, which should increase habitat complementation and positively affect on biodiversity (Law and Dickman, 1998). In this sense, "habitat fragmentation" has similar meaning of "habitat diversity". The key difference between these two concepts lies upon the boundaries which decide how the landscape may be divided (into more and different land-use classes). Considering from the landscape scale, more types of habitats constituted landscape pattern, more chances the landscape hold different species inside. However, if plenty habitats are separated by sharp border, like railways or urban areas, it actually reduces the effective habitat size and results in isolated and smaller habitats.

2.1.2.1 The model of patch boundary

Each landscape element contains an edge, the outer area exhibiting the edge effect. Two edges combined from adjacent patches compose the boundary or boundary zone (Forman, 1995). Boundaries are defined as a zone between contrasting habitat patches that delimit the spatial heterogeneity of a landscape (Strayer et al., 2003). Figure 2.2 shows a general model of boundary, which is an abstraction of the intervening boundary for two patches within a landscape. It indicates that two individual patches are connected by a gradually changing boundary which stands for a gradient of spatial heterogeneity (Figure 2.2 c). Specific models could be derived from different research questions, but have the same structure as the general model.

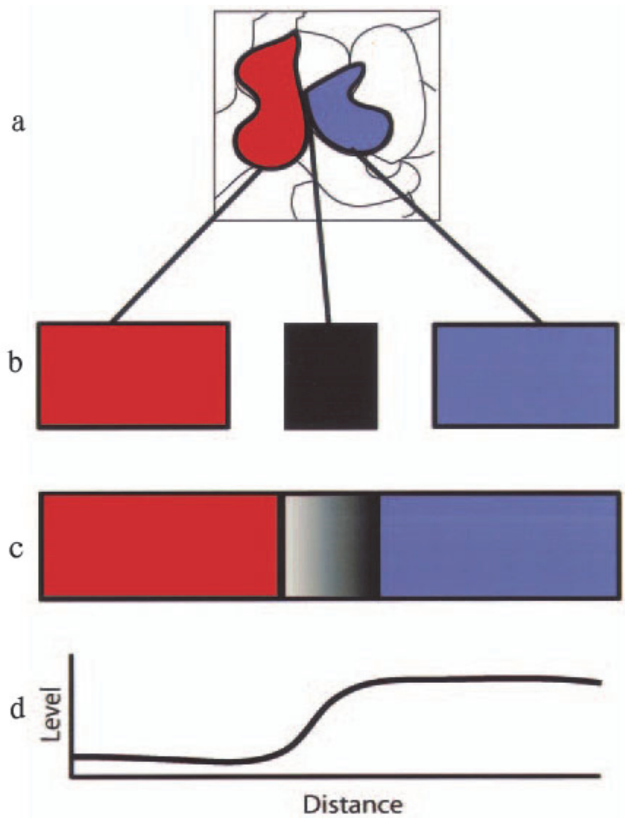

Figure 2.2: A general model for the patch boundary in landscape mosaic (a); (b) shows two patches (red and blue) are isolated by the boundary (black) between them; (c) shows a continuous structure between patches as the gradient from white to black in the boundary; (d) illustrates that the gradient is steeper in the boundary than in either of the neighboring patches (Source: Cadenasso et al., 2003).

The detailed geometry of adjacent patches can result in several kinds of boundaries (Strayer et al., 2003). The simplest case is two patches physically adjoin each other (Figure 2.3 a). The boundary may have thickness, which stands for a gradual change of the environment condition (Figure 2.3 b), as the case of forest edge extends to the field. Patches could be separated by a third structure (Figure 2.3 c), like a road or stream. The boundary geometry is decided by grain, dimensionality, and sharpness. It is important to first consider the grain, while on different grain size the interface between two patches may be different (Figure 2.3 d). Not only the boundary interface, but the dimensionality is also affected by grain size. Boundary may be considered as a thin line or a two dimensional zone between patches (Figure 2.3 e). The dimensionality as an important factor to boundary morphology and distribution is highly related to the grain size. The choice of boundary dimensionality is dependent on the research question and the features of the boundary itself may be involved. For example the sharpness (Figure 2.3 f) is an important feature for the boundary zone, which indicates the degree of the interactivity between patches. There are more spatial features of boundary, such as curvilinearity, edge contrast, that could regulate the exchange of materials, energy, and organisms across boundaries (Cadenasso et al., 2003; Forman, 1995; Hoechstetter et al., 2008).

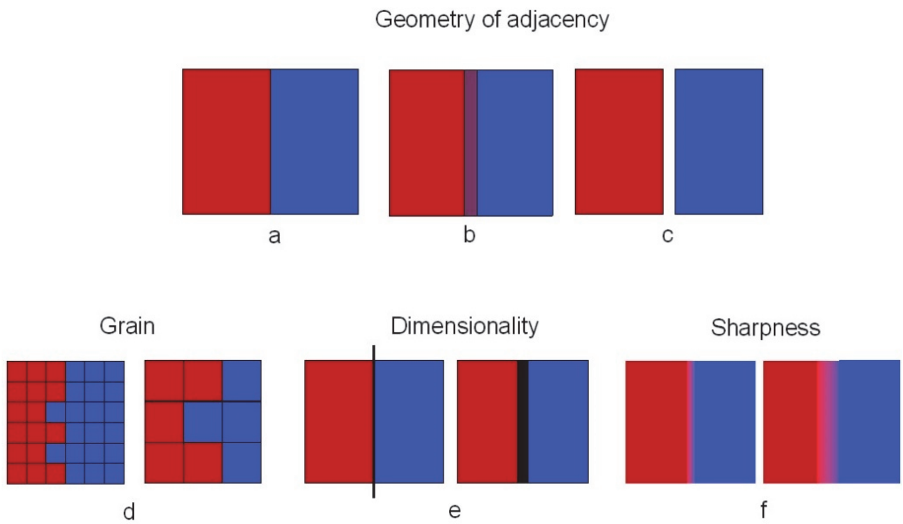

Figure 2.3: Geometry and some spatial features of boundary: (a) A simple boundary between two adjoining patches; (b) a boundary zone (with gradual change in ecological condition) between two patches; (c) a boundary between two disjunct patches; (d) the interface of the boundary is affected by grain size; (e) boundary could be a thin line or a two dimensional zone; (f) a gradient boundary between two patches may be steep or soft (Source: adapted from Strayer et al., 2003).

2.1.2.2 The ecotone concept

At the beginning of the 20th century, an ecotone has been treated as an environmentally unstable zone, which encompasses abrupt or accumulated change (Clements, 1905; Livingston, 1903). With the advent of landscape ecology, it came to think ecotones as ecological boundaries that contribute to the spatial heterogeneity of the landscape (Cadenasso et al., 2003; Fagan et al., 2003; Fortin et al., 2000; Holland et al., 1991; Senft, 2009). In short words, it is described as “the overlap or transition zone between two plant or animal communities” (Forman, 1995). A set of general characteristics should be considered when applying the ecotone term. First, the term ecotone not only refers to the gradient between different vegetation types, but also some other abiotic elements. It could be a boundary between a forest and field or a river and its estuary. Second, ecotone could be found across a range of scales, from a few centimeters to several kilometers; or in a hierarchical structure from the population level to the biosphere level depending on the research question (Gosz, 1993). Third, the ecotone more often has a multi-dimensional structure (Hufkens et al., 2009). It is not confined to one or two dimensions as a sharp boundary line or an overlapped zone between adjacent patches. The third spatial or temporal dimension could also define an ecotone. For example the forest-field ecotone could be defined by vegetation height (Strayer et al., 2003), or a variable climate as described by Allen and Breshears (1998). Therefore, the definition of ecotone should emphasize the multivariate approach. In case where multiple ecological properties jointly define a transition zone, these properties may be spatially congruent with one another (Strayer et al., 2003). However, the representation of the ecotone is often limited by the dimensionality of the technique used to characterize its multi-dimensional properties (Hufkens et al., 2009). Furthermore, ecotones have a set of characteristics defined by the magnitudes of ecological exchange like energy or material flow between ecological systems. Often multiple processes are driving this exchange and forming a transition zone between adjacent patches.

Since the ecotone is a multi-dimensional and multi-scale concept, it is necessary to specify the ecotone in the research context. For the work at hand, the ecotone is defined at the local level as a “soft” boundary between vegetation communities (forest-field boundary). It has a three dimensional structure appearing as gradual blending of the two vegetation communities on the boundary area, where the third spatial dimension (vegetation height) is used to constrain the transition zone on forest-field boundary. The boundary model in Figure 2.3 (b) represents the gradient, which combines both the edges of adjacent forest and field. This context defined boundary, along with small biotopes, are both influential in the interactions between patches and ultimately affect landscape-level dynamics. The ecological functions of small biotopes and ecotones are discussed in the following chapter.

2.1.3 Ecological functions of small biotopes and ecotones

Scientists have long been aware of the important role of small biotopes and ecotones in ecosystems. Consequently, a lot of researches have been conducted to reveal the importance of the small elements for reconstructing the linkage inside a landscape (van der Ree et al. 2004, Herrera and García 2009, Lander et al. 2010), and the speciation process in ecotones where ecosystems are dynamic and exchange of genes often take place (Schilthuizen 2000, Smith et al. 2001, Araújo 2002). As the work at hand intends to enhance landscape structure analysis by incorporating these elements, a short review of the ecological functions of small biotopes and eoctones is needed in order to understand their functional roles in landscape.

2.1.3.1 Ecological functions of small biotopes

The loss of small biotopes can decrease the landscape linkages, especially in the densely populated areas. Not only humans use landscape linkages; also plants and animals move through landscapes in their own way. Also they need their landscape linkages to move from one suitable habitat to another, on a short distance along a hedgerow or over a small grove. In this work, the ecological functions of small biotopes (including scattered trees, tree rows, (field) hedges, and (field) copses) are examined from literatures and concluded in table 2.1.

Table 2.1: Summary of the ecological functions of small biotopes in promoting biodiversity.

Small biotope	*Ecological functions*	*Sources*
Scattered tree	Provision of habitats (for birds, bats, etc.)	(Fischer and Lindenmayer, 2002a; Galindo-González et al., 2000; Luck and Daily, 2003; Lumsden and Bennett, 2005a; Oliver et al., 2006)
	Enhancement of ecological connectivity as stepping stone (seed dispersal, bird migration)	(Cascante et al., 2002; Fischer and Lindenmayer, 2002b; Graham, 2001; Guevara and Laborde, 1993; Herrera and García, 2009; Lander et al., 2010; van der Ree et al., 2004)
	Biological legacies after a disturbance (providing assistance for other species to persist; habitat for recolonization; source of energy and nutrients)	(Dorrough and Moxham, 2005; Lindenmayer and Franklin, 2002; Toh et al., 1999)
	Influences on abiotic environment (such as mineralization of nutrients, infiltration of rainfall)	(Eldridge and Freudenberger, 2005; Tiessen et al., 2003; Wilson, 2002; Yates et al., 2000)
(field) hedges / tree row	Provision of habitats or refuges (most forest edge species).	(Gelling et al., 2007; Hannon and Sisk, 2009; McCollin et al., 2000)
	Control on many major abiotic fluxes, such as fluxes soil desiccation, soil erosion and nutrient runoff.	(Baudry et al., 2000; Bu et al., 2008; Burel and Baudry, 1995; Hairiah et al., 2000)
	Function as corridors for movement of many plants and animals across a landscape	(Campagne et al., 2009; Forman and Baudry, 1984; Gelling et al., 2007; Petit and Burel, 1998; Wehling and Diekmann, 2009)
	Regulation of microclimate (wind speed, evaporation)	(Burel and Baudry, 1995; Forman and Baudry, 1984; Sánchez et al., 2010)
(field) copses / shrub	Provision of habitats and improvement of food-web.	(Beschta and Ripple, 2012; Inglis et al., 1994)
	Contribution to species distribution (e.g. seed, ants, scorpion, cicada, reptiles, small mammals).	(Daryanto and Eldridge, 2012; Li et al., 2009)
	Influence on abiotic environment (soil stabilizer and prevent water and soil erosion)	(Martínez-García et al., 2011; Wezel et al., 2000)

The review of the literature shows that small biotopes are of high natural value for the conservation of biodiversity (Ernoult and Alard, 2011; Forman, 1995; Morelli, 2013). The main functions of these small biotopes in ecosystem are either providing habitat for some edge species or forming a network to strength the species movement, such as hedgerow network (Burel and Baudry, 1995; Forman and Baudry, 1984). Except the ecological functions, the small biotopes also have influence on humans, such as: recreational value, shade and sheltered grazing for livestock, wood products (Manning et al., 2006). Hedgerows and copses perform diverse functions for society and the farmer that are both economically and ecologically significant (Forman and Baudry, 1984).

2.1.3.2 Ecological functions of ecotones

Ecotones, as zone which may conceive both characteristics of adjoining ecosystems, are widely considered to harbor higher biological diversity than each neighboring area. As unique habitat it may be optimal for some species and inhospitable for others (di Castri et al., 1988). As ecological boundary it may act as barrier or corridor for the transit of disturbance, nutrients, or organisms. From the view of patch dynamic, they are regarded as dynamic components of a landscape which enhance the strength of landscape interactions and provide habitat for many transient organisms (Senft, 2009). However, they are more or less a conceptual view, more evidences and field investigation need to be conducted to explain the mechanisms behind the underlying processes which control changes in richness.

Ecotone as part of habitat diversity

Biodiversity could be observed on different levels of genes, species, and habitats. Two manifestations of diversity are addressed here: (1) diversity of patches, and (2) diversity of species. Patch diversity here refers to both the vegetation forms that are used to characterize biomes and vegetation structure within a biome (e.g. the distribution of overstory and understory life forms). Species diversity indicates both richness and evenness. Here it is restricted to species richness.

When ecotones serve as habitat, they can strongly influence local and regional species density and diversity (di Castri et al., 1988). One reason is due to the “edge effect” (Odum, 1971) in ecotone where species from each of the adjacent communities plus species inhabiting only ecotone (ecotonal species) and multihabitat species exist (Forman, 1995). The edge effect can be visualized like in figure 2.4, which shows the species distribution along forest/field boundary. In the case of individually examining the species in forest, ecotone, and field, the number of forest species would decline from ecotone to field, and for grass species decreasing trend can also be observed from ecotone to forest. Between forest and field ecotonal and multihabitat species will reach the peak abundance. If we add the three curves of species distributed in these three habitats, the cumulated species diversity along forest/field boundary can be concluded as the curve on the top in figure 2.4. It shows a higher species diversity from adding the “edges” of both adjoining communities.

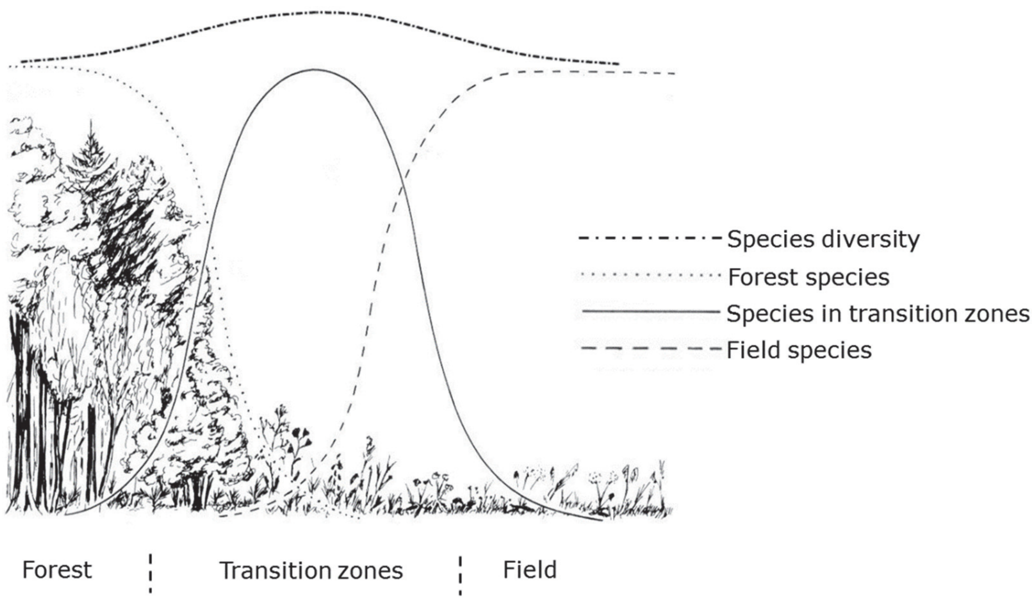

Figure 2.4: Species distribution along forest/field boundary (Source: adapted from Wolff-Straub 1984, Jedicke 1990).

However, in practice there are seldom evidences which support this biological edge effect. Some empirical studies are even contradictory. Baker et al. (2002) has studied the patterns of bird densities across heath–wood edges in southeastern Australia and found the bird density and species richness were much higher in wood habitat than in heath habitat, and no bird species could be categorized as ecotonal. Kotze and Samways (2001) investigated epigaeic amphipod, carabid and ant distribution patterns across Afromontane forest/grassland ecotones in South Africa. They found little evidence to support the edge effect, but the grassland habitats were strongly recommended to be incorporated into forest conservation strategy. Lloyd et al. (2000) examined three different types of ecotones and found that ecotonal species were significantly more frequent in two of the four investigated ecotones, but species richness was intermediate between that of adjacent communities. There are also studies that show clear edge effects at ecotones. Helle and Helle (1982) found more bird species on forest edge in Gulf of Bothnia due to more diverse resources in edge zone, e.g. food and shelter, than in the central forest. Harper and Macdonald (2002) investigated the spatial and temporal pattern at forest edge in Alberta (Canada) and detected significant edge effects. Rusek (1992) studied the distribution and function of soil organisms in three different types of ecotones in South Moravia (former Czechoslovakia) and found that some species showed an increase in the ecotones, but different group of organisms were affected not in the same way by edge effects. Empirical studies showed three possibilities of species diversity in ecotone: less than either adjacent patch; intermediate between the patches; or higher than in adjacent patches. More literatures could be found which concerned on one or several kind of species in ecotones, primarily birds. It is necessary to fully examine different categories of species along ecotone to understand the edge effect. This is not easy, because ecotone occurs at a variety of spatial and temporal scales that may be thousands of kilometers long; and organisms have also scale, from large mammals to smaller insects. Thus, a general relationship between ecotone and species diversity may not be concluded. The species diversity depends on the properties of the ecotone where it is studied. Nevertheless, ecotones as special habitats could contribute to landscape pattern diversity and influence the ecological function of landscape. With changing climate threatening on species distributions and the habitats on which they depend, more emphases have aroused on the conservation of ecological gradients which are important in diversification and speciation (Araújo, 2002; Schilthuizen, 2000; Smith et al., 2001; Smith et al., 1997).

Ecotone as boundary for regulating ecological flow

Boundaries led to heterogeneous pattern, where physical and ecological flows occur (Forman, 1995). Ecotone can be considered as a specific type of boundary which has important effects on movements of animals and materials, rates of nutrient cycling, and levels of biodiversity (Cadenasso et al., 2003; Peters et al., 2006; Shaw and Harte, 2001). In nature no absolute barriers or boundaries exist, only filters (Forman, 1995). To understand the "filter function" of ectones, a framework including three components is suggested: type of flow, patch contrast, ecotone structure (Cadenasso et al., 2003).

Four types of flow including materials, energy, organisms, and information are related to ecological system. Materials such as seeds, silt, wood, dead organic, and pollutant are carried across landscape boundaries by water, wind, flying animals, terrestrial animals, and humans. Wind, water as material flow passages require external thermal gradients from the environment; in contrast, animals and humans as material carriers need internal energy (Forman, 1995). The energy flow through landscape boundaries are in various forms: light, heat, or transformation of stored energy in biological forms (Cadenasso et al., 2003). Energy transformation often controls the material flux. Ryszkowski and Kędziora (1993) demonstrated that the horizontal passage of heat energy between cultivated fields and ecotones enhanced evaporation in shelterbelts and resulted in reduction of water flux. The thermodynamically open heterogeneous system is a requisite for the fluxes observed in a landscape (Forman and Moore, 1992). The flow of organisms and information are higher levels of organization than the flow of either material or energy. Mammals commonly move along the boundary both inside and outside the mantel, sometimes forming migration paths. Within the boundary area, there are maybe intensive interactions among animals, for example the so called "ecological traps" (Gates and Gysel, 1978), which means predators focus on edge region for food searching where herbivores usually have a higher density. Information flow, like the sound of a lion roaring is information for potential prey concerning the whereabouts of the predator. Or genetic information can be exchanged by hybridization between subspecies from different habitats in ecotone (Leaché and Cole, 2007; Yanchukov et al., 2006).

Patch contrast is the feature that is used to differentiate patches and defines the characteristics of boundaries. Patches can differ in architecture, composition, or process (Cadenasso et al., 2003). There are several features which could define patch contrast, such as population density in the edge, the chemistry of adjacent soils, the vertical vegetation structure of the edge, or landform. For example, according to height contrast the field edge width based on illumination is approximately equal to the height of the trees in forest edge (Forman, 1995). Due to the sudden drop of the wind speed in forest/field boundary sand, seeds, or mineral nutrients from fertilizer, pesticides can accumulate; consequently the composition of boundary will be changed as well.

The architecture of a boundary is its three-dimensional structure composed of biological or physical features (Cadenasso et al., 2003). Moreover, the internal structural characteristics of the boundary play a key role in determining its ecological functions.

The experiment from Ryszkowski (1992) shows that the amount of absorbed radiation energy is relatively high when the area receiving solar radiation has a high moisture content, a rough surface, and dark coloration. For instance, shelterbelts intercept more light than meadows. Jordana et al. (2000) has found that across ecotones between pine forests and shrublands in Navarra (Spain) and Sicily (Italy), soil is being actively created by certain Mediterranean shrubs which seem to play a most important role in providing adequate microclimatic and energy input conditions for the soil engineers. Moreover, the boundary structure can enhance the contrast between patch interior and patch edge. Within forest/field boundary, due to the presence of a greater surface exposed in forest edges, this may lead to lower live tree density and canopy cover, higher mortality and windthrow than interior forest (Mascarúa López et al., 2006).

Patch, ecotone, and heterogeneity are scale dependent (di Castri et al., 1988; Gosz, 1993; Wiens, 1992). According to the space-time principle, spatial scale and temporal scale are common bound each other. The larger a studied area is, the longer the relevant time scale (Forman, 1995). The effects of ecological and evolutionary processes in shaping biodiversity patterns and processes in ecotones differ among spatial scales (Karka and Rensburg, 2006). The spatial scale of a particular investigation is determined by its grain size (the limit of resolution of measurements or sampling) and its extent (the limit of the area within which samples are taken) (Wiens, 1992). As figure 2.3 (d) described, the boundary will become blurred on a coarse grain, and may even not be detected because the discontinuities that separate adjoining patches are leveled out within the large grain size. The ecotones that fall beyond the extent of investigation will likely not be detected. In this study the focus is on the forest/field boundary (ecotone) at a fine spatial scale. A conceptual framework for ecotone detection is developed and a specification of ecotonal characteristics is applied in landscape monitoring.

2.2 Landscape monitoring in Germany and China

Landscape monitoring is important for the protection of environment and insurance of sustainable development (Cassatella et al., 2011). Besides, a set of indicators based on landscape monitoring is necessary to fulfill a country's obligation for CBD (Convention on Biological Diversity) targets. According to the report for the project "National indicators, monitoring and reporting for CBD targets" (Bubb et al., 2011), 121 of the 193 CBD Parties has reported or referenced at least one biodiversity indicator in their 4th national report, but only 58 had evidenced indicators (e.g. with results or figures) in their report. "Coverage of protected area" and "Extent of forests and forest types" are the first and second most reported indicators. On one hand, habitat deterioration and land use change are important causes of known extinctions; on the other hand, monitoring on landscape degradation is a relative cost-efficient approach for biodiversity evaluation. Biodiversity is a broad issue which involves many sectors, such as forestry, fishery, and agriculture. It is necessary for a country to have a national office or institution with the responsibility for the coordination, analysis and communication of different information. In the following sections around biodiversity conservation the landscape monitoring system in both Germany and China will be shortly reviewed.

2.2.1 Landscape monitoring in Germany

Preserving nature has a long tradition in Germany. Particularly since the mid-eighties, nature conservation has constituted a central element of the German Government's environmental policy (BMU, 2007). In 1986 the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) was founded, followed in 1993 by the creation of the Federal Office for Nature Conservation (Bundesamt für Naturschutz, BfN). Some achievements in the conservation of biological diversity have appeared, e.g. water quality has improved and once-endangered plant and animal species are now on the increase (BMU, 2007), but more concrete efforts, e.g. building landscape monitoring systems for nature conservation, are needed to meet the targets of CBD internationally and its own national objectives on biological diversity.

2.2.1.1 Current situation of biological diversity in Germany

Germany has around 9,500 species of plant, 14,400 species of fungi and 48,000 species of animal (around 4 % of the world population of known living fauna) (BMU, 2007). The first volume of the updated version of the Red Lists for vertebrate groups in Germany (BfN, 2009) was published in 2009, including the mammals, breeding birds, reptiles, and amphibians as well as the freshwater lampreys and fish. 478 taxa, which covered the best-known taxa and all large land animals, are assessed in this volume. According to the Red Lists, a substantial number (132 taxa, just fewer than 28 % of the total) are under threat. *These* plus the 37 species (7 %) already extinct in the wild make up over a third (35 %) of assessed vertebrates. 44 taxa (9.2 %) are 'near threatened' and call for special attention because they are at risk of sliding into one of the threat categories. Reptiles are the most highly endangered vertebrate group with more than 60 % of taxa under threat. In all other vertebrate groups, less than 40 % of taxa are under threat. In the case of habitat types, over two thirds (72.5 %) of all habitat types found in Germany (the edition of the Red List (Riecken, 2006) distinguishes 690 habitat types) are classified as threatened. Two habitat types have been completely destroyed since only one type was extinct in 1994. The proportion of "critically endangered" habitat types has dropped to 13.8 %. In contrast, the proportions of endangered and vulnerable habitat types both increased. Some habitats types classified as not endangered (least concern) in 1994 have thus become endangered. This shows that some protection measures taken for "critically endangered" habitats have already had some effects, but the other habitats are facing increasing threats, even extinct risk.

From the perspective of landscape development, there have been two trends since the industrial revolution, homogenization and fragmentation, which have been evident for decades in the European landscape (Jongman and Pungetti, 2004). Large and intensifying agriculture modifies habitat diversity, field size, and crop availability (Schifferli, 2000) while rendering land monofunctional. In Germany, landscape fragmentation has increased since the end of the 19th century owing to increasing mobility and the settlement growth (Haase et al., 2007; Walz and Schumacher, 2005). For example, a research of landscape monitoring for the whole Federal State of Saxony (time span from 1780 to 2000) shows a significant decline in small quasi-linear structures (such as hedges and tree rows) and increasing fragmentation of open space by transport infrastructure (Walz, 2008).

Among the many reasons behind the threats to biodiversity in Germany (e.g. discharge of pollutants and nutrient, climate change, invasive non-native species, etc.), the landscape degradation and land use change accounted for a large proportion (BMU, 2007). Such as the construction of human settlements, transport routes, excavations, farmland consolidation, drainage, backfilling of water bodies, changes of use in agriculture and forestry. Urbanization, agriculture and industry have put increasing pressure on the functioning of landscape and nature.

2.2.1.2 Data used for landscape monitoring

On the level of Europe, the project for Coordination of Information on the Environment (CORINE) was initiated by the European Commission in 1985 for land cover mapping and it was a prototype project working on many different environmental issues (EEA, 1995). The CORINE Land Cover (CLC) map is composed of 44 classes, organized hierarchically in three levels and is available for most areas of Europe. The scale of the land cover map is fixed at 1:100,000; the Minimum Mapping Unit (MMU) is 25 ha. Linear features less than 100 m in width are not considered. The database was firstly established in 1990; afterwards, two updates of the CORINE database in years 2000 and 2006 were accomplished. It was developed to compile information on the environment topics which have priority for all members of European Union (EU). Therefore, the resolution is not sufficient for habitat monitoring at a very detailed level with regard to biodiversity.

ATIKIS Basis-DLM (Digital Landscape Model) is the official German nation-wide digital database for topographic spatial data[1] and is updated annually. ATKIS stands for "Amtliches Topographisch-Kartographisches InformationsSystem". The Basic-DLM has a scale of 1: 25,000 and its MMU is depending on the feature type 0.1 to 1 ha. The database consists of point, line, and polygon feature types which are thematically categorized into layers, such as built-up areas, vegetation, water, traffic, etc. It allows geometry overlapping of multiple layers, which means that one single landscape element may belong to multiple ATKIS layers, for example, a "forest" patch can also belong to "national park". This database contains detailed land surface information, especially on land use types from human perspective.

To improve the interoperability between national and pan-European geoinformation data sets, the Digital Landscape Model for Federal Purpose (DLM-DE) was established by the German Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG) in corporation with the Federal Environmental Agency (Umweltbundesamt, UBA). It contains areal information on land cover and land use in the sense of European nomenclature of CORINE Land Cover (CLC) at the scale 1: 50,000. The polygon layers of the ATKIS categories built-up areas, water, traffic, and vegetation have been adapted in modified form to the specific requirements of the DLM-DE. Some CLC-classes which are not included in ATKIS should be integrated in the DLM-DE, like sparsely vegetated areas, transitional woodland-shrub, natural grassland etc. The MMU for DLM-DE is 1 ha, meaning that every feature smaller than 1 ha will not be updated but only generalized to its neighboring features. DLM-DE can be seen as a mixed product between CORINE and ATKIS. It has more land cover classes than CORINE, and a higher resolution. Comparing to ATKIS, it contains additional land cover types integrated from CORINE concerning on natural area in landscape, but with a coarser resolution. The first edition of the DLM-DE was generated for the reference year 2009 and an update for the reference year 2012 is in plan.

The nation-wide land-cover databases are used not only for environmental monitoring; they serve as the basic data for various needs and concerns, such as spatial planning, security, etc. Besides the nation-wide land cover database, there are other databases which can be used for landscape monitoring, for instance, the biotope maps made by the state offices or local institutions.

[1] http://www.adv-online.de/Geotopography/ATKIS/ (Accessed October 13, 2014)

2.2.1.3 Landscape indicators for biodiversity conservation

In Germany, the indicator set for the National Strategy on Biological Diversity has been revised since the end of 2007 and was firstly presented in a standardized format in the German federal government report in 2010 (BMU, 2010). For the National Strategy's indicators, existing indicator systems at the international, European and national levels were taken into account, such as CBD's headline indicators. Some of the National Strategy's indicators refer to the "Streamlining European biodiversity indicators (SEBI 2010 indicators [2])" which has been undertaken by a Coordination Team with representatives from several organizations, such as EEA (the European Environment Agency), ECNC (the European Centre for Nature Conservation), UNEP-WCMC (the World Conservation Monitoring Centre) and others. It also makes use of reliable indicators which are proved to be useful in Germany or states of Germany. For example, the Indicator System for National Sustainable Development (German: Indikatorenberichte zur Nationalen Nachhaltigkeitsstrategie-NHS[3]), the Environmental Key Indicator System (German: Umwelt-Kernindikatorensystem-KIS[4]), and the State Initiative on Core Indicators (German: Länderinitiative Kernindikatoren-LIKI[5]). These indicator systems were founded by different federal departments concerning on environment protection and sustainability form different perspectives. NHS contains 21 key indicators which cover all areas of society for ensuring sustainable development, e.g. resource conservation, climate protection, renewable energy, land consumption, biodiversity, economic performance, air quality, health, education and so on. KIS comprises 58 indicators concerning on climate change, biodiversity, nature and landscape, health, quality of life, resource use and waste management. Within LIKI, a set of 24 environmental core indicators was developed to ensure a standard use of these indicators at a federal and state level. Biodiversity conservation is not only about protection, but also sustainable development. Parts of these indicator systems are highly related or identical to each other, and some environment-related indicators were also adopted by National Strategy on Biological Diversity.

The National Strategy contains 19 indicators assessing the environment form various aspects, including components of biological diversity (7 indicators), Settlement and transport (2 indicators), economic activity (8 indicators), climate change (1 indicator), public awareness (1 indicator). Since the research focus is on spatial analysis at landscape level, only the indicators related to habitat monitoring and land-use change are presented below.

Conservation status of Habitats Directive habitats and species

As an EU member Germany is obligated to monitor/observe the conservation status of natural habitats and species according to the Article 11of the Habitats Directive[6] of European Commission. In Germany, the responsibility for implementing the monitoring concept falls to the states. National government (acting through the Federal Agency for

[2] http://biodiversity.europa.eu/topics/sebi-indicators (Accessed October 13, 2014)

[3] http://www.bmu.de/themen/strategien-bilanzen-gesetze/nachhaltige-entwicklung/ (Accessed October 13, 2014)

[4] http://www.umweltbundesamt.de/en/press/pressinformation/what-is-state-of-environmental-protection-in (Accessed October 13, 2014)

[5] http://www.lanuv.nrw.de/liki-newsletter/ (Accessed October 13, 2014)

[6] Council Directive 92/43/EEC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1992L0043:20070101:EN:HTML (Accessed October 13, 2014)

Nature Conservation) is solely responsible for monitoring in the North Sea and Baltic Sea Exclusive Economic Zone. The Federal Agency for Nature Conservation (BfN) is responsible for data aggregation and the final assessment of conservation status at national level. The assessment of conservation status is classified into three levels shown as the colors of a traffic light: 'Favorable' (green), 'Unfavorable – inadequate' (yellow) and 'Unfavorable – bad' (red). An extra 'Unknown' category is used where assessment is not possible due to deficient data. The habitat assessment is based on the expertise, not from spatial analysis; but the habitat distribution data and maps will inevitably have impact on the assessment. To compile the index, habitats and species are weighted by the assessment result and the size of their range in each biogeographical region as a percentage of the total range in Germany. The indicator stands at 48 % for the reporting period 2001-2006. Target is 80 % in 2020 formulated in the National Strategy on Biological Diversity (BMU, 2007).

Protected areas

This indicator assesses the total size of strictly protected areas in Germany. The Nature Conservation Areas (NCAs) and National Parks (NLPs) are used in this purpose as a percentage of the German land surface. They are vital instruments in the conservation of biodiversity in Germany. Attention must also be paid to ensuring that protected areas are properly linked in an ecological network. The qualitative target is to secure the national habitat network and put Nature 2000 sites[7] under protection. A further target is to have 2 % of the German territory entirely out of human disturbance by 2020.

High nature value farmland

This indicator is used on both the Europe and the Germany level and it reports the area of High Nature Value farmland (HNV farmland) as a percentage of the total farmland area. HNV farmland is classified into three types: (1) farmland with a high proportion of semi-natural features; (2) farmland dominated by low intensity farming or a mosaic of semi-natural and cultivated land and small-scale features; (3) farmland supporting rare species or a high proportion of European or world populations of species (Andersen et al., 2003). In Germany, HVN farmland comprises species rich grassland, fallow land, species rich arable land, sparse orchards, and vineyards. Structurally rich landscape elements such as hedges, field margins, field copses and small water bodies that form part of the farmed cultural landscape are also given the status of HVN (BMU, 2010). The 2009 survey returns an indicator of 13 % for the proportion of HNV farmland area relative to the total farmland area of Germany. The target is to increase the area proportion of HNV farmland to 19 % by 2015 (BMU, 2010).

Increase in land use for settlement and transport

The increasing settlement and transport have direct environment impacts: loss of habitats, loss of fertile farmland, and loss of ecological soil services caused by surface sealing. This indicator tracks the average increase in land use for settlement and transport in Germany, measured in hectares per day. It covers land use including buildings and green spaces, recreation and cemeteries, and transport. The target was set for new land use for settlement and transport of an average daily maximum of 30 ha by 2020.

[7] EU wide network of nature protection areas under Habitat Directive, http://ec.europa.eu/environment/nature/natura2000/index_en.htm (Accessed October 13, 2014)

Landscape dissection

The indicator measures the degree of landscape fragmentation in Germany by transport networks at landscape level. It looks at the main elements of transport including roads (federal motorways, federal roads, state roads and district roads), railway lines, and canals. The assessment of the landscape dissection impact of roads also considers traffic volume, as roads with heavier traffic pose greater barriers to wildlife. Besides transport network, settlements and airports with an area in excess of 93 ha are also considered as ecological barriers (BMU, 2010). The Undissected, Low-Traffic Areas (ULTA) are defined as areas of at least 100 km^2 in size that are not fragmented by transport networks. There are two approaches to measure landscape dissection: (1) the proportion of total area of ULTA in Germany; (2) Effective Mesh Size (MESH), used for describing average connected area within the landscape (Jaeger, 2000). According to the statistics in 2000 and 2005, the proportion of ULTA declined from 26.5 % to 25.4 %, and MESH declined from 84 km^2 to 81 km^2 in Germany. In the National Strategy on Biological Diversity (BMU, 2007), the German federal government has set a target of holding constant the current proportion of ULTA as it is in 2005 (25.4 %).

In addition, the German government has developed a federal re-crosslinking program to complement the ecological network. The main aim of this program is to build Wildlife Bridges at key points in the network of ecological corridors (Fig. 2.5). A sub-indicator for evaluating the reverse effects of dissection (such as Wildlife Bridges) should be developed in the future.

Figure 2.5：	Wildlife Bridge over a federal motorway in Germany (Photo: Sarah. Walz)

2.2.2 Landscape monitoring in China

The relationship between nature and human is the basic question of Chinese philosophy. It is about harmony with nature – the "Unity of Man and Nature" – a concept with ancient roots in Chinese thought. In the long history of China, both governmental and nongovernmental limitations were set for firewood collection and fishing, which have played a role in the protection of nature. Some simple conservation ideas have emerged in the past. Although with superstitious meaning, some concepts could be recognized as the prototype as nature reserve, like "Fengshui forest" (Coggins et al., 2012) or "Dragon mountain". Another example is the evolution of greenway in China, which dates back to the Zhou Dynasty (1100-770 B.C.). It was written in the ritual that trees should be planted along moats outside each city's wall and water channels in the countryside (Yu et al., 2006). This ritual is well adhered in later dynasties and affects the country's landscape until today. Nowadays, with the speeding up process of industrialization and urbanization China is facing unprecedented pressure for nature conservation.

2.2.2.1 Current situation of biological diversity in China

According to the Fourth National Report for CBD (MEP, 2008), China has more than 35,000 species of higher plants, 6,347 species of vertebrates, 2,200 species of bryophytes, 2,600 species of ferns, 250 species of gymnosperms, and over 30,000 species of angiosperms. But around 15-20 % higher plants are under threat, 233 vertebrates are facing extinction, around 44 % of wild animals declined in their numbers, particularly non-national protected wild animals. Habitats conservation also face degrading situation. About 90 % of the grasslands are experiencing various degrees of salinization and desertification. It is estimated that 40 % of the major wetlands are facing threats of severe degradation, and coastal mudflats and mangroves particularly have suffered serious damage. On the contrary, forest coverage has maintained a sustainable growth since 1950s as a result of implementing several forestry projects and establishing national nature reserves. By the end of 2011, 2,640 nature protection sites were founded, which distributed disproportionally in mainland China and more than 50 % located in western provinces. The total area of the nature reserve is 1.49 million km^2, which accounts for about 15 % of the land territory (MEP, 2011).

In China, the structural degradation of landscape is due largely to intensive, ongoing industrialization and urbanization (MEP, 2008). Excessive reclamation, resource exploitation and overgrazing destroyed the habitats of many wild animals and plants. Massive water conservancy projects and dam constructions blocked lakes and rivers as well as the migrating channels of fish populations. Railway and highway constructions dissect the landscape and cause immediate threats to population multiplication (Li et al., 2010b). Pollution from industry and farming activities results in the extinction or reduction in the population of many species. In addition, climate change and invasion of alien species will continually threat the conservation of biodiversity.

In short, conservation of species and habitats in China is in a severe situation. The weak public awareness of sustainable consumption and lack of efficient government measurements are the main constraints on nature conservation in China.

2.2.2.2 Data used for landscape monitoring

The ecological value of China's nature reserves has been mainly under studied by the scientists from a regional perspective (Cao et al., 2013; Wang et al., 2013) or a national perspective (Li et al., 2010a; Quan et al., 2011; Wu et al., 2011). According to China's

“National Biodiversity Strategy and Action Plan (v.2) (2011-2030)”, a ten year project of nationwide biodiversity monitoring system has been announced including species types and populations, ecosystem types, area and the protection status (MEP, 2011). At present, there is no specific nationwide database for landscape monitoring in China. This does not necessarily mean that there is no relevant data to support the landscape monitoring, for example, the land survey data from the Ministry of Land and Resources (MLR). The first nationwide land survey in China began in May 1984 and ended in 1997, which took thirteen years. The second land survey began in July 2007, and finished in 2009. According to the requests of the overall program (MLR, 2007), a mapping scale of 1: 10,000 is used as the main scale; for parts of the mountains, grasslands, deserts and other regions mapping scale can reach 1:50,000; in economically developed regions and cities of the urban fringe the mapping scale can be 1:5,000 or 1:2,000. The land survey databases contain a set of results of maps and text, and other content of the outcome. The final databases contain land-use information on four levels (state-province-city-county), which include: land-use data at all four levels; land ownership at all levels; multi-source, multi-resolution remote sensing images; basic farmland information at all levels; city (county) level cadastral information (MLR, 2007).

Besides the land survey database, China would conduct its first national geographic condition census. This project was launched in January 2013 and scheduled to be completed at the end of 2015. “Geographic condition” means natural and human geographic elements on land surface. Natural elements concern on the spatial distribution of vegetation, water, desert and bare soil and other land cover types. Human geographic elements include transportation networks, residential areas and facilities, which are closely related to human activities. This nationwide database mainly serves for the country's economic development and environment monitoring. After the census, the information of geographic condition on land surface will be regularly collected and open to relevant departments.

2.2.2.3 Landscape indicators for biodiversity conservation

To meet the CBD target set at the 6th Conference of the Parties – “significantly reduce the current rate of biodiversity loss by the year 2010” (MEP, 2008), China has established 17 indicators in the 4th national report from seven aspects of the status and changes of biodiversity, ecosystem integrity and services, threats to biodiversity, sustainable development, genetic resources, financial support, and public awareness. In 2011 China has published its national biodiversity strategy and action plan (2011-2030) (MEP, 2011), which expressed its strategic goals for next twenty years, including the short term goal: by 2015 the trend of biodiversity losing can be significantly curbed in hotspot areas; the interim goal: by 2020 the loss of biodiversity will be basically under control; and a long term goal: by 2030 the biodiversity will be effectively protected. On other hand, because of the uncompleted biodiversity monitoring system in China, only limited data can be used for the assessment of the CBD targets[8] and national strategic goals (Xu et al., 2012). Since China has a large territory covering distinct biogeographic regions, establishing the indicators at landscape level would be an effective approach for nationwide biodiversity evaluation. Table 2.2 concluded the possible indicators for landscape monitoring towards the Aichi targets and national goals of China.

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[8] CBD targets for the period 2011-2020 set in the 10th Conference of the Parties. http://www.cbd.int/sp/targets/ (Accessed October 13, 2014)

Table 2.2: Possible indicators at landscape level for biodiversity assessment in China.

Indicators	*Meaning*	*References*
Area and proportion of land cover	Refers to a variety of land cover types and proportions in different periods and indicates status and trends of ecosystems.	China 4th national report (MEP, 2008)
Number and coverage of nature reserves	Coverage refers to the percentage of the area of terrestrial nature reserves to the national terrestrial area and reflects the status of in-situ conservation of biodiversity.	China 4th national report (MEP, 2008)
Area of natural ecosystems	Including forest, grassland, wetland, and desert.	(Li et al., 2011)
Integrity of natural ecosystems	Including following sub-indicators: area of desertified land and density of railways and highways.	China 4th national report (MEP, 2008)
Connectivity and dissection of landscape	Indicates the dissection of China's landscape by roads and urban areas, e.g. effective mesh size.	(BMU, 2010; Li et al., 2011; Li et al., 2010b)
Area and habitat quality of important ecosystems	Habitat quality can be described using the "traffic light" approach which is used in Europe (see detailed method in references).	(BMU, 2010; Defra, 2012; Li et al., 2011)
City expansion and road construction	Refers to the average increase in land use for settlement and transport.	(BMU, 2010; Li et al., 2011)
High nature value farmland	Defined as the area of high nature value farmland (HNV farmland) as a percentage of the total farmland area (see in references).	(Andersen et al., 2003; BMU, 2010; Paracchini et al., 2008; Pointereau et al., 2007)
Grassland affected by overgrazing	Overgrazing is the main driving force for grassland degradation in China. This indicator measures how overgrazing directly affect grassland, for example sheep density in pasture land.	(Li et al., 2011)

Some of the presented indicators in Table 2.2 have already been included in the 4th national report of China, and analyzed in the report based on the existing data. Other recommended indicators which have been used at the European or state levels can be the potential indicators incorporated in the landscape monitoring system for China, for example, the conservation status of habitats which is used in Germany under the Habitat Directive of Europe (BMU, 2010). The indicator "effective mesh size", which is a well-established indicator mostly used for assessing landscape fragmentation, has also been tested at the national level in China (Li et al., 2010a). For the national HNV farmland indicator, China may refer to the method using land cover data with relatively low resolution as it is calculated for Europe based on CORINE land cover data (Paracchini et al., 2008). For the region densely covered by agriculture, the monitoring method for HNV farmland applied in Germany (BMU, 2010) or France (Pointereau et al., 2007) would be appropriate at a detailed level. As 90 % of grassland in China is experiencing degradation, an indicator for assessing grassland status is necessary, such as grassland affected by overgrazing. The targets for these indicators should be set considering both the CBD targets and China's national objectives based on the current situation from the social and economic development.

2.3 Summary

Biodiversity loss as a global issue refers to every scale levels. Habitat diversity is an essential level of biological diversity, because it determines the species diversity and genetic diversity. In order to meet the targets for biodiversity conservation, it is necessary to establish the monitoring system and relative indicators at landscape level. As concluded in this chapter small biotopes and ecotones supply important ecological functions for landscape integrity, thus they should also be monitored and integrated in the landscape metrics for describing the landscape composition and structure. For example, the small biotopes are considered as key factors for the indicator of HNV farmland. In chapter 3 the proposed method of integrating small biotopes and ecotones for landscape structure analysis will be presented.

3 An enhanced approach for landscape structure analysis

In the previous chapters, the shortcomings of the traditional mosaic model were provided. In particular, the small biotopes and ecotones which are ecologically meaningful are normally absent in landscape structure analysis. The approach proposed in this chapter for dealing with these shortcomings mainly contains two parts. In chapter 3.2 a general land-cover classification procedure is described, which integrates both Object-Based Image Analysis (OBIA) and Pixel-Based Image Analysis (PBIA) using the high resolution lidar (light detection and ranging) data and multispectral images (RapidEye data). It demonstrates a data fusion concept for land use classification and the detection of fine-scale landscape elements. Chapter 3.3 presents several modified 3D-Metrics that can incorporate the small biotopes and ecotones in the landscape structure analysis. The ecological functions of these fine-scale landscape elements are measured from three aspects: landscape diversity, landscape fragmentation/connectivity, and landscape contrast.

3.1 Data basis

Using aerial photographs, Carl Troll (1939) has mapped the patterns and arrangements of landscape units for the first time, which means that he conducted ecological investigations on a landscape level. Subsequently he originally coined the term "landscape ecology" (in German "Landschaftsökologie" (Troll, 1950, 1963)). From the birth of landscape ecology we can see, remote sensing has been an important tool for recognizing the landscape pattern. The development of the remote sensing technology, particularly with the wide spread of high resolution remote sensing imagery, makes the Earth observation more extensive and more accurate. It is the basis of image understanding to extract and recognize geographic object information from remotely sensed images. In high spatial resolution images, the information about land surface is extremely rich and textural feature is prominent (Neubert, 2006). In addition, the availability of high-resolution digital elevation data gives new possibilities to understand the landscape structure in a three dimensional perspective (Hoechstetter, 2009). As the data basis for landscape monitoring, only regularly collected data is considered. Therefore, the focus is on the extraction of landscape elements from remote sensing data, land-use maps and digital surface models from official land survey.

3.1.1 RapidEye images

Since 2009, new remote sensing data from the RapidEye satellite has become available. RapidEye is a German, five satellite constellation; each satellite has five spectral bands (blue, green, red, red edge and near infrared) with a 6.5 meter nominal ground resolution (resampled to 5 m pixel size). It offers different levels (e.g. 1B and 3A) of standard image products in a format that can be easily integrated into any Geographic Information System (GIS). For the RapidEye basic product (1B) delivered with radiometric and sensor correction but without any further corrections for any terrain distortions. The RapidEye ortho product (3A) is subject to radiometric, sensor and geometric corrections and the images are rectified using a SRTM (Shuttle Radar Topography Mission) DEM (level 1) or better.