Applying Objective Data for a Multi Temporal Analysis of Habitat Suitability Indices to Monitor Biodiversity – A Case Study for the Example Key Species Red Kite (*Milvus milvus*) and Black Stork (*Ciconia nigra*)

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SUMMARY

The study describes the potential of various habitat suitability indices (HSI) using remotely sensed data (Landsat 5 and 7) and other mapped information in digital format for the characterization and monitoring of rare species habitats at the landscape level over time. The main focus was to develop a flexible and open system for habitat monitoring which allows a pragmatic overview of habitat development for a rare or umbrella species without field assessments, or with very limited field assessments. Habitat suitability is derived by a modelling approach that integrates objective information of natural conditions. Areas of habitat loss and habitat gain can be identified by modelling habitat suitability for different occasions. In addition the model can be used to predict the effect of human induced changes on the environment and on habitat suitability.

The approach concentrates on potential attributes of two example habitats for the key species Red Kite *(Milvus milvus)* and Black Stork *(Ciconia nigra)*. The potential HSI models are analysed with regard to their sensitivity to changing environmental conditions, and also with regard to the influences of individual attributes used as input for the models. To test the HSI models a heterogeneous landscape with a combination of different landscape elements such as lakes, meadows, agricultural land, and forested areas was needed. Therefore the landscape around the village Moritzburg, located close to the city of Dresden, Germany was selected as the test site. It is characterised by a pronounced heterogeneity of landscape elements such as forests, meadows and lakes.

The remote sensing (RS) data for the year 2000 were combined with ground data collected in the field campaign of the research project "MNTFR"[1]. In addition, the database "Datenspeicher Wald" provided forest information for the year 1989 based on the forest

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[1] FAIR CT98 4045 www.forst.tu-dresden.de/Informatik/mntfr/

inventories at the company level. Attributes, based on Natura 2000, such as food supply or nesting resources, were utilised as input for HSI models. The in situ data were combined with satellite data using a spatial statistic approach called kNN method for extending in situ attributes to the entire area of interest. KNN classifies the remote sensing data according to their spectral information, after the in situ data were matched with the relevant pixel information in the Landsat images. Habitat suitability maps for both occasions (1989 and 2000) were compared for the individual key species.

The combination of the Landsat data with the ground data applying the kNN method for both occasions underlay the three HSI models tested in this study:

1. The **Habitat Suitability Index (HSI)** with binary attribute maps

2. The **Enhanced Habitat Suitability Index (EHSI)** applying binary attribute maps enhanced with fuzzy sets

3. The **Habitat Suitability Index with Home Rage Aspect (HR-HSI)** applying recalculated attribute maps with an activity radius of 200 m for each pixel.

Each of these HSI models includes two levels of consideration: the attribute level and the life requisite level. In all three HSI models a number of weighted attributes, e.g. “timber volume” indicating patches with forests of more than 300m³ timber volume per hectare and “open forests” indicating patches with a canopy cover of 15%, are added to one life requisite called “nesting”. Within the final habitat modelling procedure the combination of life requisites such as “nesting” as well as the life requisites for “food” and “safety” requirements was realised with two different approaches for each model:

- The multiplicative approach with multiplicative combination of life requisites resulted in the original models **HSI**, the **EHSI** and **HR-HSI** and

- The summation approach with additive recombination of life requisites resulted in the models **HSI+**, **EHSI+** and the **HR-HSI+**

The suitability of the life requisite “safety” for Black Stork could not be detected with the HSI in the test site. Because of the tourism in the Moritzburg area there is a high density of roads and hiking paths, and consequently none of the area meets the safety requirements reflected by the attribute “infrastructure distance of minimum 3 km”. The area is also too densely populated and there were not any areas with a “resident population of less than 100 inhabitants/km², what describes the second attribute for the life requisite “safety”. Therefore the other models were not used to investigate the habitat suitability for Black Stork.

A sensitivity analysis was applied to show the influence of the individual attributes in the HSI model itself, and the different effects of the various combinations of life requisites within the original HSI model and the combinations of attributes due to the test site conditions. The sensitivity analysis was realised with a seven digit habitat image including the presence of all attributes in each image digit. Thus the influence of each attribute in the entire HSI model results could be analysed.

The HSI model indicates that from 1989 to 2000 the area of potential habitat suitability for Red Kite increased from 4,5% to 7,8% of the test site area. However, most of the patches indicating suitable habitats can be found in different locations in 2000. The HSI+ model applying an additive recombination of life requisites resulted in an increase of areas with potential habitat suitability of more than 8% of the test site area. The potential habitat suitability for the Black Stork could not be detected due to the high resident human population and the many recreation facilities around Moritzburg. These attributes are important components of the life requisite “safety”.

An EHSI model was realised by applying fuzzy sets on each attribute map. Within the fuzzy implementation a membership function simulates the linear decrease of the attribute probability from the patch borderline with the value 1 to 0 at a defined distance of 150 m. According to the EHSI model the area of potential habitat suitability increased from close to 32% to nearly 53% of the test site area from 1989 to 2000. The EHSI+ model applying an additive recombination of life requisites resulted in a decrease of areas with potential habitat suitability of more than 8% of the test site area between 1989 and 2000.

A potential habitat change assuming higher timber volumes in forests as a consequence of the desire to increase the carbon stock under the Kyoto Protocol’s Article 3.4 was simulated. The simulation resulted in a habitat suitability decrease in more than 55% of the test site area.

The habitat suitability index with home range aspects (HR-HSI) on attribute level indicates an increase of habitat suitability from nearly 13% to over 74% of the test site area between 1989 and 2000. For the approach applying an additive recombination of life requisites (HR-HSI+) the area of potential habitat suitability increases from about 33% to more than 66% of the test site area from 1989 to 2000. This is nearly half of the increase resulting in the multiplicative approach (HR-HSI).

All HSI model variations (HSI+, EHSI+ and HR-HSI+) with an additive recombination of life requisites detected more habitat losses, than the approaches applying a multiplicative combination of life requisites. The additional habitat losses caused by a drained lake in the north-eastern part of the test site were detected similarly by all variations of the HSI models with additive recombination of life requisites. Therefore the approach with summation of life requisites was chosen as the preferred model approach because of its sensitivity to detect more potential habitat changes, than the approach with multiplicative combination of life requisites. A multiplicative combination can be useful in identifying special quality requirements such as water quality.

While all HSI models are able to detect habitat changes and to predict future habitat development, the EHSI model proved to be efficient to enhance purely binary data into discrete transition probabilities along suitable pixel with a decreasing probability within a distance of 150 m. The HR-HSI model proved to be useful in describing neighbourhood relations of habitat attributes. It offers a graduation of habitat potentials calculating continuous transition probabilities. According to the assumed life requisite weights within the study the HR-HSI model is sensitive for areas of minimum 25 hectares indicating potential habitat loss or gain in the test site. The graduation of the habitat values and the definition of thresholds, even on the life requisite level, can support decision- and policy-making concerning landscape management, as well as enabling simulation of changing individual attributes.

The study tested whether a HSI model could derive objective habitat suitability information and detect potential habitat changes over time. Depending on the aims, the scale of application can vary from local to regional to national and multinational level. The HSI models were applied as an open system in terms of new knowledge achievements and additional sources of objective data. The effects of land-use and land-cover changes on the potential habitats of key species can be predicted; what opens the potential to implement the approach into decision processes for sustainable land-use planning with respect to biodiversity conservation. The study concentrated on the principal possibilities of HSI models with objective data sources on landscape level. The main obstacle to a successive implementation of the HSI models is a comprehensive description of factors driving habitat suitability that have hardly been presented in quantitative terms. Therefore an interdisciplinary knowledge transfer is recommended to realise the transition to an operational level implementing quantitative information of species specific requirements for habitat suitability modelling. The applied HSI models for Red Kite are tested with the available data in one selected test site; the results of the HSI models themselves have the character of a case study. Therefore the results cannot be generalised so far. The focus of the study was to investigate the detection of potential habitat changes, the sensitivity, and the role of the selected attributes and their combinations and weights. In order to apply the HSI models at an operational level, the species specific definitions of real habitat values for species like the Red Kite or others still have to be investigated. Attributes and life requisites with their weights still have to be defined and verified for other species or umbrella species of interest. The variability of the results show, that quantitative information for a sufficient description of complex wild life habitats requirements are still needed to achieve relevant information for a habitat modelling in operational terms.

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1 INTRODUCTION

During the last decades greater emphasis has been placed on biodiversity in terms of sustainable development and use of natural resources. During the United Nations Conference on Environment and Development (UNEP 1992) in Rio de Janeiro, biodiversity, defined as the "variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part" was recognised as an essential issue. Most European countries have ratified the "Convention of Biological Diversity" (CBD). The affiliated EU activities included the "Ministerial Conference on the Protection of Forests in Europe" (MCPFE)[1], in which Resolution H2 "General Guidelines for the conservation of biodiversity of European forests" was adopted, because forests were found to be the landscape element, which encompasses the greatest part of the entire biodiversity. Within the MCPFE "Environment for Europe" initiative the "Pan-European Biological and Landscape Diversity Strategy" was defined. Further the EU ratified conventions related to the safety of biodiversity, e.g. the NATURA 2000 and the Fauna, Flora and Habitats (FFH) Directive (EC 1992), as well as the Biodiversity Strategy (EC 1998). Besides a number of national initiatives the European Environmental Agency (EEA) is monitoring the state of the European environment.

The complexity of the concept of biodiversity necessitates the development of different criteria, indicators and factors for practical measurements and monitoring purposes, for instance in the Temperate and Boreal Forest Resources Assessment (TBFRA 2000), or in the BEAR-project (LARSSON ET AL. 2001). Additionally the monitoring purposes on European level need harmonisation of definitions (e.g. KÖHL AND PÄIVINEN 1996). In Europe there is a pronounced regional diversity in ecosystems depending on ecoregions,

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[1] Formally the "Helsinki Process"

social systems, forest history, and ownership structures (ANDERSSON ET AL. 2000). To assess biodiversity, especially on large scales such as across the European Union, the concept of key or umbrella species are widely accepted as indicators of the biodiversity and ecological potential of a particular region (MCPFE, 1998; PUUMALAINEN, 2001). The main purpose of the national initiatives and the EEA is to monitor biodiversity, while political decisions can influence landscape changes dramatically. This requires objective information about the implications of political decisions.

”Diversity” is a generic term referring to the condition of being different; a useful synonym for diversity is variety. Measures of diversity can be used as an indicator of qualitative characteristics (e.g., tree diameter) like variance can be used as a measure of quantitative characteristics (e.g. tree species) (PIELOU 1975). On the landscape level diversity indices as measures for e.g. quantifying the biodiversity of a habitat through the amount of species within a defined area (SHANNON AND WEAVER 1949) have been developed. Diversity indices are e.g. the number of individuals or even species in a defined area of interest (PATIL AND RAO 1994). Landscape indices are statistical measures to describe the structure of any landscape (MCGARIGAL AND MARKS 1994, OEHMICHEN 2001, O´NEILL ET AL. 1988, WALZ 1999). Both, the landscape indices and the diversity indices quantify biodiversity in more or less useful ways (KÖHL AND ZINGG 1996). However, the prediction of the effects of political decisions on landscapes and habitat suitability is limited especially in the case of those species that use specific habitats in landscapes with diverging structures. Simulation and modelling of habitats can offer politically relevant information by forecasting the implications of potential land use activities on spatial and temporal scales.

Many of the international reporting obligations require frequent and detailed information. The combination of former assessments and inventories with new technologies like remote sensing (RS) or geographical information systems (GIS) offer an opportunity to increase efficiency and reliability of temporal and spatial information concerning natural resources. The habitat suitability index (HSI) model is based on the application of ancillary data such as Landsat TM imagery in combination with in situ data using the k-nearest neighbour (kNN) classification method. The kNN algorithms are applied using GIS and modern image analysis software to ensure an efficient, but also flexible means of retrospective landscape analysis in terms of habitat suitability modelling.

The objective of this study is to develop an appraisal concerning the potential of habitat models for early warning and decision support properties applying a simulation of potential habitat change as a consequence of different policies. The approach chosen is concentrating on the concept of key species´ habitats, which are analysed with regard to their sensitivity to changing environmental conditions and also with regard to the influences of individual attributes used as input for the HSI models studied. The approach allows predicting the effect of political decision scenarios by an open model like the presented HSI. The HSI models reflect the potential habitat suitability as an assumption of the real habitat requirements of the two example key species, Red Kite (*Milvus milvus*) and Black Stork (*Ciconia nigra*). The results are verified by the application of the HSI models in a test area located close to the city of Dresden in Moritzburg, Germany. The test area was chosen because of its heterogeneity of landscape elements e.g. agricultural land, lakes, meadows or forested areas. The heterogeneous landscape structure is preferred by the Red Kite, whereas the Black Stork prefers a more homogeneous landscape structures with old more-or-less even-aged broadleaved tree forest stands. Both key species, which can be found in several rare species lists, are expected to be sensitive towards small scale changing conditions. This is verified within a retrospective habitat change analysis applied in the test site. For Red Kite an enhanced habitat model with fuzzy logic (EHSI) is applied by simulating a linear decrease of the attribute probability from the patch borderline with the value 1 to the value 0 at a distance of 150 m. The EHSI enhances purely binary data into discrete transition probabilities along patch borderlines. Furthermore the model for Red Kite was extended with a home range approach (HR-HSI). It allows considering the relevance of suitable attributes patches in a distances of 200 m by adding all suitable attribute pixels to the central pixel of interest as the potential position of the key species. The results of the home range approach are continuous transition probabilities, which allow the classification of different habitat suitability intensities with respect to neighbourhood relations.

All approaches were also applied in a retrospective habitat change analysis for Red Kite in the Moritzburg test site. All variations of the habitat suitability index – the Habitat Suitability Index (HSI) with binary attribute maps, the Enhanced Habitat Suitability Index (EHSI) applying binary attribute maps enhanced with fuzzy sets, and the Habitat Suitability Index with Home Rage aspect (HR-HSI) applying recalculated attribute maps with an activity radius of 200 m for each pixel – were applied with a multiplicative and an additive recombination of life requisites.

The following aspects are covered in this study:

- Biodiversity assessment in terms of a species specific approach with the application of a habitat suitability index (HSI) on the landscape level,
- Adaptation of the FFH Directive habitat requirements for the two example key species Red Kite and Black Stork, in the HSI model,
- Application of remotely sensed data in combination (kNN method) with field data and application of additional GIS layers as attribute maps
- Modelling the HSI with combination of both digital mapped GIS information and remotely sensed data,
- Application of the HSI in the test site "Moritzburg" close to Dresden, Germany,
- Sensitivity analysis of the HSI model in terms of attribute weights in the theoretical model and with regard to the conditions in the test site,
- Enhancement of the HSI model with a fuzzy set implementation to create an improved species specific relevance (EHSI),
- Application of a home range approach to reflect the spatial aspects of species specific activity areas for the model (HR-HSI),
- Analysis of the HSI, EHSI and HR-HSI with respect to a multi-temporal monitoring approach,
- Analysis of the habitat suitability indices with respect to its sensitivity to changing conditions applying a multiplicative (HSI, EHSI, HR-HIS) and an additive recombination of life requisites (HIS+, EHSI+, HR-HIS+),
- Simulation of potential habitat suitability changes as a consequence of different policies.

1.1 SCOPE OF THE STUDY

The habitat time series were developed within the scope of the research project “Development of Methods and Tools for Monitoring Forest Biodiversity as a contribution to sustainable development in Europe” (DMMD) (http://www.resgeom.slu.se/stax/projekt/dmmd/) funded by the European Commission[2]. Additionally the in situ data sources for 2000 were made available by the research project “Scale Dependent Monitoring of Non-Timber Forest Resources Assessed in Various Data Sources” (http://www.forst.tu-dresden.de/Informatik/mntfr/)[3]. The kNN method was applied and tested within the project “Kombination von terrestrischen Aufnahmen und Fernerkundungsdaten mit Hilfe der kNN-Methode zur Kartierung von Waldökosystemen”[4] funded by the German Aerospace Centre (DLR). All projects were established and finalised in close cooperation at the former Chair of Forest Biometric and Computer Sciences at the Dresden University of Technology.

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[2] Contract No 16182-2000-05 F1ED ISP SE

[3] FAIR CT98 4045

[4] Combining in situ data and remotely sensed data with the kNN method for forest ecosystem mapping (FKZ 50 EE 0037).

2 STATE OF THE ART

In this section an overview of the relevant fields of research for the applied approach is given. Biodiversity is defined and further described in chapter 3.1. Because the scale chosen for this study was the landscape, a review of landscape analyse methods (3.2) followed by brief descriptions of remote sensing techniques (3.3) are given. The habitat suitability modelling used GIS with the main objective of keeping the applied model open for adaptations of additional spatial information, additional species and additional model components. The potential of GIS in terms of modelling procedures is summarised in chapter 3.4. Modelling of habitats is one way of monitoring wildlife – modelling approaches are summarised in chapter 3.5. The emphasis in this chapter is placed on the state of the art of habitat modelling and the underlying habitat concept (3.5).

2.1 BIODIVERSITY

The United Nations Convention of Biological Diversity (CBD) (UNEP 1992) gave the following definition of biodiversity: “The variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part.” The MILLENNIUM ECOSYSTEM ASSESSMENT (2005) defined biodiversity as “the diversity among living organisms in terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. It includes diversity within and between species and the diversity of ecosystems.”

The literature review presents a selection of concepts in order to provide an overview of the topic and to introduce possible impacts for this work. Especially during the last decade a large number of papers have been published that give a variety of definitions of biodiversity or biological diversity.

Due to the fact that biodiversity is a complex concept and approached in several, sometimes diverging ways, it was necessary to establish a common understanding of the concept of biodiversity. Biodiversity is a central concept in quantitative ecology (RICOTTA AND AVENA 2000). In particular, the mechanisms underlying the relationship between species abundance and ecosystem functional properties, e.g. productivity, have been studied extensively for many decades and are still the subject of debate (TILMAN 1994, GRIME 1998). HURLBERT (1971) wrote an essay on the "non-concept of species diversity" as a result of the scarcity of unambiguous results along with a lack of an agreed-upon definition of biodiversity itself. In the 1970s biodiversity was seen as "species rarity within a community" (PATIL AND TAILLIE 1979) while it developed to "species relative abundance" in the 1980s.

An informative overview about the diversity of the term biological diversity is given by KAENNEL (1998). She describes the multiple developments of new terms and understandings under an increasing political awareness of the importance of biological diversity. The number of scientific references including terms "biodiversity" or "biological diversity" increased from around 20 at the beginning of the 1990s to over 250 in autumn 1996 (KAENNEL 1998). The given definitions were improved by introducing a spatial and temporal framework by the UNEP (1992) or, BISBY ET AL. (1995). RICOTTA AND AVENA (2000) proposed "the distribution of absolute biomass values among communities, species or even functional groups", referring to HOOPER AND VITOUSEK (1997), as a more functional definition of biodiversity. SWINGLAND (2001) provides a general definition of biodiversity and biological diversity in the Encyclopedia of Biodiversity: "Species, genetic and ecosystem diversity in an area, sometimes including associated abiotic components such as landscape features, drainage systems, and climate."

A distinction should be made between the terms "biodiversity" and "diversity" (MCMINN 1991). "Biodiversity" is an omnibus concept that incorporates the variety of life in all its forms from organic molecules, to species, to communities, landscapes, and biomes (MCMINN 1991, OFFICE OF TECHNOLOGY ASSESSMENT 1987). "Diversity", on the other hand, is a generic term referring to the condition of being different; a useful synonym for diversity is variety. It summarises for qualitative characteristics what the variance summarises for quantitative measurements (e.g., tree diameter) (PIELOU 1975).

Among manifold of definitions of biodiversity the U.S Congress (OFFICE OF TECHNOLOGY ASSESSMENT 1987), defined biodiversity as: “The variety and variability among living organisms, and the ecological complexes in which they live, encompassing genetic, species, ecosystem, and landscape levels”. This definition has become a widely accepted definition of biodiversity. However, there are authors that argue that a definition including ecosystems is not consistent with the ‘bio‘- part of biodiversity since ecosystems include the abiotic, non-living environment (DELONG 1996, DUNSTER AND DUNSTER 1996). The terms biodiversity and biological diversity are more and more used synonymously (KAENNEL 1998). The terminological confusion developed over the years and no agreement is expected to be achieved in the near future.

In a terminological survey CROW ET AL. (1994) identified a generic relationship involving three types of biodiversity: compositional-, structural- and functional biodiversity (Figure 1).

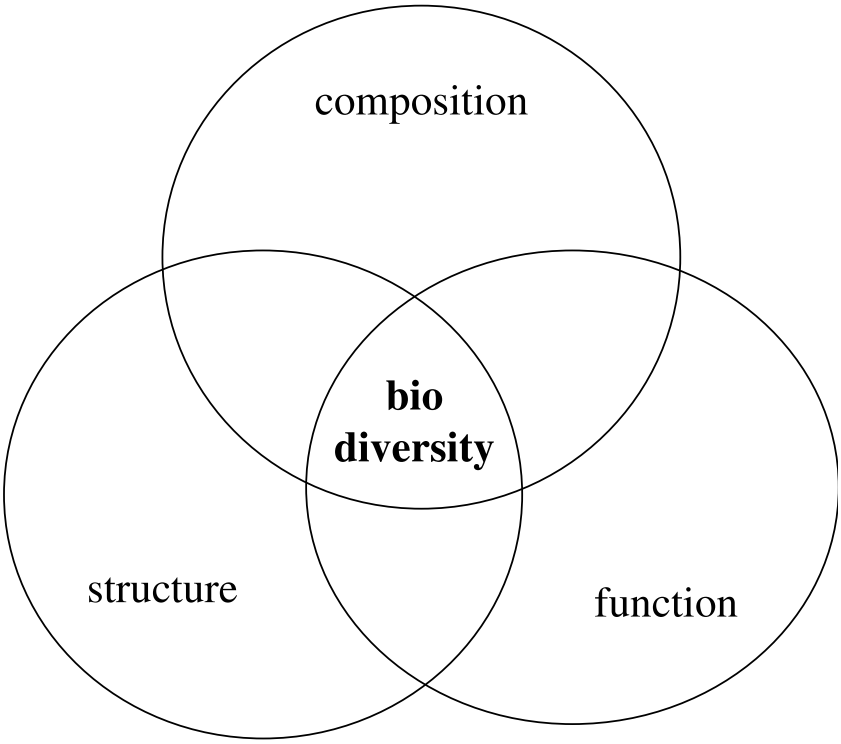


Figure 1 Concepts of biodiversity (Crow et al., 1994)

PUUMALAINEN (2001) states that forest biodiversity can be expressed both in terms of quality and quantity. She also argues that the forest area itself is one important criterion for biodiversity, but that this criterion must be used in combination with descriptions of the biological qualities of the same area.

Management requires objective information with appropriate measurement, and measures of diversity only become possible when some quantitative value can be ascribed and these values relate to a common reference or standard so that they can be compared. It is thus necessary to try to disentangle some of the separate elements of which biodiversity is composed. According to the World Resources Institute (WRI), The International Union for Conservation of Nature (IUCN), and United Nations Environment Programme (UNEP, 1992) biodiversity is the totality of genes, species, and ecosystems in a region. Biodiversity can be divided into three hierarchical categories - genes, species, and ecosystems - that describe quite different aspects of living systems (UNEP, 1992). In this concept genetic diversity, species diversity, and ecosystem diversity are all relevant, but very different entities. In addition, to meet specific management or policy goals, it is often important to examine not only compositional diversity - genes, species, and ecosystems - but also diversity in ecosystem structure and function.

In the EUNIS Habitat Classification glossary the following definitions are given (http://eunis.eea.eu.int/index.jsp):

Genetic diversity: the variation between individuals and between populations within a species;

Species diversity: the different types of plants, animals and other life forms within a region;

Community or ecosystem diversity: the variety of habitats found within an area (grassland, marsh, and woodland for instance).

According to MEFFE (1994) biodiversity is the variety of living organisms considered at all levels from genetics to through species, to higher taxonomic levels, and including the variety of habitats and ecosystems. DUNSTER AND DUNSTER (1996) defined five levels of biodiversity: genetic, taxonomic or organism, ecosystem, level of function or ecological services, and the level of abiotic matrix through time and scale.

It is widely accepted that the different scales of biodiversity can be characterised by the following definitions (WHITTAKER 1972):

Alpha (α) diversity

Alpha (α) diversity is within-area diversity, measured as the number of species occurring within an area of a given size. It therefore measures the richness of a potentially interactive assemblage of species (BISBY ET AL. 1995), the diversity of species, and the complexity of community structure in a particular ecosystem. Species diversity may simply be species richness (number of species) or one of several indices that combine species richness with some measure of relative commonness or rareness (species evenness), or some other measure of the relative abundance of species.

Beta (β) diversity

Beta (β) diversity was introduced to indicate the degree of species change, along a given habitat or physiographic gradient. As such it is a measure of between-area diversity. It is normally represented in terms of the similarity index or of a species turnover rate (BISBY ET AL. 1995). It is also described as the diversity between or among more than one community or along an environmental gradient.

Gamma (γ) diversity

Gamma (γ) diversity is also a measure of within-area diversity; however, it usually refers to overall diversity within a large region and its comprehension has direct connotations for dealing with biodiversity at the landscape level (BISBY ET AL. 1995). γ-diversity describes the diversity in a country or in its bio-geographical regions. The number of species is determined largely by changes in the populations of threatened species: it decreases when the last representative of such species disappear from a region and increases if species succeed in establishing themselves or returning to the region and when new species evolve (BISCHOFF AND DRÖSCHMEIER 2000).

Table 1 Diversity scales (according to Bischoff and Dröschmeier 2000)

	α - diversity	β - diversity	γ - diversity
Definition	Diversity within a habitat	Diversity within a mosaic of habitats, including borderline effects	Diversity in a bio geographical region/ country
Pressure	-Nutrients -Structure -Access techniques -Management	-Heterogeneity -Length of border -Size of areas of a defined area type	-Area shift -Species formation -Species extinction
Major protection strategy	Develop/optimise access techniques	-Biotope protection -Compensatory areas -Biotope networking	-Species protection -Reintegration -Large corridors -Possibly isolation
Assumed development in the 1990s	Reduction (except perhaps in woods and settlements)	-Increase in lowland areas -Decrease in mountains	-Increase in Switzerland (e.g.)
Sensitive species	Common widespread species	Widespread, uncommon species	Rare species
Suitable size of unit	Units of a defined area type	-Regions -Altitude bands	Bio-geographical regions

The use of remote sensing for the assessment of biodiversity is based on the premise that a relationship exists between (a) the composition and structure of the landscape and its units, and (b) the diversity of ecosystems, species and genotypes that may be present within it or them (INNES AND KOCH 1998). Even if this relationship is not straightforward in all cases, potential habitats e.g. for rare bird species can be found via remote sensing and GIS data (JONGMAN, 2000). The HSI model is based on remote sensing and GIS application and thus mainly considers the visible elements of biodiversity on this scale. According to CROW

ET AL. (1994) the approach of the HSI correlates to the structural- and the compositional biodiversity types (Figure 1). The HSI is a species specific analysis of landscape structure with focus on the ecological potential of a landscape, which can be measured indirectly, for example with remote sensing and GIS. Analysis on the landscape level based on remote sensing data like the HSI is often working with defined landscape elements.

2.2 LANDSCAPE ANALYSIS

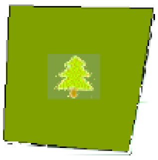
A landscape can be thought of as a hierarchically organised system (FORMAN AND GODRON 1986). In order to understand the landscape, and to be able to predict changes, three linkages must be known. Each landscape element is linked to the: 1) encompassing element at the next higher level; 2) nearby elements at the same scale; and 3) component elements at the next lower level. Each level in the hierarchy represents a single scale, from fine grained to coarse grained (FORMAN 1995). Assessment of biodiversity needs to be undertaken at several different scales. TURNER (1989) warns that the value of any such measurement is a function of how landscape units are classified. Within this aspect, a lot of estimation errors are expected. Classes that might be appropriately defined at one scale might disappear at a more generalised scale (TURNER 1990). Therefore, both class definitions and scale must be carefully considered in analysis of landscape structure (BLACKBURN AND MITLON 1996); and the assessment of biodiversity might also need to be undertaken at several different scales. Especially the combination of different ground measurements is essential for biodiversity monitoring (INNES AND KOCH, 1998).

A number of investigations deal with the relation between spatial structures and ecological processes. According to MCGARIGAL AND MARKS (1994) the structure of a landscape is defined as:"...the distribution of energy, materials and species in relation to the sizes, shapes, numbers, kinds and configurations of landscape elements or ecosystems". In the wide sense, this is the spatial relation of ecosystems or elements in general. The two other basic components of landscape ecology are: 1) "function", the interactions among the spatial elements, that is, the flows of energy, materials, and species among the component ecosystems, and 2) "change", the alteration in the structure and function of the ecological mosaic over time (MCGARIGAL AND MARKS, 1994).

During recent years, many studies in quantitative methodologies for describing spatial distribution patterns, shape of areas and fragmentation of landscape elements have been done

(McGarigal and Marks 1994, O´Neill et al. 1988, Walz 1999). The need for this development was pointed out by Turner and Gardner (1991):" ...landscape-level research requires new methods to quantify landscape patterns, compare landscapes, identify significant differences, and determine relationships of functional processes to landscape patterns....". For monitoring and assessment of landscapes, there are three different levels or scales to take into account: the patch, the class and the landscape.

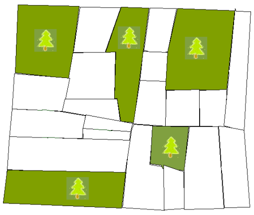
Patch:



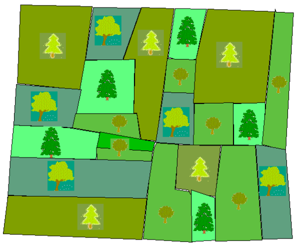
The patch is the smallest unit of a landscape, which is mainly homogeneous with respect to some attribute (Theobald, 1998), for example an old spruce stand. Landscape ecologists have used a variety of terms to refer to the basic elements or units that makes up a landscape, including ecotope, biotope, landscape component, landscape element, landscape unit, landscape cell, geotope, facies, habitat, and site (Forman and Godron, 1986). Like the landscape, patches comprising the landscape are not self-evident; patches must be defined relative to the phenomenon under consideration. For example, from a timber management perspective a patch may correspond to a forest stand. Walz (1999) emphasized that "landscape element" is the most correct and neutral term for the patch.

Class:

The next level is the class. A class includes every landscape element of the same type, for instance all old spruce stands of a landscape.



Landscape:



For every scale, from the species level to the bio-geographical area, the environment consists of a mosaic of landscape elements which is described as a "patch mosaic". All the patches and the mosaic of the patches constitute the landscape, which is a "heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar forms throughout" (Gardner and Turner, 1991). For forestry, this could be a forest landscape with the classes ”old spruce stands”, ”young beech stands”, and ”pine forests”. From the wildlife perspective, landscape could be defined as an area of land containing a mosaic of habitat patches, often within a particular “focal” or “target” habitat patch which is embedded (DUNNING ET AL. 1992). Because different organisms requiring different habitat patches such as lakes or single old trees at different scales, landscape size will differ among organisms.

If habitat suitability should be described at landscape scale where e.g. Landsat imagery should be included as ancillary data, the images need to be classified according to the requirements of the species of interest. The resolution needs to be different depending on species. A reasonable approach is to define the activity range of different species as the area that should be considered when looking at the landscape composition from a given point. Analysis of the different landscape elements were very often done with the diversity indices such as SHANNON AND WEAVER (1949) and were found to be of limited applicability (KÖHL AND OEHMICHEN 2003). KÖHL AND ZINGG (1996) found, that the main indices “Shannon, Simpson, species richness and species count” were not sufficient to describe the development of species abundance over time.

Ecologists have long acknowledged the importance of ecotones, zones of transition between adjacent ecological systems. Such transition zones were historically viewed as areas of exchange or competition between adjacent ecological communities (CLEMENTS 1905). They commonly contain more species and higher population densities than either community flanking the ecotones (ODUM 1971). In this view, early wildlife management efforts were focused on maximizing edge habitat because it was believed that most species favoured habitat conditions created by edges and that the juxtaposition of different habitats would increase species diversity (LEOPOLD 1933, DASMANN 1964).

Nevertheless, studies of, for example, DI CASTRI ET AL. (1988), RISSER (1995) have suggested that increasing the amount of edges has resulted in the population declines of several species dependent upon forest interior conditions and that most of the adverse effects of forest fragmentation on organisms seem to be directly or indirectly related to edge effects (JOHNSTON AND BONDE 1989). As a consequence, it is now widely accepted that edge effects must be viewed from an organism centred perspective because edge effects influence organisms differently; some species have an affinity for edges, some are unaffected and others (mainly interior species) are adversely affected.

Human activities have increasingly altered the extent of ecotones throughout the world, and may have altered the mediating role of ecotones in maintaining ecological flows between ecosystems. Furthermore, ecotones may be useful indicators of ecological change due to global warming, because ecotones occur where plant species are at the extreme limits of tolerance for change.

Therefore, the total amount of edge in a landscape is important to many ecological phenomena. In addition, edge distribution across the landscape (i.e., local amount of edge) is often the most critical piece of information in the study of landscape fragmentation and for habitat modelling purposes to detect the most suitable/unsuitable conditions for the survival of a given species.

In this sense landscape diversity metrics do not measure edge length or structure but they rather quantify the local information-theoretical complexity that originates from the presence of different land cover types within the selected geometric/adaptive window. Therefore, local landscape diversity maps might be helpful for differentiating the regions of interest within a given landscape that are more favourable for edge species, from those regions that are more favourable for interior species. Much of the data used for landscape analysis consist of remote sensing data. Diversity metrics or even habitat models can both be applied on this level in addition to further more detailed data or as a stand alone solution. Landscape metrics can be included into the HSI model as an additional model mapped attribute. The data source for the landscape level of the HSI is remote sensing imagery. The status of innovation and development in this rapidly growing field of science is given in the following chapter.

2.3 REMOTE SENSING

According to LANDGREBE (1978) remote sensing is “the science of deriving information about an object from measurements at a distance from the object, i.e., without actually coming into contact with it”. AVERY (1968) defines it as “the detection, recognition, or evaluation of objects by means of distant sensing or recording devices”. A similar definition can be found in KRAUS AND SCHNEIDER (1988). These definitions include not only satellite based information acquisition but also data acquired from aeroplanes or even ordinary photographic images used for different purposes. FRANKLIN (2001) emphasised that nowadays remote sensing is not only data collection by sensors designed to detect electromagnetic energy from positions on ground-based, aerial, and satellite platforms, but it includes also the methods of interpreting those data.

Remote sensing from the birds-eye started 1858 by Gaspard Felix Tournachon who photographed the village of Petit Becetre, near Paris, from a balloon. Some decades later VON HUGERSHOFF (1917) took aerial photographs of forests from balloons. The first space mission, which transmitted the first space photograph of the earth in August 1959 was Explorer 6 launched by the NASA. It took another 13 years until the first satellite provided data for civil purposes. New technologies have been developed over the years. One major step was the scanning technology as a digital recording method. Active and passive systems were developed. The active ones (e.g. RADAR) generate and send electromagnetic waves and record the information reflected by the surface of objects, while the passive systems (e.g. Landsat) just record the radiation (sunlight or other types of wave radiations) reflected from objects. The active sensors are under rapid development and may soon reach operational status (BALZTER ET AL. 2007). A summary of the current satellite systems is published online by the ENVIRONMENTAL REMOTE SENSING CENTER (2006). In the last years a number of high resolution sensors in terms of scale and time were launched for different purposes. Nowadays the QUICK BIRD satellite offers a maximum resolution of 1 m. Other systems like MODIS were launched for regional or global monitoring purposes with a lower spatial resolution of 250 m, but with a temporal resolution of a few days for total global coverage.

The most common remote sensing technologies applied in forestry are optical/infrared sensors. Among the optical/infrared sensors aerial photography has been intensively applied in the past. Nowadays mostly colour infrared images (CIR) are applied for forest mapping at a scale of 1:15.000, because of their high resolution. (FRANKLIN 2001, ALBERTZ 1991, KÖHL 1990, HILDEBRANDT 1996). The high costs and the small size of area coverage lead to the application of operational passive satellite based systems like the Landsat sensors (TOMPPO 1991). In the forestry sector remote sensing has been used for different purposes. In this context forest damage detection is a field where remotely sensed data are very often applied (KENNEWEG ET AL. 1996, MCNAMARA ET AL. 2002, REUTHERS ET AL. 1996). Generally the main advantage of remote sensing is a quick and objective acquisition of geo referenced information over large areas with a very small effort compared to other information acquisition methods and the extent of the area of interest. It allows enhanced inventories in terms of cost efficiency and data quality e.g. in the forest sector (KÖHL 1990, TOMPPO 1991). Combining remotely sensed data with ground truth information in a multi-phase approach has been found to be much cost efficient, because the number of samples on the ground can be reduced considerably (KÖHL 1994, 2003; KÖHL ET AL. 2001, BOWDEN ET AL. 1979). While only a limited number of attributes, such as presence of forests or forest cover density can be detected with remote sensing, the combination of RS with field data applying regression or stratification methods have been operationally applied by e.g. KÖHL (1994) AND KÖHL ET AL. (2001) to asses a number of other attributes (e.g. timber volume). For future developments a higher thematic resolution is still required to enable the assessment of more attributes in forests and other land use classes. The combination of national forest inventories with Landsat TM data has been established since the 1990s (TOMPPO 1991). The kNN method was applied as one of the methods for the combination of the remote sensing data with ground information on a large scale. For change detection, remotely sensed data from two or more points in time can be used in an efficient way (HÄUSLER ET AL. 1999, BODMER 1993). The applicability of Landsat data in habitat modelling has been proved by MACKINNON AND WULF (1994) applying a time series of satellite images which showed the reduction and rapid fragmentation of the giant panda habitat in China. More than any factor it was the perspective provided by satellite imagery that changed the managers` views about the main threats to panda survival.

The RS data for the HSI were satellite based information recorded by Landsat 5 (1989) and Landsat 7 ETM (2000) sensors. The information covered the whole area of Moritzburg, and was combined with local terrestrial information acquired within the MNTFR project (2000) and local forest inventories (1989). The combination was realised using the kNN method, while the major calculations of the HSI model were performed with a GIS.

2.4 GEOGRAPHICAL INFORMATION SYSTEMS

Geographical information systems (GIS) are computer based systems that are used to store and manipulate geographic information (ARONOFF 1989). During the last four decades a rapid development of the new technologies caused an enormous change in applicability, services and ease of use of GIS. In general there is a two-element structure of modern GIS: a graphic file with geographical information can be linked to an attribute database including thematic information. This combination offers new analysis methods and interpretation possibilities, besides a good visualisation tool of the information (FRANKLIN 2001).

According to the ESRI KNOWLEDGE BASE (http://www.esri.com/index.html) a GIS is "an arrangement of computer hardware, software, and geographic data that people interact with to integrate, analyse, and visualise the data; identify relationships, patterns, and trends; and find solutions to problems. The system is designed to capture, store, and update, manipulate, analyse, and display the geographic information." All GIS use two different types of data: raster (pixel) and vector data. Raster data are images divided into similar cells, which are arranged in rows and columns. Each of the so called pixels is saved with the relevant thematic information and the location coordinates. A number of pixels with the same value can contain information about a geographic feature, for instance the forest cover within a map. Vector data involve points, lines and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. An attribute can be associated with each point, line or polygon. In case of the raster data each attribute is associated with each cell. Hybrid GIS include features that merge raster data with vector data to optimize the functionality.

In terms of remote sensing RICHARDS (1993) summarises the principal tools, such as image classification, intersect or overlaying data sets. In general GIS have become more complex in terms of more additional algorithms and features, which may also cover image analysis and processing (FRANKLIN 2001). The integrative aspects of the use of remotely sensed data and GIS applications are described in BLASCHKE (1999) – for instance the modelling of ecological processes for environmental planning or the monitoring and modelling of complex habitat conditions. Environmental modelling with GIS is a frequently mentioned scientific discipline dealing with different natural or human influenced factors for different purposes (MOORE ET AL. 1993, BURROUGH 1986, MAIDMENT 1995). In the context of forest ecosystem management DALE (1998) mentioned that the influence of human disturbance can be examined within the context of the natural disturbance and succession patterns across watersheds rather than in small artificial management units. With GIS and modelling approaches it is possible to simulate empirical or natural history, and to devise experimental and comparative ecosystem studies (LIKENS 1998).

While the data merging and calculation of maps are technically done in the GIS, the input values have been defined before by experts depending on key species and their habitat requirements.

2.5 WILDLIFE MONITORING AND THE HABITAT CONCEPT

2.5.1 Wildlife Monitoring

Wildlife can be inventoried at one point in time and monitored over a period of time to detect changes. Monitoring of, for example, bird species encompass the continuous assessment of the bird populations with standardised methods to study changes of population size, distribution, birth rates, mortality rates and dispersion (FLADE 1992). Monitoring methods and ideas about how to establish a monitoring system of rare bird species in Germany are summarised in DRÖSCHMEISTER AND BOYE (1997). Wildlife monitoring can be divided into 3 different types of monitoring categories.

- Monitoring of genes
- Monitoring of species
- Monitoring of habitats

The monitoring of genetic diversity is a very young field of investigation in which rare alleles are of interest for population estimates (GEHLE AND HERZOG 1998). Since the HSI concentrates on species related habitat analysis on landscape level, the monitoring of genetic diversity will not be described in more detail.

Monitoring species can be done directly or indirectly. In the scope of total assessments direct monitoring has been done by counting species. Other methods like shooting entire populations in a specific area have been applied in a very few cases and have not been successful (GOSSOW 2003). Other methods include entrapping within a specific area, while others concentrate on the counting of individuals at game passes. Some species may have preferences for a number of different landscape elements; this presents problems for estimating the populations of these species. For these species special simultaneous assessment methods have been developed. Using video technology satellite or radio telemetry a lot of information about the species behaviour can be collected (JANSSEN ET AL. 2004, NITZE ET AL. 2003, WALLISER 2004). Other assessments are based on sampling techniques, like the counting along defined transects in the landscape or listening samples for bird inventories. Another technique is the use of video cameras that can recognise and record shapes for single species placed along paths used by the animals.

The so called "Capture-Recapture" methods have a long history, and they were first applied in the study of fish and wildlife populations (PETERSEN 1896) before being adapted for other purposes especially in health e.g. epidemiology sciences over the last century. LINCOLN (1930) used the method to estimate the size of a duck population in the early twentieth century, and one version of the capture-recapture method has become known as the Lincoln-Petersen method. Originally the simplest capture-recapture model uses two independent samples to estimate a population size. The individuals captured in the first sample are tagged and returned to the population. The population is then sampled again, and the proportion of recaptured individuals can be used to estimate the total population size. The method assumes that there is no change in the population during the investigation, that no tags are lost, and that each individual has the same chance of being caught and the two samples are independent.

Indirect methods for monitoring species means that indication (e.g. turds, tracks, nests, etc.) but not the animals themselves are counted. Indirect methods are for instance the sample trapping of species which is very often applied by entomologists (SCHMITT 2004, RATSCHKER 2001, JÄKEL AND ROTH 2004). Another method of indirect wildlife monitoring is the counting of turds, developed by VON GADOW (1978) AND SEYDACK ET AL. (1998). Estimates about the whole population in a defined area of interest are done based on the samples consisting of tracks or roadside counts, or even of hunting results.

Monitoring habitats as another indirect method of wildlife monitoring focuses on the natural resources and conditions, that could be used as potential habitat for rare species in a particular area. In most of the cases vegetation types are the focus from the nature point of view. Habitat Suitability Indices have been developed and improved since the early 1970s (U.S. FISH AND WILDLIFE SERVICE 1981).

2.5.2 The Habitat Concept

The relationship between species and environment is a basic issue in ecology. The distribution of plants and plant communities and their influence on animal populations basically caused by climate conditions was early recognised by VON HUMBOLT AND BONPLAND (1807). SALISBURY (1926) started to describe the main vegetation patterns of the world with climatic conditions and further environmental factors, an this has been followed by others, for example MCARTHUR 1972, or ELLENBERG (1988). This relationship represents the core of the habitat concept. The wide use of the habitat concept coupled with the many different meanings of the concept in circulation necessitates a definition. Habitat is a concept central to the field of conservation biology and natural resource management because it provides the link between organisms and their environment. The concepts of habitat and the closely related concept of ecological niche have changed over time. It is important that definitions of concepts such as habitat are operational, meaning they should be practical, measurable specifications of the phenomena that these terms represent (PETERS 1991).

A habitat is “the resources and conditions present in an area that produce occupancy - including survival and reproduction - by a given organism” (BLOCK AND BRENNAN 1993, GRINNELL 1917, HUTCHINSON 1957, MORRISON ET AL. 1998 AND ODUM 1971). A habitat “... is wherever an organism is provided with resources that allow it to survive” (HALL ET AL.1997). This is clarified by adding, that it is an organism-specific phenomenon which refers to the physical and biological characteristics of an area (HALL ET AL. 1997; MORRISON ET AL. 1998). It is not uncommon that species with similar requirements are grouped together to form species groups or guilds for which a suitability measure of a landscape can be given. Classically, resources have referred to food, water and shelter, while conditions have referred to temperature, precipitation, and presence or absence of predators and competitors, etc. (MORRISON ET AL. 1998).

According to the habitat definition used in the EU Habitat Directive “habitat of a species means an environment defined by specific abiotic and biotic factors, in which the species lives at any stage of its biological cycle” (EC 1992), but this does not contradict the widely accepted definition by HALL ET AL. (1997). The habitat concept is equally applicable to animals and plants, while the examples here mainly focus on animals.

For habitat to be a useful concept, the measure of habitat quality should be explicitly linked with demographic features. Habitat quality ultimately relates to the rates of survival and reproduction of the individuals that live there (VAN HORNE 1983), to the vitality of their offspring, and the length of time the site remains suitable for occupancy. A measure of habitat quality, or habitat preference should not use only density, though there is often an assumption of relationship between density and relative preference. This assumption is violated if the ability to detect animals varies among habitats of different quality (THOMAS AND TAYLOR 1990). The measure of habitat quality should range from low to medium to high if resources and conditions are sufficient for survival, reproduction and population persistence respectively (HALL ET AL. 1997). Quality is often presented as a relative, not absolute, measure which means that areas/patches within a region are compared and ranked in relation to other areas/patches.

The driving factors of habitat selection and the concept itself need to be understood especially for natural resource management and monitoring purposes, as well as for the support of political decisions. No organism is randomly distributed in the landscape because the distribution and abundance of resources and the conditions prevailing in the landscape, that species depend on, varies in space and time. The proper selection and use of habitat over time and space by an animal enhances the probability of survival and therefore positively influences its fitness. In contrast, individuals that choose the poorer, marginal habitats will raise less offspring, and therefore negatively influences its fitness (KLOPFER 1963, KREBS 1978). The dependency of animals on conditions and resources allows the application of indirect measurements of landscape parameters.

The presence of habitat is not always correlated with the presence of species associated with that habitat. Indirect measures of populations using habitat criteria have to include the behaviour of selection and the use of habitat to improve a realistic and accurate approach. The abundance of a given and defined habitat does not compromise all essential resources to the species, meaning that not all habitats can be selected and used (HALL ET AL. 1997, MORRISON ET AL. 1998). What an animal perceives as available and what an observer perceives available can be two different things. Limitations for the availability can be related to territoriality (ALLDREDGE AND RATTI 1992), human disturbance and inter-specific competition (WHITE AND GARROTT 1990), absence of another resource which is needed in combination with the one estimated. Accordingly, habitat availability is just partly discovered and can only be estimated (WHITE AND GARROTT 1990). Even if resources are rich and all other conditions are perfect in an area of interest, the habitat can still be left unoccupied.

Further, habitat use does not follow a uniform pattern, partly because not all of it is prime habitat. Another reason is that species will exhibit different patterns of habitat use, depending on what proportion of its distribution is being observed (MORRISON ET AL. 1998). Also, animals do not spend equal amounts of time at each activity and at each location. There is a difference in time and energy spent on feeding, drinking, resting, grooming but this does not indicate the importance of the activity (MORRISON ET AL. 1998, JANSSEN ET AL. 2004).

The distribution, abundance, and diversity of species populations in a landscape or region are not only determined by habitat. Habitat can provide for the conditions necessary for a species to survive, but species are also affected by human disturbance, over-harvesting, parasites, climate, and catastrophic events. These can drive a population in another direction than indicated by habitat (MORRISON ET AL. 1998, JANSSEN ET AL. 2004). Species populations and their habitat must be studied and managed in conjunction since information about population and habitat provides complementary information. Habitat management can maintain and even enhance the ecological optimum for species, but at the same time, over-harvesting or disturbance can cause different developments then would otherwise be indicated by the habitat (MORRISON ET AL. 1998). Healthy and robust populations of selected rare species are the objective of wildlife management in a region of interest. For monitoring purposes, it must be recognised that wildlife–habitat relationships are scale-dependent, reflecting the different scales at which animals live (HALL ET AL. 1997). Habitat and habitat selection includes a continuum of spatial scales, from regional to local level. JOHNSON (1980) presented a hierarchical process of habitat selection, which shows that the selection and foraging preferences are coherent activities, just undertaken at different scales. These are: First-order selection which is the selection of geographical range or region; within that range Second-order selection determines the home range of an individual or group of animals; Third-order selection is the differentiated use of the home range which determines the feeding site; and Fourth-order selection is the final choice of food items at the feeding site (HUTTO 1985).

2.5.2.1 The habitat approach to assess biodiversity

The complex and manifold content of what includes biodiversity does not allow a direct assessment. The significance of biodiversity as a human heritage is undisputable among the international community (UNEP 1992). Biodiversity encompasses so much diversity in itself, starting with its own definition (KAENNEL 1998) and ending with the great number of knowledge gaps in the different scientific disciplines, that the only option is the indirect measurement of the components or indicators at different scales (NOSS 1990, HANSSON 1997). The habitat concept is one method for the indirect assessment of biodiversity. “It is a concept that rests on solid scientific grounds as a measurable property of an area to provide for species which has, so far, been the main focus in biodiversity studies.” (HALL ET AL. 1997). Habitat has already been accepted and adopted as a term by biologists, animal ecologists, landscape ecologists, foresters and politicians alike and could very well be the unifying paradigm when working with and managing for species conservation. Habitat modelling includes potential for the support of political decisions in terms of prediction. It allows hot spots to be identified as areas of habitat loss and gain under special simulated condition as consequences of new political decisions. Habitat modelling can also be used as an early warning system. A quick and effective view on potential developments is possible to realise with an open and indicator based model. Within an open model additional attributes such as maps indicating high proportions of dead wood in forests should be quickly implement able as a further indicator which can be essential for a species of interest. In general, indicators represent key attributes that are monitored under the assumption that they are related to the condition and trend of ecological properties that can not be monitored directly (NOSS 1990). Habitat is used as an indicator of conditions perceived to be essential for species, the carriers of the smallest biodiversity units, the genes.

The habitat approach helps in clarifying what components, structures and functions should receive most attention when monitoring biodiversity. Habitat is the link that ties important landscape features, substrates, species, stand structures and the like, to particular species. A wider habitat approach includes the selection of umbrella species with different requirements perceived to cover the requirements of a large number of other species (INNES AND KOCH 1998, NOSS 1990, 1999).

2.5.2.2 Habitat models

There are various ways of differentiating between habitat models – e.g. depending on how they are constructed based on their intended use (GRAY ET AL. 1996). During the last decades descriptive, predictive and decision making models have been developed and applied.

Predictive models attempt to simulate future vegetation pattern developments by applying various statistical methods, like multiple regressions, neural networks or locally weighted approaches (e.g. GAM). Most of the predictive models, summarised by GUISAN AND ZIMMERMANN (2000), are based on statistical analyses, expert judgment, case studies, or a combination thereof. Some of the models describe potential natural conditions for rare species while others seek a further improvement for prediction purposes to formulate advices for decision making processes.

Species–habitat relationship models, including habitat suitability index (HSI) models, reflect the inherent ability of land to produce habitat, and the current ability of land to support particular species (STELFOX 1988). These HSI models are the most extensively used –

mainly in North America – models for species–habitat relationships. They can be applied for single species or species groups (umbrellas species) indicating potential habitat suitability or predicting potential habitat developments (Gray et al.1996; Morrison et al.1998). The HSI score is determined by using attributes known or perceived to be of importance to the species. It is a straight forward technique employing indices, whereby each attribute is ranked according to its relevance to the key species, and linked to other attributes by functional relationships. First, the individual habitat attributes are ranked on a scale of zero to one. The attributes are then grouped according to the life requisites (e.g. feeding or nesting, etc.) that they are relevant for. Then a composite HSI score is calculated, which is also standardised on a scale of zero to one (US Fish and Wildlife Service 1981, Tamis and Zelfde 1998). The HSI score for a species at a location indicates relative habitat quality rather than actual population levels (Kliskey et al. 1999). HSI models are based on the assumption that a species will select and use areas that are most suitable to satisfy its life requisites, and thus greater use will occur in higher quality habitat (Schamberger and O´Neil 1986).

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The species-neutral model framework (Figure 2) was applied for the HSI according to the Habitat Evaluation Procedures (HEPs) adopted by the US Fish and Wildlife Service. The HEP is set up as an expert system using attributes and weights of attributes according to ‘best knowledge’ available through expert opinion. However, the incorporation of statistical analyses provides an improvement of the habitat attributes selection. In addition, a priori statistical analyses of potentially habitat attributes can minimize time and cost, and significantly reduce subjectivity in the selection of attributes (Gray et al. 1996).

The occupation of environmental elements by organisms should be reflected by the species-neutral framework to explain the significance of key species subsistence in the landscape. Bearing this in mind, the focus should not only be on the presence of resources, but also on the spatial distribution of resources. In a study of the winter distribution of woodland birds PETIT (1989) showed that only the foraging patches close to roosting sites are usable.

A model approach with habitats grouped according to life requisites offers transparency in terms of the artificially defined requirement units for a key species. This allows overview over a group of essential attributes in one step. Especially in the case of environments where changes are caused by multiple factors, the life requisites can be re-appraised in a straightforward manner, and can be manipulated and even enhanced in an adaptive model procedure. Life requisites as an assemblage of attributes can bed adapted as units of observation, for verification purposes, and even for changing management practices. This approach allows effective scenario testing regarding life requisites as responsive elements to changing landscape compositions (LÖFSTRAND ET AL. 2003).

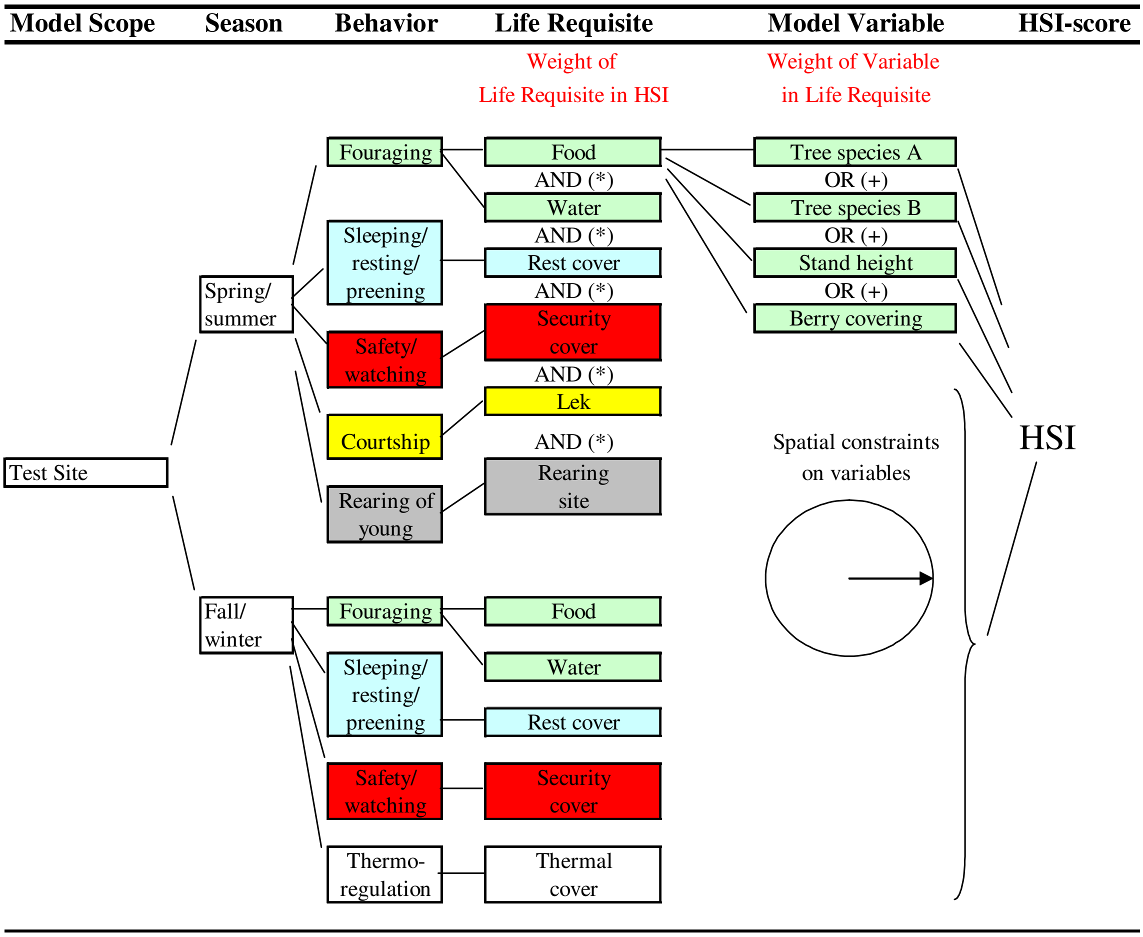

Figure 2 The model framework used for constructing the species-specific models

The model framework is based on a sequence of steps that will result in a species-specific habitat model (TAMIS AND ZELFDE 1998, GRAY ET AL.1996, KLISKEY ET AL.1999, LÖFSTRAND ET AL. 2003).

The procedure for formulating the habitat requirements and for adapting them into the framework is summarised in the following:

1) Decision on model scope – about the area that the model should be applicable for – possibly implementing a time span as well.

2) Definition of the species ecological profile, according to, for example, the following aspects of habitat requirement:

- Habitat type – e.g. annual/seasonal, feeding/breeding habitat;
- Stationary or migratory behaviour of species;
- Essential perceived behaviours of species;
- Reflection of each behaviour – e.g. food, safety cover through life requisites;
- Connection of life requisites in terms of weights, usually in the range 0-1, based on the species preferences;
- Spatial requirements – e.g. size of home range, minimum patch size, maximum distance between patches, proximity of different resources, etc.;
- Species sensitivity to disturbance – e.g. proximity to human settlements and roads/railroads.

3) Relate life requisites to model attributes:

- Best description of life requisites with model attribute(s);
- Connection of model attributes based on the species preferences in terms of weights, usually in the range 0-1.

4) Combine the weighted model attributes into a HSI score, which is also usually in the range 0-1. The model attributes are usually combined in a multiplicative fashion.

Through the above described process, it is essential to set up and maintain a meta-database over the model components included, specifying their weights and the references used.

The ecological profiles may vary between species depending on how detailed the knowledge is about the species. An important attribute should vary over the full range, 0-1, while a less important attribute may vary within a restricted range, e.g. 0.8-1. Irrelevant attributes are excluded, or all classes receive the value 1. The level of spatial resolution may also differ depending on the selected model scope, ranging from the home range of one individual to the distribution of the species. There is also a choice to model the critical habitat of a species – e.g. habitat used during breeding season or winter feeding habitat. The ecological profile can be based on empirical data from field experiments, literature study, expert judgment and statistical analyses. It should reflect the best available knowledge, which can and probably will change over time.

2.5.2.3 Temporal aspects of the HSI

The most important feature of habitat models from a monitoring perspective is the possibility to compare models at different times. The construction and comparison of bi-temporal models is possible, if both field data and image data from both time points are available. To avoid identification of false changes due to noise on pixel level estimations, the multi-temporal comparison of such models should preferably be presented as averages, which for example could be calculated with a moving-window technique. Here a value is calculated in a defined area around a pixel of interest. If the value is calculated the neighbouring pixel is calculated for the same defined area. The entire algorithm looks like a procedure which is moving across the area of interest. One suitable area for the averaging could be the home range for the species.

It is likely that increased ecological knowledge will motivate improved habitat models in future multi-temporal comparisons. Fortunately, it is possible to remake in the future, both the present day basic forest estimates, and the habitat models. The only prerequisite for this is that the present day field data, the image data, and the ancillary GIS data, is collected, archived and documented.

In case there is a lack of field data from the initial time point, there is still the possibility of using multi-temporal image-to-image comparison. For example, this could be in the form of difference images for detecting areas with major changes – e.g. due to clear-felling, or land use change. Such change detection images might also be useful as one of the image data layers for producing basic forest parameters for the habitat models. Change detection images could, for example, indicate the approximate age of clear felled areas, which may have some importance as forage for wild animals. When time series of images are available, there is also a possibility to determine the rate of growth, especially in young stands. Thus, in the ideal case, satellite data would be collected annually or at least once every two years. It is also important that the images are collected from comparable seasons of the year. For multi-temporal studies of the Scandinavian forests for example, this means that the images preferably should be collected in the period between mid-June and the end of August.

Finally, one powerful feature of HSI models is that they can be used for scenario modelling of future landscape qualities. In this context, the variation of the parameters in the landscape scenarios is relatively effortless, as well as making subsequent analysis of the influence of the single parameters in the HSI models. The growth of the tree layer in the forest landscape is predictable, using well established statistical functions from forest yield research. Many other features of the ecosystem are tied to the development of the tree layer. Thus, scenario analysis of the forest ecosystem, including habitat suitability modelling, are likely to be effective and practical approaches, which can contribute to present-day land use decisions.

3 DATA

3.1 GROUND DATA

3.1.1 Training Area: Moritzburg

The training area is located in the Moritzburger Wald, a highly heterogeneous and diverse district near Dresden, the capital of the federal state of Saxony in Germany.

The Moritzburger Wald is an area which is characterised by a moderate dry climate, with danger of late frosts in depressions. The average temperature is about 8,2°C and the average precipitation is 660 mm/m²/year.

The forest stands on a plain with a slope from the south-east to the north-west. The altitude ranges between 120 m and 200 m above sea level. The area is also characterised by deep narrow valleys with a slope to the River Elbe. It is dominated by the Meißener Syenit-Granit-Massiv, the genesis of which is difficult to specify as there are many different rock types of different ages. The main part of the geological ground consists of sediments of the Pleistocene epoch.

The Moritzburger Wald is owned and managed by the federal state of Saxony. Its size is about 4000 ha. The forest was used as a hunting area for the kings of Saxony. The forest structure was influenced by the high population of red deer, roe deer and wild boar. Some 1600 ha of the forest was fenced over a whole century. Since the 15th century a number of fishing ponds were established in depressions. Nowadays 30 ponds cover about 400 ha of the area. At the beginning of the 19th century the forest growing stock was low and there were large gaps and a lot of old oak trees left for the forage of wild animals. In the early 20th century, spruce and pine made up about 80% of the forest. After 1920 the management changed and no clear-cutting was carried out.

The test site is about 15 km far away from Dresden (Figure 3). It is highly frequented for recreation because of the castle in the middle of the area, the ponds, and the game enclosure in the forest.

The test site was chosen because of its heterogeneous landscape patterns with a mixture of lakes, forests and other landscape elements, its tree species composition and the history of human impact in the area.

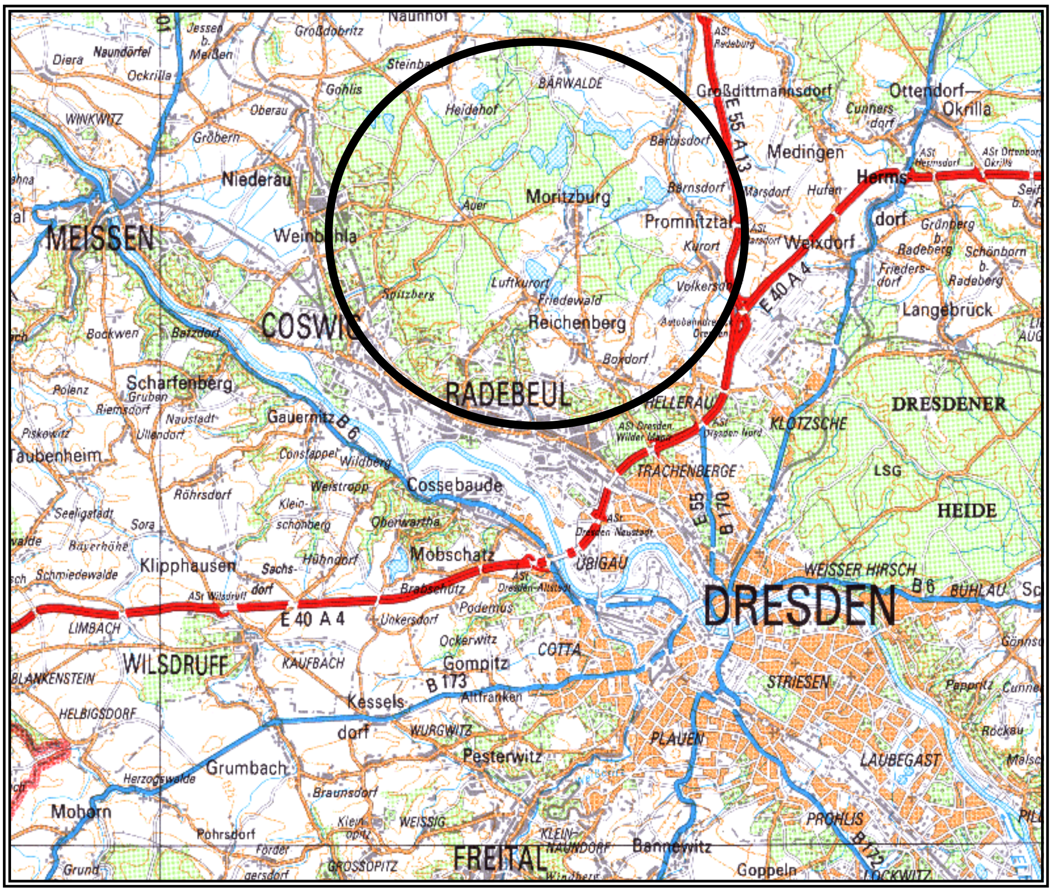

Figure 3 Location of the Moritzburg test site

The tree species composition of the forested area within the test site is presented in Figure 4.

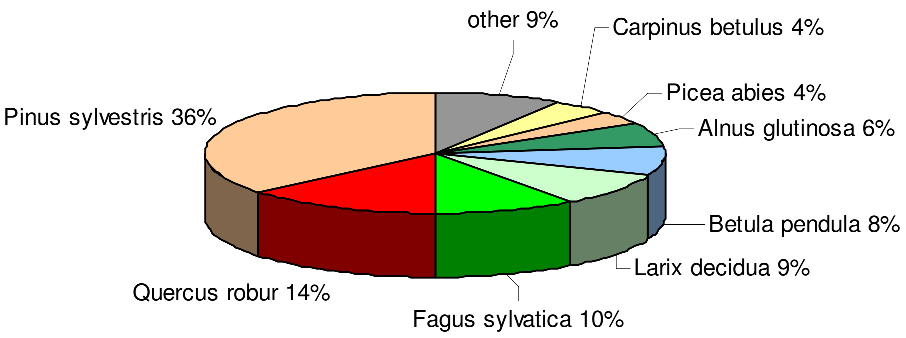

Figure 4 Tree species composition of the forest of Moritzburg in [%] according to the MNTFR field campaign 2000

For the monitoring purposes of the HSI, the EHSI and the HR-HSI two sets of ground truth data, one for 1989 and the other for 2000 were necessary. While field assessments took place in 2000 as a sample plot based inventory with geo-reference information, the data for 1989 were extracted from the Datenspeicher Wald, which includes stand-wise forest assessments without geo-reference.

3.1.2 Datenspeicher Wald (1989)

The Datenspeicher Wald is a database which contains information on forest inventories at the company level. The inventory is a stand-wise assessment with six randomly selected sample points per stand for the estimation of basal area, tree species composition and tree height (BITTERLICH 1948, SCHÖPFER 1969). The major inventory objective was to assess the productive function of the forests. Age dependent tree growth models were used to calculate the growing potential and to plan the management for the stand. Some additional attributes such as proportion of natural regeneration, different vertical layers and game damage were also assessed in some of the different inventories.

3.1.3 MNTFR Field Data (2000)

Within the MNTFR project[1] ("Scale Dependent Monitoring of Non-Timber Forest Resources Based on Indicators Assessed in Various Scales"), attributes describing Non Woods Goods and Services (NWGS) of forests are mainly assessed using ground and remotely sensed data for five different test sites in Europe. Moritzburg was on of the test sites where a field campaign was organised in summer 2000. Beside the assessment of NWGS, the traditional forest inventory information like timber volume, or tree height was also collected.

The detailed sampling design in the test site near Dresden is illustrated in Figure 5. The design consists of a sparse cluster with five field plots connected with assessment lines and a dense cluster of nine field plots. The distance between the field plots of a sparse cluster is 100 m. The distance between the field plots of a dense cluster is 25 m. The cluster system is orientated according to the 1 km net of the topographical map 1:25.000, where every first plot of the sparse cluster is located.

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[1] FAIR-CT98-4045, http://www.forst.tu-dresden.de/Informatik/mntfr)

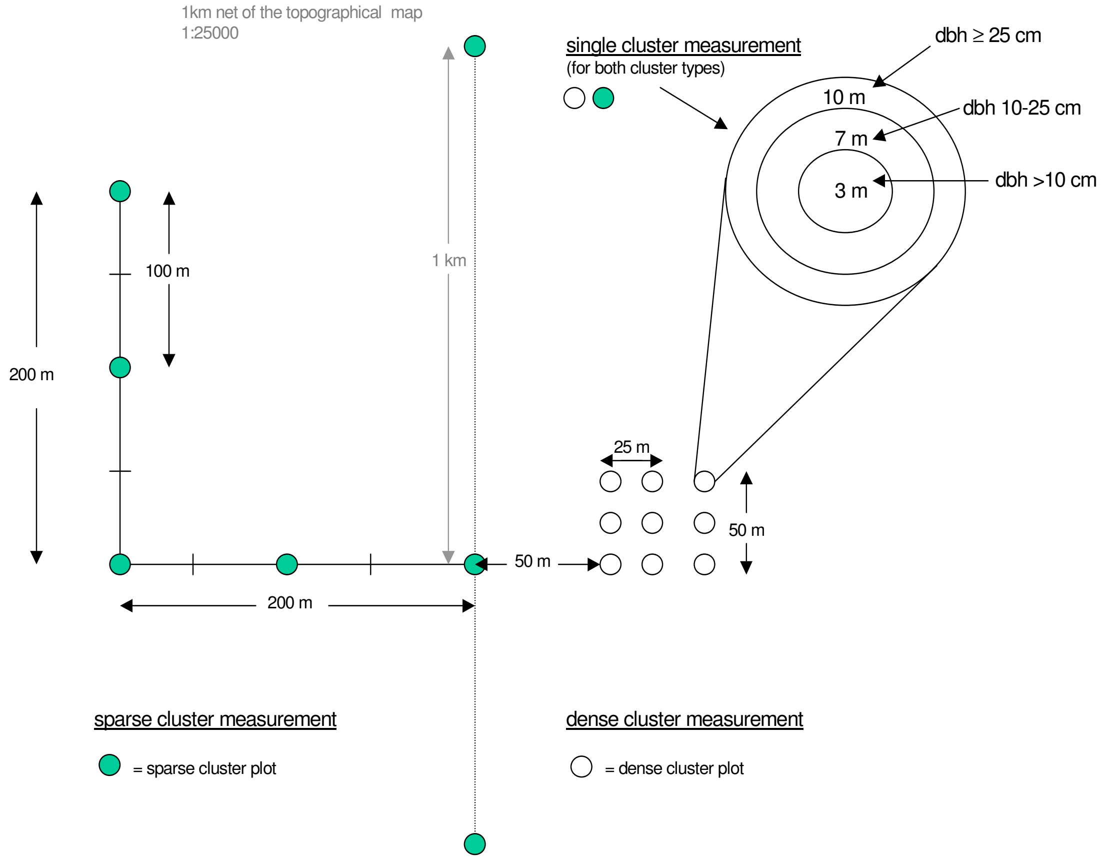


Figure 5 Sampling design in the test site Moritzburg (MNTFR project)

The systematic plot design from the MNTFR project covers an area of 30 km² around Moritzburg. The plots were localised by measurements of a GPS system and topographical maps (1:25000). The location of the clusters used in the study is shown in Figure 6.

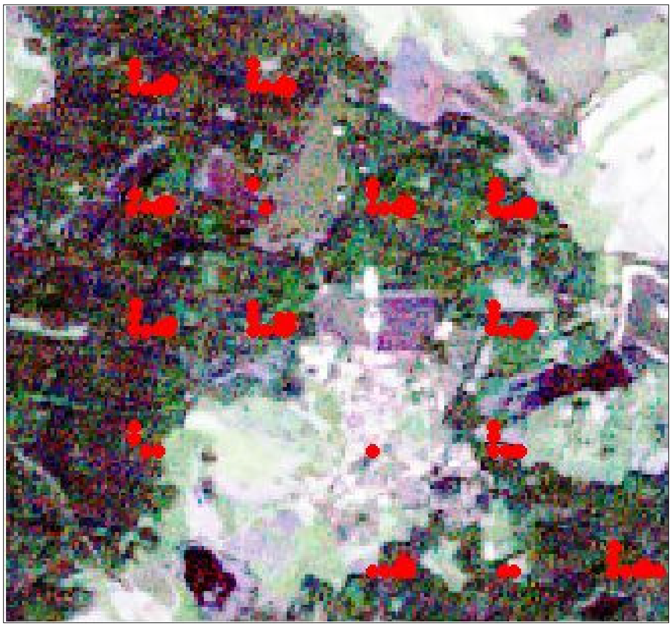


Figure 6 Cluster location in the Moritzburg test area

Ground truth data of the non-forested parts like meadows, lakes or agricultural land were not used within this study. During summer 2000 the following clusters in total were measured:

Table 2 Sample plots measured in 2000 in the Moritzburg MNTFR test area

Test site: Moritzburg	
Dense clusters:	12
Sparse clusters:	21
Total clusters:	33
Total lines:	141
Dense cluster plots:	108
Sparse cluster plots:	90
Total plots:	198

All relevant information of the 198 dense and sparse cluster plots was used for the habitat modelling in this study.

The data of the MNTFR field campaign 2000 were collected by data loggers and input into a database (MS Access).

3.2 REMOTE SENSING DATA

For the HSI model, satellite imagery of the years 2000 and 1989 were applied. For 1989, a Landsat 5 TM scene was utilised, while a Landsat 7 ETM+ scene was available for the year 2000.

The main characteristics of the Landsat program are described on the websites of the USGS (http://edcwww.cr.usgs.gov/guides/landsat_tm.html) and the NASA (http://geo.arc.nasa.gov/sge/landsat/l7.html).

For the habitat suitability estimation in Moritzburg, the following Landsat scenes were applied:

Table 3 Landsat scenes for Moritzburg

Satellite	Path/Row	Acquisition date	Coverage	Sensor	No. bands	Resolution
Landsat 7	192/24	24.09.2000	5,5 km * 5,5 km	ETM+	8	30 m
Landsat 5	193/24	07.07.1989	5,5 km * 5,5 km	TM	7	27 m

The Landsat 7 data were acquired by the Eurimage company located in Rome Italy (http://www.eurimage.com/), while the Landsat 5 data were made available by the German Aerospace Centre "DLR" (http://www.dlr.de/dlr). The area of interest, where the HSI model was applied extends to 2,5 km around the village Moritzburg. The extent of the whole area is about 30 km².

3.3 THE HABITAT REQUIREMENTS FOR THE SELECTED KEY SPECIES

In this section the habitat requirements of the two selected key species - the Red Kite (*Milvus milvus*) and the Black Stork (*Ciconia nigra*) - are described. They were selected for the HSI because of their different relations to structural diversity. The main focus concentrates on the requirements of the species which are mainly reflected by the arrangement of different landscape elements. They are relevant for this study because remote sensing imagery is one of the main data sources.

Two different levels of biodiversity can be differentiated for its maintenance. The first level deals with the landscape, where typical biodiversity sources can be found in e.g. patch structure, the variety and extension of sites or biotopes. Remotely sensed data have been successfully applied for the assessment of these attributes (HUNSAKER ET AL. 1994, MCCORMICK AND FOLVING 1998, MCGARIGAL AND MARGS 1994, RITTERS ET AL. 1995, TURNER 1990). On the second level the interest is concentrated on the preference of the described structural diversity by “key species”. The abundance of the species and the structural diversity can be related in three different cases: (1) the population is positively correlated with structural diversity; (2) the population is negatively correlated with structural diversity; and (3) there is no relationship between the population and structural diversity.

On the second level of biodiversity maintenance two potential key species, for which the ecological background and habitat requirements are well known, have to be identified. There is a large body of knowledge of the ecological requirements for the species chosen for this study. A proposal of possible key species is given by the Bird Directive (EC 1972) which is included in the Fauna, Flora and Habitats (FFH) Directive (EC 1992) on the European level. In the Bird Protection Directive the bird species listed in the Annex include a number of species that are closely related to wooded land (like the two key species selected for this study).

The following three steps were undertaken to select two key species (LÖFSTRAND ET AL. 2003):

First step: Derive well fitting key species

- Natural distribution within the observed area
- High ecological value in terms of representing qualities of wooded land
- Habitat size larger than 100 ha
- Key factors of habitat assessable with remotely sensed data

Second step: Derive potential habitats in the observed region by identification of assessable habitat features

- Identification of habitat and visible key factors (FFH species)
- Identification of assessable habitat features
- Transformation of the features into attributes developed in the MNTFR project
- Adaptation of the MNTFR attributes to the Datenspeicher Wald

The two key species had to fulfil the following criteria:

Table 4 Main selection criteria for the key species

species	**main habitat**	**common patch size**	**visible key factors of the habitat**
depending on the FFH Annex	according to CORINE system	according to current state of knowledge	depending on field studies

After the procedure the Black Stork and the Red Kite were found to be suitable key species for the HSI in Moritzburg. They are both mentioned in the FFH Directive, their habitat can be found according to the CORINE land cover definitions, their patch size fits with the area of interest in Moritzburg and the visible key factors could be well defined with the current knowledge of experts.

Third step: Habitat analysis of two key species with different correlation to diversity metrics

The two key species are mentioned in the Bird Directive and were expected to be differently related to structural diversity. It was expected that the Black Stork is negatively correlated with structural diversity, and that the Red Kite is positively correlated with structural diversity.

3.3.1 The Red Kite (*Milvus milvus*)

In this section the main habitat requirements of the Red Kite are described. On one hand a number of publications (ORTLIEB 1989, SCHREIBER ET AL. 2000, STUBBE ET AL. 1995, CRAMP 1977, VON BLOTZHEIM ET AL. 1966) offer the main characteristics of the required habitat conditions, on the other hand the requirements according to the Habitat Directive are summarised. It was not the objective to reflect all described details in the HSI, but to concentrate on the main landscape elements which could be easily detected by remote sensing technology. For the HSI model it was essential just to start with a rough landscape monitoring to test the applicability of the main model features. Later on more detailed information like maps of e.g. water quality or recreation activities can be added to the HSI model.

The total European breeding population of the Red Kite is between 18,000 to 28,000 pairs. In Germany the population is about 9000 to 19,000, while in Russia the population is around 1 to 50 breeding pairs (BIRDGUIDES 1999A, SIEVERT 2000). The population is covering Europe from the Northern parts of Scandinavia as summer breeding areas down to the Northern parts of Africa for winter breeding. KIEFER (1998) described the breeding behaviour of Black Kites and Red Kites in Luxembourg. Besides his results about successful breeding and the population density of the area of interest, he found that 45% of the nests were close to the forest border. Some 40% of the other nests were close to forest glades and roads. In Table 5 open forest and distance to forest borders was defined as an attribute for the life requisite “food”. The change from forest to other landscape elements seems to be very important for the Red Kite for the selection of its nesting sites. The Red Kite often prefers old trees for breeding, and prefers agricultural land as close as possible to its breeding trees for feeding (SIEVERT 2000, LOTZING 2000). In Table 5 these attribute are listed for the considered life requisites “nesting” and “food”. Old trees are also considered as important “watching” possibilities. The main food of the Red Kite consists of hamsters, moles, field mice and other small invertebrates. In the Hakel, an area in the South of the Harz Mountains in Germany, the population of the hamsters has decreased considerably because of the changing plantation activities of the local farmers after the reunification of Germany. This caused the decrease of the Red Kite population in the area (SIEVERT 2000, LOTZING 2000). In contrast to this, the Red Kite population has increased in some areas of Wales (WELSH KITE TRUST 2004). In the Hakel area the Red Kite settles close to the border of forest to agricultural land. Very often the nests can be found close to water bodies. Thus the Red Kite prefers heterogeneous landscapes consisting of old forests, agricultural land, and water bodies (compare with Table 5).

The attributes for the Red Kite habitat definition for the Moritzburg area are shown in Table 5. They were chosen from the attributes as listed in the FFH Directive.

Table 5 Red Kite – list of the attributes and their definitions for the HSI in Moritzburg

life requisite	attribute	definition	MNTFR definition
food	**water bodies**	small lakes and ponds	
	forest border	distance max. 0,5 kilometre	
	open sites		class 2 (other wooded land) or class 3 (agricultural land) [1]
nesting	**open forest**		areas with a canopy cover of 15%
	timber volume	minimum 300 m³/ha	
safety/watching	**tree species composition**	minimum 80% broadleaved trees	
	tree height	minimum 25 m	

[1] Class 2 is defined as "other wooded land": Land either with a tree crown cover (or equivalent stocking level) of 5-10% of trees able to reach a height of 5 m at maturity in situ; or a crown cover (or equivalent stocking level) of more than 10% of trees not able to reach a height of 5 m at maturity on situ and shrub or bush cover with a minimum area of 0,5 ha and a width of 20 m.
Class 3 is defined "agricultural land": areas used for seasonal and permanent crops; two categories: tree crops and other crops (According to the MNTFR field manual)

3.3.2 The Black Stork (*Ciconia nigra*)

Experts like JANSSEN ET AL. 2004, CRAMP 1977, VON BLOTZHEIM ET AL. 1966, BIRD GUIDES 1999B offer the main characteristics of the needed habitat conditions and on the other hand the requirements according to the Habitat Directive are summarised. Similar to the Red Kite, it was not the objective to fulfil all the described details in the HSI, but to concentrate on the main landscape elements which could be easily detected by remote sensing technology.

According to CRAMP (1977) and VON BLOTZHEIM ET AL. (1966) the following characterisation of the Black Stork can be given. Black Storks are far less numerous than White Storks. The total number Black Storks in Europe amounts to 2600 to 3000 pairs. Most of them live in the eastern part of Europe, while 40-50 pairs live in Germany. At the beginning of the last century the Black Stork began to settle again in the western countries like Germany, France, the Benelux countries and Scandinavia for reproduction. In opposite to that a decline of the population is monitored in parts of Estonia (ROSENVALD ET AL. 2003). During winter the bird mitigates to Western Africa to countries like Senegal or Mali. The Black Stork is well known as a big bird which hardly prefers old homogenous stands of mainly broadleaved trees. They settle in old quiet forests where the nest is placed on a big tree, often near an open space (slopes, clear forests), which allows them an easy access. Their hunting field consists of streams and small rivers, of marshy ponds, of meadows with low vegetation DEPARTMENT OF THE PRESERVATION OF NATURE OF THE MINISTRY OF THE WALLOON REGION 1995, JANSSEN ET AL. 2004). Another very important aspect for the Black Stork is its shyness and his vulnerability towards any disturbances especially during the breeding period (JANS ET AL. 2000, JANSSEN ET AL. 2004, VON BLOTZHEIM ET AL. 1966). Wet meadows and miry banks in small rivers or ponds are its favoured feeding areas, where it can find small fishes or amphibians. The attributes for the Black Stork habitat definition for the Moritzburg area are shown in Table 6.

Table 6 Black Stork – list of the attributes and their definitions for the HSI in Moritzburg

life requisite	*attribute*	*definition*	*MNTFR definition*
food	**stand structure**	several layers	
	forest border	distance max. 1,0 kilometre	
	broadleaved trees	minimum 80% broadleaved trees	
nesting	**tree height**	minimum 25 m	
	timber volume	minimum 300 m³/ha	
safety/watching	**infrastructure distance**	minimum 3 kilometre	
	resident population	maximum 100 in habitants /km²	

3.4 APPLIED SOFTWARE AND TOOLS

The described data were aggregated and merged in multiple ways for the HSI and its modifications. All algorithms and methods mentioned were applied using GIS and image analysis software. The kNN method (chapter 4.1.3) was applied by utilising software developed by STÜMER (2004), (KÖHL ET AL. 2001). ArcView by ESRI INC. was used for the GIS application in the procedures for the HSI, the EHSI and the HR-HSI. For Image analysis algorithms ERDAS software was applied. Additionally Microsoft Office products were used for writing and calculating single basic algorithms.

4 THE HABITAT SUITABILITY INDEX (HSI)

4.1 HSI ANALYSIS METHODS

The following figure shows the data flows and aggregation for the basic HSI in detail. Variations of the illustrated HSI were applied for approaches like the enhanced habitat suitability index (EHSI) applying fuzzy sets in chapter 5, and the habitat suitability with home range aspects (HR-HSI) in chapter 6.

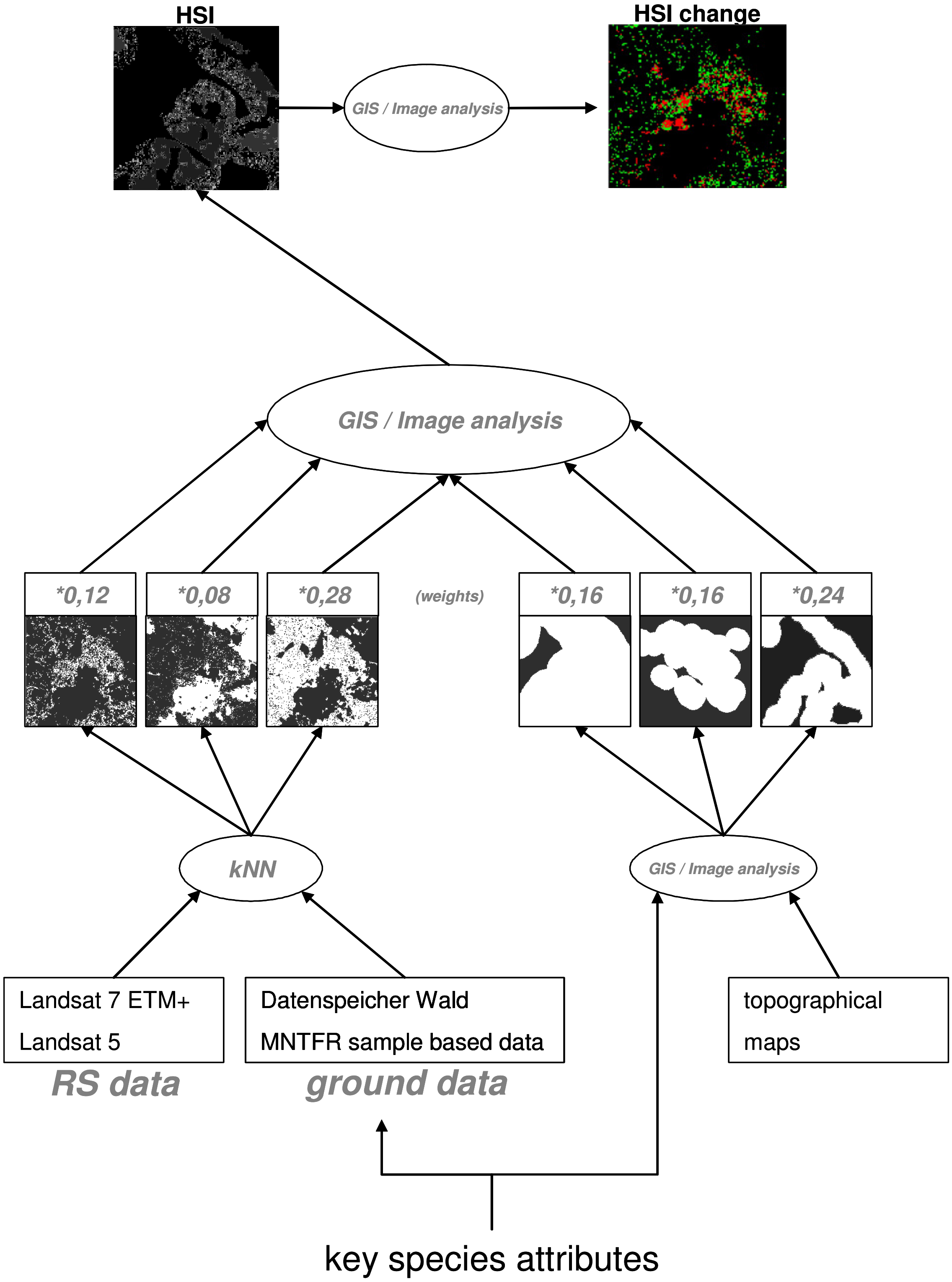


Figure 7 Overview of the HSI data flow and aggregation

4.1.1 Ground Data

4.1.1.1 Datenspeicher Wald (1989)

The Saxonian forestry administration provided a data set extracted from the database “Datenspeicher Wald” for the year 1989. As the data set was not geo-referenced a topographical map of Moritzburg (1:25.000) and former stand maps were utilized for geo-referencing the stand-wise information.

In order to enable a time series approach the ground data of the field campaign carried out in the year 2000 had to be aggregated for different attributes utilized as input attributes to the HSI models. For the calculation of the individual attributes over the entire area of interest, the data from both points in time (the field campaign 2000 and the Datenspeicher Wald 1989) had to be aggregated. Table 9 gives an overview of the attributes and the approach applied to calculate appropriate attribute values.

Buffers were created by using the GIS functionality of ArcView. The shape file created by ArcView was exported into a raster format (ERDAS) including binary colour coding (black and white), so that every single attribute could be provided as a binary map. The binary maps are presented on a per pixel basis for the abundance (white) or absence (black) for each attribute (Table 9).

4.1.1.2 Field Data (2000)

The relevant field data had to be aggregated out of the MNTFR project database. The plot coordinates were extracted for the GIS applications and the kNN algorithm.

4.1.2 Remote Sensing Data

The satellite scenes were geo-referenced in order to overlay scenes from different points in time, and to match individual pixels with ground data as a preparation for the application of the kNN method. In a following step a slope-aspect correction was performed for the geo-referenced satellite scenes. This was realised by applying the Non-Lambertian Correction normalisation algorithm (ERDAS 1997). The following equation is, according to COLBY (1991) and SMITH AND RANSON (1980), used to normalize the brightness values in the image.

$$BV_{normal\lambda} = (BV_{observed\lambda} \cos e)/(\cos^k i \cos^k e) \qquad \textbf{[1]}$$

where:

$BV_{normal\lambda}$ = normalized brightness values

$BV_{observed\lambda}$ = observed brightness value

cos I = cosine of the incidence angle

cos e = cosine of the existence angle, or slope angle

k = the empirically derived Minnaert constant

The Minnaert (MINNAERT AND SZEICZ, 1961) constant (k) may be found by the regression of a set of observed brightness values from the remotely sensed imagery on known slope and aspect values, provided that all the observations in this set are the same type of land cover. The k value is the slope of the regression line (HODGSON AND SHELLY 1993):

$$\log(BV_{observed\lambda}\cos e) = \log BV_{normal\lambda} + k\log(\cos i \cos e)$$

[2]

The algorithm was applied in the ERDAS IMAGINE software.

4.1.3 Data Combination with the kNN Method

For habitat modelling the satellite data have to be combined with data from the ground surveys. The combination was realised using the "k nearest neighbour (kNN) method". The kNN method is an automatic technique which optimises the behaviour of a system (NIEMANN 1983). The optimised behaviour is described with a function, which is approximated by a given number of samples (NIEMANN 1983). For classification purposes the kNN method is applied with the objective of finding the location value with the help of its similarity to an already known location value. The process can be described in the following way. For the entire set of pixels without associated ground assessments, the k nearest neighbours in the spectral image space are determined among those pixels which coincide with the location of field samples. A search algorithm identifies the nearest neighbours of the pixels in the spectral image space, while k is the potentially derived number of neighbouring pixels for one spectral image class. The entire image is classified according to its spectral image space and distance to pixels which coincide with field sample locations. They are the already known location values (NIEMANN 1983). The estimates are plotted to produce maps that show the spatial distribution of attributes assessed on the ground in the resolution of the remote sensing data.

In the kNN method, attribute values (v) for a specific pixel is calculated as the weighted average of the k field plots that are closest to the pixel in the space distance (d) (equation [3]). In this study, the feature space distance is measured as the Euclidean distance in the spectral space defined by the bands in the EO data (Landsat). The weights (w) given to the bands are proportional to the inverse squared distance (equation [3]). This is essentially an inverse distance weighted averaging method, as commonly used for spatial interpolation (ISAAKS AND SRIVASTAVA, 1989).

$$\boldsymbol{v}_p = \sum_{j=1}^{k} w_{j,p} \cdot \boldsymbol{v}_{j,p},$$

[3]

where

$$w_{j,p} = \frac{1}{d_{j,p}^2} \Big/ \sum_{i=1}^{k} \frac{1}{d_{i,p}^2},$$

$$d_{1,p} \le d_{2,p} \le \ldots \le d_{k,p},$$

$d_{j,p}$ = feature space distance from pixel p to plot j, and

$v_{j,p}$ = attributes for the plot with distance $d_{j,p}$.

In the context of forest resource assessments the kNN method was firstly described by KILKKI AND PÄIVINEN (1987) and later enhanced by TOMPPO (1991, 1993, 1997A, 1997B). In Finland the kNN method was applied to obtain results for Forest Board Districts (TOMPPO 1993). The multi-temporal analysis of habitat suitability for Black Stork or Red Kite does not only concentrate on forested landscape elements, but also on elements such as lakes, agricultural fields and other land cover classes. For non-wooded areas, a number of fictional points in the images had to be created in order to receive any input into the kNN e.g. for the lakes or the agricultural land around Moritzburg.

The programming for the applied kNN algorithm was done in Visual Basic (STÜMER, 2004; KÖHL ET AL. 2001). The software utilised has a user interface for different settings. For providing kNN estimates an analysis program was used in which all relevant kNN functions and estimation approaches were implemented. Not only nominal data, but also ordinal data could be analysed by the kNN method. The different bands of on satellite scene or image data can be activated for the calculation.

4.1.4 The Habitat Suitability Index Model (HSI)

The applied HSI model approach was chosen because of its potential to detect hotspots on the landscape level in a simple and effective way. The objective was not to develop a method for supporting management decisions on the local level, but to create an early warning system with habitat quality as an indicator for potential consequences of land use changes. The other essential issue was to create a HSI model for the implementation of different information on spatial and temporal scales. Thus the HSI or the two key species offers the possibility to predict potential habitat changes in future.

The defined habitat descriptions of the FFH Directive have been analysed and compared according to the available data for the time series application. Because some of the defined life requisites could be reflected together in one of the indicators of this landscape level approach, the list of describing features for each species will be a subset of the list of the FFH Directive within these HSI models.

Red Kite (*Milvus milvus*) represents a species that is listed as a major protection priority in the Council Directive 79/409/EEC on the Conservation of Wild Birds (EC 1972), whereas the Black Stork (*Ciconia nigra*) is declared as a key species in the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (EC 1992).

Table 7 Red Kite: life requisites, model attributes and their weights in the HSI

life requisite	life requisite weight in HSI	model-attribute/thresholds	abbreviation	attribute weight in life requisite
Food	**6**	**Water bodies**: distance max. 1 km	**Dist$_{water}$**	**0,4**
		Forest border: distance max. 0,5 km	**Dist$_{forest}$**	**0,4**
		Open sites: class 2 or 3 [1]	**Sites$_{open}$**	**0,2**
Nesting	**6**	**Open forest**: minimum 30 ha	**Forest$_{open}$**	**0,7**
		Timber volume: minimum 300 m³/ha	**Vol**	**0,3**
Safety	**3**	**Tree species composition** : minimum 80% broadleaved trees	**Comp$_{tree}$**	**0,5**
		Tree height: minimum 25 m	**Height$_{tree}$**	**0,5**

[1] Class 2 is defined as "other wooded land": Land either with a tree crown cover (or equivalent stocking level) of 5-10% of trees able to reach a height of 5 m at maturity in situ; or a crown cover (or equivalent stocking level) of more than 10% of trees not able to reach a height of 5 m at maturity on situ and shrub or bush cover with a minimum area of 0,5 ha and a width of 20 m.
Class 3 is defined "agricultural land": areas used for seasonal and permanent crops; two categories: tree crops and other crops (According to the MNTFR field manual)

The HSI model contains no territorial constraints and the HSI has been calculated strictly on a per pixel basis.

$$\mathbf{HSI_{Red\ Kite} = 6*(0.4*Dis_{water}+0.4*Dist_{forest}+0.2*Sites_{open})*6*}$$
$$\mathbf{(0.7*\ Forest_{open}+0.3*Vol)*3*(0.5*Comp_{tree}+0.5*Height_{tree})} \quad [4]$$

$$\mathbf{HSI_{Red\ Kite} = 6*(Food)*\ 6*(Nest\ sites)*\ 3*(Safety)} \quad [5]$$

Table 8 Black Stork: life requisites, attributes and their weights in the HSI

life requisite	life requisite weight in HSI	model-attribute /thresholds	abbreviation	attribute weight in life requisite
Food	**5**	**Stand structure**: several layers	$\mathbf{Struc_{stand}}$	**0,3**
		Forest border: distance max. 1 km	$\mathbf{Dist_{forest}}$	**0,4**
		Tree species composition: minimum 80% broadleaved trees	$\mathbf{Comp_{tree}}$	**0,3**
Nesting	**10**	**Tree height**: minimum 25 m	$\mathbf{Height_{tree}}$	**0,7**
		Timber volume: minimum 300 m³/ha	**Vol**	**0,3**

As for Red Kite no territorial constraints are considered for Black Stork and the HSI has been calculated strictly on a per pixel basis.

$$\mathbf{HSI_{Black\ Stork} = 5*(0.3*Struc_{stand}+0.4*Dist_{forest}+0.3*\ Comp_{tree})*10*}$$

$$\mathbf{(0.7*\ Height_{tree}+0.3*Vol)}$$

[6]

In order to enable a time series approach the ground data of the field campaign carried out in 2000 had to be aggregated for the different attributes utilised as input attributes to the HSI models. For the calculation of the individual attributes over the entire area of interest, the data from both points in time (the field campaign 2000 and the Datenspeicher Wald 1989) had to be aggregated. Table 9 gives an overview of the attributes and the approach applied to calculate appropriate attribute values.

Table 9 List of habitat attributes and their calculations using the kNN and GIS functionality

Key species	Attribute	kNN output	Arc View output
Red Kite	Water bodies: distance max. 1 km	-	buffer creation (1km) around every lake in the scene; buffer outside the lake
	Forest border: distance max. 0,5 km	-	buffer creation (0,5 km) in both directions; border between the forest area and the large fields
	Open sites: class 2 (other wooded land) or 3 (agricultural land) *(MNTFR nomenclature)*	Map with 1 for every pixel with class 2 or 3; 0 for everything else	-
	Open forest (basal area under 15 m²/ha) minimum 30 ha	Map with 1 for open forests; 0 for everything else	-
	Timber volume: min. 300m³/ha	Map with 1 for pixel with 300m³/ha or more; 0 for less than 300m³/ha	-
	Tree species composition: min. 80% broadleaved trees	Map with 1 for pixels with 80% broadleaved trees or more; 0 for less than 80% broadleaved trees	-
	Tree height: min. 25 m	Map with 1 for every pixel with trees of 25 m height or higher; 0 for pixels with smaller trees	-
Black Stork	Stand structure:	Map with 1 for pixels with several vertical layers; 0 for pixel without any vertical structure in the forests	-
	Forest border: distance max. 1 km	-	buffer creation (1 km) in both directions; border between the forest area and the large fields
	Tree species composition: min. 80% broadleaved trees /ha	Map with 1 for pixels with 80% broadleaved trees or more; 0 for less than 80% broadleaved trees	-
	Tree height: min. 30 m	Map with 1 for every pixel with trees of 30m height or higher; 0 for pixels with smaller trees	-
	Timber volume: min. 300m³/ha	Map with 1 for pixel with 300m³/ha or more; 0 for less than 300m³	--
	Infrastructure distance: min. 3 km	-	buffer creation (3 km) in both directions; on every road
	Recreation facilities: no	-	identify recreation facilities on the map
	Resident population: max. 100 habitants	Map with 1 for habitants numbers below 100; 0 for pixels with higher population	-

The ground truth assessments of both occasions are the geo-referenced basis for the attributes defined during the habitat definition process. Image elements which coincide with the sample plots were taken as starting points for the kNN application, identifying the k nearest neighbours in the spectral image space to be classified for an attribute of interest (e.g. timber volume). The potential result is a binary map including the value 1 for the respective elements of e.g. minimum timber volume of 300 m³/ha according to their spectral information and 0 for those pixels which do reflect lower timber volume.

Attributes like “water bodies” were digitised on topographical maps and used for GIS buffer applications. The areas within the defined zones are related to a positive spatial attribute reply (1) on the binary result maps, while districts lying outside were defined as 0.

$$x_i = \begin{cases} 0, & \text{for area outside the defined zone} \\ 1, & \text{for area inside the defined zone} \end{cases}$$

[7]

where x_i is the attribute reply value for the attribute of interest.

Both procedures were applied for each appropriate habitat attribute resulting in individual binary maps as input for the final habitat modelling. The approach described here is a Boolean approach using overlaying procedures, while each model unit has a distinct binary character (BOOLE 1854).

4.1.5 Retrospective Change Analysis of the HSI

The main interest of the study was to analyse the development and change of potential habitats for rare species with various HSI models. The changes of the potential habitats were analysed by using the data of the Datenspeicher Wald as retrospective data source for 1989, and the field campaign 2000 respectively. Earth observation images were available for the same points in time to obtain objective information over the entire area of interest in an effective way. For forest related habitats this has been successfully done by MACKINNON AND WULF (1994). For the change analysis of the HSI the difference image methodology was applied for: (i) the remotely sensed imagery, (ii) the entire HSI, (iii) the life requisites and (iv) the individual attribute maps.

4.1.6 The Difference Image

In the multi-temporal analysis, emphasis was put on the potential differences between the two habitat suitability maps of 1989 and 2000. The focus was to identify whether the differences could be identified with the applied methods like kNN on a scale of maximum 30 m resolution. The habitat suitability maps are 8 bit images presenting 256 different grey pixel values in one image, where light components represent high habitat suitability and dark components represent low habitat suitability. Every shade grey is the result of the merged binary information of the weighted individual attribute map by the addition to life requisites. The life requisites were weighted a second time, and then finally multiplied in HSI maps with 8 bit character. The image values for 1989 were subtracted from image values for 2000, thus producing a difference image. The same procedure was used in comparing the maps for a single attribute (e.g. timber volume) derived using the kNN procedure.

ERDAS Modeler (ERDAS 1997) was used to calculate the difference images by applying a methodology developed by IGBOKWE (1994):

$$\Delta p_k = p_k(1) - p_k(2)$$

[8]

Δ pk = changed pixel over time

pk (1) = grey values of the imagery of 1989

pk (2) = grey values of the imagery of 2000

k = the single channel (only one available for the HSI)

The procedure results in positive values for some areas and negative values for others that represent changes over time. For further investigations on the results the images were reconverted into the normal 8 bit character. Beside the HSI maps the two Landsat images of Moritzburg were also subtracted to receive the spectral image changes within the Moritzburg scene.

4.1.7 Evaluation of the HSI – A Sensitivity Analysis

The HSI for the Red Kite was evaluated, as all selected attributes were present around Moritzburg. For the understanding of the HSI results, a sensitivity analysis was applied. The aim was to elucidate the influence of a single attribute in the entire model. Multiplying all attributes indicating life requisites of the Red Kite (4.1.4) leads to a very small effect of the applied weights of the model output. For instance the life requisite “nesting” consists of the two attributes “open forest” and “timber volume”. Pixels indicating the “open forests” with a canopy cover of less than 15% cannot coincide with pixels indicating a minimum timber volume of 300 m³/ha. Due to this attribute definition the location of pixels have to be different. Thus the attributes are auto-correlated (ANDERSON AND WALKER 1964). The roles of the life requisite and the individual attribute for the entire HSI are limited. Areas which are not covered by a single attribute of a life requisite obtain the value zero in the entire model, because of the multiplication. The HSI more or less describes the areas providing the optimum habitat (i.e. those providing all life requisites) around Moritzburg. Transfer habitat suitability probabilities are of interest for the quantification of different suitability classes, besides the optimum. The original pixel-wise approach of the HSI was chosen because the area of interest lies inside the home range of the Red Kite. Thus the individual species does not have to have all life requisites including all attributes in one location, because the mobility to reach a missing requirement is given in all positions of the test site. On the one hand this allows summing up the weighted attribute maps in a modified habitat suitability model (HSI+) to quantify different classes beside the optimum of habitat suitability with transfer habitat suitability probabilities (see equations [12], [15]). On the other hand the role of the single attribute for the total area of interest can be examined with a sensitivity analysis applying a seven digit image (Figure 8 and equation [16]). The original habitat model is described by the equations [9] and [10].

$$\mathrm{HSI}_{\mathrm{Red\ Kite}} = 6*(0.4*\mathrm{Dis}_{\mathrm{water}}+0.4*\mathrm{Dist}_{\mathrm{forest}}+0.2*\mathrm{Sites}_{\mathrm{open}})*6*(0.7*\mathrm{Forest}_{\mathrm{open}}+0.3*\mathrm{Vol})*3*(0.5*\mathrm{Comp}_{\mathrm{tree}}+0.5*\mathrm{Height}_{\mathrm{tree}}) \quad [9]$$

Summarised in terms of life requisites the HSI can be reformulated into:

$$\mathrm{HSI}_{\mathrm{Red\ Kite}} = (6*[\mathrm{FOOD}]) * 6*[\mathrm{NESTING}] * 3*[\mathrm{SAFE}]$$

$$= 6*6*3* [\mathrm{FOOD}] *[\mathrm{NESTING}] *[\mathrm{SAFE}]$$

$$= a* [\mathrm{FOOD}] *[\mathrm{NESTING}] *[\mathrm{SAFE}] \quad [10]$$

a = factor, no weighting

While the weights are defined within the life requisites, the multiplication of the requisites in the second step leads to an abrogation of the weights in the model output. Modifying the HSI by summing the life requisites gives:

$$\mathrm{HSI}_{\mathrm{modified\ Red\ Kite}} = 6*[\mathrm{FOOD}] + 6*[\mathrm{NESTING}] + 3*[\mathrm{SAFE}] \quad [11]$$

or

$$\mathrm{HSI}_{\mathrm{modified\ Red\ Kite}} = (6*(0.4*\mathrm{Dis}_{\mathrm{water}}+0.4*\mathrm{Dist}_{\mathrm{forest}}+0.2*\mathrm{Sites}_{\mathrm{open}})) + (6*(0.7*\mathrm{Forest}_{\mathrm{open}}+0.3*\mathrm{Vol})) + (3*(0.5*\mathrm{Comp}_{\mathrm{tree}}+0.5*\mathrm{Height}_{\mathrm{tree}})) \quad [12]$$

In other terms the HSI model can be expressed as the sum of all attribute weights (p_i), defined as 1 in all attribute maps, multiplied with the presence of the attribute (f_i) of a single location in the area of interest.

$$HSI(x,y) = \sum_{i=1}^{n} p_i * f_i(x,y)$$

[13]

i = 1 to n for habitat attributes

p_i = weight of attribute with $\sum_{i=1}^{n} p_i = 1$

f_i = presence of attribute (1 or 0) at position (x,y)

x, y = position of attribute

$$\mathrm{f_i} = \begin{cases} 0, & \text{for attibute absence at position x, y} \\ 1, & \text{for attribute presence at position x, y} \end{cases}$$

[14]

The maximum habitat value of 1 can be achieved by converting the attributes according to the weight of the attribute and by the weight of the requisite. This results in the equation:

$$\mathbf{HSI_{modified\ Red\ Kite} = 0.16*Dis_{water}+0.16*Dist_{forest}+0.08*Sites_{open}+0.28*Forest_{open}}$$

$$\mathbf{+0.12*Vol+0.10*Comp_{tree}+0.10*Height_{tree}}$$

[15]

Another reason for modifying the HSI is to calculate the influence of the natural circumstances in terms of spatial patch arrangement in Moritzburg.

If the sum of all weighted attributes should sum to 1, the single attribute weight would relatively change into a value smaller than 1 according to the weight of the life requisite itself and according to the weight of the individual attribute within the life requisite. The conversion is presented in the following table:

Table 10 Conversion of attribute weights into a Red Kite HSI with the maximum value one

Life requisite (LR)	**attribute**	**LR weight**	**converted LR weight**	**attribute weight**	**converted attribute weight**
Food	**1) Water bodies**	**6**	**0,4**	0,4	0,16
	2) Forest border			0,4	0,16
	3) Open sites			0,2	0,08
Nest site	**4) Open forest**	**6**	**0,4**	0,7	0,28
	5) Timber volume			0,3	0,12
Safety/watching site	**6) Broadleaved trees**	**3**	**0,2**	0,5	0,10
	7) Tree height			0,5	0,10
total		15	1	3	1

The table includes the already shown HSI weights and the attribute weights of the individual attributes, when their values are summed to 1. According to the converted HSI model, it is obvious that “open forest” has the most relevance followed by “water bodies” and “forest border”.

The modified HSI is upgraded by merging the attributes maps with an image analysis algorithm. The procedure is illustrated in Figure 8.

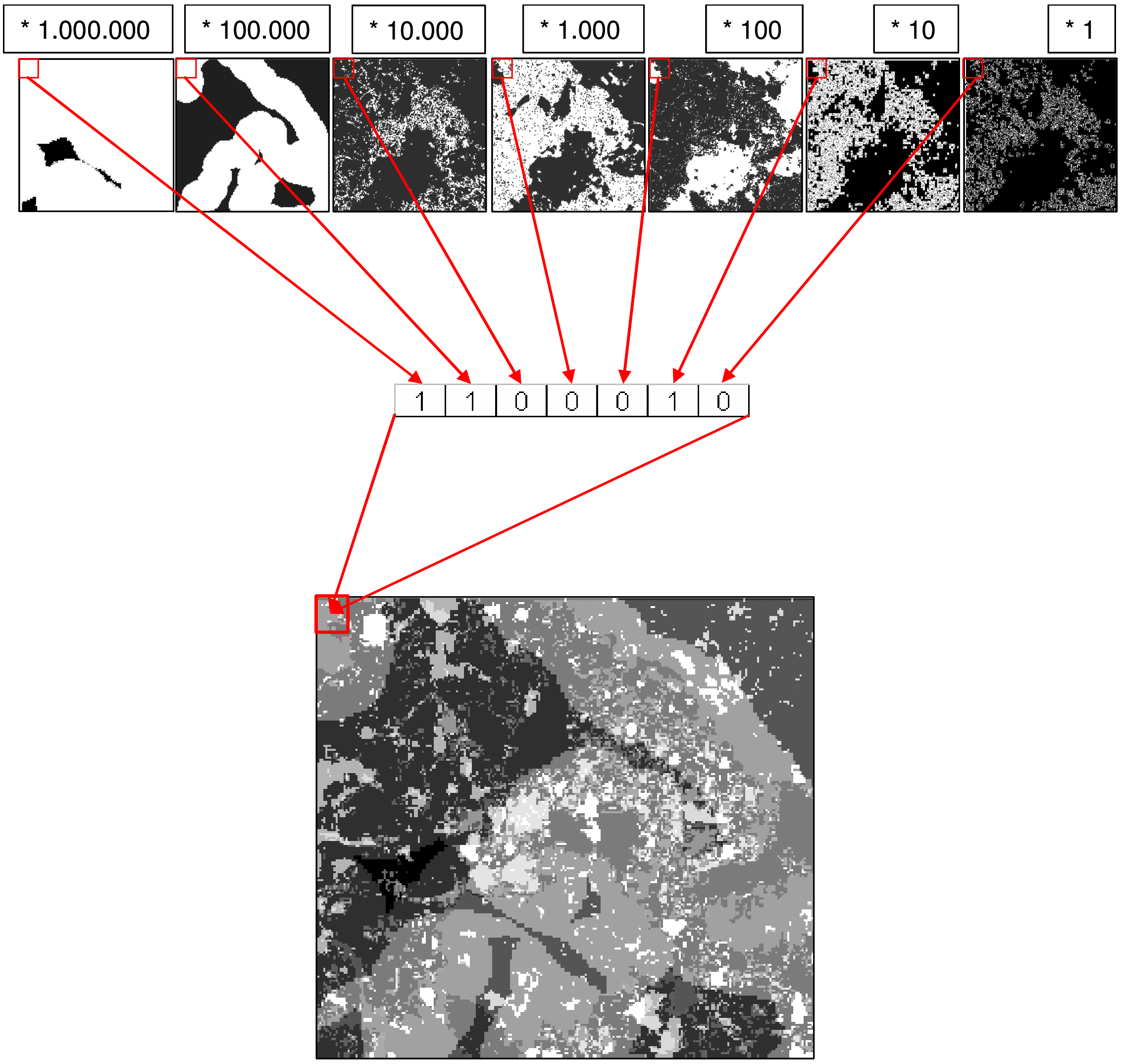


Figure 8 Seven digit image creation for the sensitivity analysis

The calculation can be described by the following equation:

$$\mathbf{HSI = (1.000.000*Dis_{water}) + (100.000*Dist_{forest}) + (10.000*Sites_{open}) + (1.000*Forest_{open}) + (100*Vol) + (10*Comp_{tree}) + (1*Height_{tree})}$$

[16]

Each attribute pixel value (1 or 0) is multiplied with a value from 1 to 1.000.000 according to numerical position of the result map pixel value, so that every suitable attribute pixel is reflected in the output image. The output is a 7 digit image map, including the information about which attribute contributes to the final HSI value. A further calculation algorithm considers the weights for the single pixel values in each of the 7 digit result pixels. With the frequencies of the different 7 digit combinations of the image, where one digit reflects the presence or absence of a defined attribute, the influence of an individual attribute for the entire HSI model can be identified. The procedure considers each attribute independently from its position in the life requisite or the entire HSI model. The presence and absence of an individual attribute as well as its weight within the entire HSI model was utilised. The results of the HSI with summed life requisites and the results of the sensitivity analysis are shown in chapter 4.2.7.

4.2 RESULTS OF THE HSI

4.2.1 Remote Sensing Data

The differences between the two digital signatures of the Landsat images of 2000 and 1989 were analysed. The grey values of the image of 2000 were subtracted form the values of the image of 1989. The result is a difference image, which is limited to the difference of the digital image information. Table 9 presents the result of the procedure. The top of the images represents north.

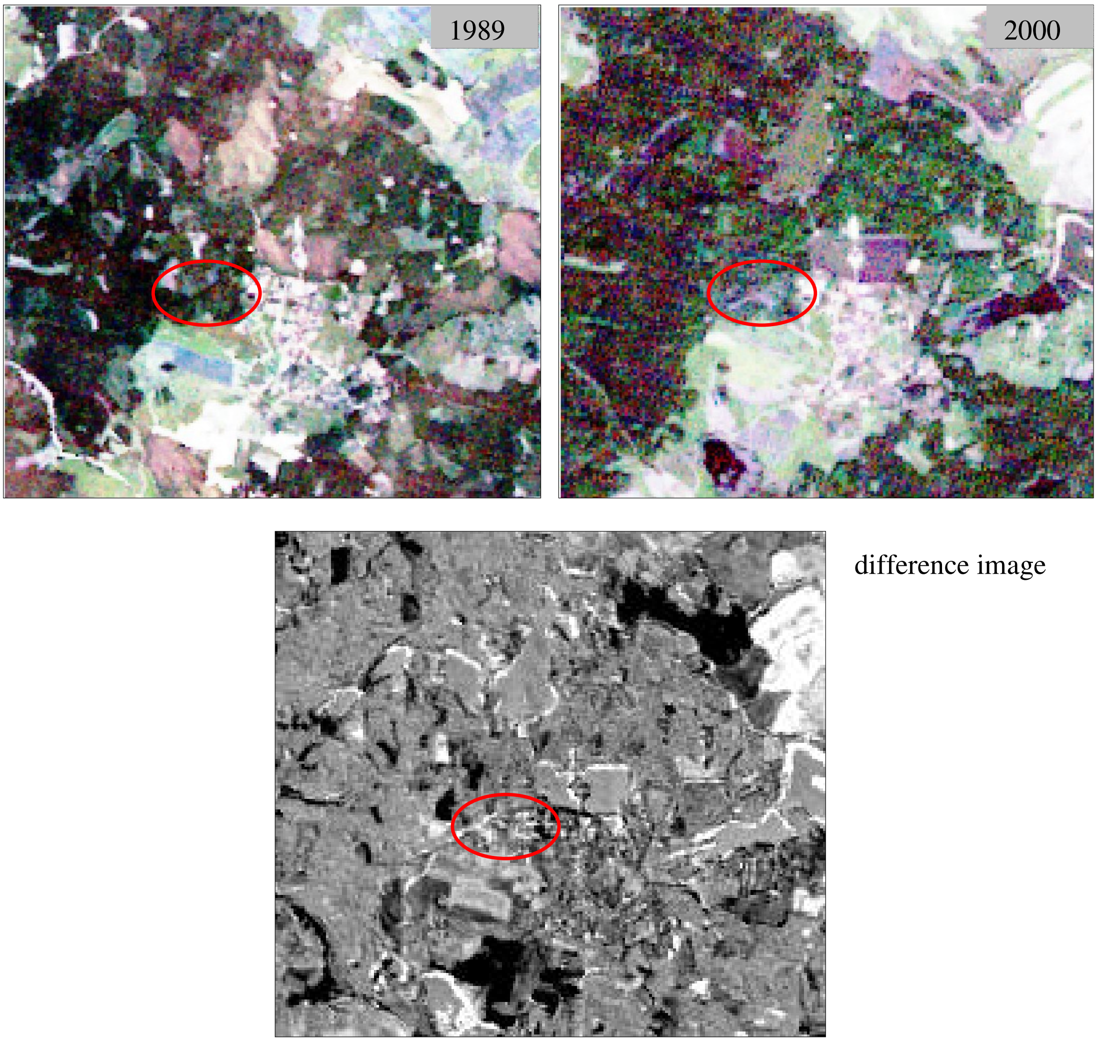
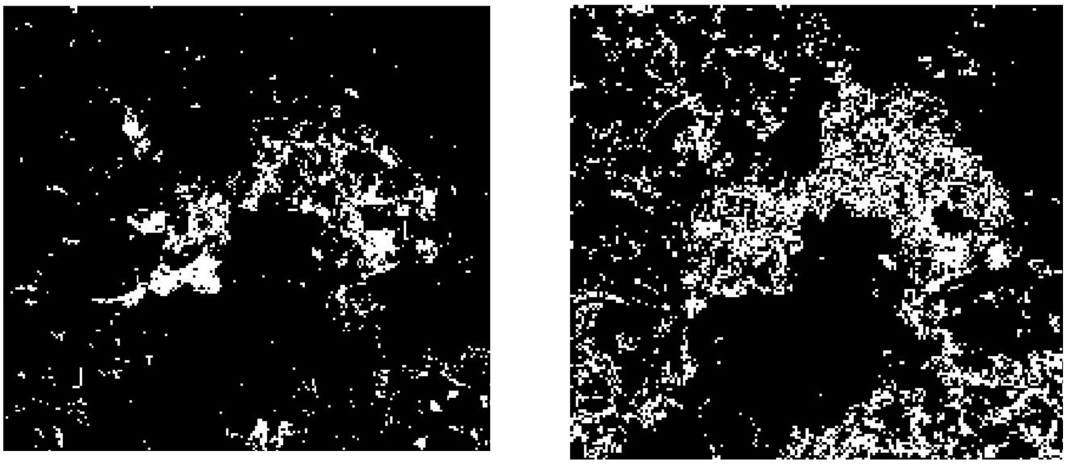


Figure 9 Difference image of the Moritzburg satellite images

In the difference image dark and bright areas indicate changes in the digital information of the two images. The grey areas indicate small or even no changes of the digital information. The red ellipse shows an area with a considerable change when comparing the two images visually, which was not shown clearly in the difference image. The dark area in the north-eastern part indicates conspicuous changes, which encompass the area of a drained lake in 1989. Additionally some more dark areas can be found in the north-western as well as in the southern parts of the difference image. A conspicuous light area indicating changes can be found in the north-eastern part.

4.2.2 HSI Attributes

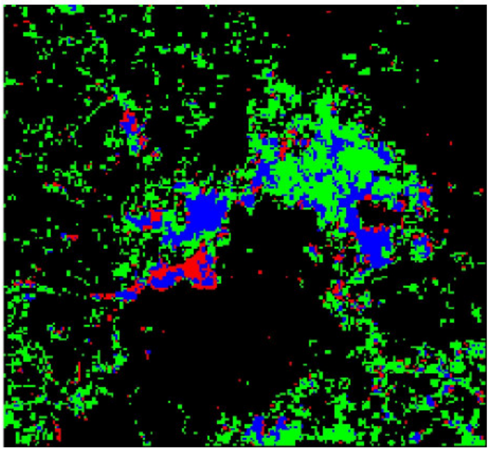
For the HSI models, the kNN method was used to combine the ground survey data with the satellite images. This was done for each attribute in terms of one HSI attribute map for each of the years 1989 and 2000. For example the attribute “broadleaved trees” (80% broadleaved trees per ha) was essential for both key species. The resulting maps are shown in Figure 10.



Tree species composition of broadleaved trees (minimum 80% per ha) in 1989

Tree species composition of broadleaved trees (minimum 80% per ha) in 2000

white: “broadleaved trees” detected
black: no “broadleaved trees” detected

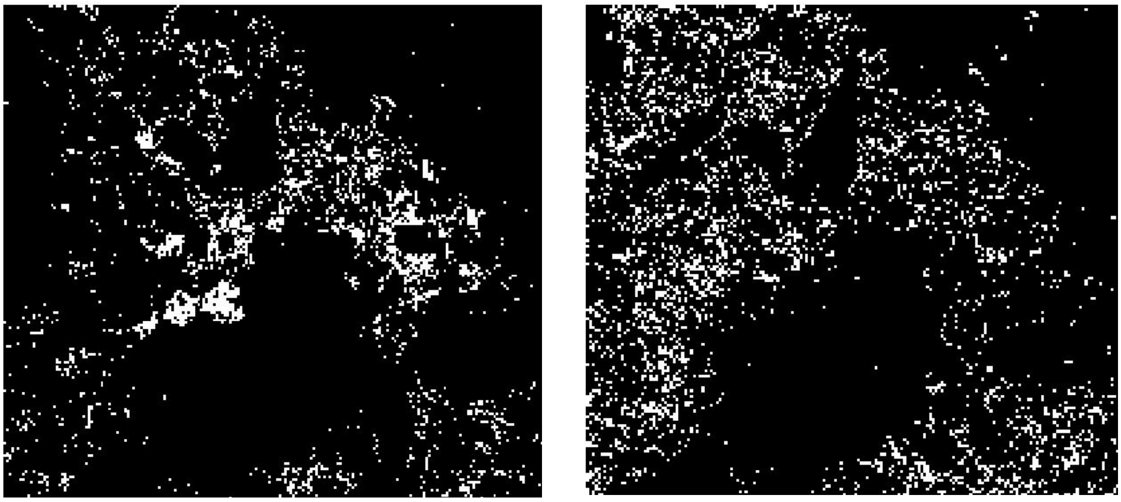


red: loss of “broadleaved trees”
green: increase of “broadleaved trees”
blue: no change of “broadleaved trees”
black: no “broadleaved trees” detected

Change of the attribute “broadleaved trees” from 1989 to 2000

Figure 10 kNN result maps of the attribute “broadleaved trees” for 1989 and 2000 and its changes

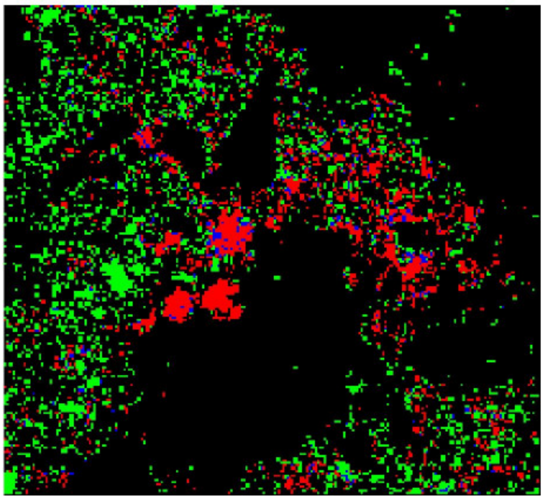
In the centre of the map of 1989 an accumulation of pixels with 80% broadleaved trees per ha is visible. In the map of 2000 this accumulation could not be found in such a pronounced intensity. A similar development could be visually detected with the attribute “timber volume” (timber volume minimum 300 m³/ ha) which should represent old stands in the area around Moritzburg. This attribute was also essential for both key species.



Timber volume of minimum 300m³/ha for 1989

Timber volume of minimum 300m³/ha for 2000

white: “timber volume” detected
black: no “timber volume” detected



red: loss of “timber volume”
green: increase of “timber volume”
blue: no change of “timber volume”
black: no “timber volume” detected

Change of the attribute “timber volume” from 1989 to 2000

Figure 11 kNN result maps of the attribute “timber volume” for 1989 and 2000 and its changes

Within the HSI the different attribute layers were calculated with kNN or GIS. For the kNN layers the input maps for each attribute were:

- timber volume **Vol**
- open sites **$\mathbf{Sites_{open}}$**
- open forest **$\mathbf{Forest_{open}}$**
- broadleaved trees **$\mathbf{Comp_{tree}}$**
- tree height **$\mathbf{Height_{tree}}$**

The development of the single attributes over the considered time period were calculated and analysed. Examples for the spatial distribution of the development can be seen in the illustrations of Figure 10 and Figure 11. The rest of the spatial illustrations are presented in the Annex (p.185). The numerical description of the changes is presented as follows.

Table 11 Development of "timber volume" from 1989 to 2000 [% of the test site area]

Vol

2000	**1989**		
	timber volume ≥ 300 m³/ha	**timber volume < 300 m³/ha**	
timber volume ≥ 300 m³/ha	1,12%	9,60%	Σ 10,72%
timber volume < 300 m³/ha	6,23%	83,04%	
	Σ 7,35%		

relative change of suitable area: + 3,37%

Table 12 Development of "open sites" from 1989 to 2000 [% of the test site area]

Sites$_{open}$

2000	**1989**		
	open sites	**non open sites**	
open sites	26,46%	3,17%	Σ 29,64%
non open sites	7,14%	63,22%	
	Σ 33,60%		

relative change of suitable area: **- 3,97%**

Table 13 Development of "open forest" from 1989 to 2000 [% of the test site area]

Forest$_{open}$

2000	**1989**		
	open forest	**non open forest**	
open forest	2,36%	8,57%	Σ 10,93%
non open forest	8,52%	80,55%	
	Σ 10,88%		

relative change of suitable area: **+ 0,05%**

Table 14 Development of "broadleaved trees" from 1989 to 2000 [% of the test site area]

$Comp_{tree}$

2000	**1989**	
	broadleaved trees ≥ 80%/ha	**broadleaved trees < 80%/ha**
broadleaved trees ≥ 80%/ha	5,43%	15,50%
broadleaved trees < 80%/ha	2,30%	76,77%

Σ 20,93%

Σ 7,73%

relative change of suitable area: + 13,21%

Table 15 Development of "tree height" from 1989 to 2000 [% of the test site area]

$Height_{tree}$

2000	**1989**	
	tree height > 25 m	**tree height < 25 m**
tree height > 25 m	0,94%	7,75%
tree height < 25 m	5,33%	85,97%

Σ 8,69%

Σ 6,27%

relative change of suitable area: + 2,42%

“Open sites” (**$\mathbf{Sites_{open}}$**) is the only attribute which showed a small decrease of relative suitability in the test site from 1989 to 2000 (compare Annex figure 1, p. 185). The location of “open forest” (**$\mathbf{Forest_{open}}$**) suitability has changed, while the relative suitable are of “open forest” has remained fairly stable (+0,05%). The suitable area in 1989 (lower left cell of Table 13) is more than 8%. The value describes the decrease of suitability of “open forest”. A similar value can be found in the upper right cell of Table 13. Here the suitable area of “open forest” is about 8% in 2000. The value describes the increase of suitability. A bit more than 2% of the test site area is suitable in both occasions (upper left cell of Table 13). The values of the cells on the left side of the table can be added together to give the total suitability of 1989, and the values of the upper cells of the table can added together to give the total suitability of 2000. Thus the relative change of suitable area can be calculated by subtracting the total suitability value of 1989 from the value of 2000. In the case of “open forest” the relative change of suitable area is +0,05%. The highest relative suitability increase of over 13% of the test site area could be found for “broadleaved trees” (**$\mathbf{Comp_{tree}}$**) in Table 14 and Figure 12.

An overview of all changed attributes for the habitat suitability model is shown in the following figure. Here the proportions of the attribute increases or deceases become visible.

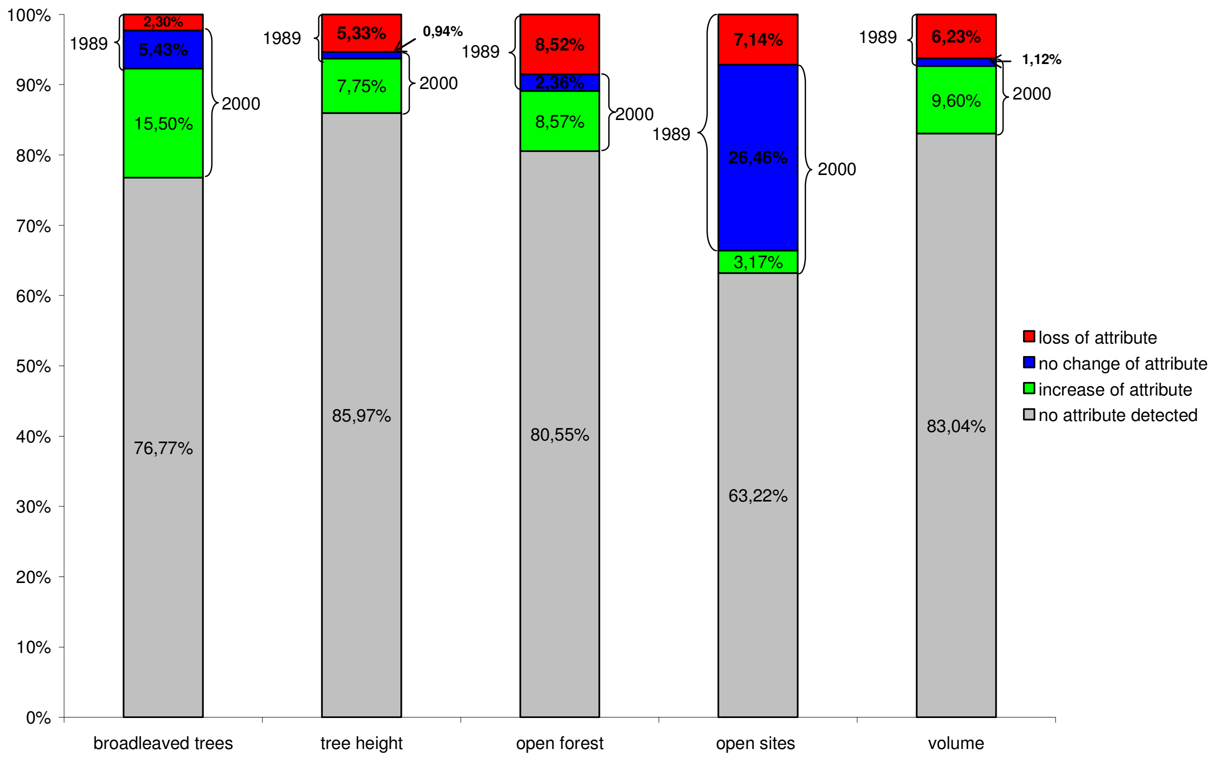
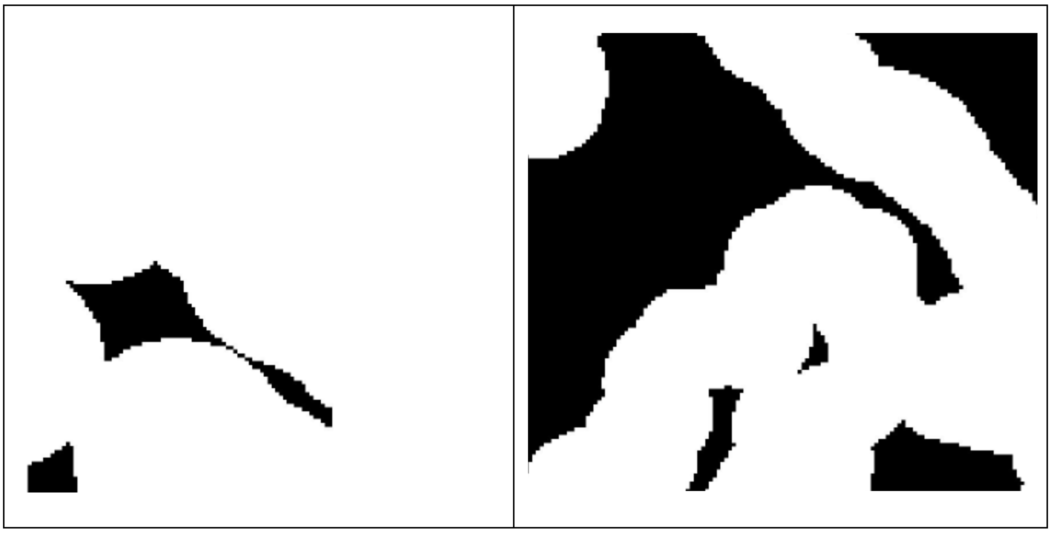


Figure 12 Overview over all HSI attribute developments from 1989 to 2000 [% of the test site area]

As the single kNN attribute maps show changes, the results of the GIS layers are calculated attributes mostly depending on constant natural conditions in the areas. They do not change in a time period of 11 years as the German Forest law does not allow to change forest land into other land use. The shapes of the lakes have not been changed over the years as well, even if some of them are sometimes drained because of fishing activities. The following attributes were created within the GIS:

• water bodies distance	$\mathbf{Dist_{water}}$
• forest border distance	$\mathbf{Dist_{forest}}$
• infrastructure distance	*not detected*
• recreation facilities	*not detected*

The mapping of the 0.5 km distance to "forest borders" and the mapping of the 1 km distance to "water bodies" is illustrated in Figure 13. The maps are also in a binary character for the calculation of the HSI. The black areas showing those areas where there is no water body within 0,5 km or no forest border within 1 km distance.


Water bodies in 1 km distance

Forest border in 0,5 km distance

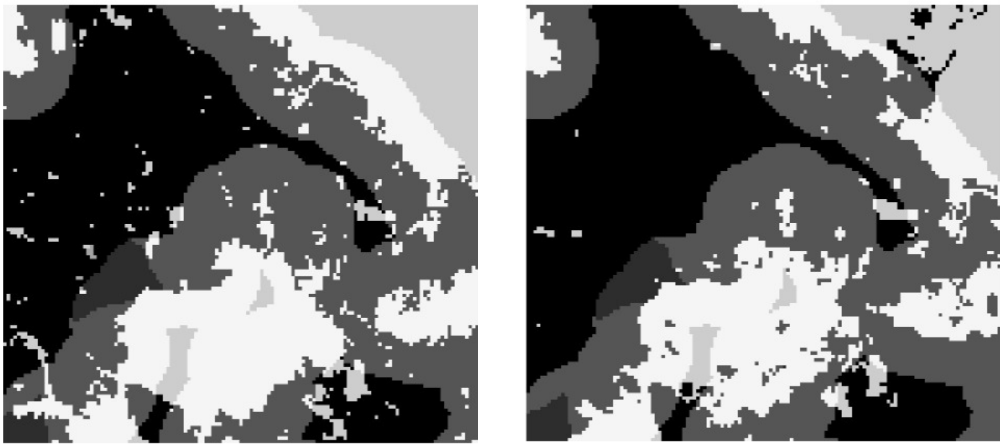
white: attribute detected; black: no attribute detected

Figure 13 Map of buffers around the water bodies (1 km distance) and around the forest border (0.5 km distance) in the test area

4.2.3 HSI Life Requisites

According to the calculation of the HSI for Red Kite in Table 7 the single attributes were weighted and summed for three different life requisites "food" "nesting" and "safety". The maps for the life requisites are illustrated in the following section.

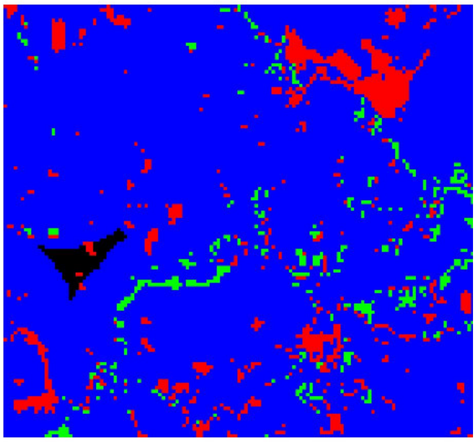
The life requisite "food" consists of "water bodies" ($\mathbf{Dis}_{\mathbf{water}}$), "forest border" ($\mathbf{Dist}_{\mathbf{forest}}$) and "open sites" ($\mathbf{Sites}_{\mathbf{open}}$). They are merged according to the equation [4].



HSI life requisite “food” for Red Kite 1989

HSI life requisite “food” for Red Kite 2000

bright areas: high suitability for “food”
dark areas: less suitability for “food"

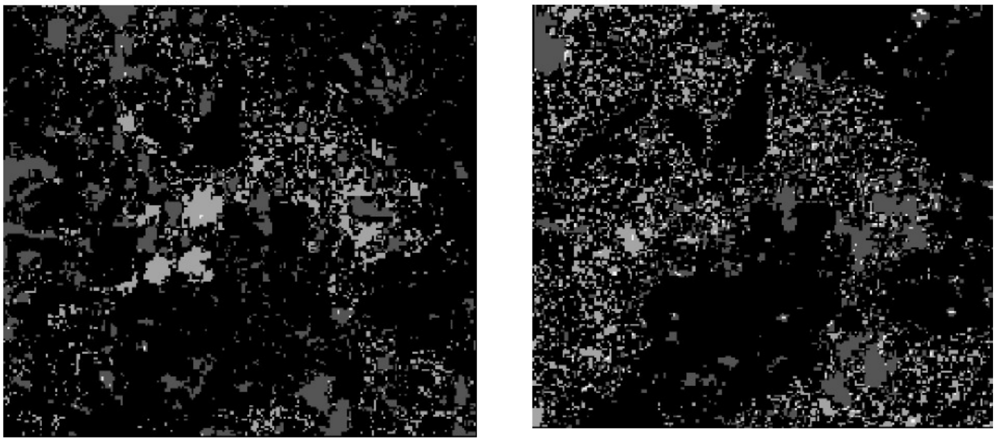


red: loss of “food”
green: increase of “food”
blue: no change of “food”
black: no “food” detected

Change of the HSI life requisite “food” for Red Kite from 1989 to 200

Figure 14 HSI result maps of the life requisite “food” for 1989 and 2000 and its changes

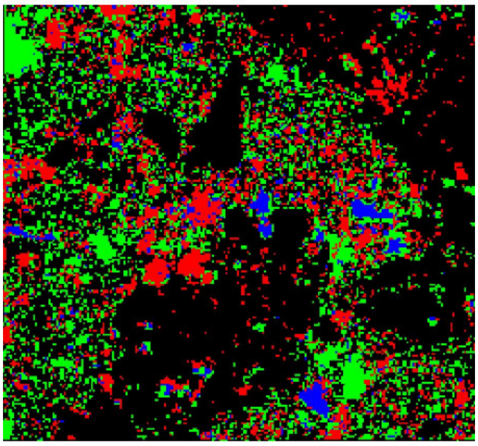
In Figure 14 the unchanged area of the “food” requisite (the blue coloured parts of the map) is mainly caused by the unchanged “water bodies” (including the 1 km buffer zone around the lakes) and the “forest borders” (including the 0.5 km buffer zone around forests for Red Kite). The loss is a result of changes in the “open sites” attribute.



HSI life requisite “nesting” for Red Kite 1989

HSI life requisite “nesting” for Red Kite 2000

bright areas: high suitability for “nesting”
dark areas: less suitability for “nesting"

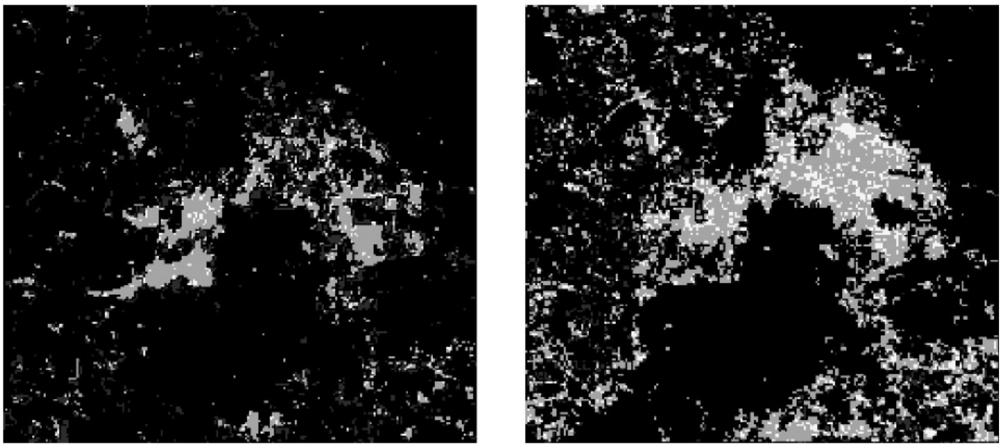


red: loss of “nesting”
green: increase of “nesting”
blue: no change of “nesting”
black: no “nesting” detected

Change of the HSI life requisite “nesting” for Red Kite from 1989 to 200

Figure 15 HSI result maps of the life requisite “nesting” for 1989 and 2000 and its changes

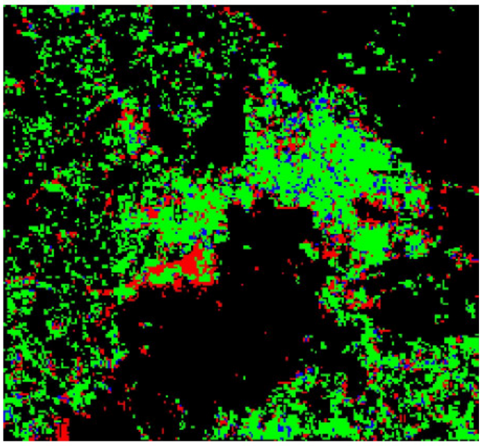
“Nesting” consists of the attributes “open forest” (**Forest$_{\mathbf{open}}$**) (Annex figure 2, p.186) and “timber volume” (**Vol**) (Figure 11). The relative change of suitability of “nesting” is calculated with 2,72%. Compared with the life requisite “food” the attributes for “nesting” cover smaller areas of the test site, while e.g. “water bodies” covers nearly the entire test site (Annex figure 4, p.188).



HSI life requisite “safety” for Red Kite 1989

HSI life requisite “safety” for Red Kite 2000

bright areas: high safety suitability for “”
dark areas: less suitability for “safety"



red: loss of “safety”
green: increase of “safety”
blue: no change of “safety”
black: no “safety” detected

Change of the life requisite “safety” for Red Kite from 1989 to 2000

Figure 16 HSI result maps of the life requisite “safety” for 1989 and 2000 and its changes

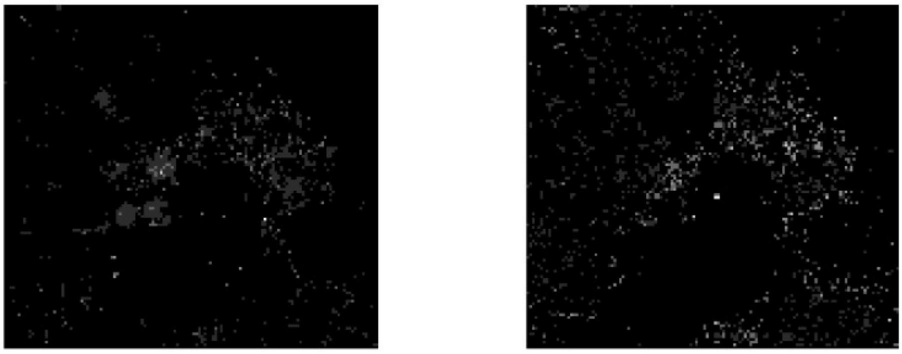
The life requisite “safety” includes the attributes “broadleaved trees” ($\mathbf{Comp}_{\mathrm{tree}}$) (Figure 10) and “tree height” ($\mathbf{Height}_{\mathrm{tree}}$) (Annex figure 3, p.187). The increase of the life requisite covers large parts of the test site area, while only a very small proportion did not change (blue parts). The relative change of suitability was calculated with more than 16%.

4.2.4 Habitat Suitability Model (HSI)

In the following section the results of the HSI models for Red Kite and Black Stork are illustrated. The life requisites were multiplied to the final HSI model (Table 7 and Table 8) according to equations [4] and [5] for the Red Kite and according to equation [6] for the Black Stork. The results are illustrated and described for the Red Kite and the Black Stork separately.

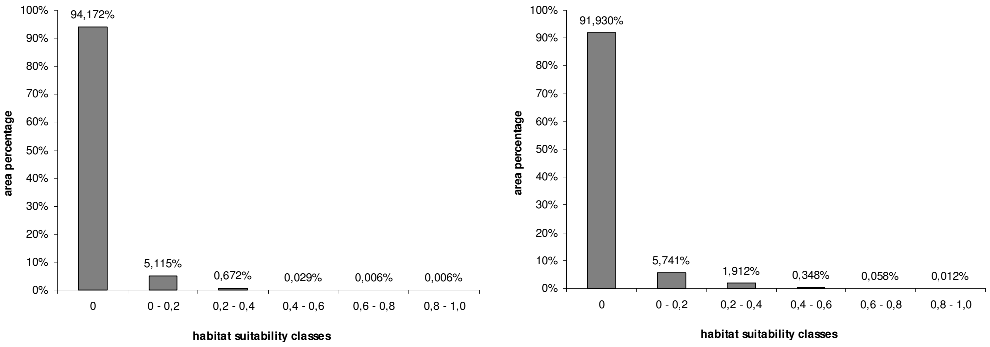
4.2.4.1 HSI of the Red Kite

The HSI for the potential habitat of Red Kite 1989 and 2000 is illustrated and quantified in Figure 17.



Habitat Suitability for Red Kite 1989

Habitat Suitability for Red Kite 2000



Habitat Suitability values for Red Kite 1989

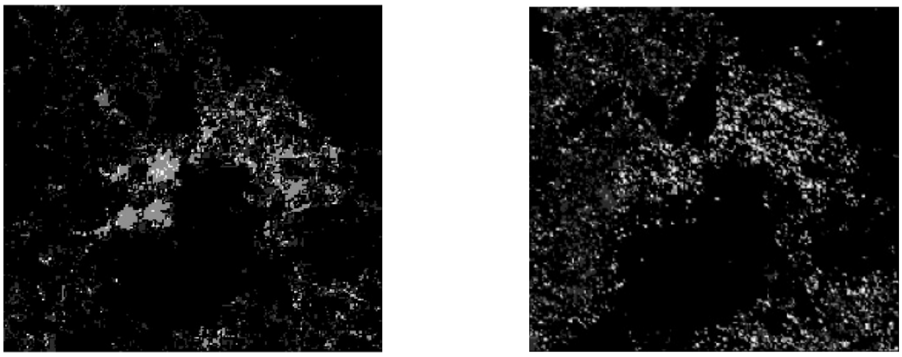
Habitat Suitability values for Red Kite 2000

Figure 17 HSI result maps and distribution of HSI values for Red Kite

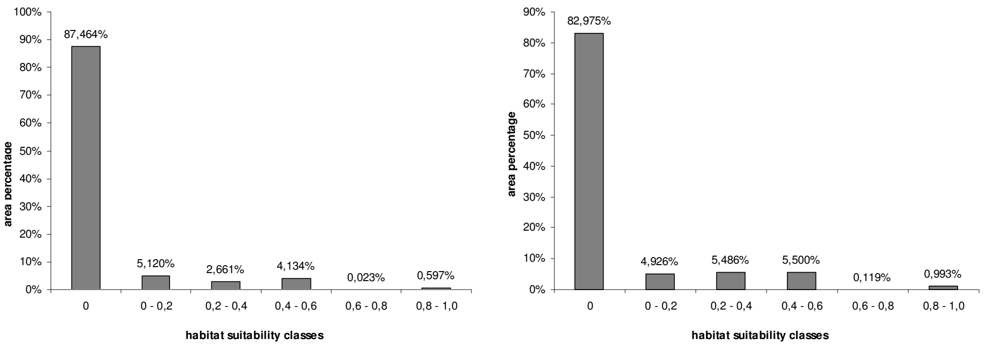
Figure 17 shows only a very small part of the area as potential habitat suitability in 1989 and 2000 for Red Kite. Only 5.8% of the entire area of interest is a suitable area for a potential habitat in 1989, while in 2000 the suitable habitat is about 8% of the test site area.

4.2.4.2 HSI of the Black Stork

The Black Stork habitat suitability is more concentrated in the forested area of Moritzburg. Compared with the Red Kite a higher suitability of 12,5% of the test site area is available.



Habitat Suitability for Black Stork 1989 Habitat Suitability for Black Stork 2000



Habitat Suitability values for Black Stork 1989 Habitat Suitability values for Black Stork 2000

Figure 18 HSI result maps and distribution of HSI values for Black Stork

After the application of the habitat attributes for the Black Stork, the lack of two essential attributes “infrastructure distance” and “recreation facilities” for the life requisite “safety” lead to the result that there is no suitable habitat condition found in Moritzburg as far as the results of the HSI are taken as a basis for this. If the distance from the recreation facilities and the road system to the potential position of the bird is too small and if there is too much resident population around the Moritzburg area, the complete safety requisite for the Black

Stork habitat is not met. According to a bird database created by local ornithologists, no Black Stork has been detected in the area around Moritzburg (LUDWIG 2003). If one ignores the safety aspect for the Black Stork, the results given in Figure 18 can be calculated. In 1989 12.5% of the test site area is a suitable habitat for the Black Stork, without any safety requisites. From the visual point of view the rest of the HSI of the Black Stork shows a similar picture to the HSI of the Red Kite. In 2000 the potential habitat suitability is about 17% of the test site area.

4.2.5 Retrospective Changes of the HSI

4.2.5.1 Change of the Red Kite HSI

The time series of the Red Kite habitat shows the following changes within the suitable area in the test site by analysing the differences between the digital signatures of the Landsat images of 2000 and 1989.

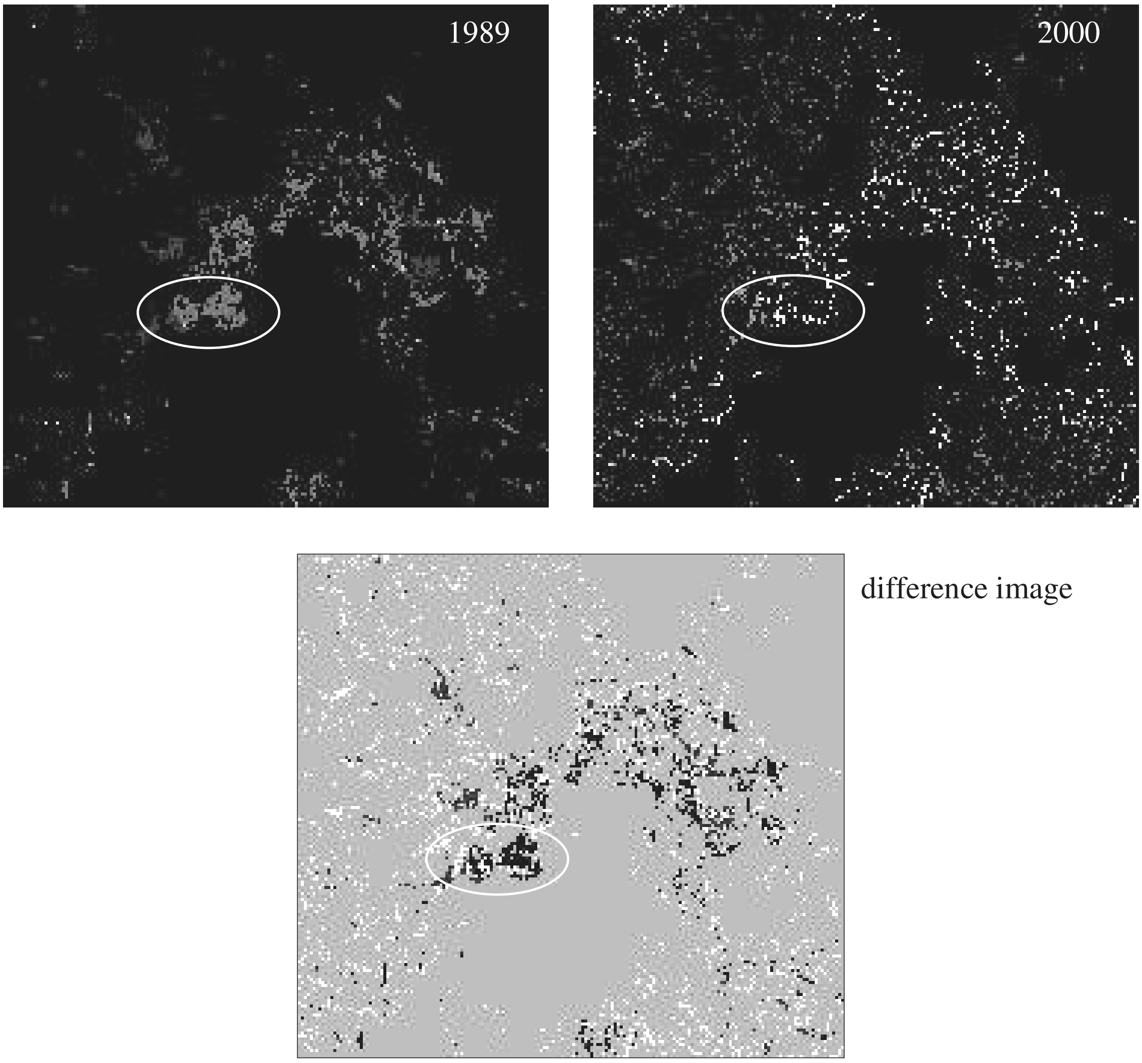
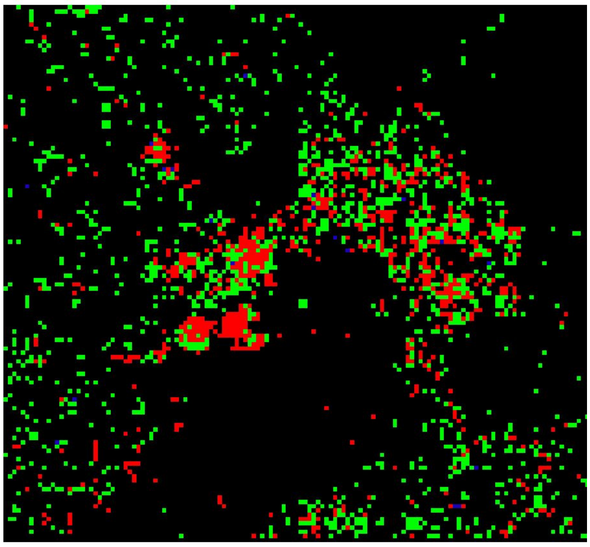


Figure 19 Red Kite habitat suitability index maps of 1989 and 2000 and the difference image

The visualisation of the data shows the spatial distribution of pixels indicating suitable habitats in the test site area. In the difference image light values indicate positive habitat change, while dark values indicate a negative habitat development. The increase of habitat took place in the north-western and the south-eastern part of the test site (white pixels). The area indicating a habitat decrease (dark pixels) is concentrated in the central part of the map and coincides with the change of the attributes “timber volume” and “broadleaved trees”. The area changes of the class “broadleaved trees” between 1989 and 2000 were compared with the areas of the entire Red Kite habitat for both occasions. It was found that more than 50% of the pixels assigned to the class “broadleaved trees“ indicated a decrease of suitability at the same location as the pixels indicating a decrease of the habitat suitability for Red Kite.



red: loss of habitat suitability
green: increase of habitat suitability
blue: no changes of habitat suitability
black: no habitat suitability detected

Figure 20 Change of the Red Kite habitat suitability index from 1989-2000

After exporting the raster images of both occasions to polygons, the area of habitat increase, or decrease and the area of no-change habitat conditions could be defined in size and shape (Figure 20).

Table 16 Development of the HSI for the Red Kite from 1989 to 2000 [% of the test site area]

HSI

2000	**1989** **suitable habitat**	 **no suitable habitat**	
suitable habitat	0,11%	7,83%	Σ 7,94%
no suitable habitat	4,52%	87,54%	
	Σ 4,63%		

relative change of suitable area: + 3,3%

The Red Kite suitability indicated by the HSI model changed as well as the suitability of individual attributes such as “timber volume”. The results show that the HSI model in this multi-temporal analysis reacts to changing ground conditions. A field trip was conducted in order to identify the causes of the changes indicated by the HSI model. The main changes were observed in an area that was originally stocked by an old beech stand, where a shelter wood cut was done in the second part of the 1990s. In the following years serious storm damages considerably reduced the standing timber volume in the stands.

Figure 21 Storm damage after a shelter wood cut in the centre of the Moritzburg test site

Figure 21 illustrates the reason for the reaction of the HSI and especially of the two attribute maps “timber volume” and “broadleaved trees”. As the same attributes were also relevant for Black Stork, the reaction of the HSI is obviously based on the same effect (chapter 4.2.5.2). While the HSI includes a multiplicative combination of life requisites the HSI+ applies the additive recombination of life requisites. The results are described in the following chapter.

4.2.5.2 Changes of the Black Stork HSI

The estimated habitat suitability for both key species increased in the period studied. The Black Stork model did not indicate any of the attributes within the life requisite “safety” reflected by the attributes “infrastructure distance of minimum 3 km” and “no recreation facilities”. A “resident population of less than 100 inhabitants per km²”, could not be found in the test area as well. Leaving out the “safety” aspects, the modelled Black Stork HSI increased particularly in the north-western and the south-eastern part of the Moritzburg forest indicated by the bright areas (Figure 22).

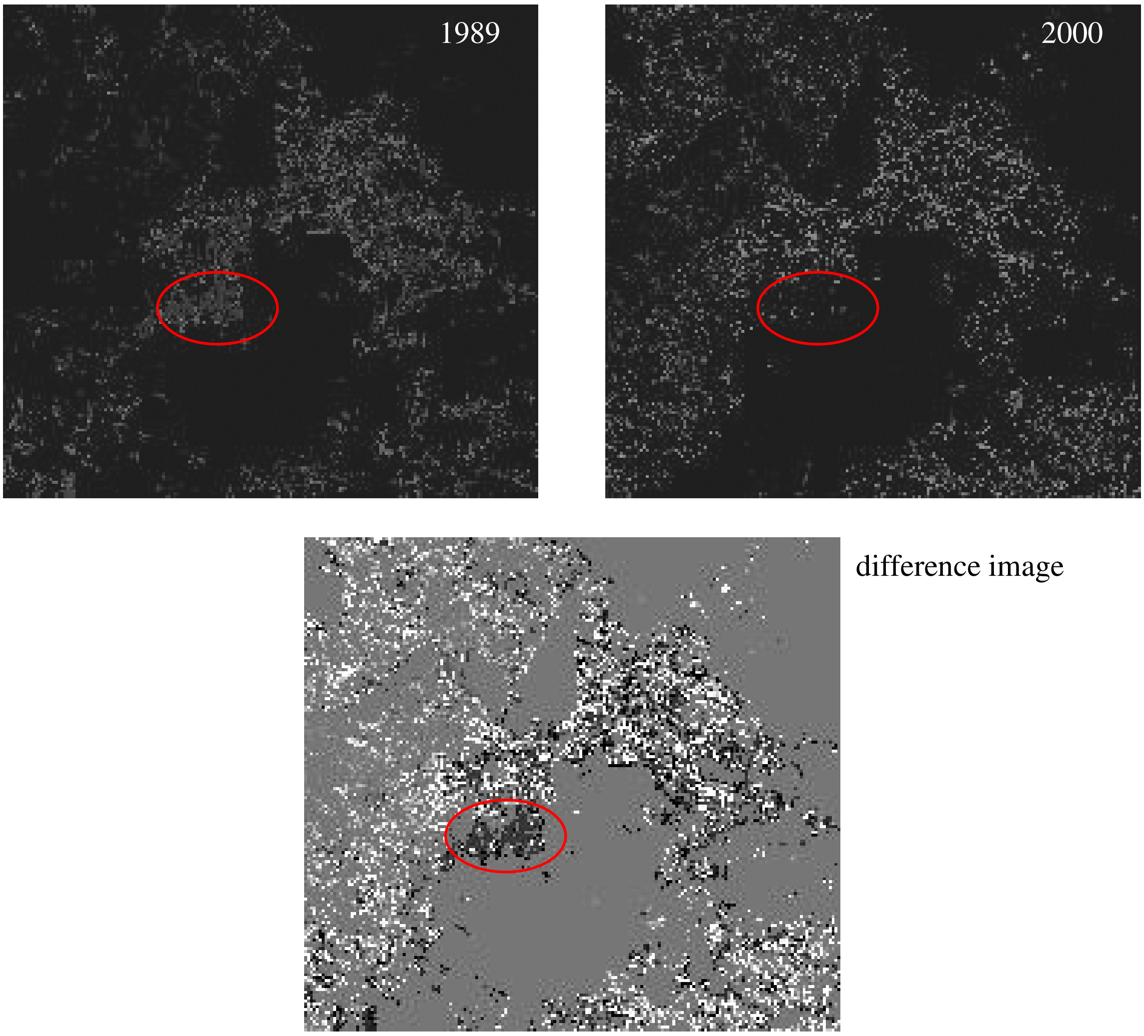
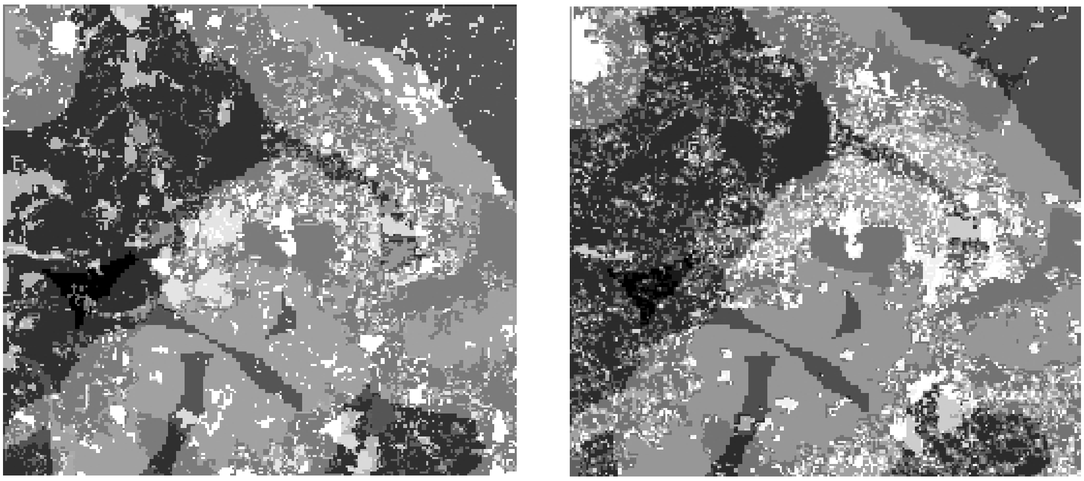


Figure 22 Black Stork habitat suitability maps of 1989 and 2000 and the difference image

The Black Stork HSI model without the “safety” life requisite shows a similar habitat development compared with the Red Kite HSI model results. The dark areas indicate a loss of suitability while the grey values indicate no changes of suitability. The change in the centre of the image could be detected, because of the similar attributes used for the rest of the Black Stork habitat analysis. Due to the missing essential “safety” life requisite for the Black Stork, the following analysis on sensitivity and the modifications of the HSI, such as the additive recombination of life requisites (HSI+), the application of fuzzy sets (EHSI, EHSI+) and home range approaches (HR-HSI, HR-HSI+) are applied for the attributes of the example habitat for Red Kite.

4.2.6 Retrospective Changes of the HSI+

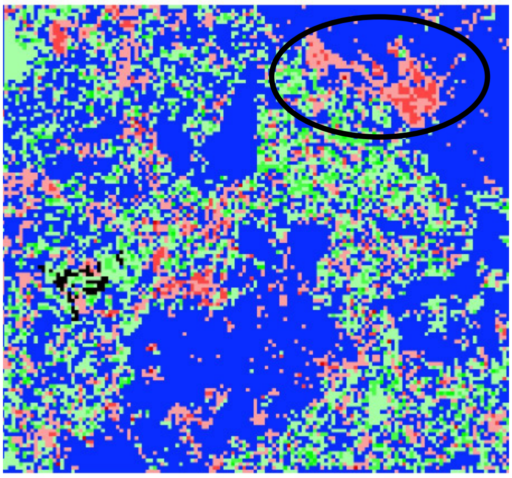
The results of a modified HSI model for Red Kite with additive recombination of life requisites (HSI+) according to the equations [12] and [15]) is shown in the Figure 23. The HSI+ was applied for the example habitat of Red Kite, as all attributes required for model input are detectable in the area of Moritzburg.



Habitat Suitability Index 1989 indicated by additive recombination of life requisites

Habitat Suitability Index 2000 indicated by additive recombination of life requisites

bright areas: high habitat suitability
dark areas: less habitat suitability



Change of the habitat suitability index indicated by the HSI with additive recombination of life requisites

reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability
blue: no changes of habitat suitability
black: no habitat suitability detected

Figure 23 HSI+ with additive recombination of life requisites for 1989 and 2000 and its changes

Figure 23 shows an additional area of habitat decease in the north-eastern part of the test site, which was not detected by the original HSI for the Red Kite. A quantitative overview of the development of the HSI+ is given in the Table 17.

Table 17 Development of the HS+I with additive recombination of life requisites from 1989 to 2000 [% of the test site area]

HSI+

2000	1989		
	suitable habitat	**no suitable habitat**	
suitable habitat	57,79%	25,83%	Σ 83,61%
no suitable habitat	16,01%	0,38%	
	Σ 73,79%		

relative change of suitable area: + 9,82%

The suitability of the test site around Moritzburg as potential habitat of Red Kite is much higher according to the results of the HSI+, than for a model with multiplicative combination of the life requisites (HSI). Thus the HSI difference image between the two occasions shows pronounced differences, as the entire set of attributes was incorporated in the maps of the HSI+ model. In the original satellite images the differences in reflectance of the lake in the north-eastern part of the region has caused a habitat decrease, as the classification changed from “open sites” to non “open sites” patches when applying the kNN algorithm.

4.2.7 HSI Evaluation – Results of the Sensitivity Analysis

In this section a seven digit image map according to the equation [16] underlay the sensitivity analysis of the HSI (4.1.7). In the seven digit image each attribute is reflected per assigned digit. All applied HSI models include one final result value in one digit of the habitat map. In the seven digit image each of the seven attributes is represented by one digit (water bodies=1, open forest=2, etc.), what also is illustrated in Figure 8. Thus the map allows the analysis of the influence of the individual attributes in the theoretical HSI model and in the results of the applied HSI model according to the natural condition of the test site. The results are shown in Table 18.

Table 18 Overview of the attributes and their influence on the HSI for Moritzburg [% of the test site area]

%	**food**			**nesting**		**safety**	
	$\mathbf{Dist}_{water}$	**$\mathbf{Dist}_{forest}$**	**$\mathbf{Sites}_{open}$**	**$\mathbf{Forest}_{open}$**	**Vol**	**$\mathbf{Comp}_{tree}$**	**$\mathbf{Height}_{tree}$**
proportion of entire test site	96%	61%	34%	11%	7%	8%	6%
proportion in HSI results	6%	7%	0%	5%	68%	66%	16%
HSI model weights	16%	16%	8%	28%	12%	10%	10%

The first line includes the proportion of the area in which the attribute was found in Moritzburg; the second line shows the proportional attribute area within the original HSI results; the last line illustrates the HSI model weights of each attribute. The habitat relevant "water bodies" (**$\mathbf{Dist}_{water}$**) has been found in 96% of the test site area, while only 6% are reflected in the results of the HSI. The pure model weight was originally chosen with 16%. The attribute "open sites" (**$\mathbf{Sites}_{open}$**) is not at all reflected by the HSI, although the model weight is 8%. The model weights for "timber volume" (**Vol**) (12%) and "broadleaved trees" (**$\mathbf{Comp}_{tree}$**) (10%) are much lower than their proportion in the HSI of roughly 70%. Thus it becomes obvious, that these two attributes are the driving factors in the HSI.

For the understanding of the constellation of the patches in Moritzburg the individual life requisites are considered. "food" consists of the three attributes "water bodies" (**$\mathbf{Dist}_{water}$**), "forest border" **$\mathbf{Sites}_{open}$** and "open sites" (**$\mathbf{Sites}_{open}$**).

Table 19 Attribute suitability within the life requisite "food" in Moritzburg [% of the test site area]

Dist$_{\text{water}}$	**Dist**$_{\text{forest}}$	**Sites**$_{\text{open}}$	
		open sites	**non open sites**
in the distance to water bodies of 1 km	**in** the distance to forest borders of 0,5 km	**22,9%**	**9,6%**
in the distance to water bodies of 1 km	**outside** the distance to forest borders of 0,5 km	**28,2%**	**34,9%**
outside the distance to water bodies of 1 km	**in** the distance to forest borders of 0,5 km	**1,1%**	**2,3%**
outside the distance to water bodies of 1 km	**outside** the distance to forest borders of 0,5 km	**0,0%**	**1,0%**

Table 19 illustrates that nearly a quarter of the area around Moritzburg is covered by all three attributes. The distance to "water bodies" (**Dist**$_{\text{water}}$) relevant for habitat suitability can be found in almost the entire area, while the distance to "forest border" (**Dist**$_{\text{forest}}$) together with "open sites" (**Sites**$_{\text{open}}$) can only be found in roughly 1% of Moritzburg. Additionally "open sites" cannot be found without being associated with the distance of "water bodies" or "forest borders" at the same time. The life requisite "nesting" consists of the attributes "open forest" (**Forest**$_{\text{open}}$) and "timber volume" (**Vol**). The locations of these two attributes do not coincide in the Moritzburg test area (Table 20).

Table 20 Attribute suitability within the life requisite "nesting" in Moritzburg [% of the test site area]

Vol	**$Forest_{open}$** **open forest**	**$Forest_{open}$** **non open forest**
timber volume < 300 m³/ha	**0%**	**11%**
timber volume ≥ 300 m³/ha	**7%**	**82%**

About 20% of the test site is covered by both attributes without being associated. Thus the entire life requisite "nesting" is a limiting element of the HSI and the weight of the requisite within the HSI model of at least 40% could never be reached (Table 20). A similar situation could be found for the requisite "safety" with "broadleaved trees" (**$Comp_{tree}$**) and "tree height" (**$Height_{tree}$**). Here in 1% of the area both attributes coincide, while 12% are covered by one of both (Table 21).

Table 21 Attribute suitability within the life requisite "safety" in Moritzburg [% of the test site area]

$Height_{tree}$	**$Comp_{tree}$** **broadleaved trees > 80%/ha**	**$Comp_{tree}$** **broadleaved trees < 80%/ha**
tree height > 25 m	**1%**	**5%**
tree height < 25 m	**7%**	**87%**

The contribution of the requisite "safety" is 1% in the entire HSI. Limitations become clear analysing the multiplicative HSI. In these terms only 18% of the life requisite "nesting" and 13% of the life requisite "safety" could potentially be visible in the HSI+ if the life requisite "food" is not set to zero at the same location. As more than half of the area covered by the life requisite "food" equals zero, only about 5% of the Moritzburg test site could be considered as suitable habitat.

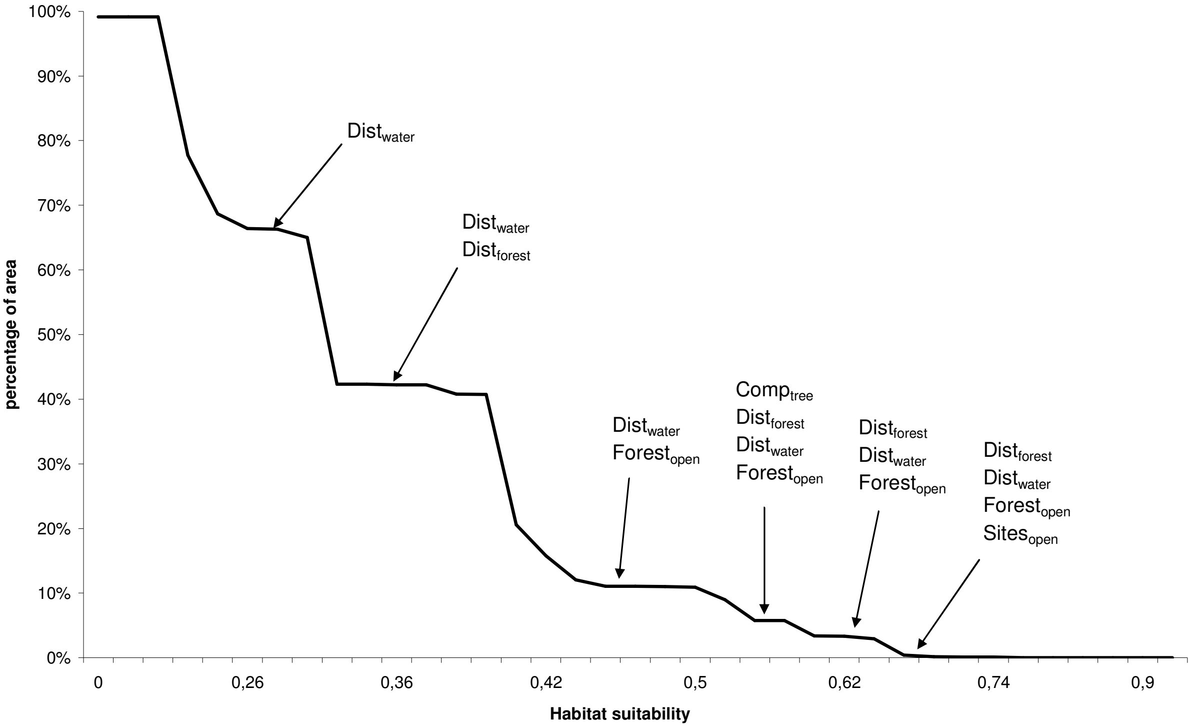


Figure 24 Influence of different attributes for the increases of habitat suitability in the test site

Figure 24 shows the influence of individual attributes on habitat suitability for the single steps of suitability increase and the decrease of area percentage in the test site. It illustrates the influence of the natural circumstances in terms of spatial attribute patch arrangements in the test site on the modelled habitat suitability. A suitability of more than 50% can only be found in roughly 10% of the Moritzburg test site. As shown in Figure 24 the attribute "water bodies" ($\mathbf{Dist_{water}}$) is one of the driving factors followed by the attributes "forest border" ($\mathbf{Dist_{forest}}$) and "open forest" ($\mathbf{Forest_{open}}$) for the suitability increase. The rest of the suitability increase is caused by the influence of the attributes "broadleaved trees" ($\mathbf{Comp_{tree}}$) and "open sites" ($\mathbf{Sites_{open}}$).

4.3 DISCUSSION OF THE HSI

4.3.1 Attribute Map Creation

Attributes analysed for the HSI approach are obtained from two different in situ data

Attributes analysed for the HSI approach are obtained from two different in situ data sources. The MNTFR field campaign had the objective of non-timber forest resources assessments while the Datenspeicher Wald preferably includes the traditional forest management planning information with the main focus on timber production. Because of the different motivation of the inventories, the information shown in the pixels after the kNN transformation can be interpreted differently. For the time-series approach of the HSI, the Datenspeicher Wald provides information that had to be geo-referenced to the MNTFR plots. The procedures applied for geo-referencing are subject to errors. The stand-wise information of the Datenspeicher Wald may vary within large stands due to differing stand structures, tree species composition or potential gaps in the canopy. Depending on the stand size and the pixel size in the ancillary data, classification errors with the kNN method are possible. Uncertainties can be expected due to the GPS accuracy, which varied by about 20 m during the MNTFR field campaign. Check assessments on the systematic grid were applied to improve the accuracy of the inventory, while the assessments for the Datenspeicher is based on randomly selected sampling locations only. A sample plot design like the MNTFR cluster system with geo-referenced plots at both occasions would most probably offer more heterogeneous and comparable data for the following estimations. Also, if only the plots are assessed in the field, the costs for the inventory would decrease and the calculation over the entire region would be more reliable. The use of sampling in the field combined with remote sensing data might improve accuracy and cost efficiency (KÖHL 2003, 1990). The use of permanent sample surveys was evaluated by KÖHL ET AL (1995) as an appropriate method for reliable monitoring purposes. Additionally sub sampling with permanent field plots can improve cost efficiency of subsequent inventories.

A further impact on the results was probably caused by the different ground data availability. Even if several maps have been used for the location of the old forest stands to find the corresponding data in the Datenspeicher Wald, wrong interpretation of the maps is possible. This could result in the kNN classification being less reliable. The exact position of edges between different forest stands were especially difficult to locate, if a plot cluster covers such edges. Due to the different motivations of the two inventories, the Datenspeicher Wald turned out to include insufficient information, while the MNTFR inventory offered more information than required for the applied HSI approach. This becomes obvious when comparing the kNN maps for the attribute “structure”, as shown in Figure 25.

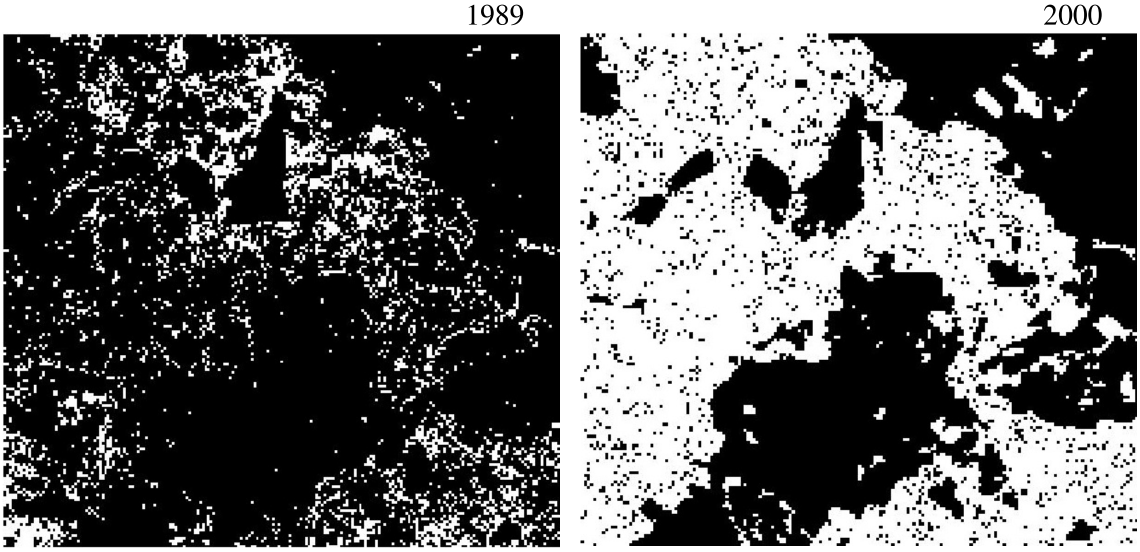


Figure 25 kNN result maps of the attribute “structure” in 1989 (Datenspeicher Wald) and 2000 (MNTFR data).

While attributes like “berry cover” and “other woody plants over 10 cm height” and the “different layers of the forests” describe the attribute “structure” in the MNTFR field campaign 2000, only “tree layers” and “shrubs” were available as attributes for “structure” in the Datenspeicher Wald. Therefore a lot more information for “structure” could be found on the MNTFR plots, and this caused the large areas of suitability for “structure” in the kNN result map for 2000 (Figure 25).

During the analysis of the HSI the different resolutions of the two Landsat images (30 m for the Landsat 7, and 27 m for the Landsat 5) caused errors. For the HSI model the Landsat scenes provided the ancillary data source to expand local information over the entire area of interest with the kNN method. The kNN method was the method for combining in situ with ancillary data. It has been operationally applied since the early 1990s (TOMPPO 1991). Depending on the natural condition in an ecoregion of Europe the kNN method performs well as long as the number of attributes is very limited. In most of the cases the "timber volume" can be assessed with the highest accuracy (TOMPPO 1991 1997, STÜMER 2004, KÖHL ET AL. 2001). Compared with "timber volume" the other classified attribute maps for the HSI have to be considered as less reliable. Since the kNN method is an automatically running program which classifies satellite images according to their spectral pixel information and specified rules, the results for attributes such as "tree height" cannot be considered as reliable. According to the kNN result maps, forest stands with broadleaved trees and those with high timber volumes coincide frequently. Most of the older broadleaved stands have accumulated high timber volumes unlike coniferous stands. In Moritzburg the oak or beech stands are old stands with high timber volumes; this explains the correlation of the attributes "timber volume" and "broadleaved trees". Additionally it has been shown, that the kNN method reacts sensitively for attributes like "timber volume" (STÜMER 2004, TOMPPO 1997A).

Comparing the differences of the digital image information of the two Landsat images of 1989 and 2000 some changes can be found in the difference image of Figure 9. These observed changes are different to those of the habitat model (Figure 20). The reason for that are the application of the kNN method as an image classification tool and the application of the different weights of the attributes. The change reflectance of the lake in the north-eastern part of Moritzburg in the difference image of the two Landsat images can also be found in the habitat model modifications with additive recombination of life requisites (Figure 23). In opposite to that the changes of the wind throw can not be visualised with the difference image of the Landsat images. Therefore the application of a difference image can help to identify areas of changes, but it is not sufficient to analyse all relevant information for a potential habitat.

However, the utilised data sources were fitting the objective to achieve spatial attribute information for the habitat modelling approach within these limitations. The application of kNN for mapping attribute information fitted the purpose of investigating the attribute's significance within the HSI model and their development over time. Depending on the key species of interest or the scale of modelling approaches in future, other data sources – for instance information about water quality, or maps including information of climatic details in digital format – might be included in HSI models. At first the information of the data sources were utilised to achieve spatial attribute information for a demonstration of the habitat modelling and the development of the model results over time.

4.3.2 The HSI Model

The applied HSI models with multiplicative combination of life requisites, and the HSI+ with additive recombination of life requisites show the changes of the habitat suitability over a time period of 11 years in the test site. Only habitat suitability for Red Kite could be estimated completely with all defined attributes. Black Stork prefers more homogeneous landscapes with old forests spread over wide areas without, or with minor interruption by small water bodies or streams and little disturbance of the preferred landscape elements. The region of Moritzburg is characterized by heterogeneous structures of landscape elements such as lakes, agricultural land and forested patches. Therefore the area around Moritzburg is not suitable for the Black Stork if the FFH derived attributes are considered with respect to the size of the different elements. Furthermore the Black Stork is a very sensitive and remotely living species. Non of the attributes describing the life requisite “safety” was met in Moritzburg. There is a high density of roads and hiking paths in the Moritzburg area, and therefore the safety requirements (reflected by the attributes “infrastructure distance of minimum 3 km” and “no recreation facilities”) were not met. The area is also too densely populated, and a “resident population of less than 100 inhabitants per km²”, could not be found in the test area. For Red Kite, all attributes taken from FFH were met in some locations around Moritzburg. This indicates that in accordance with the hypothesis given above not all landscapes with a high rate of structural diversity necessarily have suitable habitats for all kinds of rare or umbrella species. Therefore the qualitative approach followed by the development and application of the species specific HSI models proved to be appropriate, even if individual attributes, which describe the contrary living requirements of Red Kite and Black Stork in more detail, could not be compared directly.

The shelter wood cut followed by wind throw in the old beech stand near the village of Moritzburg (Figure 21) caused differences in different spectral values in the Landsat image for the year 2000. This change seemed to influence the classification (kNN), so that for this region a different class was assigned as a result of the kNN method. As the kNN algorithm is operationally applied for attributes such as “timber volume” and “broadleaved trees”, the shelter wood cut and the wind throw seem to be highly relevant for the observed changes between the two occasions. As the two attributes are essential for modelling the habitats of both species, the differences in the two HSI can easily be explained. Even if the attributes “infrastructure distance”, “no recreation facilities” and “resident population” were ignored in the HSI model for Black Stork, the HSI models seem to react to changing ground conditions.

Because of the different spatial resolutions of the satellite images used in this study; the calculation of the areas of habitat change was subject to errors and could result in the observed shift of suitable habitat locations.

The presence of old trees is essential for the habitat of the Red Kite (KIEFER 1998) because they are used as breeding trees. The loss of those due to felling or storm damage is essential for the existence of the species, given the results of KIEFER (1998) being relevant for the conditions in Moritzburg. In this view the HSI reflects these properties, by including kNN maps on attributes like “timber volume” and “broadleaved trees”.

The applied HSI model offers a useful methodology to monitor the development of habitat suitability at the landscape level, what is shown in chapter 4.2.4. The HSI approach with habitat divided into life requisites offers transparency in terms of the artificially defined requirement units. This allows the critical overview of a group of essential attributes in one step. The attributes, following the FFH Directive are added with different weights to one life requisite, which are multiplied with different weights to the entire HSI model result. Multiplying the life requisites indicates that habitat suitability can only be achieved in areas with presence of all life requisites. If one requisite is missing, no suitable habitat can be defined with the HSI. The HSI model implies that a species needs every attribute defined in life requisites concentrated in one location of the test site to find a suitable habitat. This aspect reflecting a strong binary character of the HSI seems to be restrictive especially when the key species are birds, which are able to reach all locations in the test site in a reasonable time. Suitable life requisites or single attributes in the neighbourhood, or the distances between them are not considered in the original HSI.

Aside from the possible improvement of attribute combination for the chosen species and the possibility to introduce additional seasonal life requisites, the applied HSI model proved to be operational. It seems to be able to detect changes including potential threats for rare species in the chosen test site. In the following chapter the influence of the individual attribute in the theoretical HSI model and according to the test site conditions is discussed to evaluate the model results.

4.3.3 The Sensitivity Analysis

The sensitivity analysis showed the weights of the attributes in the theoretical HSI model. The influence of the individual attribute is described by their distribution around Moritzburg after the application of the HSI model in the test site. The sensitivity could be described with the applied sensitivity study (Table 18). The original HSI applying a multiplicative combination of life requisites reduces the influence of the individual attribute [5]. As far as a life requisite does not coincide with all the others in a defined location, the attribute is distinct in the HSI model result. The HSI+ with an additive recombination of life requisites reflects the development of all attributes [12]. As attributes like “water bodies” and “forest border” cover large areas of the test site they are responsible for most of the detected habitat suitability (Figure 24) whereas the rare attributes such as “broadleaved trees” or “timber volume” have a relatively minor influence on the detection of habitat suitability around Moritzburg. Additionally the diverging distribution of the rarely detected attributes in the test site might be another effect on the role of those attributes, especially while the life requisites are multiplied. Therefore it is not only the weight of the individual attribute which might affect the HSI model results, but also the presence and distribution of the attribute in an area.

The constant influence of the life requisite “food” is caused by the high presence of the constant attributes “water bodies” and “forest border” (Figure 13). In this context the third attribute “open sites” has a relatively small influence in the HSI model with multiplicative combination of life requisites. A view on the development and the changes of “open sites” within the sensitivity analysis indicates that one lake in the northern part of the test site has been detected as a loss of suitability from 1989 to 2000. It is the only attribute with a decrease of suitability (Table 12). In terms of the “open sites” in Moritzburg the lake was classified as an open site in 1989. Obviously the lake was drained during the time of the Landsat data acquisition. During the second data acquisition in 2000 the lake was full again and therefore not classified as an “open site” by kNN. Even in the difference image the shape of the lake can be identified. In Moritzburg all lakes have been artificially built in former times and some of them are still used for fishing. Once a year the lakes are drained after the fishing season and this affected the changes of “open sites” in the HSI model. This effect proved the sensitivity of the HSI+ with additive recombination of life requisites towards changing ground conditions. The HSI model applying a multiplication of life requisites did not detect on the effect of dry lakes in the retrospective analysis.

However a multiplicative approach can be suggested when two symbiotic attributes are of relevance within a specific habitat modelling. Two mutually dependent attributes – for instance an attribute map of water bodies and one with water quality information – might be multiplied to achieve only the water bodies with a defined water quality. The combination of the two essential requirements can be merged to one attribute for a species of interest. Therefore the described approach can be operationally applied in the HSI model.

The sensitivity analysis explained the influence of the individual attributes in the HSI model itself, and the effect of the multiplied life requisites within the original HSI. Additionally the influence due to the test site Moritzburg and the advantages of the additive life requisite approach could be analysed. Since the attributes may be weighted differently for a species specific view on habitat potential within an area of interest, the sensitivity of the HSI model with different combination of life requisites towards changes could be described.

However the estimates can be enhanced by introducing territorial constraints, where index calculation is based on an average or sum of suitable information of a larger area, producing more variation in the index. There is also the possibility of introducing fuzzy sets, where the values of membership attributes vary continuously between 0 and 1. The latter one is applied and presented in the following chapter.

5 THE ENHANCED HABITAT SUITABILITY MODEL (EHSI) – FUZZY SETS

5.1 EHSI ANALYSIS METHODS

ZADEH (1965) introduced the idea of fuzzy sets for working with inexact concepts in a definable way. Since then operational tools have been developed by KANDEL (1986), KAUFFMAN (1975) and ROBINSON (1988). BURROUGH AND MCDONNELL (1998) described the field of application for fuzzy sets in the following way: “It is appropriate to use fuzzy sets whenever we have to deal with ambiguity, vagueness and ambivalence in mathematical or conceptual models of empirical phenomena. If one accepts that spatial processes interact over a wide range of spatial scales in ways that cannot be completely predicted, then one can appreciate the need for ‘fuzzy’ concepts in geographical information.” This situation can be found for the habitat suitability attributes. The Boolean habitat model structure (BOOLE 1854) of the original HSI defines the area each attribute covers in the test site. The habitat function changes abruptly from zero to one, at the attribute threshold, what is converse to a fuzzy set function. This opposite of a fuzzy set is called a crisp (Boolean) set. In a crisp set the attributes may have a value of either 0 or 1. In a fuzzy set the attributes may have a value of 0 or 1 or anything in between. The HSI is crisp when:

$$x_i = \begin{cases} 1, \text{for true habitat attibute} \\ 0, \text{for false habitat attribute} \end{cases}$$

[17]

The fuzzy set approach allows a more realistic reflection of natural circumstances for selected key species. On the selected scale of the HSI the implementation a fuzzy set seems to be appropriate, because the natural imprecision of a habitat element is defined through a fuzzy set. Additionally it is essential to include these considerations into estimates on minimum habitat patch sizes on the scale of interest. According to BURROUGH AND MCDONNELL (1998) the degree to which an individual observation z is a member of the set (e.g. **Height$_{\mathbf{tree}}$** areas in Moritzburg) is expressed by the Membership function MF^{B}, which can take the value 0 or 1 for crisp (Boolean) sets.

$$\mathrm{MF}^{\mathrm{B}}(\mathrm{z}) = \begin{cases} 1 \text{ for } \mathrm{b}_1 \leq \mathrm{z} \leq \mathrm{b}_2 \\ 0 \text{ for } \mathrm{z} > \mathrm{b}_1 \text{ or } \mathrm{z} < \mathrm{b}_2 \end{cases}$$

[18]

z attribute value for e.g. found **Height$_{\mathbf{tree}}$** pixels

b_1, b_2 thresholds of a set of e.g. **Height$_{\mathbf{tree}}$** areas/pixels in the test site

The upper functions express the HSI and each of its attributes in its basic method and can be enhanced with the extension of a fuzzy set. A fuzzy set is defined in the equation [19] where z can take the value 0 or 1 or anything in between:

$$A = (z, MF_A^F(z)) \text{ for all } z\, \varepsilon\, Z$$

[19]

If Z denotes a space of objects, then the fuzzy set A in Z is the set of ordered pairs. The membership function $MF_A^F(z)$ is known as the "grade of membership of z in A" and $z\ \varepsilon\, Z$ means that z belongs to Z". For the HSI the $MF_A^F(z)$ is a number in the range of 0 and 1, with 1 representing membership of the set. $MF_A^F(z)$ of z in A specifies the extent to which z can be regarded as belonging to A. It offers the impression of what degree the observation z is a member of the class A. Fuzzy sets theory uses concepts of admitted possibility which is described in terms of the fuzzy membership function (BURROUGH AND MCDONNELL 1998) and can also be efficiently applied for each habitat attribute map.

The fuzzy transition zone is the zone in which z can be defined as a member until it reaches a defined maximum distance to the selected suitable patches of an attribute. In terms of the HSI the transition zone ends at a fixed distance from the suitable patch borderline. Within the study a linear function has been chosen to illustrate the effects of a HSI extension with fuzzy sets. In Figure 26 the red line shows the binary function chosen, while non-linear functions (Poisson, hyperbolic, etc.) could also be applied.

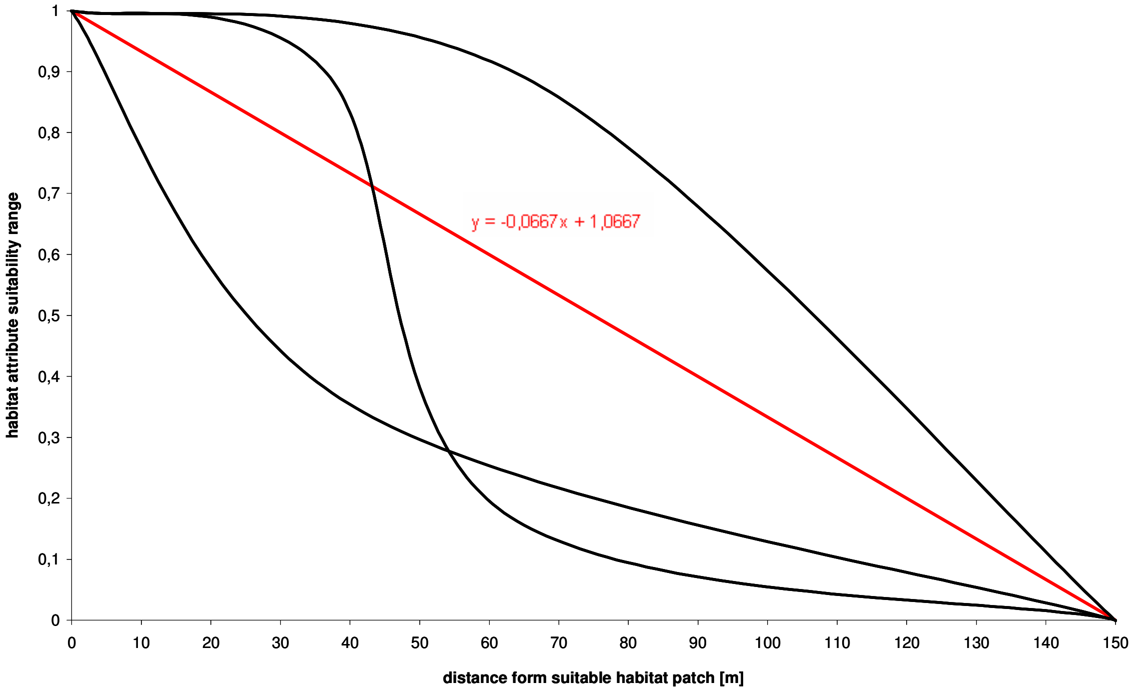


Figure 26 Membership function for the Enhanced Habitat Suitability Index (EHSI) for the Red Kite (red)

The value of the membership is 1 at the patch borderline, where the transition zone starts and it decreases linear and takes the value 0 at a fixed distance (150 m in this case). As there are different approaches of probability distributions, it is possible to apply different kinds of fuzzy membership functions (Figure 26) – e.g. for other key species with different requirements concerning their habitat attributes. The chosen approach is called the semantic import approach which relies on expert knowledge concerning precision associated with the standard Boolean model (BURROUGH AND MCDONNELL 1998, ROBINSON 1988). For this approach it was not of major interest to define the most realistic habitat description function for Red Kite. The focus was to replace the binary character of the HSI with an improved model reflecting more continuous decreases of attributes along their edges. It is assumed, that the probability of suitable attributes can abruptly change from zero to one. Another important objective was to identify changes of the HSI after the implementation of the fuzzy set, and to study the continuity of both models.

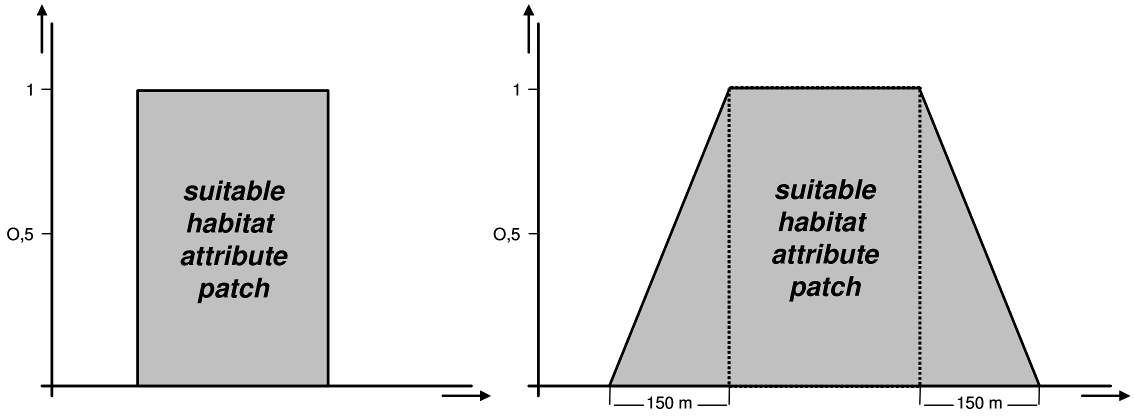


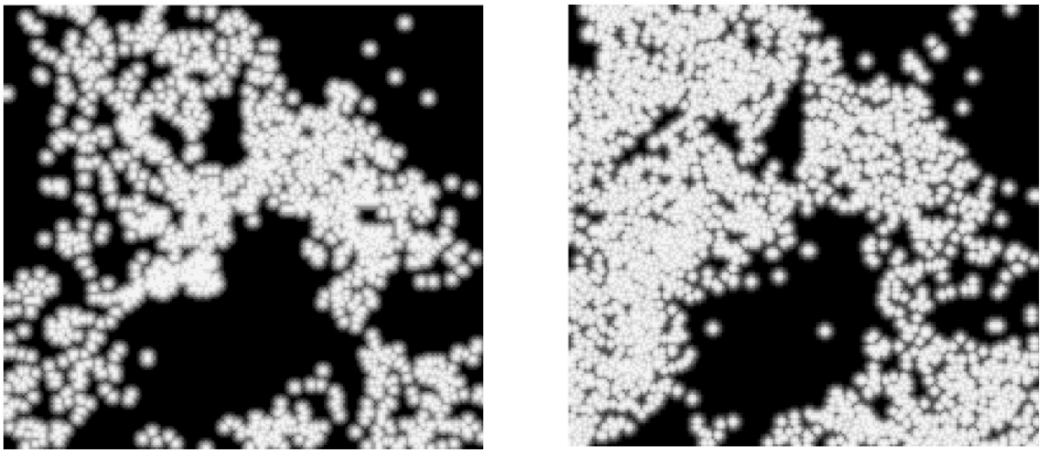
Figure 27 Schematic fuzzy set implementation in the HSI

Patches of suitable habitat with respect to a particular attribute are given a value of 1. The values for the area surrounding the patch of suitable habitat decrease linearly from 1 (at the edge of the suitable habitat) to 0 (at a defined distance of 150 m). Figure 27 shows the membership function of this study applied on attribute level.

5.2 RESULTS OF THE EHSI

5.2.1 EHSI Fuzzy Set Attributes

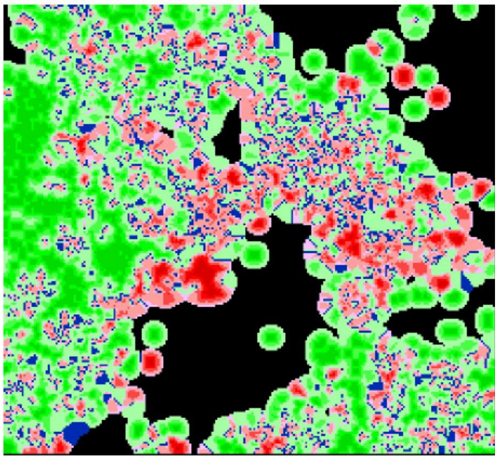
The EHSI was calculated for Red Kite only, because all attributes for this HSI could be calculated. The individual attribute maps were enhanced with the described probability function [19].



Enhanced attribute map of “timber volume” 1989 indicated by the EHSI

Enhanced attribute map of “timber volume” 2000 indicated by the EHSI

bright areas: high “timber volume” suitability
dark areas: less “timber volume” suitability

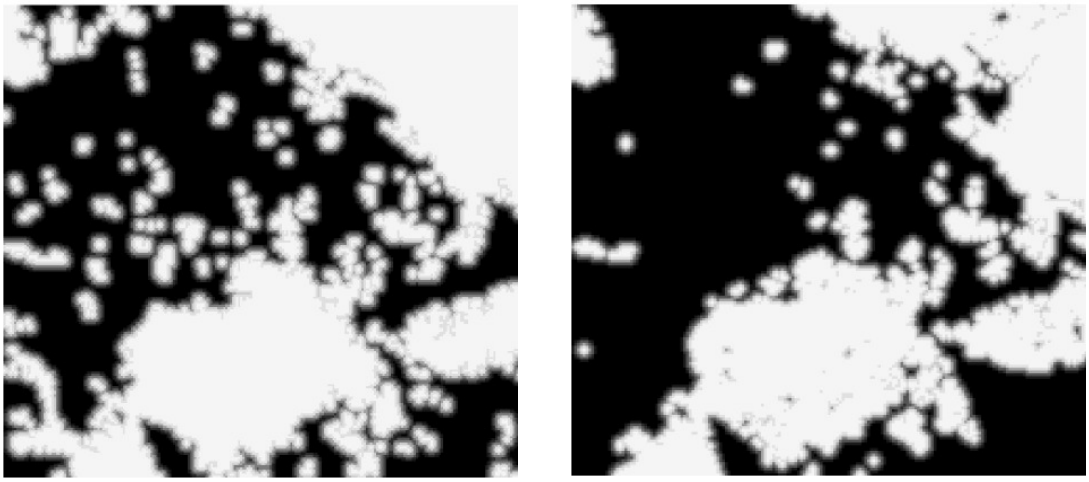


reddish colours: loss of “timber volume”
greenish colours: increase of “timber volume”
blue: no change of “timber volume”
black: no “timber volume” detected

Change of enhanced attribute map “timber volume” indicated by the EHSI

Figure 28 EHSI result maps of the attribute “timber volume” for 1989 and 2000 and its changes

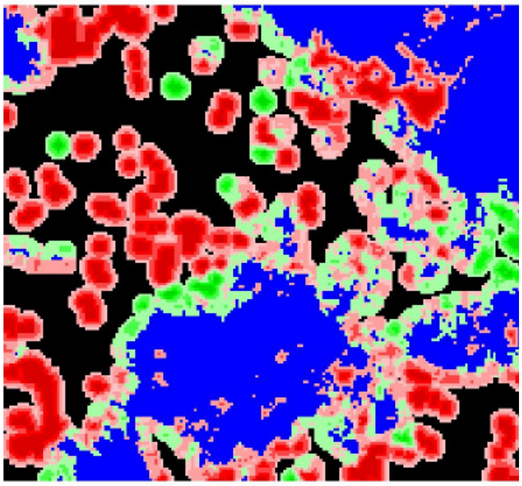
The suitability of the individual attributes increased, because of the application of the membership function along the attribute edges. This can be seen in the result maps of the HSI attribute “timber volume” in Figure 11 compared with the images of the EHSI attribute maps in Figure 28. The difference image of the EHSI attribute map for “timber volume” in Figure 28 shows a decrease of suitable pixels in the middle of the map. This is also similar to the results of the HSI attribute “timber volume” in Figure 11 and to the results of the entire HSI (Figure 19).



Enhanced attribute map of “open sites” in 1989 indicated by the EHSI

Enhanced attribute map of “open sites” in 2000 indicated by the EHSI

bright areas: high “open sites” suitability
dark areas: less “open sites” suitability



reddish colours: decrease of “open sites”
greenish colours: increase of “open sites”
blue: no changes of “open sites”
black: no “open sites” detected

Change of the attribute “open sites” form 1989 to 2000 indicated by the EHSI

Figure 29 EHSI result maps of the attribute “open sites” for 1989 and 2000 and its changes

The constant attribute areas are located in the forested areas around Moritzburg. The loss of "broadleaved trees" can be found in the centre of the map. They are similarly located to the results of the original HSI. The developments of all single attributes can be found in the following section. As fuzzy sets have been applied, the developments of the different attributes diverge from the original HSI.

Table 22 Development of "timber volume" from 1989 to 2000 utilising fuzzy sets [% of the test site area]

Vol

2000	1989		
	timber volume ≥ 300 m³/ha	**timber volume < 300 m³/ha**	
timber volume ≥ 300 m³/ha	7,10%	48,20%	Σ 55,30%
timber volume < 300 m³/ha	23,12%	21,58%	
	Σ 30,23%		

relative change of suitable area: + 25,07%

Table 23 Development of "open sites" from 1989 to 2000 utilising fuzzy sets [% of the test site area]

Sites$_{open}$

2000	1989		
	open sites	**non open sites**	
open sites	26,41%	13,22%	Σ 39,68%
non open sites	36,39%	23,98%	
	Σ 62,80%		

relative change of suitable area: -23,18%

Table 24 Development of "open forest" from 1989 to 2000 utilising fuzzy sets [% of the test site area]

Forest$_{open}$

2000	**1989**		
	open forest	**non open forest**	
open forest	2,36%	49,19%	Σ 51,56%
non open forest	44,09%	4,35%	
	Σ 46,46%		

relative change of suitable area: + 5,10%

Table 25 Development of "broadleaved trees" from 1989 to 2000 utilising fuzzy sets [% of the test site area]

Comp$_{tree}$

2000	**1989**		
	broadleaved trees ≥ 80%/ha	**broadleaved trees < 80%/ha**	
broadleaved trees ≥ 80%/ha	4,11%	61,55%	Σ 65,66%
broadleaved trees < 80%/ha	15,81%	18,53%	
	Σ 19,92%		

relative change of suitable area: + 45,74%

Table 26 Development of "tree height" from 1989 to 2000 utilising fuzzy sets [% of the test site area]

Height$_{tree}$

	1989		
2000	**tree height ≥ 25 m**	**tree height < 25 m**	
tree height ≥ 25 m	0,90%	43,61%	Σ 44,51%
tree height < 25 m	36,18%	19,31%	
	Σ 37,08%		

relative change of suitable area: + 7,43%

The only attribute with a relative decrease of suitable area in Moritzburg from 1989 to 2000 is "open sites" (**Sites$_{open}$**). The attribute decreased by more than 23% over the time period. The location of the suitability for "open forests" (**Forest$_{open}$**) has changed, while the relative change of suitable area has remained fairly stable. Although the suitable pixels for "open forests" cover more than 40% of the test site area at each point of time, the relative change of suitable area is slightly more than +5%, due to the change in the locations of suitable pixels over time. The highest absolute increase of over 45% attribute availability was calculated for "broadleaved trees" (**Comp$_{trees}$**) followed by "timber volume" (**Vol**) with more than 25% increase. An overview of the development of the attributes after the application of fuzzy sets is given in Figure 30.

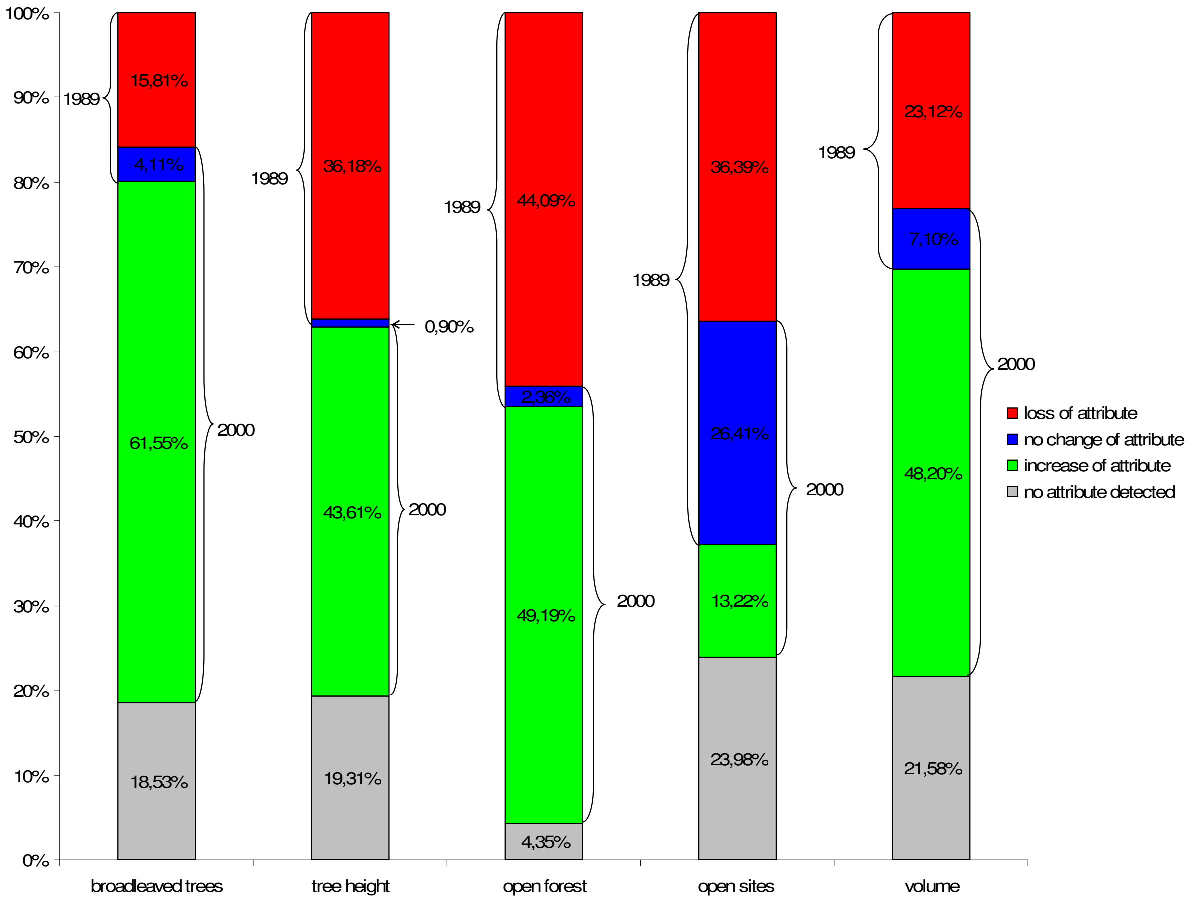


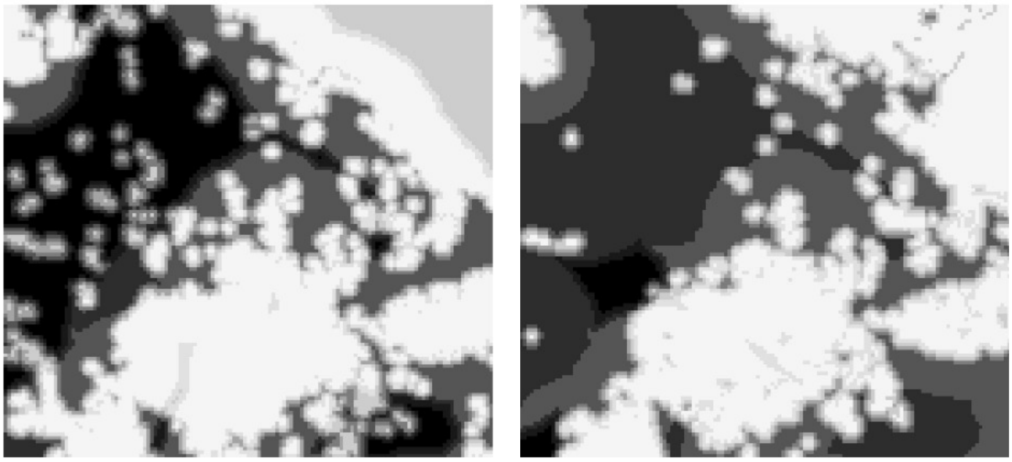
Figure 30 Overview of all EHSI attribute developments from 1989 to 2000 [% of the test site area]

Figure 30 shows that intensive changes of all attributes took place over the time period according to the application of the fuzzy sets in the EHSI. The suitability of the individual attributes, such as “broadleaved trees”, “tree height” or “timber volume” increased. The proportion of decreasing suitability is greater than the proportion of increasing suitability for the attribute “open sites”. The attribute has also the highest proportion of constant attribute suitability in the test site (Figure 29).

5.2.2 EHSI for Life Requisites

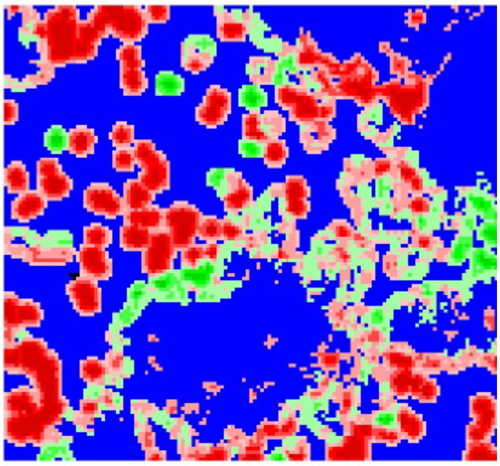
According to the calculation of the HSI for the Red Kite in Table 7 the single EHSI attributes were recalculated into three different life requisites “food” “nesting” and “safety”. For the final model algorithm the different attribute layers were weighted and added to life requisites for “food”, “nesting” and “safety” according to equation [4]. The maps for the EHSI life requisites are illustrated in the following section.

The EHSI life requisite “food” consists of the attributes “water bodies” ($\mathbf{Dis_{water}}$), “forest border” ($\mathbf{Dist_{forest}}$) and “open sites” ($\mathbf{Sites_{open}}$). The attributes are merged to the life requisite “food” according to original HSI calculations [5] and [4].



EHSI life requisite “food” 1989

EHSI life requisite “food” 2000



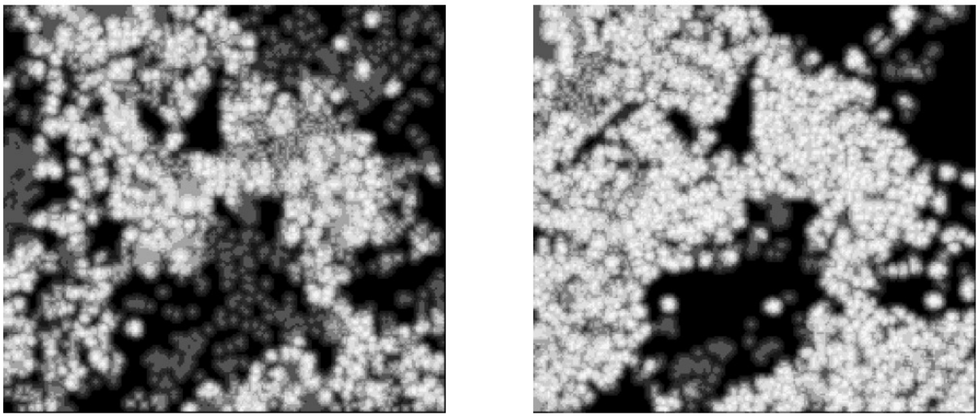
bright areas: high “food” suitability
dark areas: less “food” suitability

reddish colours: loss of “food”
greenish colours: increase of “food”
blue: no change of “food”
black: no “food” detected

Change of the EHSI life requisite “food” from 1989 to 2000

Figure 31 EHSI result maps of the life requisite “food” of both occasions 1989 and 2000 and its changes

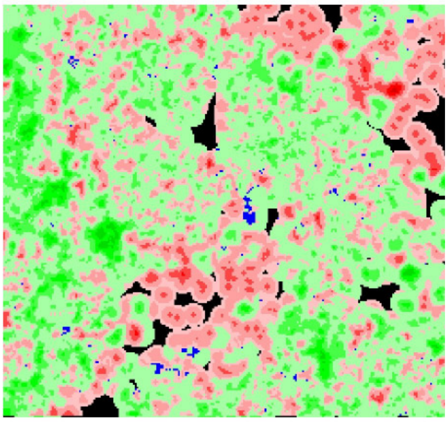
The unchanged area of the life requisite “food” is mainly caused by the unchanged “forest border” ($\mathbf{Dist_{forest}}$) attribute. The loss is caused by the decrease of the “open sites” ($\mathbf{Sites_{open}}$) attribute (Figure 29). The relative change of suitable area for “food” is minus 23,26%.



EHSI life requisite “nesting” 1989

EHSI life requisite “nesting” 2000

bright areas: high “nesting” suitability
dark areas: less “nesting” suitability

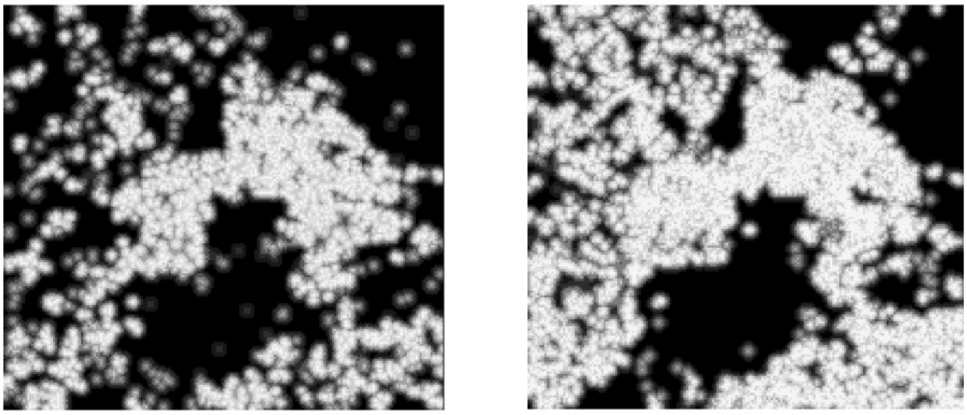


reddish colours: loss of “nesting”
greenish colours: increase of “nesting”
blue: no change of “nesting”
black: no “nesting” detected

Change of the EHSI life requisite “nesting” from 1989 to 2000

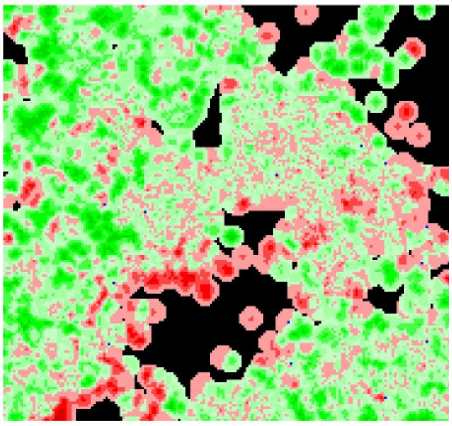
Figure 32 EHSI result maps of the life requisite “nesting” for 1989 and 2000 and its changes

“Nesting” consists of the attributes “open forest” ($\mathbf{Forest_{open}}$) and “volume” (**Vol**). Like the results of the HSI the loss of the potential life requisite can be found in the centre and the north-eastern parts of the test site. Since the relevant attributes are mostly distributed as single pixels across the test site area, the enhancement with the fuzzy set approach caused an increase of suitable life requisite area and of its changes. Thus the relative change of suitability is an increase of 24,52%.



EHSI life requisite “safety” 1989

EHSI life requisite “safety” 2000



bright areas: high suitability of “safety”
dark areas: less suitability of “safety”

reddish colours: loss of “safety”
greenish colours: increase of “safety”
blue: no change of “safety”
black: no “safety” detected

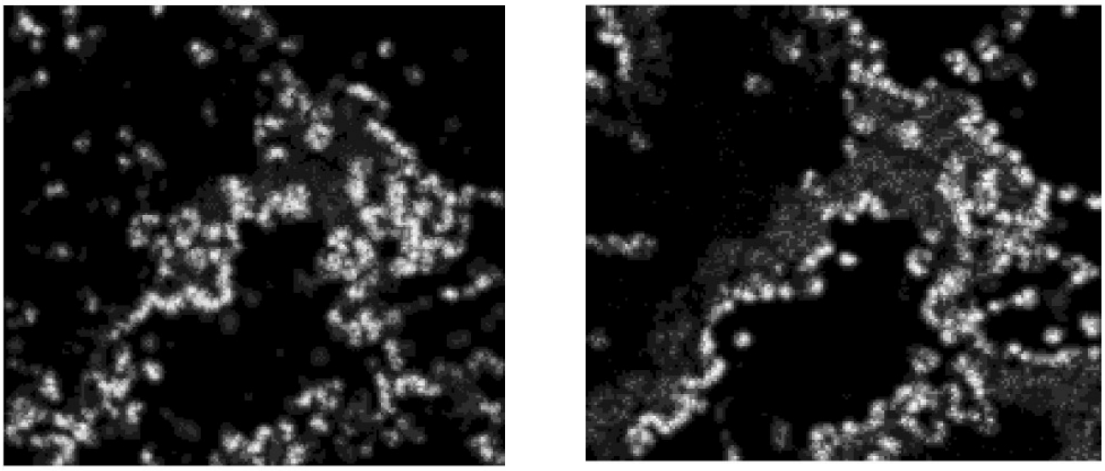
Change of the EHSI life requisite “safety” from 1989 to 2000

Figure 33 EHSI result maps of the life requisite “safety” for 1989 and 2000 and its changes

The life requisite “safety” includes the attributes “broadleaved trees” ($\mathbf{Comp_{tree}}$) and “tree height” ($\mathbf{Height_{tree}}$). The effects of the loss of the attributes in the middle of the test site can be detected with the EHSI as well. According to the EHSI the relative change of suitable area of “safety” is an increase of 35,79%, what is more than the double of the HSI increase.

5.2.3 Retrospective Changes of the EHSI

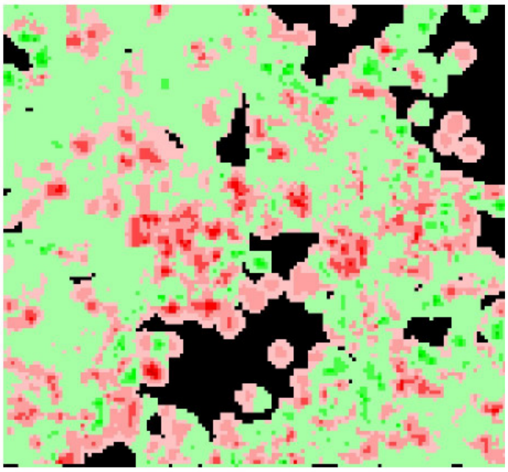
After the application of the membership function for each attribute map and the calculation of the entire EHSI with the same weights like in the HSI (equation [4]) the maps in Figure 34 were derived.



Enhanced Habitat Suitability Index 1989
indicated by multiplied life requisites

Enhanced Habitat Suitability Index 2000
indicated by multiplied life requisites

bright areas: high habitat suitability
dark areas: less habitat suitability



reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability
black: no habitat suitability detected

Change of the Enhanced Habitat Suitability
Index indicated by multiplied life requisites

Figure 34 EHSI result maps with multiplied combination of life requisites for 1989 and 2000 and its changes

If the pixel values of the EHSI map of 1989 are subtracted from the map values of 2000, the areas with habitat increase and decrease can be visualised in Figure 34. Beside new areas with increased habitat suitability the detected decrease in the centre of the test site becomes obvious again (Figure 19). The high habitat potentials along the border lines from forested areas to agricultural land or meadows become obvious in the EHSI of 2000.

A quantitative overview of the development of the EHSI with multiplicative combination of life requisites is given in the following table.

Table 27 Development of the EHSI with multiplicative combination of life requisites from 1989 to 2000 [% of the test site area]

EHSI

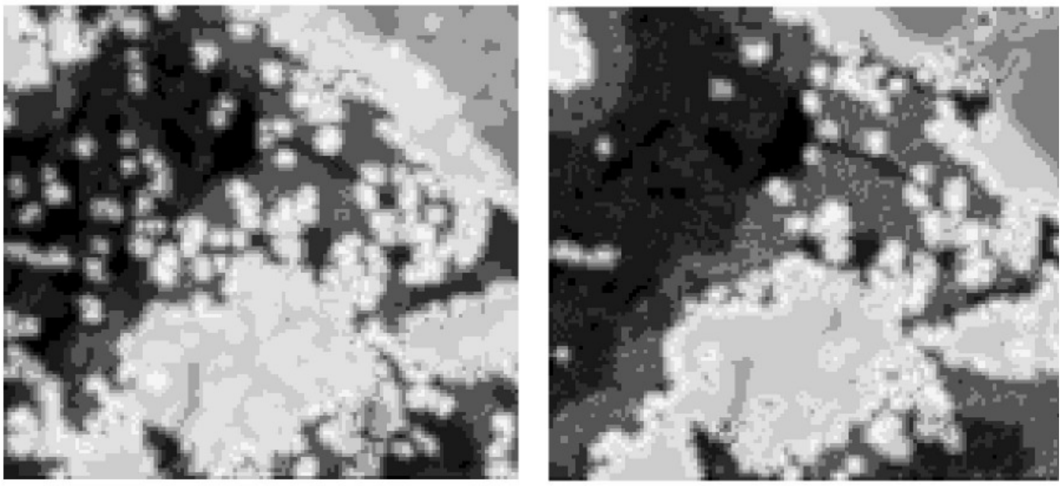
2000	**1989**		
	suitability	**no suitability**	
suitability	0,00%	52,69%	Σ 52,69%
no suitability	31,86%	15,44%	
	Σ 31,86%		

relative change of suitable area: + 20,83%

No constant habitat suitability was found on both occasions. This explains the lack of blue coloured areas in the map of Figure 34. Applying the EHSI with multiplicative combination of life requisites an increase of the habitat suitability of more than 20% can be detected. In the following figure the results of the EHSI with additive recombination of life requisites (see equations [11] and [12]) are illustrated.

5.2.4 Retrospective Changes of the EHSI+

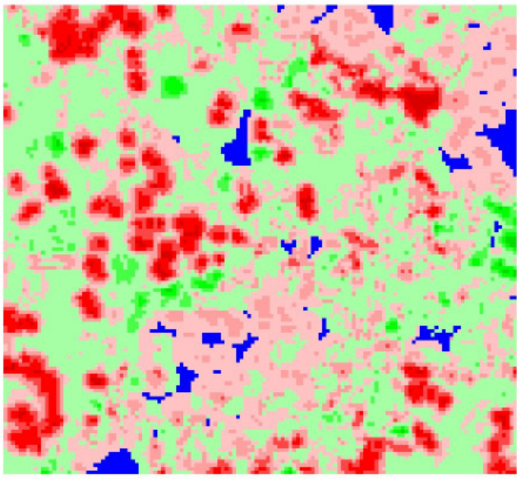
In the following figure the results of the EHSI+ with additive recombination of life requisites (see equations [11] and [12]) are illustrated.



Enhanced Habitat Suitability Index 1989 indicated by additive recombination of life requisites

Enhanced Habitat Suitability Index 2000 indicated by additive recombination of life requisites

bright areas: high habitat suitability
dark areas: less habitat suitability



reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability
blue: no change of habitat suitability

Change of the Enhanced Habitat Suitability Index indicated by additive recombination of life requisites

Figure 35 EHSI+ result maps with additive recombination of life requisites for 1989 and 2000 and its changes

The effect of the drained lake in the north-east becomes visible after the life requisites are additively recombined within the EHSI+ model of Figure 35 (compare with Figure 29 and Figure 31). Compared with the multiplied combination of life requisites in the EHSI, most of the areas with habitat loss are different in location, intensity and extension. In Table 28 the development of the additive EHSI is quantified.

Table 28 Development of the EHSI with additive recombination of life requisites from 1989 to 2000 [% of the test site area]

EHSI +

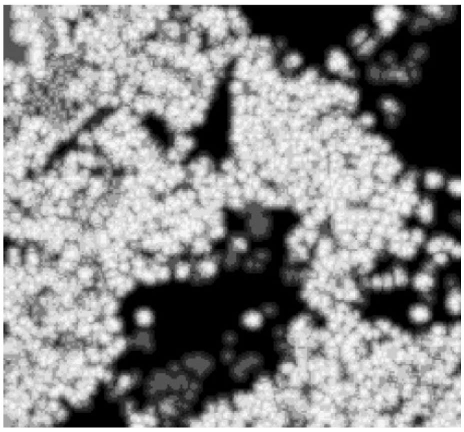
	1989		
2000	**suitability**	**no suitability**	
suitability	2,69%	44,45%	Σ 47,14%
no suitability	52,86%	0,00%	
	Σ 55,55%		

relative change of suitable area: **- 8,41%**

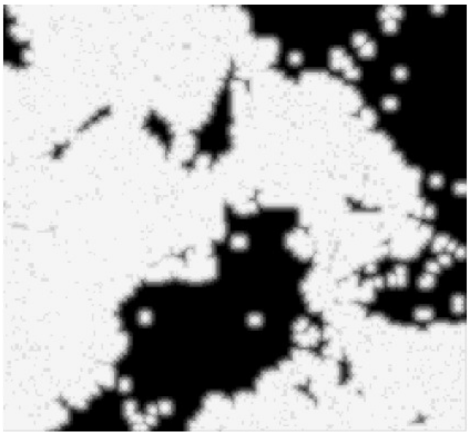
Table 28 illustrates the effect of the lake in the north-eastern part of the test site, after the additive recombination of life requisites. A decrease of the total habitat suitability of more than 8% can be detected applying fuzzy sets with additive recombination of life requisites.

5.2.5 Simulation of a changed habitat applying EHSI+

The objective in the following section is the simulation of a potential change of habitat suitability due to different political conditions. According to Article 3.4 of the Kyoto Protocol (KP) it is possible for Annex I countries to account for anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from any or all of the human-induced activities. One explicitly mentioned activity as a sink under the KP is forest management (UN-FCCC, 2002). Germany has elected to report forest management as an activity according to Article 3.4 KP. Therefore this has some consequence for forest management and thus e.g. the timber volume. This may result in land being managed in such a way that there is less open forest and more timber volume is accumulated in forests. For the applied HSI model this can cause the reduction, or even the disappearance of the attribute “open forests”, while the timber volume might increase in the forested parts of the test site. If the effects are introduced in the EHSI+ for the Red Kite, the potential habitat will change. In this case all “open forest” patches within the forest have been turned into patches with high timber volume, while the “timer volume” attribute itself has been increased for the forests around Moritzburg. Figure 36 shows the effects within the life requisite “nesting”, which consists of 70% “open forests” and 30% “timber volume”.

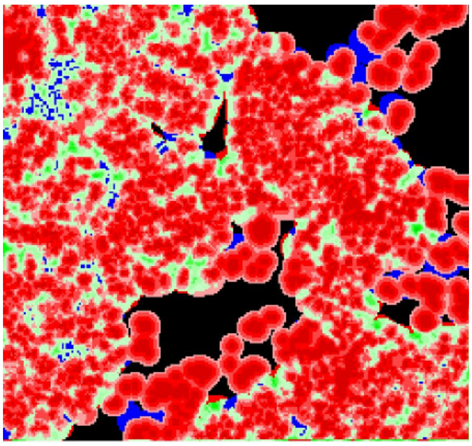


Enhanced Habitat Suitability Index 2000 for life requisite “nesting”



Simulated Enhanced Habitat Suitability Index 2000 for life requisite “nesting”

bright areas: high suitability of “nesting”
dark areas: less suitability of “nesting”

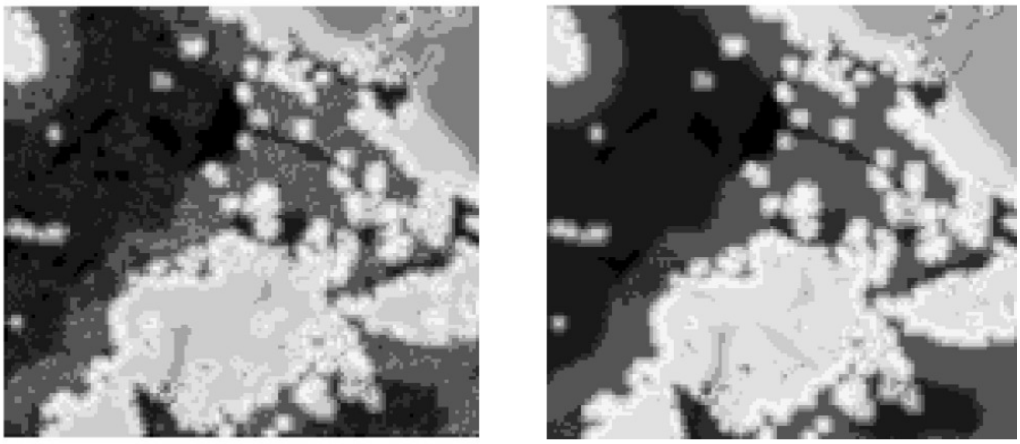


reddish colours: loss of “nesting”
greenish colours: increase of “nesting”
blue: no change of “nesting”
black: no “nesting” detected

Changes of the EHSI life requisite “nesting” indicated by the simulated EHSI+ life requisite and the original EHSI+ life requisite “nesting”

Figure 36 EHSI+ result maps of the life requisite “nesting” for the Red Kite, the simulated EHSI life requisite “nesting”, and its changes

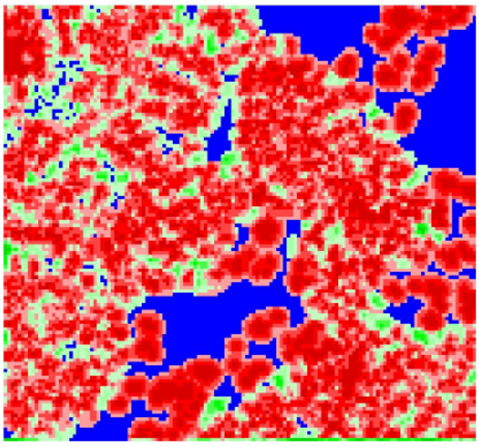
The development of the life requisite “nesting” would be dominated by the loss of “open forest”. The red areas reflect the losses, while the few green areas reflect an increase of the “nesting” requisite due to the increased “timber volume”. The habitat suitability in total would be influenced as well, and this is shown in Figure 37.



Enhanced Habitat Suitability Index 2000

Simulated Enhanced Habitat Suitability Index 2000

bright areas: high habitat suitability
dark areas: less habitat suitability



reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability
blue: no change of habitat suitability

Changes of the EHSI indicated by the simulated EHSI+ and the original EHSI+

Figure 37 EHSI+ result maps of 2000, the simulated EHSI+, and the changes of the potential habitat suitability

The loss of “open forests” would cause a loss of the habitat suitability in more than 71% of the area around Moritzburg. Slightly more than 15% of the area is covered by an increase of the habitat suitability because of the increasing "timber volume". Due to the important role of "open forests" as part of the "nesting" life requisite for the Red Kite an important part of its habitat would be lost if increasing the carbon stock in forests would become an economic objective for forest owners.

Table 29 Development of the simulated EHSI with additive recombination of life requisites from 1989 to 2000 [% of the test site area]

Simulated EHSI+

2000	1989		
	suitability	**no suitability**	
suitability	13,57%	15,35%	Σ 28,92%
no suitability	71,08%	0,00%	
	Σ 84,65%		

relative change of suitable area: **- 55,72%**

Table 29 quantifies the development of the simulated EHSI. The total habitat suitability would decrease by more than 55% of the test area.

5.3 DISCUSSION OF THE EHSI

In comparison to the results indicated by the original HSI, the application of fuzzy sets in the EHSI model lead to an increase of suitability on the level of attribute, life requisite, and habitat model. The effect of the fuzzy implementation is especially noticeable along the edges of different class assignments between neighbouring pixels (Table 22 to Table 26). Habitat suitability indicated by the application of fuzzy sets increases depending on the relation of patch size to length of the edges. Attributes which are mostly distributed as single pixels across the test site area show an increase of suitable area after the application of fuzzy sets, because of the relation of relatively small patch sizes to the edges along patches. In the case of the EHSI attribute “tree height”, the suitability with more than 37% of the test site area in 1989 is nearly 6 times greater than the suitable area of “tree height” according to the HSI (Table 15 and Table 26). In contrast, the suitable area of attributes which cover large areas of the test site does not increase that much after the application of the EHSI due to the short edge length in relation to the attribute patch size. This is the case for the attribute “water bodies” (compare with Figure 48).

Basically the effect of the fuzzy implementation is a larger area of habitat suitability and habitat changes in the EHSI results. Compared with the HSI model in Figure 19 there is a larger area of habitat suitability according to the EHSI model (Figure 34). The cause is the additional suitable area due to the fuzzy set application in the EHSI. If the results of the HSI+ and the EHSI+ results are compared, the EHSI+ results in more areas with habitat decrease and results in a relative change of suitable area of -8,41% (Table 28). In contrast to that the HSI+ results in a relative change of suitable area of +9,82%. Thus the application of fuzzy sets yields to a decrease of potential habitat, because of the facts that more suitable area is considered in the retrospective change analysis of the EHSI model.

An effect could be detected by comparing the EHSI including a multiplicative combination of life requisites with the EHSI+ applying an additive recombination of life requisites. While the EHSI with multiplied life requisites results in an relative increase of suitable area of the test site of more than 20%, the suitability decreases by more than 8% after the application of the

EHSI+ with additive recombination of life requisites (Table 27 and Table 28). The EHSI+ seems to be more sensitive to changing ground conditions and is able to detect even more areas of habitat suitability decrease.

For simulation purposes introducing new or simulated maps with binary data, the implementation of fuzzy sets offers the opportunity to realise graduated transitions along different class assignments of an attribute. As rigid transitions are lost, the spatial distribution of suitable areas becomes more realistic. In chapter 5.2.5 the application of fuzzy sets for the simulation of potential future developments in the test site is described. A potential habitat change assuming higher timber volumes in forests as a consequence of the desire to increase the carbon stock under Article 3.4 of the Kyoto Protocol is simulated. The simulation results in a reduction of the life requisite “nesting” and a decrease of the habitat suitability in more than 55% of the test site area. The results are based on the consideration of two attributes “open forest” and “timber volume”. “Timber volume” was expected to increase, while the “open forest” attribute was expected to decrease for most of the forested areas around Moritzburg. The loss of the life requisite in more than 55% of the test site area is caused by the weight of “open forest” (0,7) compared to the weight of timber volume (0,3) within the “nesting” life requisite. Only in some relatively small areas, where the attributes do not coincide with the increase of timber volume, there is an increase in suitability of the life requisite and the simulated habitat (Figure 36, Figure 37). The simulation study was realised for the most essential attributes and the most affected life requisite for such a scenario as a potential consequence of forest management aiming at an increase of carbon storage in forests. If future developments resulted in changes to forest management regimes, there would be other attributes than those considered in this study that would change for the test site. However the effect of even two considered attributes and their influence on the entire habitat suitability of the area around Moritzburg could be demonstrated. The possible negative effects on potential habitats for Red Kite became obvious. As the habitat approach is species specific the same development can affect living conditions for different species in positive and negative directions, and result in changes of species abundance and community composition.

However the area with suitable pixel increased after the application of the EHSI. The main effects of changing ground conditions in terms of major habitat loss and gain were detectable. Some of the EHSI models results were similar to those of the HSI models. Similar areas of habitat suitability decrease could be detected in the centre of the test site. Therefore the application of fuzzy sets proved to be an effective tool to work with binary attribute maps as an additional input for the HSI model, especially for simulation purposes.

6 HSI WITH HOME RANGE ASPECT (HR-HSI)

In the following section the application of a home range approach with a defined range from each location of the Moritzburg test site is described and the results are presented and discussed for the attribute and life requisite levels. The first approach multiplies life requisites while the second applies an additive recombination of life requisites in the individual attribute as input for the home range habitat suitability model (HR-HSI).

6.1 HR-HSI ANALYSIS METHODS

The HSI was originally applied for the Moritzburg area using a purely pixel based binary approach. In most of the ornithological reports home rage aspects have been considered as significant factors for the evaluation of a potential habitat of a rare species (OKIA 1976, TERBORGH ET AL. 1990, BAILLON ET AL. 1992, FREEMARK ET AL. 1995). Even during different seasons, various activity ranges of birds in the tropical zone have been reported by HILTY (1994). Facing spatial considerations in terms of home range activities within the HSI modification have been taken into account by assuming a wider scale for the application in Moritzburg.

For the application of an activity home range with the same distance in every direction for each central pixel of interest a circle approach was chosen. The reason for implementing the approach is the widely accepted behaviour of Red Kite to occupy every suitable landscape patch within the range. In relation to the test site size an activity radius of 200 m was assumed for each individual pixel of an attribute map or a life requisite map. All suitable pixels within the defined range were combined by summation and assigned to the central pixel of the circle. Applying a moving window approach, the circle was calculated for each individual pixel of the test area (Figure 38). This was realised on the attribute and on the life requisite level including the related maps and weights (compare Table 7). An edge effect of the home range approach has to be considered. According to the radius of the home range circle of 200 m a 200 m buffer was assigned to the test site borders and left our for considerations on the suitability of the affected pixel.

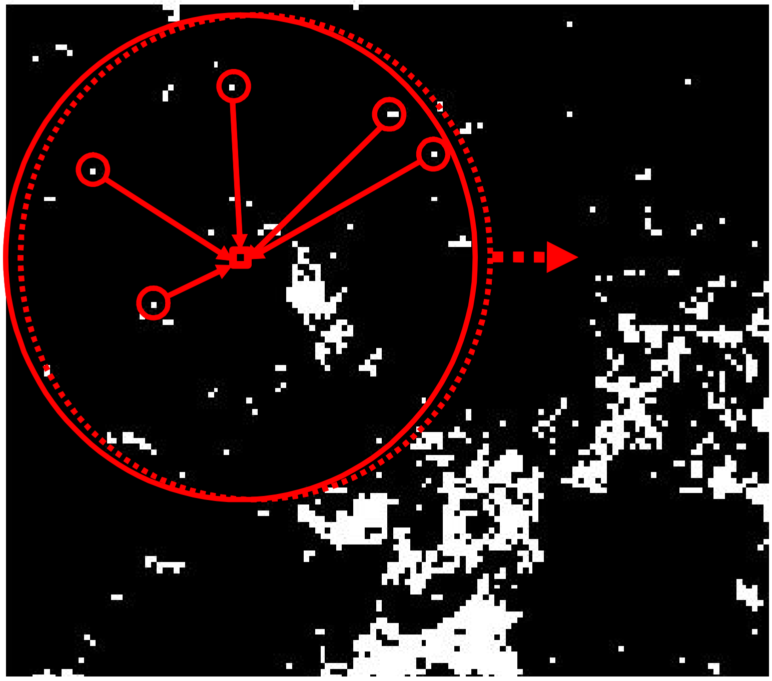


Figure 38 Calculation of home range activity maps with 200 m radius circle

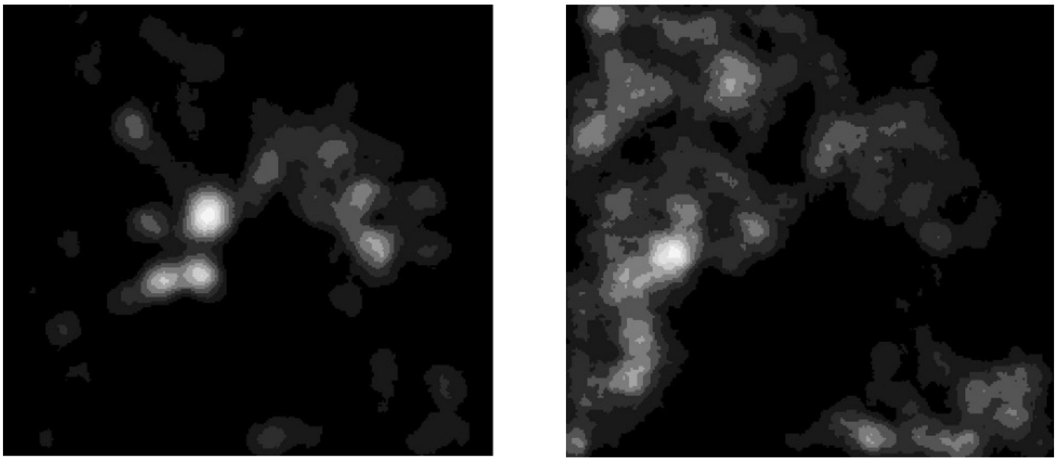
On the life requisite level the different attribute maps were merged to binary outputs for each life requisite. In the following procedure the home range approach was applied on the binary life requisite information. The results of the home range maps were merged to new home range habitat suitability index maps (HR-HSI) with different minimum requirement thresholds for each requisite. For the applied modification the life requisite “food” was expected to be available for 80% of the current location in the activity range of 200 m, while “nesting” and “safety” facilities should be available in 50% of the current location. On the attribute level each individual map was recalculated with the home range approach (Figure 38) and weighted according to the original HSI. In the final step the life requisite information were merged to the final HR-HSI. This is described in the following chapter.

6.2 RESULTS OF THE HR-HSI

The considered home range activities of Red Kite are reflected through the spatial analysis of the life requisite maps and the individual attribute maps what leads to different results compared to the original HSI model. Now the binary character of the individual attribute maps has changed into areas of different suitability insensitivities for a considered area of 200 m around each individual pixel. The discrete transition probabilities from suitable pixels to unsuitable pixels have changed into continuous transition probabilities (CTP). This allowed for choosing different intensities for life requisites or attributes to simulate the effects of decreasing attributes or life requisites of the potential habitat.

6.2.1 Transition Probabilities for Attributes

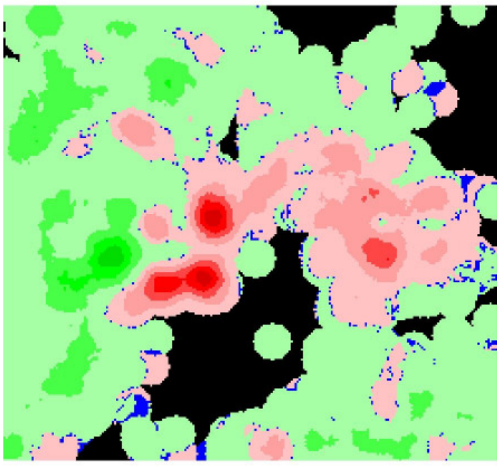
The results of the home range recalculation of the single attributes maps are presented in the following section.



Continuous transition probabilities of the attribute “timber volume” 1989 indicated by home range recalculation

Continuous transition probabilities of the attribute “timber volume” 2000 indicated by home range recalculation

bright areas: high “timber volume” suitability
dark areas: less “timber volume” suitability

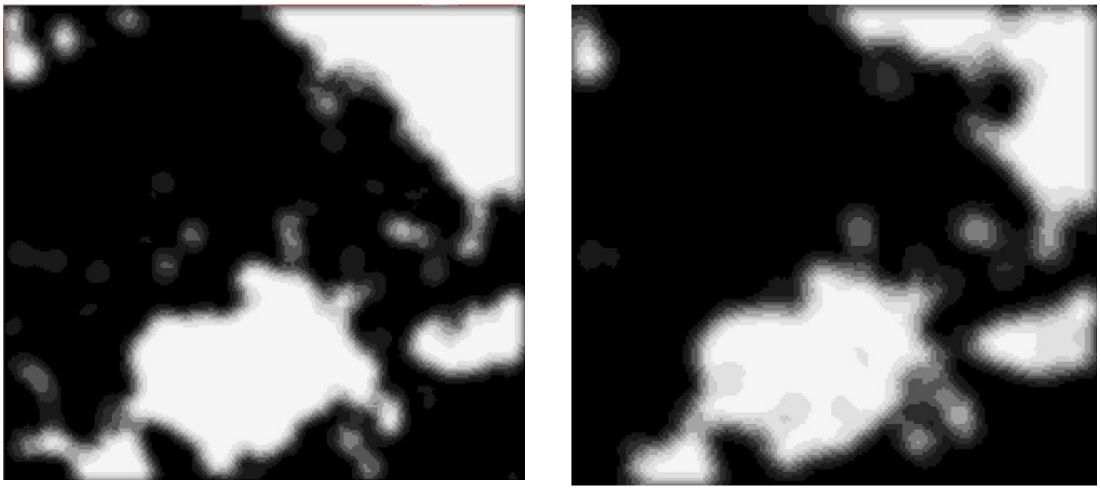


reddish colours: loss of “timber volume”
greenish colours: increase of “timber volume”
blue: no change of “timber volume”
black: no “timber volume” detected

Change of the attribute “timber volume” indicated by home range recalculation

Figure 39 HR-HSI result maps of the attribute “timber volume” for 1989 and 2000 and its changes

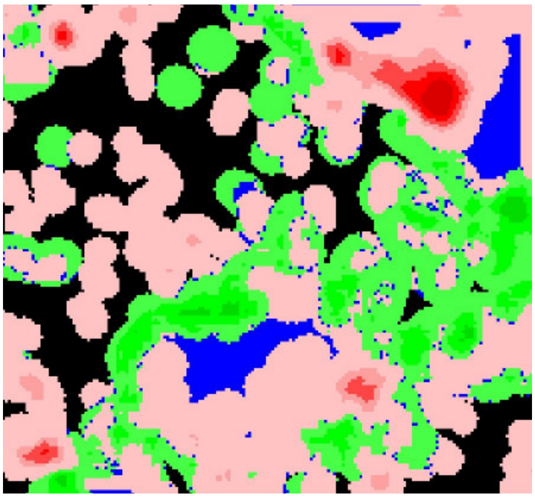
The home range approach for the attribute “timber volume” (Figure 39) produces similar results than the HSI in Figure 11. The same decrease of timber volume in the middle of the test site could be detected. Now the pixels inside a range of 200 m around the centre are reflected in each pixel value of the entire attribute map.



Continuous transition probabilities of the attribute “open sites” in 1989 indicated by home range recalculation

Continuous transition probabilities of the attribute “open sites” in 2000 indicated by home range recalculation

bright areas: high “open sites” suitability
dark areas: less “open sites” suitability



reddish colours: decrease of “open sites”
greenish colours: increase of “open sites”
blue: no changes of “open sites”
black: no “open sites” detected

Change of the attribute “open sites” indicated by home range recalculation

Figure 40 HR-HSI result maps of the attribute “open sites” for 1989 and 2000 and its changes

The attribute “open sites” was recalculated with the home range approach. The results are similar to the results of the EHSI attribute maps in Figure 29. In this case the result pixel value represents the sum of all pixels in a distance of 200 m. Therefore the individual activity range is included in the calculations. The decrease of suitability in the north-eastern part of the test site is visible.

Table 30 Development of "timber volume" from 1989 to 2000 utilising the home range approach [% of the test site area]

Vol

2000	**1989** **timber volume ≥ 300 m³/ha**	**1989** **timber volume < 300 m³/ha**	
timber volume ≥ 300 m³/ha	1,70%	59,05%	Σ 60,75%
timber volume < 300 m³/ha	24,00%	15,25%	
	Σ 25,70%		

relative change of suitable area: + 35,05%

Table 31 Development of "open sites" from 1989 to 2000 utilising the home range approach [% of the test site area]

Sites$_{open}$

2000	**1989** **open sites**	**1989** **non open sites**	
open sites	5,92%	26,15%	Σ 32,07%
non open sites	49,21%	18,73%	
	Σ 55,13%		

relative change of suitable area -23,06%

Table 32 Development of "open forest" from 1989 to 2000 utilising the home range approach [% of the test site area]

Forest$_{open}$

2000	1989 open forest	1989 non open forest	
open forest	2,02%	46,83%	Σ 48,85%
non open forest	50,18%	0,96%	
	Σ 52,20%		

relative change of suitable area **- 3,35%**

Table 33 Development of "broadleaved trees" from 1989 to 2000 utilising the home range approach [% of the test site area]

Comp$_{tree}$

2000	1989 broadleaved trees ≥ 80%/ha	1989 broadleaved trees < 80%/ha	
broadleaved trees ≥ 80%/ha	0,93%	78,99%	Σ 79,92%
broadleaved trees < 80%/ha	7,26%	12,82%	
	Σ 8,19%		

relative change of suitable area **+ 71,73%**

Table 34 Development of "tree height" from 1989 to 2000 utilising the home range approach [% of the test site area]

$\text{Height}_{\text{tree}}$

2000	1989 tree height ≥ 25 m	1989 tree height < 25 m	
tree height ≥ 25 m	2,67%	50,23%	Σ 52,90%
tree height < 25 m	29,47%	17,63%	
	Σ 32,14%		

relative change of suitable area + 20,76%

Tables 30-34 indicate the development of the single attributes recalculated with the home range approach. All attributes except "open sites" (**$\text{Sites}_{\text{open}}$**) and "open forest" (**$\text{Sites}_{\text{open}}$**) show suitability increase over the time period of 11 years. The area of suitable "open forest" patches decreased by more than 3%, while the area of suitable "open sites" decreased by more than 23% of the test site area.

An overview of the development of the attributes after the recalculation with the home range approach is given in the following figure.

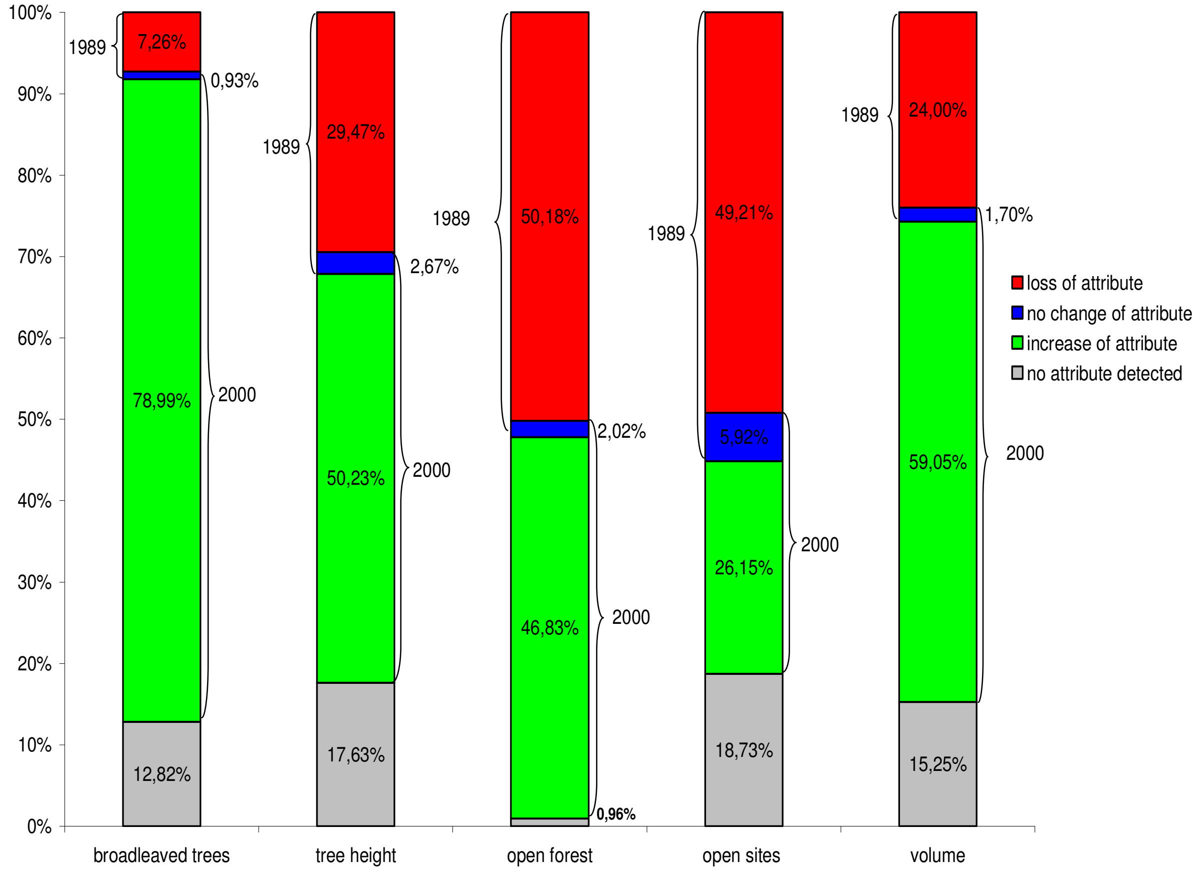


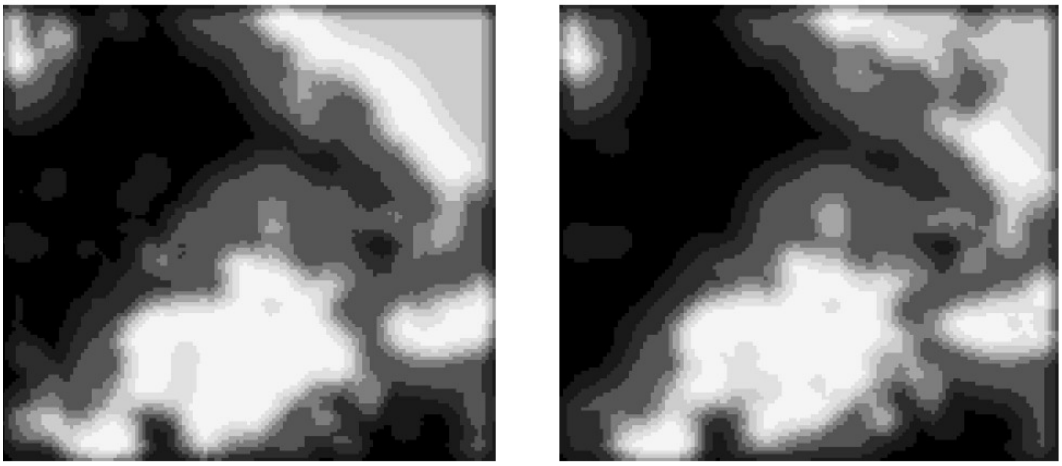
Figure 41 Overview of all HR-HSI attribute developments from 1989 to 2000 [% of the test site area]

Figure 41 illustrates that intensive changes of all attributes took place over the time period according to the application of the home range approach. The suitability of the individual attributes, such as “broadleaved trees”, “tree height” or “timber volume” increased. The proportion of decreasing suitability is higher than the proportion for increasing suitability for the two attributes “open forest” and “open sites”. “Open sites” has also the highest proportion of constant attribute suitability in the test site.

6.2.2 Transition Probabilities for Life Requisites

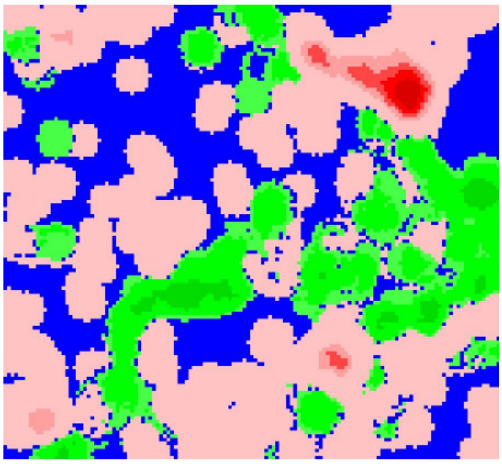
In the following section the home range habitat suitability maps are shown under consideration of life requisites as the main object of observation in habitat evaluations (LÖFSTRAND ET AL. 2003).

The life requisite “food” was recalculated with the home range aspect after the attribute have been merged according equation [4] (Figure 42).



Continuous transition probabilities of the life requisite “food” 1989 indicated by home range recalculation

Continuous transition probabilities of the life requisite “food” 2000 indicated by home range recalculation



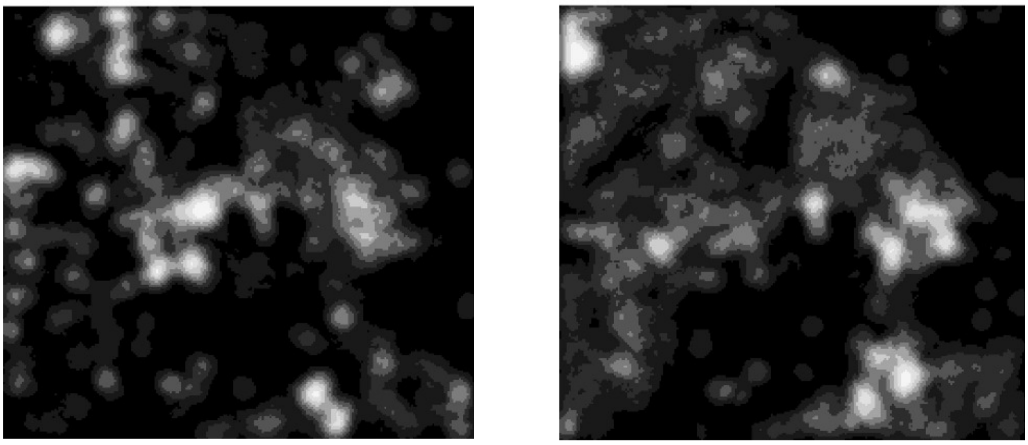
bright areas: high “food” suitability
dark areas: less “food” suitability

reddish colours: loss of “food”
greenish colours: increase of “food”
blue: no change of “food”
black: no “food” detected

Change of the potential life requisite “food” indicated by home range recalculation

Figure 42 HR-HSI result maps of the life requisite “food” for 1989 and 2000 and its changes

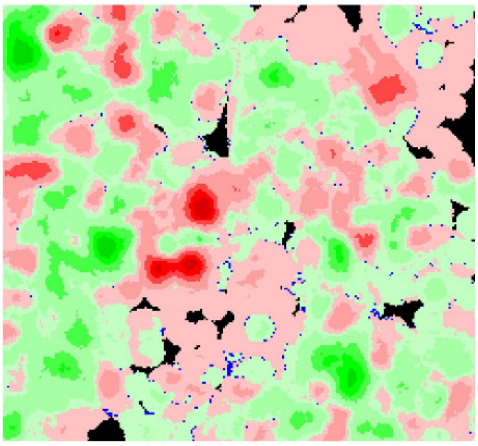
“Food” consists of the attributes “water bodies” ($\mathbf{Dis}_{\mathbf{water}}$**),** “forest border” ($\mathbf{Dist}_{\mathbf{forest}}$) and “open sites” ($\mathbf{Sites}_{\mathbf{open}}$). In 1989 there was a dry lake in the north-east of the area. In 2000 the lake was full, and therefore there was a decrease of the attribute “open sites” ($\mathbf{Sites}_{\mathbf{open}}$) (compare with Figure 29 and Figure 40). The effect for the entire life requisite can be recognised in the red area in the north-east of the map. Because the rest of the attributes did not change, the effects in Figure 42 are only caused by “open sites”. The increase in the middle of the image is detected due to the windthrow. This caused a reduction in the attributes “timber volume” (**Vol**) and “broadleaved trees” (**Comp$_{tree}$**), and an increase in the attribute “open site” (**Sites$_{open}$**). The relative change of suitable area of “food” was calculated with a decrease of -25,92% (Annex table 6, p.198). In the following figure the changes of the life requisite “nesting” are illustrated.



Continuous transition probabilities of the life requisite “nesting” 1989 indicated by home range recalculation

Continuous transition probabilities of the life requisite “nesting” 2000 indicated by home range recalculation

bright areas: high “nesting” suitability
dark areas: less “nesting” suitability

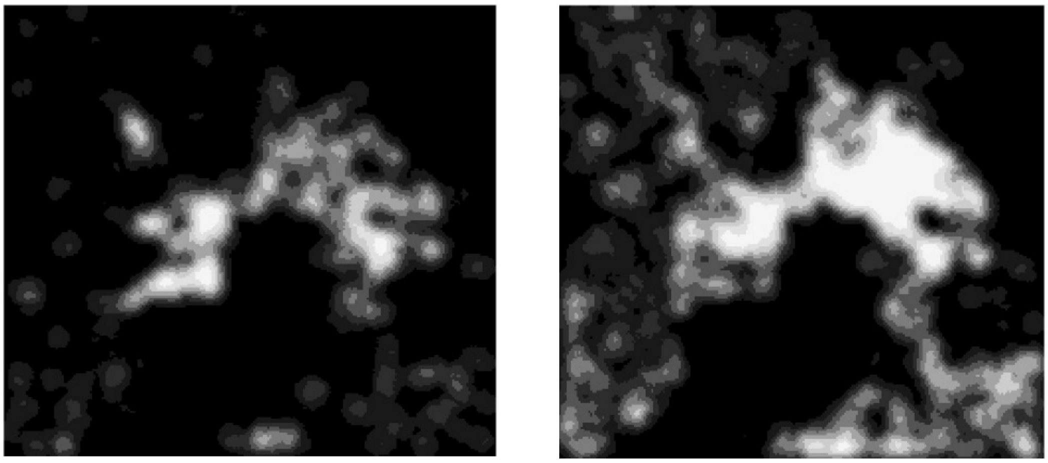


reddish colours: loss of “nesting”
greenish colours: increase of “nesting”
blue: no change of “nesting”
black: no “nesting” detected

Change of the life requisite “nesting” indicated by home range recalculation

Figure 43 HR-HSI result maps of the life requisite “nesting” for 1989 and 2000 and its changes

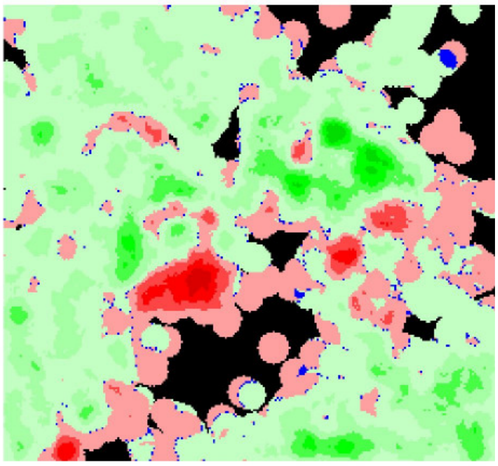
The suitability of “nesting” has decreased in the centre and in various other locations of the test site. Some decreases can be found in the north-eastern part of the image. “Nesting” consists of “open forest” (**Forest$_{open}$**) and “timber volume” (**Vol**). The effect of the drained lake in the north-eastern part of the test site could also be found to some extent in the results of “nesting” according to the HSI (Figure 15) and in the results of “nesting” according to the EHSI (Figure 32). The attribute “open forest” offers a similar result in the retrospective analysis (Annex figure 10, p.194), as the reason for the changes of the life requisite “nesting”. In total the relative change of the suitability for “nesting” is an increase of 13,58% (Annex table 9, p.200). The life requisite “safety” was recalculated with the home range approach after merging of the relevant attributes. The results are illustrated in Figure 44.



Continuous transition probabilities of the life requisite “safety” 1989 indicated by home range recalculation

Continuous transition probabilities of the life requisite “safety” 2000 indicated by home range recalculation

bright areas: high suitability of “safety”
dark areas: less suitability of “safety”



reddish colours: loss of “safety”
greenish colours: increase of “safety”
blue: no change of “safety”
black: no “safety” detected

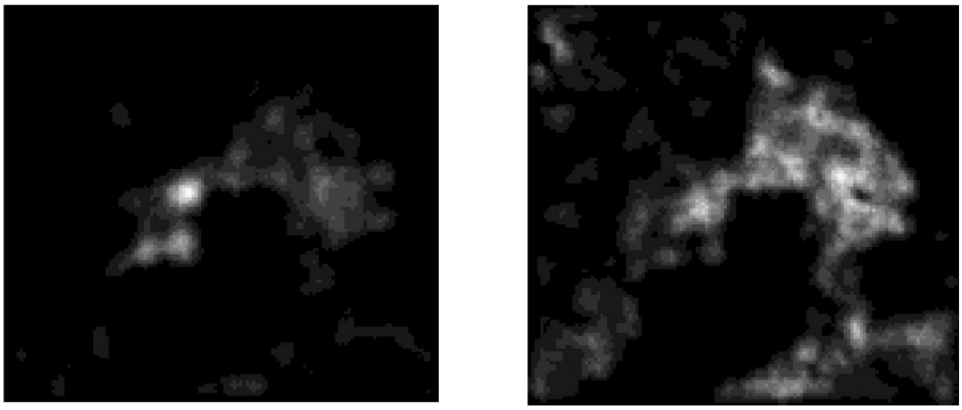
Change of the potential life requisite “safety” indicated by home range recalculation

Figure 44 HR-HSI result maps of the life requisite “safety” for 1989 and 2000 and its changes

The life requisite “safety” includes the attributes “broadleaved trees” (**Comp$_{tree}$**) and “tree height” (**Height$_{tree}$**). The HR-HSI model reacts in a similar way to the original HSI with a decrease in the centre of the test site as a consequence of the storm damage. In total the relative change of suitable area of “safety” is an increase of 45,15%, what is nearly the double increase compared with the results of “safety” according to the HSI (Annex table 12, p. 202).

6.2.3 Retrospective Changes of the HR-HSI

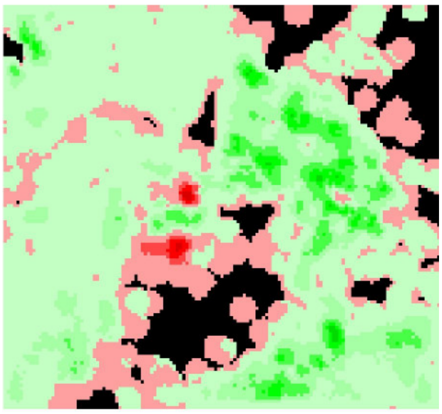
Figure 45 shows the results when the individual attribute maps are recalculated with the home range distance and the original HSI algorithm is applied according to the equations [4] and [5].



Continuous transition probabilities of the home range habitat suitability index 1989 indicated by multiplicative combination of life requisites

Continuous transition probabilities of the home range habitat suitability index 2000 indicated by multiplicative combination of life requisites

bright areas: high habitat suitability
dark areas: less habitat suitability



reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability
black: no habitat suitability detected

Change of the home range habitat suitability index indicated by multiplicative combination of life requisites

Figure 45 HR-HSI result maps with multiplied combination of life requisites for 1989 and 2000 and its changes

Within this image the weights of the single attribute are lost because of the multiplication and have been turned into a factor for the life requisites (see chapter 4.1.7).

Table 35 Development of the HR-HSI with multiplicative combination of life requisites from 1989 to 2000 [% of the test site area]

HR-HSI

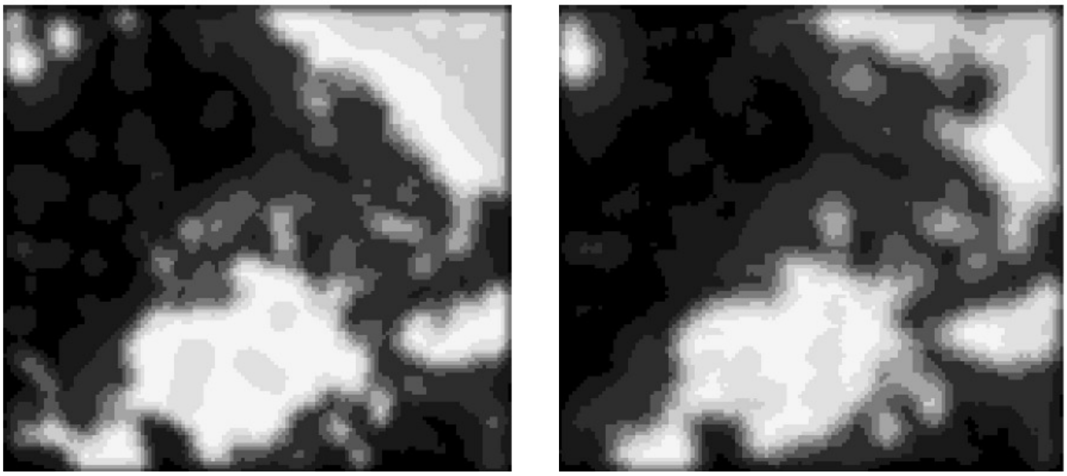
2000	**1989**		
	suitability	**no suitability**	
suitability	0,00%	74,35%	Σ 74,35%
no suitability	12,92%	12,73%	
	Σ 12,92%		

relative change of suitable area: + 61,42%

No constant habitat suitability was indicated retrospectively by the HR-HSI as well as by the EHSI+. This is also indicated in the change map of Figure 45 where no blue coloured areas can be found. The results of the HR-HSI with multiplicative combination of life requisites indicate an increase of the habitat suitability of more than 60%. In the following chapter different results can be described if life requisites are additively recombined in the HR-HIS+.

6.2.4 Retrospective Changes of the HR-HIS+

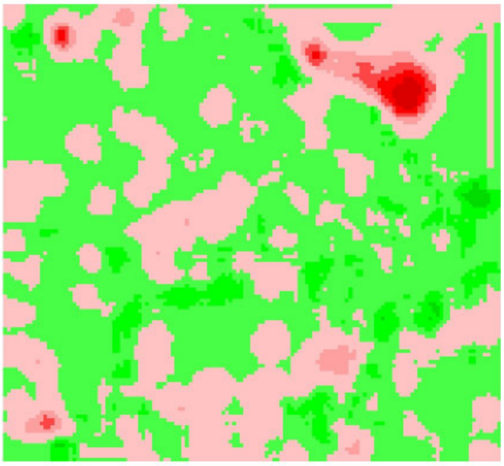
As applied for the HSI+ and the EHSI+ the additive recombination of life requisites reflects the weights of each habitat attribute in the entire HR-HSI model and allows further detailed investigation towards additional areas of habitat loss and gain for Red Kite in Moritzburg. The following illustration gives an overview of the modified HSI into a home range suitability index according to the equations [11]and [12].



Continuous transition probabilities of the home range habitat suitability index 1989 indicated by additive recombination of life requisites

Continuous transition probabilities of the home range habitat suitability index 2000 indicated by additive recombination of life requisites

bright areas: high habitat suitability
dark areas: less habitat suitability



reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability

Change of the home range habitat suitability index indicated by additive recombination of life requisites

Figure 46 HR-HSI+ with additive recombination of life requisites for 1989 and 2000 and its changes

In the results of the HR-HSI+ model the effect of the drained lake in the north-eastern part of the test site is dominating the difference image as a serious decrease of habitat suitability. Similar results can be found in the HSI+ (Figure 23) and the EHSI+ model (Figure 35). The suitable locations in both HR-HSI+ result maps of 1989 and 2000 are in different locations compared to the HR-HSI with multiplied life requisites in Figure 45. Additionally the effect of the storm damage in the centre of the test site is less visible in Figure 46. Compared to the

HR-HSI applying the multiplicative approach, the habitat suitability is higher with the approach (HR-HSI+) applying an additive recombination of life requisites in 2000 (Table 35). Table 36 quantifies the development of the HR-HSI+.

Table 36 Development of the HR-HSI with additive recombination of life requisites from 1989 to 2000 [% of the test site area]

HR-HSI+

2000	**1989**	
	yes	**no**
yes	0,00%	66,38%
no	32,52%	0,00%

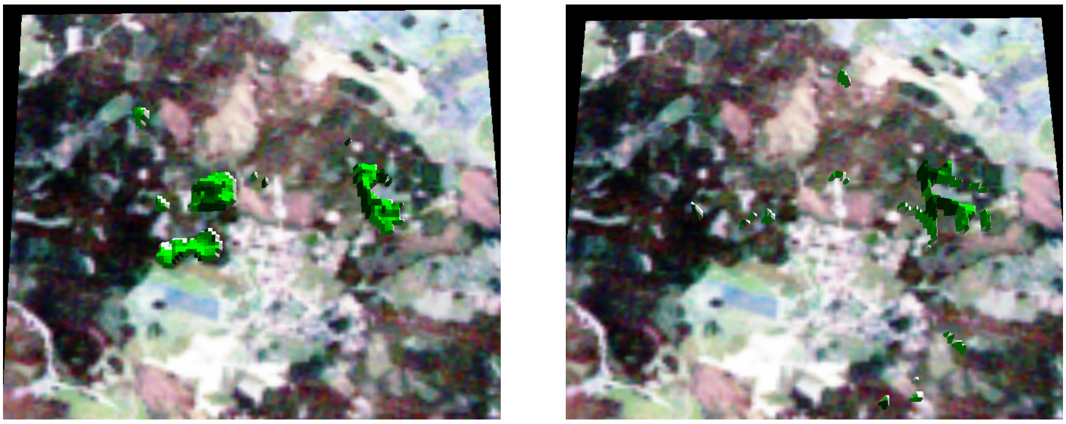
Σ 61,46%

Σ 38,54%

relative change of suitable area: + 22,92%

The results of the HR-HSI+ are remarkable because of the amount of relative habitat suitability increase compared with the HR-HSI applying multiplicative life requisite combination. The habitat suitability increase of the HR-HSI+ is close to one third of the habitat increase of the HR-HSI.

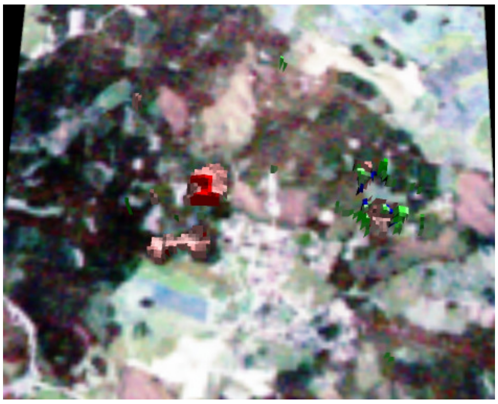
Utilising the different transition probabilities within an approach of dynamic weighting of life requisites, the home range habitat suitability illustrated in Figure 47 shows the most suitable areas for the assumption that the Red Kite would prefer 80% availability for ”food”, 50% for “nesting” and 50% for “safety” purposes in a home range of 200 m around its current position.



Habitat Suitability Index 1989 indicated by the HR-HSI+ with redefined life requisites

Habitat Suitability Index 2000 indicated by the HR-HSI+ with redefined life requisites

greenish colours: detected habitat suitability consisting of 80% suitability for the life requisite ”food”, 50% for the life requisite “nesting” and 50% for the life requisite “safety”



reddish colours: loss of habitat suitability
greenish colours: increase of habitat suitability
blue: no change of habitat suitability

Change of the potential habitat indicated by the HR-HSI+ with redefined life requisites

Figure 47 HR-HSI+ with redefined life requisite weights of both occasions,1989 and 2000 and its changes

Figure 47 shows the suitable habitat area in 1989 and 2000 and its changes, when life requisites are redefined with minimum 80% suitability for ”food”, 50% suitability for “nesting” and 50% suitability for “safety”. The transition probabilities of the home range approach allow the application of different life requisite weights within one model to estimate areas with intensive habitat loss and gain. The green parts show the highest suitability for the defined criteria in the centre of the test site for 1989. At the second occasion suitable areas can be found in the eastern part of the area, but the highly suitable area in 1989 is lost. This can also be seen in the difference image. During all modifications of the original HSI, the habitat loss in the centre of the Moritzburg area could be reflected by the calculations. In general the area with the highest habitat suitability for the Red Kite has changed over the time from 1989 to 2000. According to the chosen intensities of life requisites the location size of habitat change is about 25 hectares.

6.3 DISCUSSION OF THE HR-HSI

In comparison to the results indicated by the original HSI and EHSI, the application of home range approach in the HR-HSI model lead to different of suitability on the level of attribute, life requisite, and HR-HSI model. Still major changes could roughly be found similar to the results of the original HSI and the EHSI. The effect could mainly be induced by the different locations depending on the distribution of the suitable neighbourhood pixels.

The HR-HSI with multiplicative combination of life requisites resulted in an area of habitat suitability which is almost three times bigger compared with the results of the HR-HSI + with additive recombination of life requisites. According to the summation of suitable pixels in a circle of 200 m radius to the central pixel the information base within the HR-HSI is wider. Areas with suitable patches are larger, and areas with suitability loss and gain are also larger in the retrospective change analysis. The additive recombination of life requisite in the HR-HSI+ model seems to be more sensible towards changing ground conditions in terms of habitat losses, because larger areas of both, suitability loss and gain are subtracted in the difference image.

The effect of the drained lake in the north-eastern part of the test site is visible similar to the results of the HSI+ (Figure 23) und the EHSI+ (Figure 35). On the other hand the habitat suitability decrease in the centre of the test site as an effect of the storm damage is less visible in the HR-HSI+ result map. The reason for this is the applied home range circle of 200 m around each central pixel of interest (Figure 38) in which all suitable pixels are summed to the central pixel. Therefore patches indicating habitat suitability have a wider information base, what might compensate the relative small effect of the habitat suitability decrease due to storm damages in the centre of the test site.

The advantage of the approach is the implementation of the aspect of home range for a single species of interest. Using this approach the information utilised is not constrained to individual pixels, but the existence of a relevant habitat feature in a defined distance of 200 m to a current location is reflected in each pixel of the output maps. Thus the home range approach considers the relation of neighbouring suitable pixels to the considered location of interest. Therefore the additive recombination of the neighbouring pixel values reflects the sum of the suitability in a defined distance around the considered location.

The home range approach offers a graduation of habitat potentials. As the life requisites can be considered separately and the influence can change, new thresholds for an individual life requisite map can be applied (Figure 47). The graduation of the habitat values and the definition of thresholds can also support decisions of landscape management and policies, beside a simulation of changing individual attributes.

7 DISCUSSION

The six analysed HSI models share the same basic data and calculation algorithms. Each of these HSI models includes two levels of consideration: the attribute level and the life requisite level. In all six HSI models a number of weighted attributes are identically added to each of three life requisites for each model. Within the final habitat modelling procedure the recombination of life requisites was realised with two different approaches (multiplicative or summation) for each HSI model:

Multiplicative recombination of life requisites resulted in the HSI models:

1. **Habitat Suitability Index (HSI)** with binary attribute maps;
2. **Enhanced Habitat Suitability Index (EHSI)** applying binary attribute maps enhanced with fuzzy sets;
3. **Habitat Suitability Index with Home Rage Aspect (HR-HSI)** applying recalculated attribute maps with an activity radius of 200 m for each pixel.

The summation approach with additive recombination of life requisites resulted in the HSI models

4. **HSI+** with binary attribute maps;
5. **EHSI+** applying binary attribute maps enhanced with fuzzy sets;
6. **HR-HSI+** applying recalculated attribute maps with an activity radius of 200 m for each pixel.

The in situ data, RS data and the kNN combination method have been applied for the original HSI and for the modifications EHSI, and HR-HSI. The in situ data for 1989 consist of the Datenspeicher Wald, while the data for 2000 were taken from the MNTFR field campaign.

Landsat 5 TM data with a spatial resolution of 27 m were available for 1989 and Landsat 7 ETM+ data with a spatial resolution of 30 m were available for 2000. The combination of the remotely sensed data sources with the in situ data was realised with the kNN algorithm, which classified the Landsat data according to their spectral information. Although errors might occur by different data sources, georeferencing or by classification, changing ground conditions could be detected by all six the HSI models. Within the sensitivity analysis the influence of the individual attributes in the theoretical HSI model as well as the effects of the conditions in the test site were investigated.

The effects of the different models such as the HSI, EHSI and the HR-on the results of the attributes, the life requisites are discussed and illustrated in the following sections (chapter 7.1and 7.2). The effects of the different combination of life requisites on the entire habitat suitabilities and their changes are discussed in chapter 7.3. Finally the potentials of the HSI model approaches for future operational services are discussed in chapter 7.4.

7.1 EFFECTS OF THE HSI, EHSI AND THE HR-HSI MODEL ON ATTRIBUTE SUITABILITY

In this section the attribute results of the different HSI model modifications, such as the original HSI with binary attribute maps, the EHSI applying binary attribute maps enhanced with fuzzy sets and the HR-HSI applying recalculated attribute maps with an activity radius of 200 m for each pixel, are compared. The effects on the attribute results of the different modifications are shown in Figure 48.

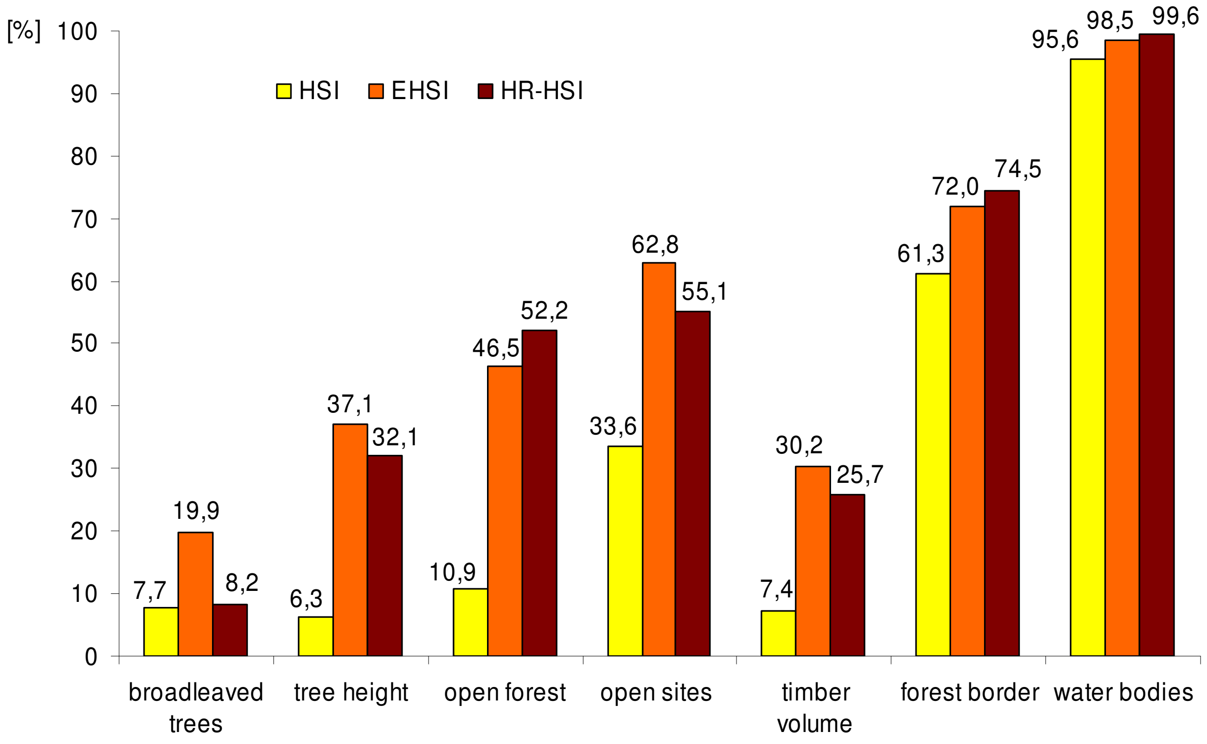


Figure 48 Effects of the HSI models (HSI, EHSI, HR-HSI) on attribute suitability in 1989 [% of the test site area]

The figure shows the effects of the application of the different HSI model variations on the different habitat attributes for Red Kite. For instance suitable “timber volume” pixels were expanded by the application of fuzzy sets within the EHSI and with the home range approach utilized in the HR-HSI. Conspicuous effects can be found in attributes which are mostly distributed as single pixels across the test site, because of small suitable areas and the high proportion of edges along these patches. The most intensive effect shows the application of the EHSI model on the attribute “tree height”. The suitability according to the EHSI is close to 6 times higher than the suitability according to the HSI model. On the other hand the suitability increase of attributes covering wide areas of the test site such as “water bodies” is close to 3% after the fuzzy sets are applied. Among the attribute which are mostly distributed as single pixels across the test site, only “open forest” shows an increase of suitable area to 52,2% after the application of the home range approach (Figure 48). All the other pixel-wise distributed attributes show a decrease compared to the EHSI results. A reason for this can be the pixel-wise distribution. The distance between the suitable pixels seems to be too far to be added to high values in the home range circle with a radius of 200 m.

The results of the different HSI models on the attribute “broadleaved trees” are presented in Figure 49.

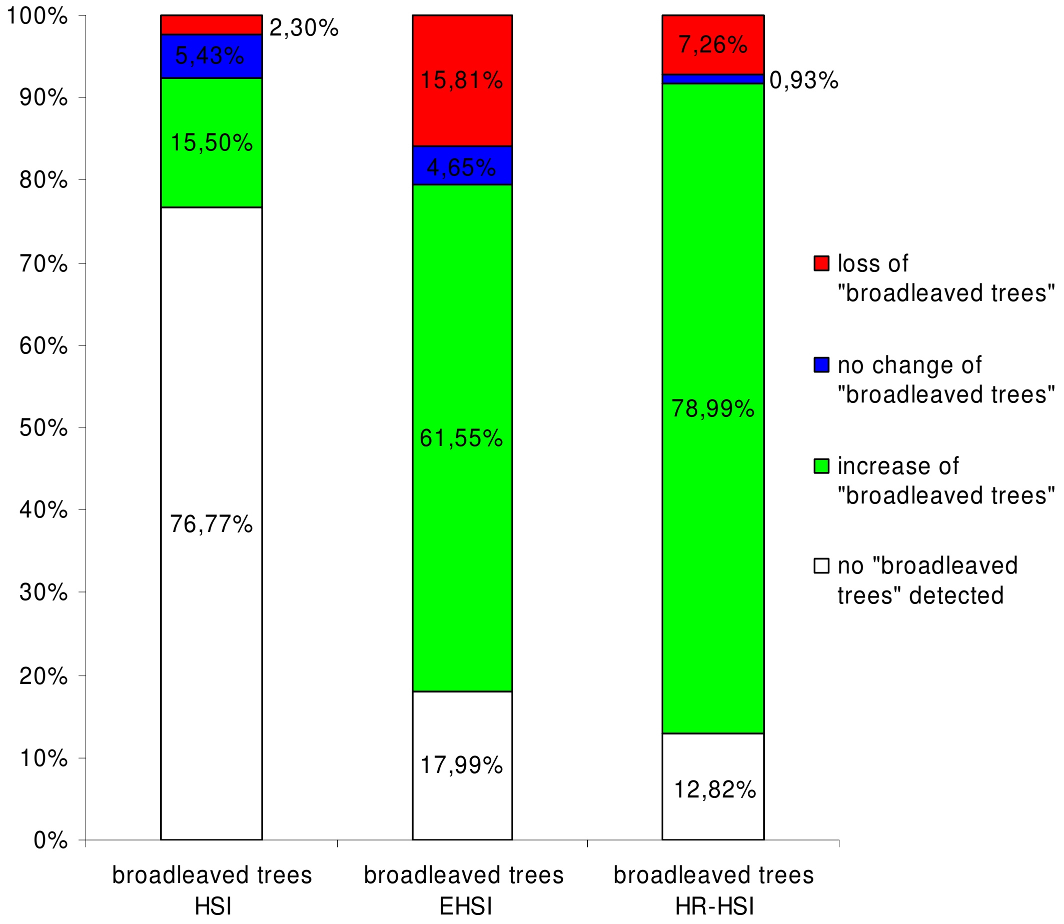


Figure 49 Effects of the HSI models on attribute suitability of “broadleaved trees” [% of the test site area]

Attribute suitability for “broadleaved trees” changed remarkably after the application of the EHSI and the HR-HSI models. More than 80% of the test site is suitable after the application of fuzzy sets within the EHSI, and close to 90% is suitable after the HR-HSI adaptation. While the highest increase of about 80% of the area could be found in the HR-HSI application, the most notable suitability decrease can be found in the EHSI approach with more than 15% of the test site. The differences are the results of the different model methodologies. While the EHSI expands suitability onto the edges of the suitable attribute patches, the HR-HSI considers the relation to suitable neighbouring pixels for one location of interest. The results are dependent on the individual procedure and the area selected for recalculation of the attribute maps. Figure 50 illustrates the effects for the attribute "timber volume".

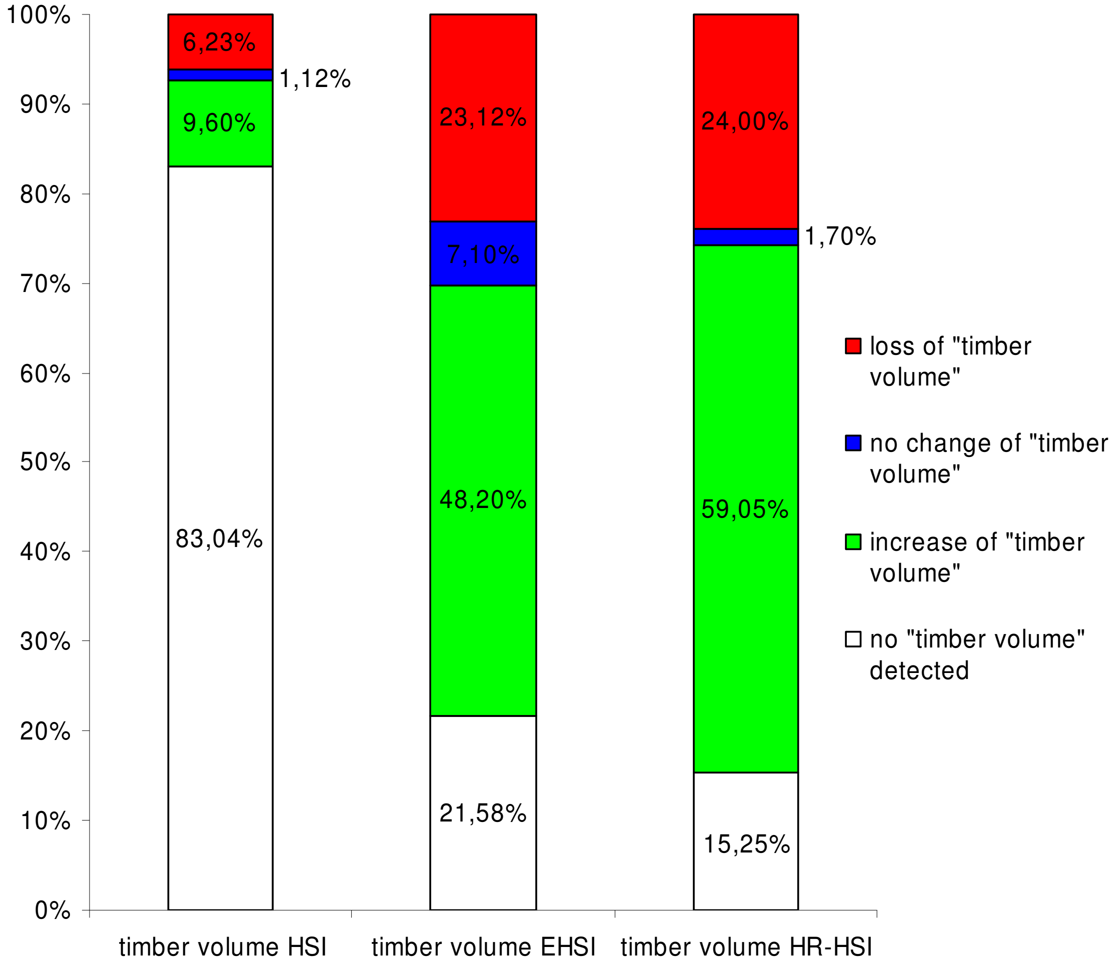


Figure 50 Effects of the HSI models on attribute suitability of "timber volume" [% of the test site area]

Similar to "broadleaved trees" the attribute "timber volume" changed in increasing suitability after the application of the HSI modifications. The proportion of constant attribute within the fuzzy set applications of the EHSI is more than 7%. The proportion of suitability decrease with fuzzy sets is equivalent to the decrease after the application of the home range approach. A similar effect is found for the attribute “tree height” in Figure 51.

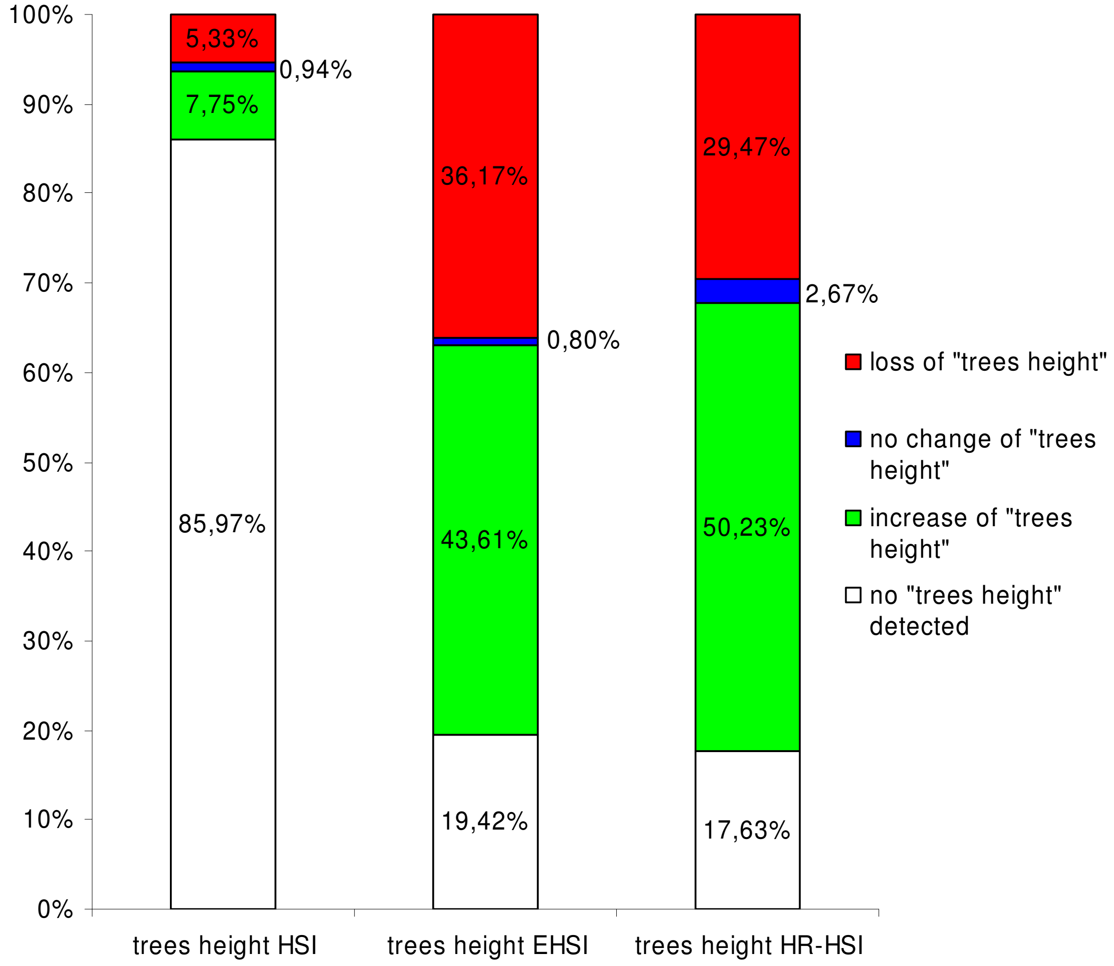


Figure 51 Effects of the HSI models on attribute suitability of “trees height” [% of the test site area]

The suitability for trees with a minimum height of 30 m changed remarkably after the application of the EHSI and HR-HSI models. The area of suitability loss for “tree height” is smaller for the HR-HSI than the EHSI (red portions of the graph), while the area of increasing suitability is greater for HR-HSI than the EHSI results (green portions of the graph). Attributes such as “broadleaved trees”, “timber volume” or “tree height” are subject to a high spatial variability. Other attributes such as “open forest” or “open sites” show a different spatial distribution. The effects of the EHSI and the HR-HSI application on their suitability results are illustrated in Figure 52 and 53, respectively.

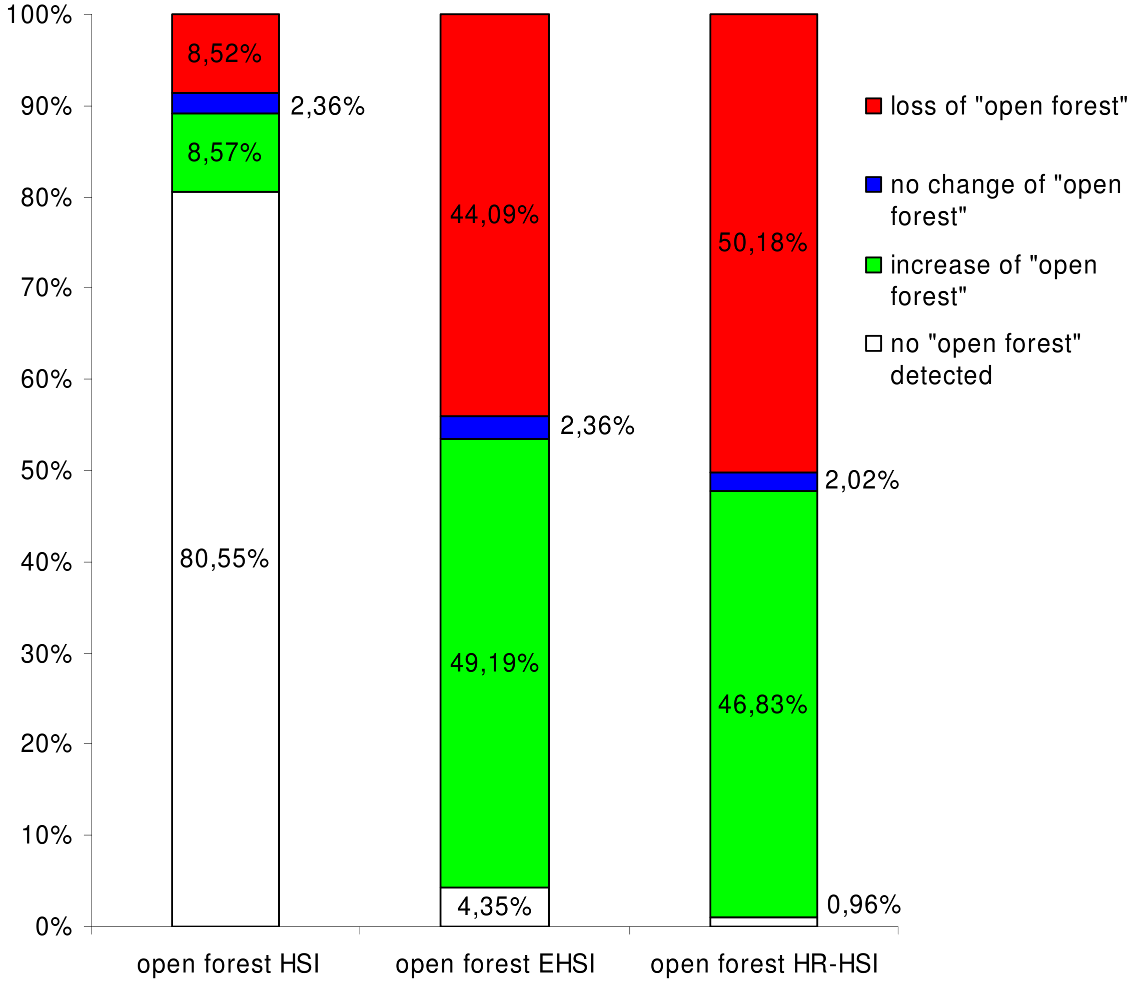


Figure 52 Effects of the HSI models on attribute suitability of “open forest” [% of the test site area]

The small suitable areas in the HSI results are caused by the binary character of the HSI model and the multiplication of the life requisites. Compared to the HSI, the application of the EHSI and the HR-HSI resulted in an increase of attribute suitability by about 40%. While the areas of decreasing patches in the EHSI results are slightly smaller (column in the middle) the relative change of suitable area for “open forest” is a bit more than 5%. The application of the fuzzy sets in the EHSI caused larger areas of suitability. Large patches with pixel values indicating no habitat suitability in 2000 were subtracted by large patches with pixel values indicating habitat suitability in 1989. After the application of the HR-HSI the patches with pixel values indicating no habitat suitability in 2000 became larger and therefore the relative change of suitable area for “open forest” became -3,35%. This is a result of moving from a pixel-based approach to an approach taking into account the proximity of pixels.

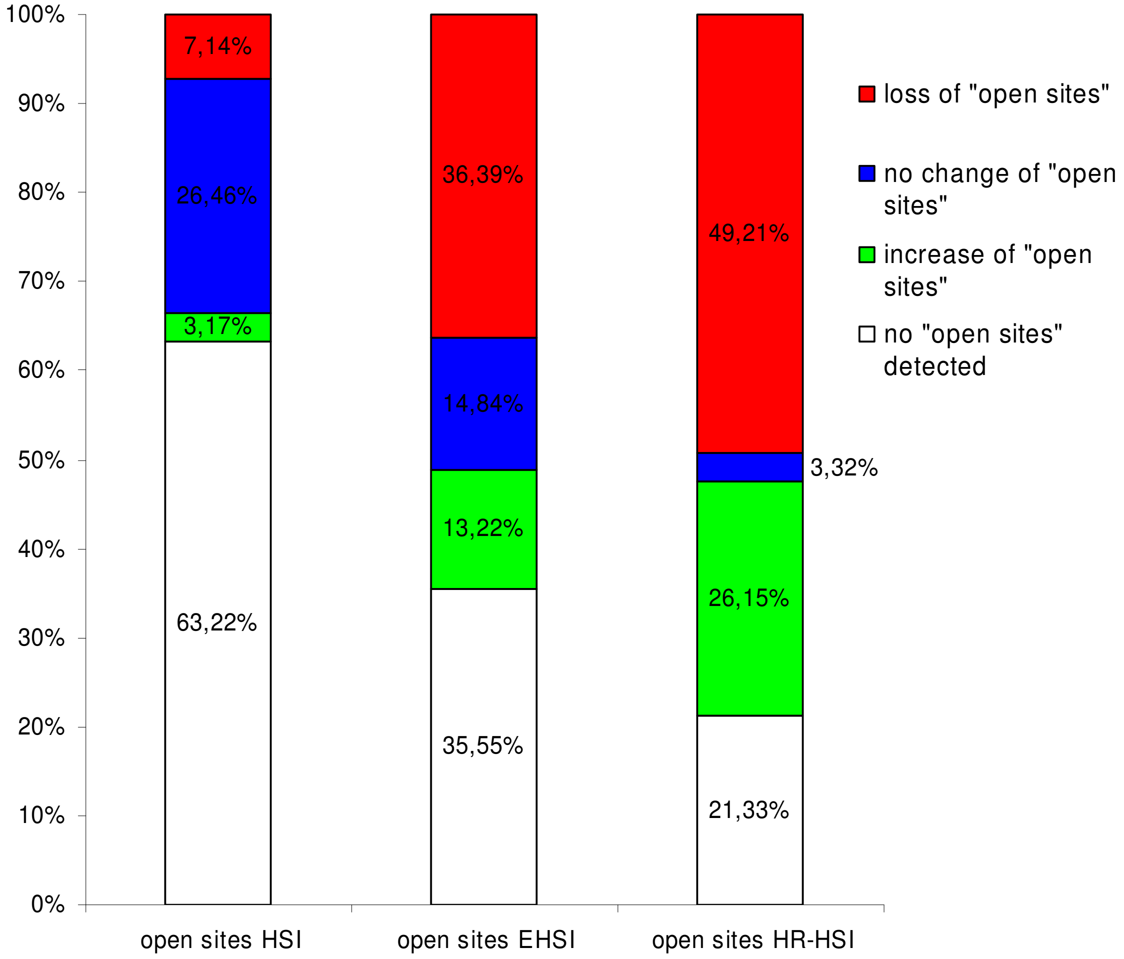


Figure 53 Effects of the HSI models on attribute suitability of “open sites” [% of the test site area]

The green portions of the graph indicate an increase of suitability for “open sites”, while the red portions of the graph indicate a decrease of suitability for “open sites”. Both become larger if the three columns in Figure 53 are compared from the left to the right. In opposite to that the blue portions of the graph indicating a constant suitability for “open sites” become smaller if the EHSI and the HR-HSI approach are applied. “Open sites” is the only attribute with a conspicuous decrease of relative suitable area in all HSI models. The relative change in the HSI is -3,97%, while in the EHSI the relative change is -23,18%. The reason for this is the application of the fuzzy sets in the EHSI, which leads to the subtraction of large areas with unsuitable “open sites” patches of 2000 from large areas with suitable patches of 1989. Comparable to the EHSI results the relative change of suitable area decreased by -23,06% after the application of the HR-HSI. Therefore the home range approach does not have a remarkable influence on the relative change of the suitable area of “open sites”. The main reason for this is the distribution of the attribute over mainly larger areas of the test site (compare with Annex figure 1, p.185). Similar effects can be found when applying the EHSI and the HR-HSI on the attributes “water bodies” and “forest border” (compare Figure 48).

The main reason for the conspicuous decrease of relative suitable area of the attribute “open sites” is the dry lake in the north-eastern part of the test site. Since the lake was empty during the Landsat data acquisition in 1989, it was assigned to a different land cover class.

7.2 EFFECTS OF THE HSI, EHSI AND THE HR-HSI MODEL ON LIFE REQUISITE SUITABILITY

In this section the results of the individual attributes are combined to the life requisites “food”, “nesting” and “safety”. The effects of the HSI, EHSI and the HR-HSI on life requisite level are described.

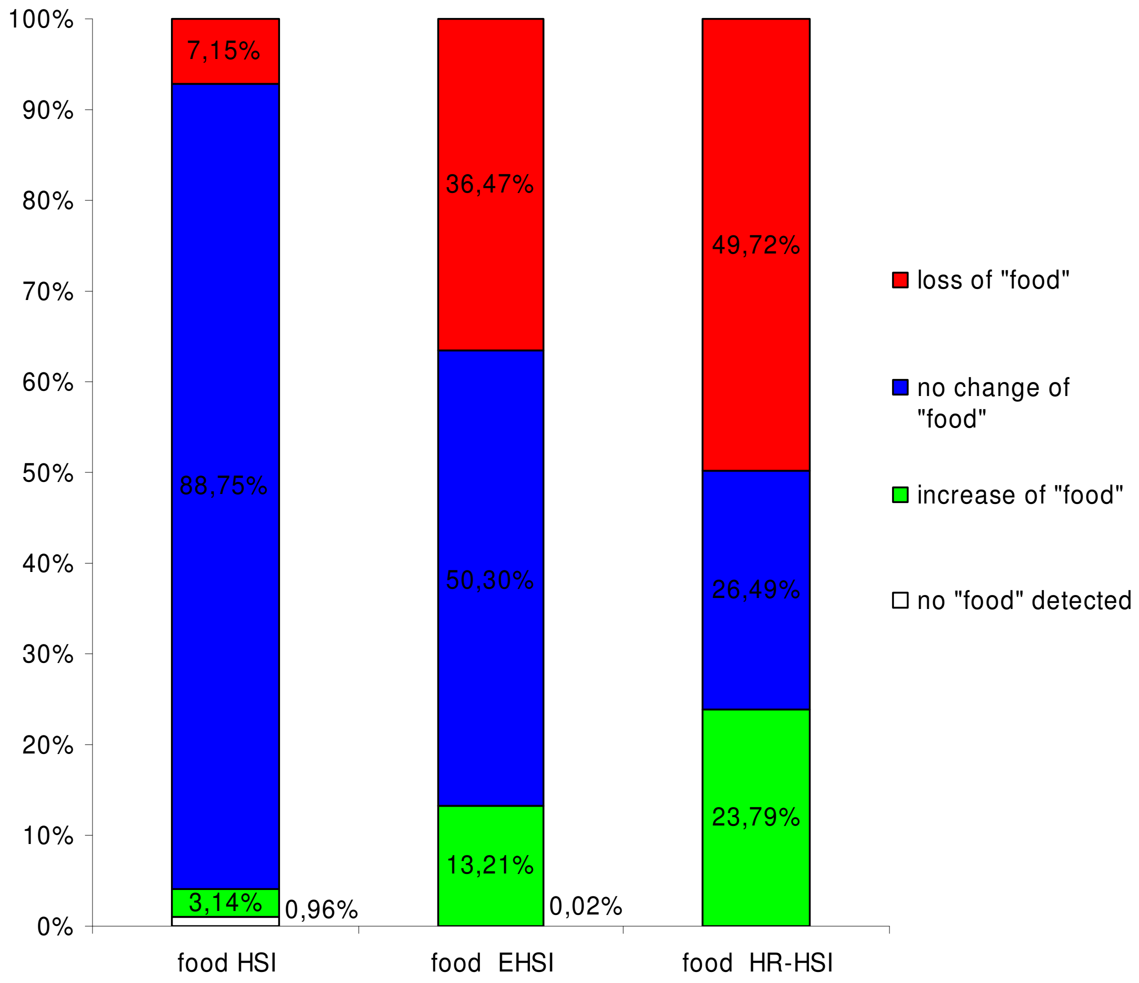


Figure 54 Effects of the HSI models on the suitability of the life requisite “food” [% of the test site area]

The EHSI life requisite “food” consists of “water bodies” (**Dis**$_{\mathbf{water}}$), “forest border” (**Dist**$_{\mathbf{forest}}$) and “open sites” (**Sites**$_{\mathbf{open}}$). Due to the fact that the first two attributes did not change, the proportion of no changes for “food” in the area is high. Where there are changes these are caused by changes in the attribute “open sites”. Comparing the different HSI modifications from HSI to HR-HSI, the area of constant suitability decreased, while areas for increasing suitability and suitability loss increased.

In total the relative suitability of “food” is a decrease of more than 4% according to the HSI, 23% (EHSI) and close to 26% according to the HR-HSI model results (Annex table 4 and

Annex table 5, p.197). Thus the effect of the "open site" attribute classification caused more suitability losses, as the EHSI and the HR-HSI include additional spatial information in their algorithms.

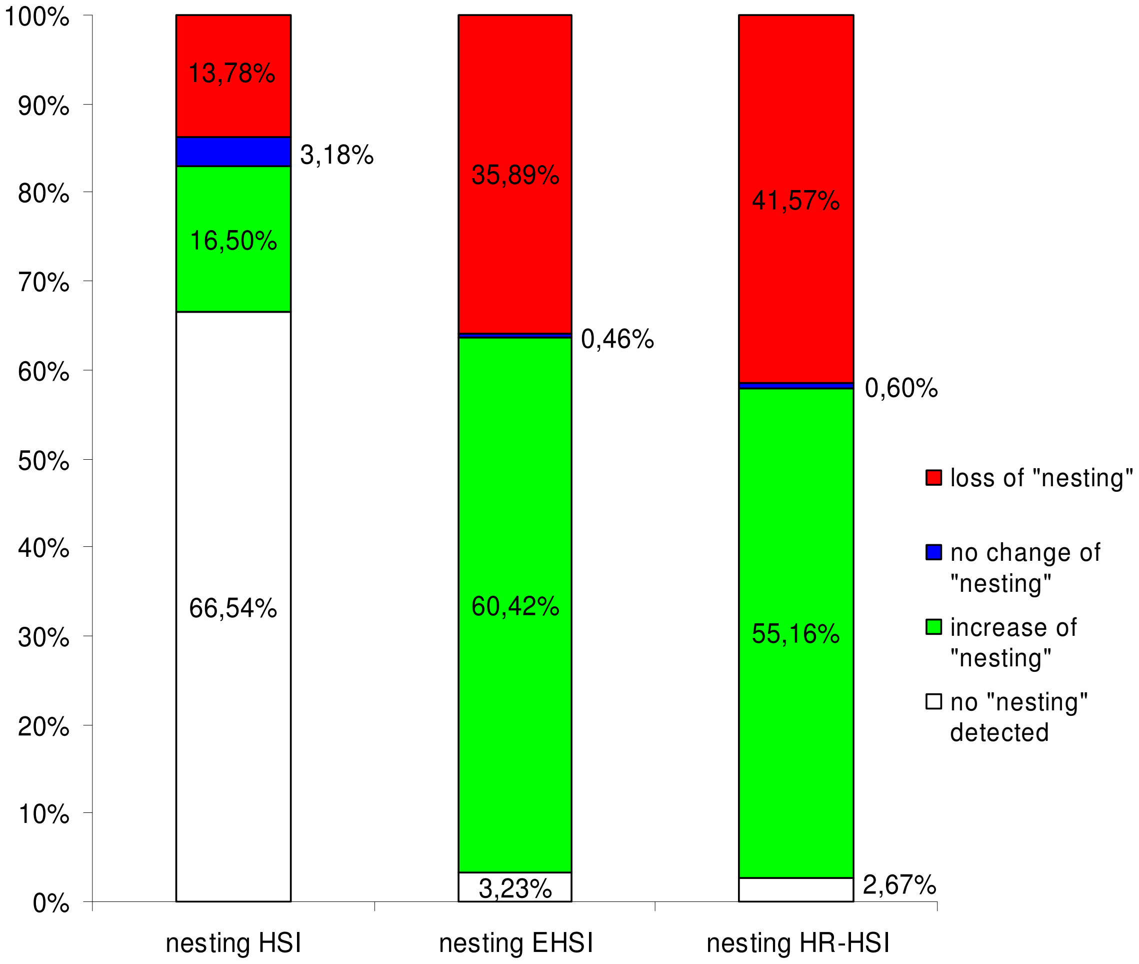


Figure 55 Effects of the HSI models on the suitability of the life requisite "nesting" [% of the test site area]

"Nesting" consists of "open forest" (**Forest$_{open}$**) and "timber volume" (**Vol**). The high proportion of no suitability within the original HSI is explained by the two pixel-wise distributed attributes. The remarkable decrease of no detected suitability within the two models EHSI and HR-HSI is caused by the fact that the small suitable attribute patches have relative long edges in relation to their patch area. "Nesting" increases in terms of its relative suitability from the HSI with 2,72%, to the EHSI with 24,52% (Annex table 7 and Annex table 8, p.199). According to the results of the HR-HSI the increase is 13,58% of the test site area (Annex table 9, p.200). Thus the pixel wise distribution of the attributes "open forest" (**Forest$_{open}$**) and "timber volume" (**Vol**) caused less suitability compared with the results of the HSI and EHSI models. After the home range approach with 400 metre around each central pixel, the distribution was too wide to calculate high suitability values for each attribute.

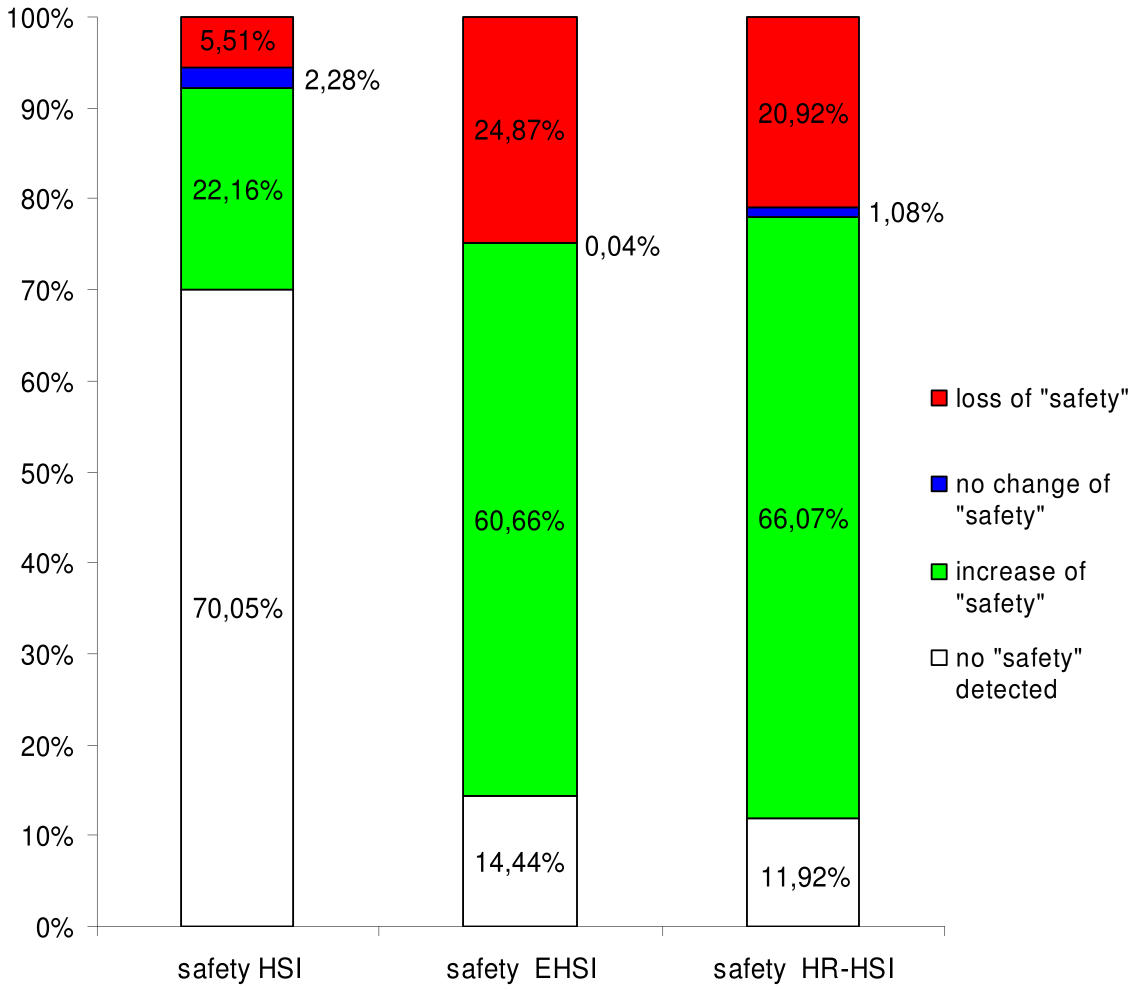


Figure 56 Effects of the HSI models on the suitability of the life requisite "safety" [% of the test site area]

The life requisite "safety" includes the attributes "broadleaved trees" (**Comp$_{tree}$**) and "tree height" (**Height$_{tree}$**). The two pixel-wise distributed attributes caused the high proportion of pixels assigned to the class “no safety detected” in the HSI. The application of the EHSI and the HR-HSI results in a suitability gain for areas with an increase of the life requisite “safety”. In more than 60% of the area an increase of the life requisite suitability could be observed between the two occasions, while only 22% of the area was detected as an increase of life requisite suitability applying the original HSI. Comparing the three HSI model approaches the relative suitability of “safety” increased from 16,65% in the HSI to 35,79% in the EHSI and to 45,15% of the test site area in the HR-HSI (Annex table 10-12, p.201). The reason for this can be found on the distribution of the attribute as well. Here “broadleaved trees” ($\mathbf{Comp_{tree}}$) and “tree height” ($\mathbf{Height_{tree}}$) are more concentrated and this results in a higher suitability even after the application of the home range approach.

The HSI, EHSI and the HR-HSI were applied on the same data with identical weights of the attributes and the life requisites to show the effects of the different methods of the models on attribute, life requisite and on HSI model level. Since the applied methods of the models HSI, EHSI and the HR-HSI are different; the results of the models are also different in an expected way (Figure 48). For instance the application of fuzzy sets within the EHSI caused more suitability on all levels of consideration. Similar changes could be detected with HSI as well as with fuzzy sets of the EHSI and with home range aspects of the HR-HSI.

7.3 EFFECTS OF THE MULTIPLICATIVE AND THE ADDITIVE RECOMBINATION OF LIFE REQUISITES ON HABITAT SUITABILITY

Since the application of the HSI models result in various suitability on attribute and life requisite level, the different habitat suitability gain and losses according to the combination of life requisites is discussed in this section. The potential habitat suitability changed according to the application of the HSI, the EHSI and the HR-HSI. The effect of the different combination of life requisites for the HSI and the HSI+ model is shown in Figure 57.

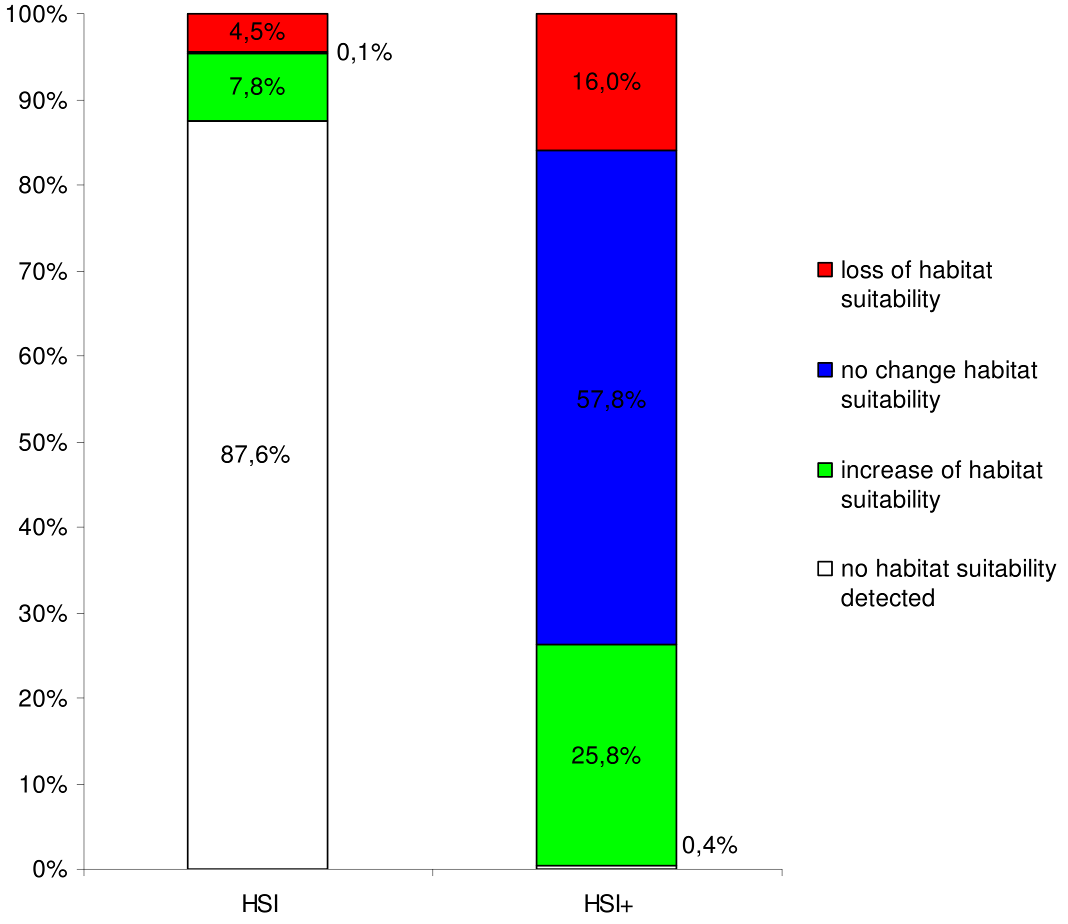


Figure 57 Effects of the different life requisite combination on habitat suitability according to the HSI [% of the test site area]

The Figure 57 illustrates that the areas of unchanged habitat suitability increased from nearly 0% (according to the HSI), to more than half of the test site area (according to the HSI+). The areas assigned to a decreased and an increased of habitat suitability increased after the application of the HSI+. Since all attributes are reflected in the HSI+ model results the area where no habitat suitability was detected decreased from close to 90% to less than 1% of the test site area. Similar effects can be found for the HR-HSI. Different results can be found after the application of the EHSI and the EHSI+ models, and these are illustrated in Figure 58.

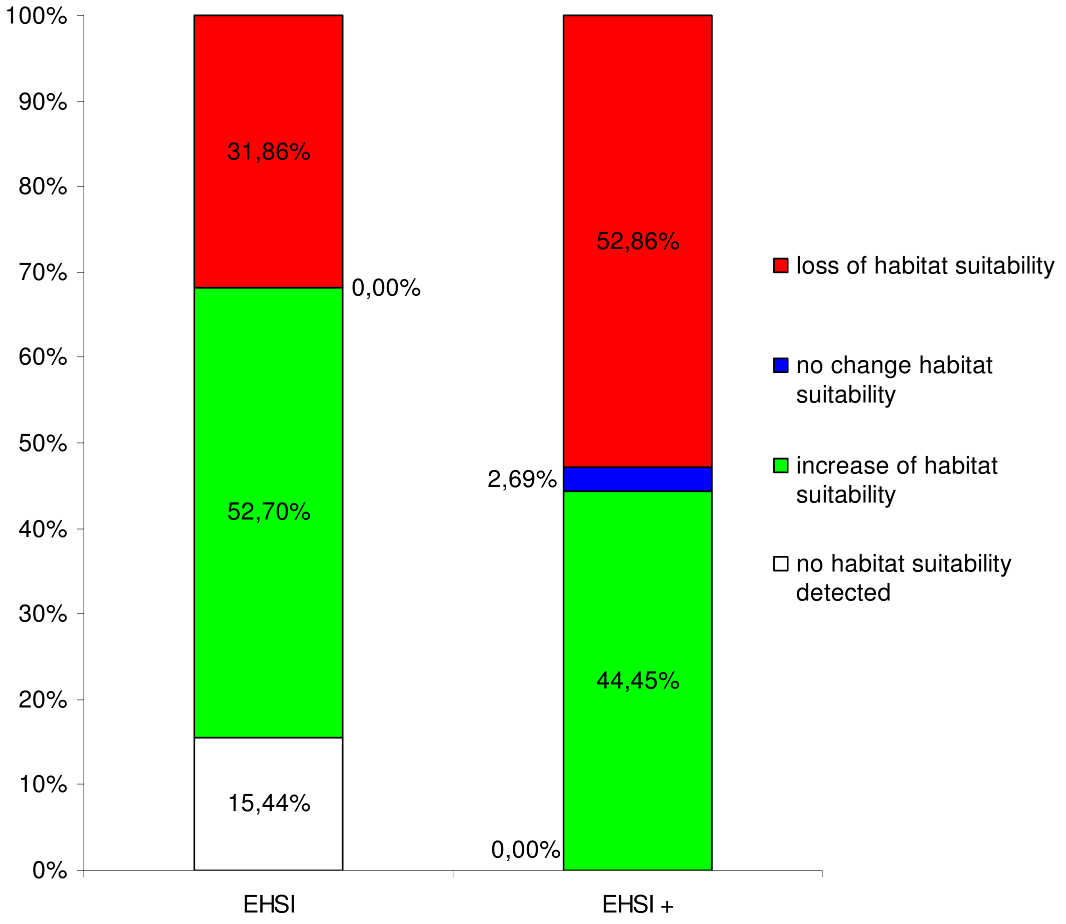


Figure 58 Effects of the different life requisite combination on habitat suitability according to the EHSI [% of the test site area]

Figure 58 shows that the areas of habitat suitability loss increased after the application of the EHSI+, while the area with an increase of habitat suitability decreased. The relative change of suitable area decreased applying the EHSI+ model.

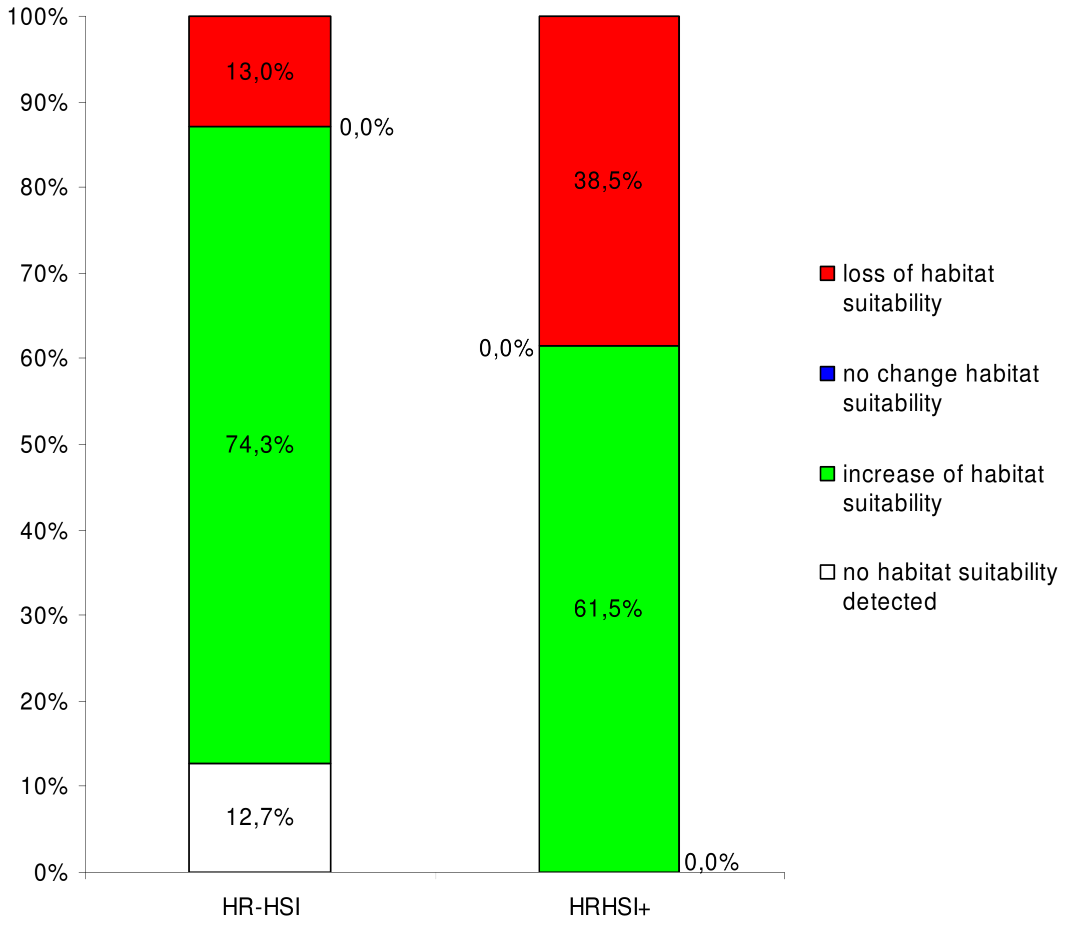


Figure 59 Effects of the different life requisite combination on habitat suitability according to the HR-HSI [% of the test site area]

Figure 59 shows that areas with habitat suitability loss increased after the application of the HR-HSI+, while areas with an increase of habitat suitability decreased. The relative change of suitable area decreased applying the HR-HSI+ model. The effects of the application of the HR-HSI are similar to those of the EHSI. An overview of the relative change of all six HSI models applied is given in Figure 60.

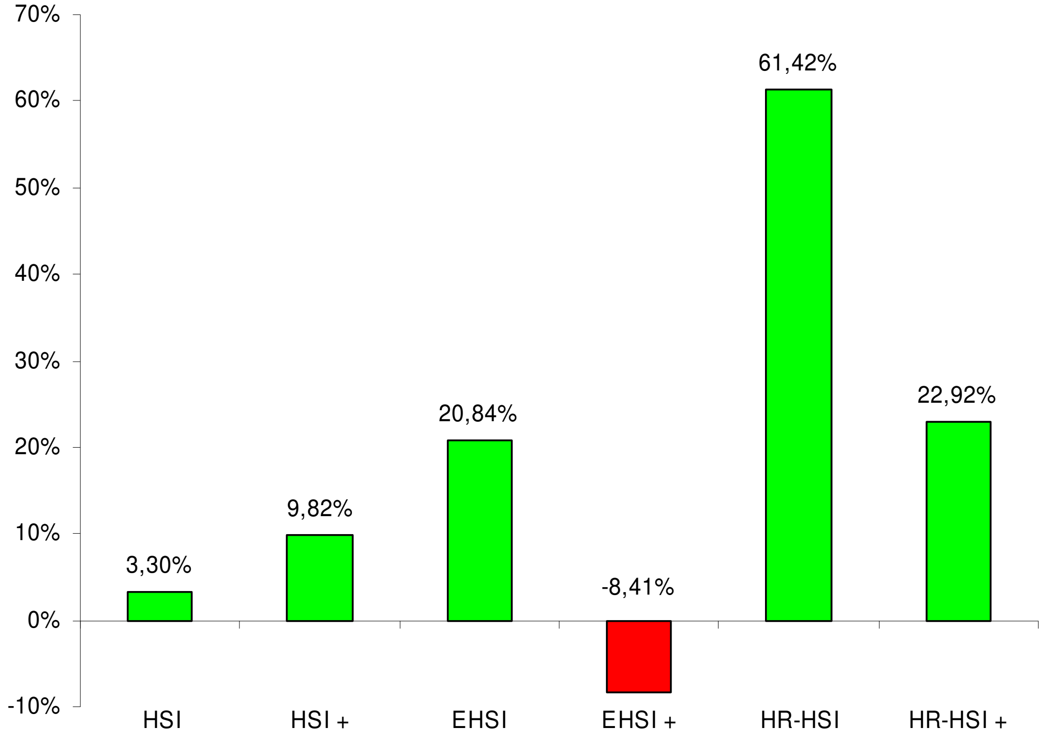


Figure 60 Relative change of suitable area from 1989 to 2000 according to all habitat suitability models applied [% of test site area]

Figure 60 illustrates that the relative change of suitable area of the EHSI+ and the HR-HSI+ is smaller compared to the results of the EHSI and the HR-HSI. The EHSI+ even indicates a decrease of habitat suitability of more than 8% of the test site area. The HSI+ with additive recombination of life requisites indicates an increase of habitat suitability compared with the HSI with multiplicative life requisite combination, but the EHSI+ and the HR-HSI+ indicate less habitat suitability compared with the results of the EHSI and HR-HSI models with multiplicative combination. The suitability increase within the HSI+ can be explained by the presence of all binary attribute maps in the model results compared with the HSI result maps where only coinciding attributes are reflected. The decrease of suitability of the EHSI+ and the HR-HSI+ is caused by the large areas with suitable and suitable habitat reflected in both model results as well as in the results of the retrospective change analysis. Here large patches with pixel values indicating habitat suitability at one occasion were subtracted by large patches with pixel values indicating unsuitable habitat of the other occasion. Therefore the relative change of suitable areas is smaller in the EHSI+ and the HR-HSI+ models.

The HSI+, EHSI+ and HR-HSI+ with additive recombination of life requisites detect more habitat suitability changes than the HSI models with multiplicative combination of life requisites (HSI, EHSI, HR-HSI). Since all attributes are reflected in the entire HSI model results with additive recombination the approaches proved to be more sensitive to change detection than the HSI models applying a multiplicative combination of life requisites. The loss of habitat suitability in the centre of the test site was detected by all tested HSI models, the dried lake in the northern part of Moritzburg was detected after the life requisites were additively recombined.

7.4 DISCUSSION OF THE TESTED MODELS FOR FUTURE APPLICATIONS

The detected habitat suitability according to the different models such as the HSI, EHSI, HR-HSI, the HSI+, EHSI+ and the HR-HSI+ depend on the attribute and life requisite weights chosen. Since the weights are identically applied for each HSI model, a direct comparison is possible. Habitat suitability might vary, if the weights are chosen differently. Since the habitat requirements of the Red Kite were summarised and assumed to be reflected through the chosen attributes and their, quantitative information of ecological case studies still have to be adapted to develop the HSI models to operational tools. Thus the models need to be modified in terms of attribute and life requisite and in terms of their weights if more objective expert knowledge of ecologists will be available in future. Additionally the test site around Moritzburg with its heterogeneous landscape elements has influence on the HSI model results. Therefore the HSI models need to be tested for other areas as well. Additionally the key species of interest might be conformed to the individual natural conditions of a particular area. In that case different habitat requirements in terms of attributes and life requisites depending on the area might be considered for future modelling purposes. These aspects lead to the question of whether the HSI models can be implemented for different species or umbrella species or for different test sites at all. In these terms it is not clear whether the tested HSI models can be developed to an operational level, because even the tested models of the study are part of a case study.

The application of the HSI models only on individual key species level is open. Basically the change of a species specific habitat might have completely different consequences for other species. Clearly adapting HSI models for many species would require a lot of effort. Therefore it might be appropriate to test an adapted HSI model for selected umbrella species in order to reduce effort.

The habitat changes were detected by the HSI models based on the available information, such as Landsat 7 and Landsat 5. Whether the detected changes would actually cause habitat changes, or even threatening situations, for the key species still has to be investigated. Therefore the scale of the HSI model applied in this study might need to be changed. This also depends on the key species of future interest. If the species requirements might be detectable on a different scale the HSI model have to be modified. Various other remote sensing data sources are available to achieve high resolution information for different needs. New LIDAR sensors can directly measure vegetation height, and can penetrate the vegetation canopy (MALTANO ET AL. 2006). RADAR sensors are tested for biomass estimates (BERGEN AND DOBSEN 1999). The mentioned RS data sources with a much higher resolution can be used as ancillary data for a HSI model, depending on scale.

In the applied HSI models, only the potentials of habitat suitability have been tested. There are other comparable models that are frequently applied in ecology e.g. the potential natural vegetation (ELLENBERG, 1988).

The HSI models might be applied on different scales, depending species, and area of interest after necessary tests. The HSI models could be applied at various spatial scales from local scales to regional, national or multinational scales. As the HSI models are open to further inputs they can also reproduce local or landscape management purposes in different formats as digital spatial information. Therefore it is possible to consult local policy decision makers in an objective way (WALZ, 1999). The HSI model approach can also help to establish new protection areas. Further implementation of three-dimensional indices (HOECHSTETTER ET AL. 2006) is possible. The indices might improve habitat modelling and allow an improved reflectance of e.g. specific topographical requirements.

8 CONCLUSIONS

The study describes the potential of various habitat suitability indices (HSI) using remotely sensed data (Landsat 5 and 7) and other mapped information in digital format for the characterization and monitoring of rare species habitats at the landscape level over time. The main focus was to develop a flexible and open system for habitat monitoring which allows a pragmatic overview of habitat development of a rare or umbrella species without, or very limited field assessments. Habitat suitability is derived by a modelling approach that integrates objective information of natural conditions. Areas of habitat loss and habitat gain can be identified by modelling habitat suitability for different occasions. In addition the HSI model can be used to predict the effect of human induced changes of the environment and on habitat suitability.

The approach concentrates on potential attributes of two example habitats for the key species Red Kite *(Milvus milvus)* and Black Stork *(Ciconia nigra)*. The potential HSI models are analysed with regard to their sensitivity towards changing environmental conditions and towards the influences of individual attributes used as input for the studied HSI models. To test the HSI models, a heterogeneous landscape with a combination of different landscape elements (such as lakes, meadows, agricultural land, or forested areas) was needed. Therefore the landscape around the village Moritzburg, located close to the city of Dresden, Germany was selected as the test site. It is characterised by a pronounced heterogeneity of landscape elements such as forests, meadows and lakes.

The remote sensing data for the year 2000 were matched with in situ data. In addition, the database “Datenspeicher Wald” provided forest information for the year 1989 based on the forest inventories on company level. Attributes, based on Natura 2000, such as food supply or nesting resources, were utilised as input for HSI models. The in situ data were combined with satellite data using a spatial statistic called kNN method for extending in situ attributes to the entire area of interest. Habitat suitability maps for both occasions (1989 and 2000) were compared for the individual key species.

The described data and methods underlay the six HSI models tested in this study:

1. The **Habitat Suitability Index (HSI)** with binary attribute maps
2. The **Enhanced Habitat Suitability Index (EHSI)** applying binary attribute maps enhanced with fuzzy sets
3. The **Habitat Suitability Index with Home Rage Aspect (HR-HSI)** applying recalculated attribute maps with an activity radius of 200 m for each pixel.

Each of these HSI models includes two levels of consideration: the attribute level and the life requisite level. For all three HSI models a number of weighted attributes are identically added to one of three life requisites. Within the final habitat modelling procedure, the combination of life requisites was realised with two different approaches for each HSI model:

- The multiplicative approach with multiplicative combination of life requisites resulted in the models HSI, the EHSI and HR-HSI and
- The summation approach with additive recombination of life requisites resulted in the models HSI+, EHSI+ and the HR-HSI+

The suitability of the life requisite “safety” for Black Stork could not be detected in the test site. Because of the tourism in the Moritzburg area a high density of roads and hiking paths avoids the safety requirements reflected by the attributes “infrastructure distance of minimum 3 km” and “no recreation facilities”. The area is also too densely populated and there were not any areas with a “resident population of less than 100 inhabitants/km². Therefore, all other HSI model variations were compared with the original HSI model for Red Kite. The HSI resulted in less habitat suitability compared with the results of the EHSI applying fuzzy sets and the HR-HSI with home range aspects. HSI models with an additive recombination of life requisites (HSI+, EHSI+ and HR-HSI+) detected additional habitat losses similarly, because of the reflection of all attributes in the final model results. Therefore the approach with additive recombination of life requisites was considered to be the best HSI model approach because of its sensitivity to detect more potential habitat changes, than the approach with multiplicative combination of life requisites. A multiplicative combination – e.g. of attributes – could be a useful way to realise special quality requirements such as water quality and water depth in one attribute map.

While all HSI models are able to detect habitat changes and to predict future habitat development, the EHSI proved to be efficient to enhance purely binary data into discrete transition probabilities from suitable pixel to unsuitable pixel. The HR-HSI proved to be operational to describe neighbourhood relations of habitat attributes. It offers a graduation of habitat suitability with continuous transition probabilities. In addition to simulating changing individual attributes, the graduation of the habitat values and the definition of thresholds (even on life requisite level) can support decisions of landscape management and policies.

The study concentrated on the principal possibilities of habitat suitability models with objective data sources on the landscape level. The main obstacle to a successive implementation of the HSI models is a comprehensive description of factors driving habitat suitability; these have hardly been presented in quantitative terms. The habitat requirements of the Red Kite were summarised and assumed to be reflected through the chosen attributes and their weights. Quantitative information of ecological case studies still have to be adapted to develop the HSI models to an operational level. The applied habitat models for Red Kite are tested with the available data for one selected test site; the results of the models themselves have the character of a case study. Therefore the results should not be generalised too far. An interdisciplinary knowledge transfer is recommended to realise the transition to an operational level implementing quantitative information of species specific requirements for habitat suitability modelling. Accordingly the results of the habitat models need to be verified with real habitat occupation data for different test sites. Quantitative habitat information has only been collected for relatively few species – e.g. by HOFFMANN (2000) for species like red deer (*Cervus elaphus*). Quantitative definitions of habitat requirements are still needed for a lot of other key species.

Even though the applied HSI models cannot be generalised, the approaches show that changing land use influences the potential habitats of the studied species. Therefore the principal applicability of the tested approaches is verified for the effects of changing landscapes on habitat suitability.

The focus of the study was to investigate the detection of potential habitat changes, the sensitivity, and the role of the selected attributes, and their combinations and weights. In order to apply the HSI models at an operational level, the species specific definitions of real habitat values for species like the Red Kite or others still have to be investigated. Since most of the ecological investigations only concentrated on local species specific conditions for a single species of interest, the results cannot be applied more generally to supply quantitative and objective analysis of habitat suitability with the applied HSI models. Ecologists have to define more common habitat requirements for threatened species to improve an efficient and objective observation, monitoring and conservation of rare species habitats within landscapes influenced by human activities.

9 REFERENCES

ALBERTZ J. 1991 Grundlagen der Interpretation von Luft- und Satellitenbildern: Eine Einführung in die Fernerkundung. Wissenschaftliche Buchgesellschaft Darmstadt. S. 93-153.

ALLDREDGE J.R. RATTI J.T. 1992 Further comparison of some statistical techniques for analysis of resource selection. Journal of Wildlife Management. 56 (1). p.1-9.

ANDERSON T.W. WALKER A.M. 1964 On the asymptotic distribution of the autocorrelations of the sample from a linear stochastic process. Annals of. Statistics 35. p.1296-1303.

ANDERSSON F.A. FEGER K.H. HÜTTL R.F. KRÄUCHI N. MATTSSON L. SALLNÄS O. SJÖBERG K. 2000 Forest ecosystem research – priorities for Europe. Forest Ecology and Management. 132. p.111-119.

ARONOFF S. 1989 Geographic Information Systems: A Management Perspective. WDL Publications. Ottawa. Canada.

BAILLON F. BENVENUTI S. IOALE P. 1992 Fidelity to nonbreeding site in some species of birds in Senegal. Tropical Zoology. 5. p.31-43.

BAKER WL. 1999 Spatial simulation of the effects of human and natural disturbance (model und simulating!) regimes on landscape structure. In: MLADENOFF D.J. BAKER W.L. (EDS.) 1999 Spatial Modeling of Forest Landscape Change – Approaches and Applications. Cambridge University Press. 352p.

BERGEN K.M. DOBSON M.C. 1999 Integration of remotely sensed radar imagery in modelling and mapping of forest biomass and net primary production. Ecological Modelling 122 (3). p.257-274.

BIRDGUIDES 1999A The Red Kite http://www.birdguides.com/html/vidlib/species/Milvus_milvus.htm

BIRDGUIDES 1999B The Black Stork http://www.birdguides.com/html/vidlib/species/Ciconia_nigra.htm

BISBY F.A. CODDINGTON J. THROPE J.P. SMARTT J. HENGEVELD R. EDWARDS P.J. DUFFIELD S.J. 1995 Characterization of biodiversity. In: HEYWOOD V.H. WATSON R.T. BASTE I. 1995 Global biodiversity assessment. Cambridge Cambridge University Press. p.21-106.

BISCHOFF C. DRÖSCHMEISTER R. (EDS.) 2000 European Monitoring for Nature

Conservation. Schriftenreihe Landschaftspflege Naturschutz 62. 199p.

BITTERLICH W. 1948 Die Winkelzählprobe. Allgemeine Forst - und Holzwirtschaftliche Zeitung 59. p.4-5.

BLACKBURN G.A. MILTON E.J. 1996 Filling the gabs: remote sensing meets woodland ecology. Global Ecology and Biogeography Letters. 5. p.175-191.

BLASCHKE T. 1997 Landschaftsanalyse und -bewertung mit GIS. Methodische Untersuchungen zu Ökosystemforschung und Naturschutz am Beispiel der bayrischen Salzachauen. Forschungen zur Deutschen Landeskunde 243. 320 S. Trier.

BLASCHKE T. 1999 Umweltmonitoring und Umweltmodellierung: GIS und Fernerkundung als Werkzeuge einer nachhaltigen Entwicklung. Heidelberg. Wichmann Verlag.

BLOCK W.M. BRENNAN L.A. 1993 The habitat concept in ornithology: Theory and Applications. Current Ornithology. 11.

BLOTZHEIM VON G.U. BAUER K. 1966 Handbuch der Vögel Mitteleuropas. Band 1. Gaviiformes-Phoenicopteriformes. Akademische Verlagsgesellschaft Frankfurt am Main.

BODMER H.C. 1993 Untersuchung zur forstlichen Bestandeskartierung mit Hilfe von Satellitenbildern. Dissertation. Professur für Forsteinrichtung und Waldwachstum. ETH-Zürich.

BOOLE G. 1854 An Investigation of the Laws of Thought, on which are founded the Mathematical Theories of Logic and Probability. 1854. Reprint. New York: Dover 1958. ISBN 0-486-60028-9.

BOWDEN D.C. DIXON G.E. FRAYER W.E. GRAYBILL F.A. JEYARATNAM S. JOHNSTON D.C. KENT B.M. LABAU V.J. ROBERTS E. 1979 Multi-level sampling designs for resource inventories. Dept. of Forest and Wood Sciences. Colorado State University. Rocky Mountain Forest and Range Exp. Station. USDA Forest Service. Ft. Collins. CO.

BURROUGH P.A. 1986 Principles of Geographic Information Systems for Lands Resources Assessment. Oxford. 196p.

BURROUGH P.A. MCDONNELL R.A. 1998 Principles of geographical information systems. Oxford University Press. New York.

CLEMENTS F.C. 1905 Research Methods in Ecology. University Publishing Company. Lincoln. Nebraska.

COLBY J.D. 1991 Topographic Normalization in Rugged Terrain. Photogrammetrc Engineering & Remote Sensing. 57 (5). p.531-537.

CORINE 2000 Landcover Classes http://terrestrial.eionet.eu.int/CLC2000/classes

CRAMP S. 1977 Handbook of the Birds of Europe the Middle East and North Africa.

Vol. 1. Ostrich to Ducks. Oxford University Press. Oxford New York.

CROW T.R. HANEY A. WALLER D.M. 1994 Report on the scientific roundtable on biological diversity convened by the Chequamegon and Nicolet National Forests. St. Paul MN. General Technical Report NC - 166 USDA Forest Service North Central Forest Experiment Station.

DALE V.H. 1998 Management of forests as ecosystems: a success story or a challenge ahead? In: PACE M.L. GRAFFMAN (EDS.) Success, Limitations, and Frontiers in Ecosystem Science. Springer-Verlag. New York. p.50-68.

DASMANN R.F. 1964 Wildlife Biology. Wiley. New York.

DELONG D.C. 1996 Defining Biodiversity. Wildlife Society Bulletin. 24. p.738-749.

DEPARTMENT OF THE PRESERVATION OF NATURE OF THE MINISTRY OF THE WALLOON REGION 1995 The Black Stork. http://www.explorado.org/solon-new/intro/introen/id.htm

DEWULF R.R. GOOSENS R.E. MACKINNON J.R. CAY W.S. 1988 Remote sensing for wildlife management: Giant Panda habitat mapping from LANDSAT images. Geocano International 1. p.41-50.

DICASTRI F. HANSEN A. HOLLAND M.M. 1988 A new look at ecotones: emerging international projects on landscape boundaries. Biology International. Special Issue 17.

DRÖSCHMEISTER R. BOYE P. 1997 Vogelwelt Vogelschutz und Vogelmonitoring in Deutschland. Eine Rezension mit weiterführenden Gedanken. Natur und Landschaft 72 (5). p.257-258.

DUNNING J.B. DANIELSON B.J. PULLIAM H.R. 1992 Ecological processes that affect populations in complex landscapes. Oikos 65. p.169-175.

DUNSTER K. DUNSTER J. 1996 Dictionary of natural resource management. Vancouver UBC Press. 363p.

EC 1972 Council Directive 79/409/EEC of 2 April 1979 on the Conservation of Wild Birds. http://europa.eu.int/comm/environment/nature/directive/birdshome_en.htm

EC 1992 Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. http://www.ecnc.nl/doc/europe/legislat/habidire.html

EC 1997 Study of European Forest Information and Communication System. Reports on forestry inventory and survey systems. Vol. 1-2. Office for Official Publications of the European Communities.

EC 1998 First report on the implementation of the convention on biological diversity by the European Community. European Commission. 82p.

ELLENBERG H. 1988 Vegetation ecology of Central Europe. Fourth edition. Cambridge University Press. Cambridge.

ENVIROMENTAL REMOTE SENSING CENTER 2006 http://www.ersc.wisc.edu/resources.php

ERDAS. 1997 Field Guide Manual. Atlanta. Georgia: ERDAS Inc.

ESRI http://www.esri.com/index.html

FLADE M. 1992 (ed.) Zur Situation des Brutvogelmonitorings in Deutschland. Vogelwelt. 113. p.154-157.

FORMAN R.T.T. GODRON M. 1986 Landscape ecology. John Wiley & Sons. New York. Chichester. 619p.

FRANKLIN S.E. 2001 Remote Sensing for Sustainable Forest Management. Lewis Publishers. CRC Press LLC. 424p.

FREEMARK K.E. DUNNING J.B. HEJL S.J. PROBST J.R. 1995 A landscape ecology perspective for research, conservation, and management. In: MARTIN T.E. FINCH D.M. (EDS.) Ecology and Management of Neotropical Migratory Birds. Oxford University. New York. p.145-197.

FRITZ R. 1999 Digitale Forstkartenerstellung und Feldgrenzendelinierung mit Hilfe hochauflösender Satellitensysteme. Dissertation. Abteilung Fernerkundung und Landschaftsinformationssysteme. Forstwissenschaftliche Fakultät. Universität Freiburg. 138p.

GADOW VON K. 1978 Apeelet count of blue duiker and bushbuck in the Knysna forests. Southern African Forestry Journal. 107. p.77-81.

GARDNER R.H. TURNER M. 1991 Quantitative Methods in Landscape Ecology. Springer Verlag. Ecological Studies. 82. p.77-103 (536p.) New York.

GEHLE T. HERZOG S. 1998 Genetic inventories of European deer populations (Cervus sp.): Consequences for wildlife management and land use. Gibier Faune Sauvage - Game and Wildlife 15. p.445-450.

GOSSOW H. 2003 Wildökologie. Reprint Verlag Dr. Kessel. ISBN 3-935638-03-5.

GRAY P.A. CAMERON D. KIRKHAM I. 1996 Wildlife habitat evaluation in forested ecosystems: some examples from Canada and the United States. IN: DEGRAAF R.M. MILLER R.I. Conservation of Faunal Diversity in Forested Landscapes. Springer. Conservation Biology. 648p.

GRIME J.P. 1998. Benefits of plant diversity to ecosystems: immediate, filter and founder effects. Journal of Ecology. 86. p.902-910.

GRINNELL J. 1917 The niche-relations of the California Thrasher. Auk 34. p.427-433.

GUISAN A. ZIMMERMANN N.E. 2000 Predictive habitat distribution models in ecology. Ecological Modelling. 135. p.147-186.

HALL S.L. KRAUSMANN P.R. MORRISON M.L. 1997 The Habitat Concept and a Plea for Standard Terminology. Wildlife Society Bulletin. 25 (1). p.173-182.

HANSSON L. 1997 Boreal ecosystems and landscapes: Processes and conservation of biodiversity. Ecological Bulletins. 46. 203p.

HÄUSLER T. AKGÖZ E. EKSTRAND S. GALLAUN H. LAGARDE I. LÖFMARK M. SCHARDT M. PELZ D.R. OBERGFÖLL P. 1999 Monitoring changes and indicators for structural diversity of forested areas. Proceeding of International Remote Sensing Conference 1999. Rogov. Poland.

HÄUSSLER T. KÖHL M. LAUTNER M. SCHEUBER M. STÜMER W. ZIESE H. 2000 Teilvorhaben HEZEW. In: ProSmart Endbericht. Daimler Chrysler Aerospace. Dornier Satellitensysteme. Friedrichshafen: 9/1 – 9/119.

HILDEBRANDT G. 1996 Fernerkundung und Luftbildmessung. Wichmann Verlag. Heidelberg.

HILLE S. 1995 Nahrungswahl und Jagdstrategien des Rotmilans (Milvus milvus) im Biosphärenreservat Rhön/Hessen. Vogel und Umwelt. 8. p.99-126.

HILTY S. 1994 Birds of Tropical America. Chapters. Shelburne. VT.

HODGSON M.E. SHELLY B.M. 1993 Removing the Topographical effect in Remotely sensed Imagery. ERDAS Monitor. Atlanta. Georgia: ERDAS Inc.

HOECHSTETTER S. THINH N.X. WALZ U. 2006 3D-Indices for the Analysis of Spatial Patterns of Lands cape Structure. In: KREMERS, H.; TIKUNOV, V. (EDS.) 2006 InterCarto-InterGIS 12. International Conference on Geoinformation for Sustainable Development. Berlin. Germany. August 28-30. 2006. Proceedings. Berlin : Deutsche Gesellschaft für Kartographie. p.108-118.

HOFFMANN H. 2000 Die Verbreitung des Rotwildes (Cervus elaphus L.) im Freistaat Sachsen - Erarbeitung eines Lebensraummodells. Diplomarbeit, Fakultät für Forst-, Geo- und Hydrowissenschaften der Technischen Universität Dresden. 117 S.

HOOPER D. VITOUSEK P.M. 1997 The effects of plant composition and diversity on ecosystem processes. Science 277. p.1302-1305.

HORNE, VAN B. 1983 Density as a misleading indicator of habitat quality. Journal of Wildlife Management. 47. p.893-901.

HUGERSHOFF VON R. 1917 Kartographische Aufnahmen und geographische Ortsbestimmung auf Reisen. Göschen Verlag. Berlin. 178p.

HUMBOLDT VON A. BONPLAND A. 1807 Essai sur la géographie des plantes. Paris.

HUNSAKER C.T. O´NEILL R.V. JACKSON B.L. TIMMINS S.P. LEVINE D.A. NORTON D.J. 1994 Sampling to characterize landscape patterns. Landscape Ecology. 9 (3). p.207-226.

HURLBERT S.H. 1971 The non concept of species diversity: a critique and alternative parameters. Ecology 52. p.577-586.

HUTCHINSON G.E. 1957 Concluding remarks. Cold Spring Harbor Symposia on

Quantitative Biology 22. p.415-427.

HUTTO R.L. 1985 Habitat selection by nonbreeding migratory land birds. pp 455-476 in CODY M.L. (ED.)1985 Habitat Selection in birds. Academic press. Orlando. USA.

IGBOKWE I.J. 1994 Multitemporale Satellitenbild-Auswertung zur Erfassung von Landbedeckungs- und Landnutzungsänderungen in der Sahelzone in Westafrika. Diss. Universität Hannover. Fachbereich Bauingenieur- und Vermessungswesen. 159 S.

INNES J.L. KOCH B. 1998 Forest biodiversity and its assessment by remote sensing. Global Ecology and Biogeography Letters. 7. p.397-419.

JÄKEL A. ROTH M. 2004 Conversion of single-layered Scots pine monocultures into close-to-nature mixed hardwood forests: effects on parasitoid wasps as pest antagonists. European Journal of Forest Research. 123. p.203-212.

JANS M. LORGÉ P. WEISSJ. 2000 Der Schwarzstorch Ciconia nigra in Luxemburg. Regulus Wissenschaftliche Berichte. 18. S.15-30.

JANSSEN G. HORMANN M. ROHDE C. 2004 Der Schwarzstorch - Ciconia nigra. Die Neue Brehm-Bücherei Bd. 468. 1. Aufl. 414. ISBN: 3-89432-219-5.

JOHNSON D.H. 1980 The comparison of usage and availability measurements for evaluating resource preference. Ecology. 6 (1). p.65-71.

JOHNSTON C.A. BONDE J. 1989 Quantitative analysis of ecotones using a geographic information system. Photogrammetric Engineering and Remote Sensing. 11. p.1643-1647.

JONES P.F. HUDSON R.J. FARR D.R. 2002 Evaluation of a Winter Habitat Suitability Index Model for Elk in West-Central Alberta. Forest Science. 48 (2). p.417-425.

JONGMAN R.H.G. 2000 Biodiversity versus landscape diversity in multifunctional landscapes. Brandt J. Tress B. Tress G. workshop.3. p.72-83.

KAENNEL M. 1998 Biodiversity: A Diversity in Definition. In: BACHMANN P. KÖHL M. PÄIVINEN R. (EDS.) Assessment of Biodiversity for an Improved Forest Planning Monte Verità. Switzerland. European Forest Institute. Proceedings no.18. Kluwer Academic Publishers. p.71-81.

KANDEL A. 1986 Fuzzy mathematical techniques with applications. Addison Welsey. Reading. Mass.

KAUFMAN A. 1975 Introduction to the Theory of Fuzzy Subsets. Academic Press New York.

KENNEWEG H. SCHARDT M. SAGISCHEWSKI H. 1996 Beobachtungen von Waldschäden im Gesamtharz mit Methoden der Fernerkundung. Berlin. im Selbstverlag. 229p.

KIEFER J. 1998 Brutbiologische Notizen zum Rotmilan (Milvus milvus) und Schwarzmilan (Milvus migrans) in Ost-Luxemburg. REGULUS

Wissenschaftliche Berichte. (ISSN 1727-088X). 17. S. 32-37.

KILKKI P. PÄIVINEN R. 1987 Reference Sample Plots to Combine Field Measurements and Satellite Data in Forest Inventories. University of Helsinki. Department of Forest Mensuration and Management. Research Notes 19. p.209-215.

KLISKEY A.D. LOFROTH E.C. THOMPSON W.A. BROWN S. SCHREIER H. 1999 Simulating and evaluating alternative resource-use strategies using GIS-based habitat suitability indices. Landscape and urban planning 45. p.163-175.

KLOPFER P.H. 1963 Behavioural aspects of habitat selection: The role of early experience. Wilson Bull. 75. p.15-22.

KÖHL M. 1990 Stichprobenkonzepte für das zweite Schweizer Landesforstinventar. Schweizerische Zeitschrift des Forstwesens. 141. p.745-755.

KÖHL M. 2003 New approaches for multi-resource forest inventories. In: CORONA P. KÖHL M. MARCHETTI M. (EDS.) Advances in Assessments for Sustainable Forest Management and Biodiversity Monitoring. Kluwer Academie Publishers

KÖHL M. OEHMICHEN K. 2003 Zur Verwendung von Landschaftsindizes bei Wald- und Landschaftsinventuren: Überblick und Kritik. Schweizerische Zeitschrift für Forstwesen. 154 (1). p.8-16.

KÖHL M. PÄIVINEN R. (EDS.) 1996 Definition of a system of nomenclature for mapping European forests and for compiling a pan European forest information system. FIRS Final Report.

KÖHL M. SCOTT C.T. ZINGG A. 1995 Evaluation of permanent sample surveys for growth and yield studies: A Swiss example. Forest Ecology and Management. 71. p.187-194.

KÖHL M. STÜMER W. SCHEUBER M. ZIESE H. 2001 Combining hyperspectral data and ground surveys for the assessment of non-wood goods and services of forests. In: BUCHROITHNER M.F. 2001 A Decade of Trans European RS Cooperation. Dresden. Proceedings of the 20th EARSeL Symposium Dresden. Germany. 14-16

KÖHL M. UND ZINGG A. 1996 Eignung von Diversitätsindizes bei Langzeituntersuchungn zur Biodiversität in Waldbeständen. Allgemeine Forst- und Jagdzeitung. 167 (4). p.76-85.

KRAUS K. SCHNEIDER W. 1988 Fernerkundung. Band 1. Physikalische Grundlagen und Aufnahmetechniken, Bonn.

KREBS C.J. 1978 Ecology: The Experimental Analysis of Distribution and Abundance. Harper & Rowe Publications. New York.

KRÜGER T. HERZOG S. 2000 Zur Entwicklung des Birkhuhnbestandes (Tetrao tetrix Linné) im sächsischen Erzgebirge von 1980 bis 2000. European Journal of Wildlife Research. 46. p.1-8.

LANDGREBE D.A. 1978 The quantitative approach: concept and rationale. In: SWAIN P.H. DAVID S.M. (EDS.) Remote Sensing: A Quantitative Approach. McGraw-

Hill. New York.

LARSSON T.B. SVENSSON L. ANGELSTAM P. BALENT G. BARBATI A. BIJLSMA R.J. BONCINA A. BRADSHAW R. BUCKING W. CIANCIO 0. CORONA P. DIACI J. DIAS S. ELLENBERG H. FERNENDES F.M. FERNANDEZ GONZALEZ F. FERRIS R FRANK G. MELLER P.F. GILLER P.S. GUSTAFSSON L. HALBRITTER K. HALL S. HANSSON L. INNES J. JACTEL H. KEANNEL DOBBERTIN M. KLEIN M. MARCHETTI M. MOHREN F. NIEMELA P. O'HALLORAN J. RAMETSTEINER E. REGO F. SCHEIDEGGER C. SCOTTI R. SJOBERG K. SPANOS I. SPANOS K. STANDOVAR T. TAMMENLS A. TRAKOLIS D. UUTTERA J. WALSH P.M. VANDEKERKHOVE K. WATT AD. & VEN DEN MEERSSCHAUT D. 2001 Biodiversity evaluation tools for European forests. A report from the FAIR project "Indicators for monitoring and evaluation of forest biodiversity in Europe" CT97-3575 within the EU Commission RTD Programme. p.154. & Appendices. Ecological Bulletins 50.

LE CREN E.D. 1965 A note on the history of mark-recapture population estimates. Journal of Animal Ecology. 34. p.453-454.

LEOPOLD A. 1933 Game Management. Schreiber. New York.

LIKENS G.E. 1998 Limitations to intelligent progress in ecosystem science. In: PACE M.L. GRAFFMAN (EDS.) Success, Limitations, and Frontiers in Ecosystem Science. Springer-Verlag. New York. p.247-271.

LINCOLN F.C. 1930 Calculating waterfowl abundances on the basis of banding returns. U.S. Department of Agriculture. Circular 118.

LÖFSTRAND R. FOLVING S. KENNEDY P. PUUMALAINEN J. COCH T. KENTER B. KÖHL M. LÄMÅS T. PETERSSON H. TUOMINEN S. VENCATASAWMY C. 2003 Habitat characterization and mapping for umbrella species – An integrated approach using satellite and field data. In: CORONA P. KÖHL M. MARCHETTI M. (EDS.) 2003 Advances in Forest Inventory for Sustainable Management and Biodiversity Monitoring. Forestry Sciences. 76. Kluwer Academic Publishers.

LOTZING K. 2000 Der Rotmilan (Milvus milvus) – Vogel des Jahres 2000. - halophila - Mittbl. FG Faun. u. Ökol. Staßfurt 40. 13.

LUDWIG S. 2003 Wasservogel-Datenbank „Moritzburger Teichgebiet“. In: KÖHL M. QUEDNAU H. D. 2002 Tagungsband der 14. Tagung der Sektion Forstliche Biometrie und Informatik der DVFFA in Tharandt. ISBN 961-6020-32-3.

LUTZE G. WIELAND R. SCHULTZ A. 1999 Habitatmodelle für Tiere und Pflanzen – Instrumente zur integrativen Abbildung und Analyse von Lebensraumansprüchen mit direktem Bezug zur Landschaftsstruktur und zur Landnutzung. In: BLASCHKE T. (ED.) 1999 Umweltmonitoring und Umweltmodellierung: GIS und Fernerkundung als Werkzeuge einer nachhaltigen Entwicklung. Heidelberg. Wichmann Verlag.

MACARTHUR R.H. MACARTHUR J.W. 1961 On bird species diversity. Ecology 42. p.594-598.

MACKINNON J. DE WULF R. 1994 Designing protected areas for giant pandas in China. In: MILLER R.I. (ED.) Mapping the Diversity of Nature. Chapman and Hall. London. p.127-142.

MAIDMENT D.R. 1995 GIS/Hydrologic Models of non-point source pollutants in the vadose zone. Proceeding Bouyoucos Conference. Riverside Canada.

MAKATSCH W. 1959 Die Vögel in Wald und Heide. Neumann Verlag. Radebeul 1959.

MALTAMO M. HYYPPÄ J. MALINEN J. 2006 A comparative study of the use of laser scanner data and field measurements in the prediction of crown height in boreal forests. Scandinavian Journal of Forest Research. 21. p.231-238.

MCARTHUR R.H. 1972 Geographical Ecology: Patterns in the Distribution of Species. Harper and Row. New York.

MCCORMICK N. FOLVING S. 1998 Monitoring European Forest Biodiversity at Regional Scales Using Satellite Remote Sensing. In: BACHMANN P. KÖHL M. PÄIVINEN R. (EDS.) 1998 Assessment of Biodiversity for Improved Forest Planning. p.283-289. European Forest Institute Proceedings. 18. Kluwer Academic Publishers.

MCGARIGAL K. AND MARKS B. 1994 FRACSTATS. Spatial pattern analysis program for quantifying landscape structure. Version 2.0. Corvallis. 67p.

MCMINN J.W. 1991 Biological diversity research: an analysis Southeast. For. Exp. Stn. U.S. Forest Service. Gen. Tech. Rep. SE 71. 7p.

MCNAMARA D. STEPHENS G.RAMSAY B. PRINS E. CSISZAR I. ELVIDGE C. HOBSON B. SCHMIDT C. 2002 Fire Detection and Monitoring Products at the National Oceanic and Atmospheric Administration. Photogrammetric Engineering & Remote Sensing. 68. (8). p.774-775.

MCPFE 1998 Sustainable Forest Management in Europe. Special Report on the Follow-up on the Implementation of Resolutions H1 and H2 of the Helsinki Ministerial Conference 1998. Follow-up reports on the Ministerial Conferences on the Protection of Forests in Europe. Volume II. Third Ministerial Conference on the Protection of Forests in Europe. Liaison Unit in Lisbon. 274p.

MILLENNIUM ECOSYSTEM ASSESSMENT 2005 Ecosystems and Human Wellbeing: Current States and Trends. Island Press.

MINNAERT J.L. SZEICZ G. 1961 The Reciprocity Principle in Lunar Photometry. Astrophysics Journal. 93. p.403-410.

MOORE I.D. TURNER A.K. WILSON J.P. JENSON S.K. BAND L. 1993 GIS and Land-surface-subsurface Process Modelling. In: GOODCHILD M.F. PARKS B.O. STEYAERT L.T. (EDS.) Environmental Modelling with GIS. Oxford University

Press. New York. p.196-230.

MORRISON M.L. MARCOT B.G. MANNAN R.W. 1998 Wildlife-habitat relationships: concepts and applications. University Wisconsin Press. Madison.

NEE S. 2004 More than meets the eye. Nature. 429 (24). p.804-805.

NIEMANN H. 1983 Klassifikation von Mustern. Springer-Verlag. Berlin.

NITZE M. FUCHS K. STIER N. ROTH M. 2003 Raumnutzung von Muffelwild in landwirtschaftlich geprägten Einstandsgebieten Sachsens. – Beiträge zur Jagd- und Wildtierforschung Bd. 28. p.407-415.

NOSS R.F. 1990 Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4. p.355-364.

NOSS R.F. 1999 Assessing and monitoring forest biodiversity: A suggested framework and indicators. Forest Ecology and Management 115. p.136-146.

O`NEIL R.V. KRUMMEL J.R. GARDNER R.H. SUGIHARA G. JACHSON B. DEANGELIS D.L. MILNE B.T. TURNER M.G. ZYGMUNT B. CHRISTENSEN S.W. DALE V.H. GRAHAM R.L. 1988 Indices of landscape patterns. Landscape Ecology. 5. p.153-162.

ODUM E.P. 1971 Fundamentals of Ecology. W.B. Saunders. Philadelphia. Pennsylvania.

OFFICE OF TECHNOLOGY ASSESSMENT 1987 Technology to maintain biological diversity Washington. DC U.S. Gov. Print. Off. Stock #052-003-01058-5.

OEHMICHEN K. 2001 Vergleich von Landschaftsindizes unter besonderer Berücksichtigung des geometrischen- und geographischen Window-Konzeptes. Diplomarbeit. Professur Biometrie und forstliche Informatik der TU Dresden. Tharandt.

OKIA N.O. 1976 Birds of the understorey of lake-shore forests on the Entebbe Peninsula. Uganda. Ibis. 118. p.1-13.

ORTLIEB R. 1989 Der Rotmilan. Neue Brehm-Bücherei. 532. A. Ziemsen Verlag. Wittenberg Lutherstadt.

PATIL G.P. RAO C.R. (EDS.) 1994 Handbook of Statistics 12: Environmental Statistics. Elsevier. 948p.

PATIL G.P. TAILLIE C. 1979 An overview of diversity. In: GRASSLE J.F. PATIL G.P. SMITH W. TALLIE C. (EDS.) Ecological diversity in theory and practice. International Co-operative Publishing House. Fairland. MD. p.3-27.

PETERS R.H. 1991 A Critique for Ecology. Cambridge University Press. Cambridge.

PETERSEN C.G.J. 1896 The yearly immigration of young plaice into the Limfjord from the German Sea. Report of the Danish Biological Station. 6. p.1-77.

PETIT D.R. 1989 Weather-dependent use of habitat patches by wintering woodland birds. Journal of Field Ornithology. 60. p.241-247.

PIELOU E.C. 1975 Ecological Diversity. Wiley and Sons. New York.

PIELOU E.C. 1995 Biodiversity versus old-style diversity measuring biodiversity for conservation. In: BOYLE T.J.B. BOONTAWEE B. (EDS.) Measuring and monitoring biodiversity in tropical and temperate forests. Proceedings of a IUFRO Symposium. Chiang Mai. Thailand. 27 August - 2 September 1994. Borgor. Indonesia: Center for International Forestry Research. p.5-17.

PUUMALAINEN J. 2001 Structural Compositional and Functional Aspects of Forest Biodiversity in Europe. Geneva Timber and Forest Discussion Papers. 87p.

RATSCHKER U.M. 2001 Die Zönose der Spinnen und Weberknechte in der Agrarlandschaft des Biosphärenreservates Schorfheide-Chorin. Technische Universität Dresden. Institut für Forstbotanik und Forstzoologie. Tharandt.

REUTHER M. HÄUSLER T. AKGÖZ E. HOFFMANN K. STÄTTER R. 1996 Waldzustandserfassung im Fichtelgebirge und Erzgebirge mit Hilfe der Fernerkundung. Forstliche Forschungsberichte München. 160. München.

RICHARDS J.A. XIUPING J. 1999 Remote Sensing Digital Image Analysis: An Introduction. Third Edition. Springer Verlag Berlin. p.363.

RICHARDS J.N. 1993 Remote Sensing and Digital Image Analysis. Springer Verlag. 340p.

RICHARZ K. MEYBURG B.U. HORMANN M. (EDS.) 1995 Der Rotmilan. Ergebnisse einer internationalen Fachtagung. Vogel und Umwelt. 8. Sonderheft.

RICOTTA C. AVENA G. 2000 The remote sensing approach in broad-scale phenological studies. Applied Vegetation Science 3 (1). p.117-122.

RISSER P.G. 1995 The status of science examining ecotones. BioScience 45. p.318-325.

RITTERS K.H. O´NEILL R.V. HUNSAKER C.T. WICKHAM J.D. YANKEE D.H. TIMMINS S.P. JONES K.B. JACKSON B.L. 1995 A factor analysis of landscape patterns and structure metrics. Landscape Ecology. 10 (1) p.23-29.

ROBINSON V.B. 1988 Some implications on fuzzy set theory applied to geographical databases. Computers and Geosciences. 16 (7). p.875-872.

ROSENVALD R. LOHMUS A. 2003 Nesting of the black stork (Ciconia nigra) and white-tailed eagle (Haliaeetus albicilla) in relation to forest management. Forest Ecology and Management. 185 (3). p.217-223.

ROSENZWEIG M.L. 1981 A theory of habitat selection. Ecology 62. p.327-335.

SALISBURY E.J. 1926 The geographical distribution of plants in relation to climatic factors. Geographical Journal. 57. p.312–335.

SCHAMBERGER M.L. O´NEIL L.J. 1986 Concepts and constraints of habitat-model testing. In: VERNER J. MORRISON M.L. RALPH C.J. (EDS) Wildlife 2000: Modelling Habitat Relationships of Terrestrial Vertebrates. Univ. of Wisconsin

Press Madison. WI. p.5-10.

SCHMITT G. 2004 Die Parasitoidengemeinschaft (Hymenoptera) in einer Agrarlandschaft: Effekte von Nutzungstypen und Bewirtschaftungsmaßnahmen auf strukturelle Parameter. – Dissertation. Technische Universität Dresden. Tharandt. 200 S.

SCHÖPFER W. 1969 Die 6-Baum-Stichprobe in der Forsteinrichtung. AFZ 24.Jg., S. 533-536 u. 588-591.

SCHREIBER A. STUBBE M. STUBBE A. 2000 Red kite (Milvus milvus) and black kite (Milvus migrans): minute genetic interspecies distance of two raptors breeding in a mixed community (Falconiformes: Accipitridae). Biol. Journal of the Linnean Society 63. p.351-365.

SEYDACK A.H.W HUISMAN J. KOK R. 1998 Long Term Antelope Population Monitoring in Southern Cape Forests. Southern African Forestry Journal. 182. p.9-20.

SHANNON C. AND WEAVER W. 1949 The Mathematical theory of communication. University of Illinois Press. Urbana 1949.

SIEVERT R. 2000 Jäger zwischen Wald und Feld. Naturschutz heute. Ausgabe 1/00.

SMITH J.T. RANSON K. 1980 The Lambertian Assumption and Landsat Data Photogrammetric Engineering and Remote Sensing. 46. (9). p.1183-1189.

STELFOX H.A. 1988 Wildlife resource evaluation and land/wildlife relationship models.

In: STELFOX H.A. AND IRONSIDE G.R. (EDS.) Land Wildlife Integration No. 3. Environ. Can.Ecol. and Land Class. Series 22. Canadian Wildlife Service. Ottowa. Ont.

STUBBE M. MAMMEN U. GEDEON K. 1995 Erfassung des Rotmilans (Milvus milvus) im Rahmen des Monitoring Greifvögel und Eulen Europas - Perspektiven eines internationalen Rotmilan-Monitorings Z. Vogelk. u. Natursch. in Hessen. Vogel und Umwelt 8 (Sonderheft). S.165-171.

STÜMER W. 2004 Kombination von terrestrischen Aufnahmen und Fernerkundungsdaten mit Hilfe der kNN-Methode zur Klassifizierung und Kartierung von Wäldern. Dissertation. Technische Universität Dresden. Lehrstuhl für Fortlisch Biometrie und Informatik.

SWINGLAND I.R. 2001 Definition of Biodiversity. Encyclopedia of Biodiversity. Volume 1. Academic Press. p.377-391.

TAMIS W.L.M. VAN´T ZELFDE M. 1998 An expert habitat suitability model for the disaggregation of bird survey data Bird counts in the Netherlands downscaled from atlas block to kilometre cell. Landscape and Urban Planning. 40. p.269-282.

TBFRA (2000) Forest Resources of Europe, CIS, North America, Australia, Japan and New Zealand. UN-ECE/FAO Contribution to the Global Forest Resources Assessment 2000. United Nations Publications. Sales. 99-II-E-36. ISBN 92-1-116735-3.ISSN 1020-2269.

http://www.unece.org/trade/timber/fra/pdf/contents.htm

TERBORGH J. ROBINSON S.K. T.A.P. III MUNN C.A. PIERPONT N. 1990 Structure and organization of an Amazonian forest bird community. Ecological. Monographs. 60. p.213-238.

THEOBALD D. M. 1998 Tools Available for Measuring Habitat Fragmentation. Annual Meeting of the Colorado Chapter of the Wildlife Society. 5.

THOMAS D.L. TAYLOR E.J. 1990 Study designs and tests for comparing resource use and availability. Journal of Wildlife Management 54. p.322-330.

TILMAN D. 1994 Competition and biodiversity in spatially structured habitats. Ecology. 75. p.2-16.

TOMPPO E. 1991 Satellite image-based national forest inventory of Finland. International Archives of Photogrammetry and Remote Sensing. 28 (7-1). p.419-424.

TOMPPO E. 1993 Multi-source National Forest Inventory of Finland. Nyssönen ed. Proceedings of the Ilvessalo symposium on National Forest Inventories Finish Forest Research Institute Research Paper. 444. p.52-59.

TOMPPO E. 1997A Application of remote sensing in Finnish national forest inventory. In: Application of remote sensing in European forest monitoring. International workshop proceedings (pp. 375-388) Vienna Austria: European CommissionCL-NA-17685-EN-C (14-16 October 1996).

TOMPPO E 1997B Recent status and further development of the Finnish multi-source forest inventory. In: Managing the resources of the world's forests. Lectures given at the 1997 Marcus Wallenberg Prize Symposium. p.53-69. The Marcus Wallenberg Foundation Symposia Proceedings. p. 11 Falun. Sweden: The Marcus Wallenberg Foundation.

TOMPPO E. PEKKARINEN A. 1997 Methodenerprobung der Finnischen Nationalen Multiquellen-Waldinventur in Nordrhein-Westfalen. In: Landeswaldinventur – Konzeption Verfahrenstest Ergebnisse Schriftenreihe der Landesforstverwaltung Nordrhein-Westfalen. 5. S.52-67.

TURNER M.G. 1990 Spatial and temporal analysis of landscape patterns. Landscape Ecology. 4 (1). p.21-30.

UNEP 1992 Convention on Biological Diversity. UNEP (United Nations Environment Programme). Nairobi. p.24. [http://www.biodiv.org]

UN-FCCC 2002 Report of the conference of the parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001. FCCC/CP/2001/13/Add.1. 69 p.

US FISH AND WILDLIFE SERVICE 1981 Standards for the Development of Habitat Suitability Index Models. US Dep. of the Interior Fish and Wildlife Service Div. of Ecol. Serv Ecol. Services Manual 103. Washington DC.

US FISH AND WILDLIFE SERVICE 2000 Bull Trout Occurrence and Habitat Selection.

US Dep. of the Interior Fish and Wildlife Service Div. of Ecol. Serv. Ecological Services. Manual. Washington DC.

WALLISER G. 2004 Auswirkungen anthropogener Landnutzung auf die Siedlungsstruktur Raum- und Habitatnutzung des europäischen Dachses (*Meles meles L.1758*) auf der Insel Rügen. – Dissertation. Technische Universität Dresden. Tharandt. 125 S.

WALZ U. 1999 Charakterisierung der Landschaftsstruktur mit Methoden der Satelliten-Fernerkundung und der Geoinformatik (Dissertation). TU Dresden. 190p.

WELSH KITE TRUST 2004 http://www.gigrin.co.uk/w/index.htm

WHITE G.C. AND GARROTT R.A. 1990 Analysis of wildlife radio-tracking data. Academic Press. California. USA.

WHITTAKER R.H. 1972 Evolution and Measurement of Species Diversity. Taxon. 21 (2/3). p.213-251.

WIELAND 1997 Habitatmodellierung biotischer Komponenten. Archiv für Natur und Landschaft. 35. p.227-237.

ZADEH L.A. 1965 Fuzzy sets. Information and Control. 8 (3). p.338-358.

10 LIST OF ABBREVIATIONS

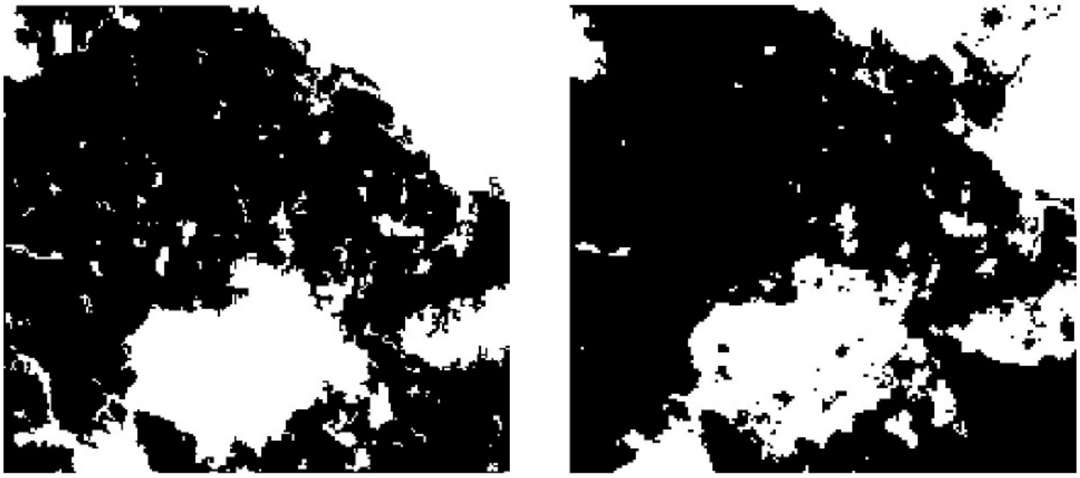
CBD	Convention of Biological Diversity
CIR	Colour infrared
CORINE	Coordination of Information of the Environment
CTP	continuous transition probability
DLR	Deutsches Luft und Raumfahrt Zentrum (German Aerospace Centre)
DMMD	Development of Methods and Tools for Monitoring Forest Biodiversity as a contribution to sustainable development in Europe
EC	European Commission
EEA	European Environmental Agency
EHSI	Enhanced Habitat Suitability Index Model with fuzzy sets
EHSI+	Enhanced Habitat Suitability Index Model with fuzzy sets with additive recombination of life requisites
EU	European Union
EUNIS	European Nature Information System
FFH	Flora Fauna Habitat Directive
GAM	generalised additive model
GIS	Geographic Information System
HEP	Habitat Evaluation Procedure
HR-HSI	Home Range Habitat Suitability Index
HR-HSI+	Home Range Habitat Suitability Index with additive recombination of life requisites

HSI	Habitat Suitability Index Model
HSI+	Habitat Suitability Index Model with additive recombination of life requisites
km	kilometre
kNN	k-nearest neighbour
KP	Kyoto Protocol
LR	life requisite
MCPFE	Ministerial Conferences on the Protection of Forests in Europe
m	metre
MNTFR	Scale Dependent Monitoring of Non-Timber Forest Resources Based on Indicators Assessed in Various Data Sources
RS	Remote Sensing
SFM	Sustainable Forest Management
SHSI	Spatial Habitat Suitability Index Model
TBFRA	Temperate and Boreal Forest Resources Assessment
UNEP	United Nations Environment Programme

11 ANNEX

HSI Attribute Maps

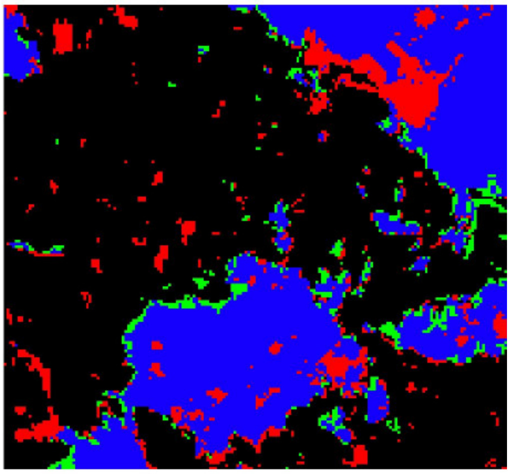
Sites$_{open}$



Attribute map of “open sites” in 1989

Attribute map of “open sites” in 2000

white: “open sites” detected
black: “open sites” not detected

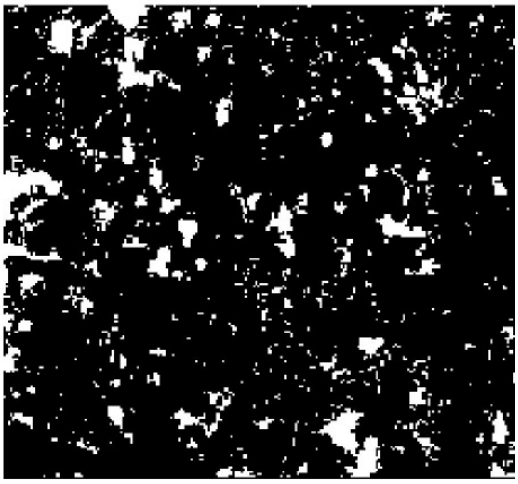


red: decrease of “open sites”
green: increase of “open sites”
blue: no changes of “open sites”
black: no “open sites” detected

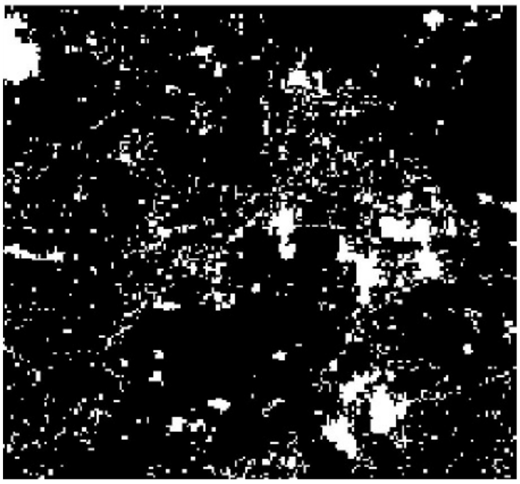
Change of the attribute “open sites” form 1989 to 2000

Annex figure 1 HSI result map of the attribute “open sites” for 1989 and 2000 and its changes

Forest$_{\text{open}}$

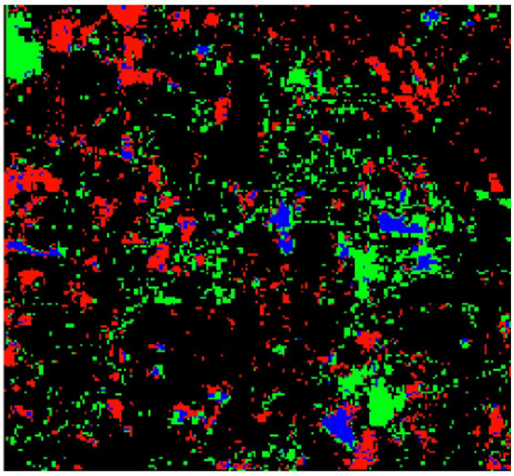


Attribute map of “open forest” in 1989



Attribute map of “open forest” in 2000

white: “open forest” detected
black: “open forest” not detected

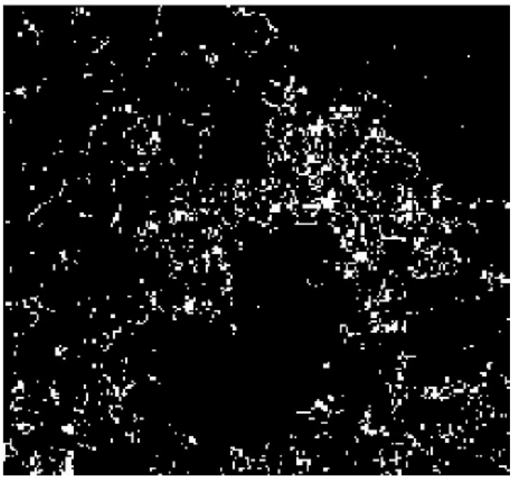


Change of the attribute “open forest” form 1989 to 2000

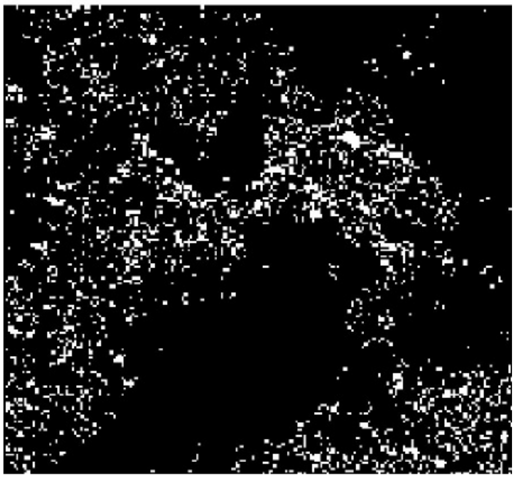
red: decrease of “open forest”
green: increase of “open forest”
blue: no changes of “open forest”
black: no “open forest” detected

Annex figure 2 HSI result map of the attribute “open forest” for 1989 and 2000 and its changes

Height$_{tree}$

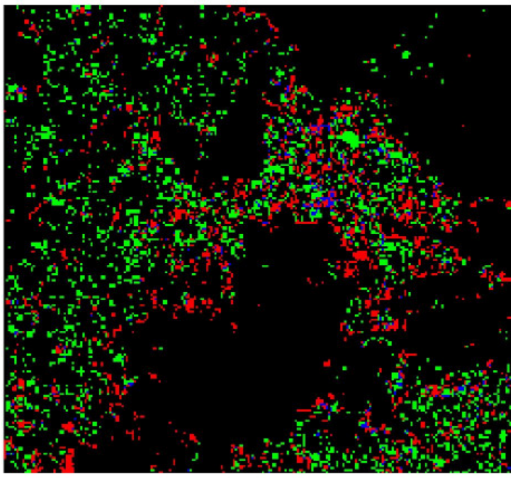


Attribute map of “tree height” in 1989



Attribute map of “tree height” in 2000

white: “tree height” detected
black: “tree height” not detected



Change of the attribute “tree height” form 1989 to 2000

red: decrease of “tree height”
green: increase of “tree height”
blue: no changes of “tree height”
white: no “tree height”

Annex figure 3 HSI result map of the attribute “tree height” for 1989 and 2000 and its changes

Dist_{water} **Dist_{forest}**

Attribute map of distance to “water bodies” Attribute map of distance to “forest border”

white: attribute detected; black: no attribute detected

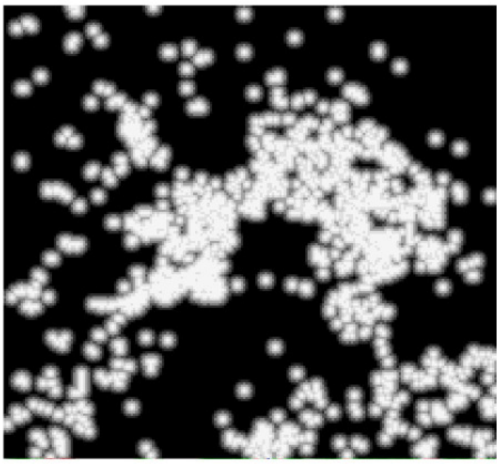
Annex figure 4 Map of buffers around the water bodies (1 km distance) and around the forest borders (0,5 km distance) in the test area

Annex table 1 Suitability of the attributes “water bodies” (1 km distance) and around the “forest border” (0,5 km distance) [% of the test site area]

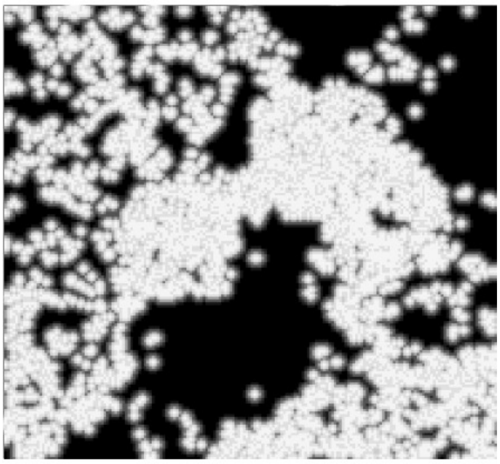
	Dis_{water}	Dist_{forest}
suitable	95,57%	61,26%
not suitable	4,43%	38,74%

EHSI Attribute Maps

Comp$_{tree}$

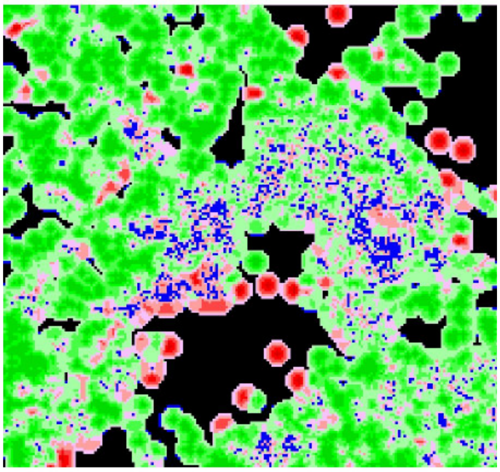


Enhanced attribute map of "broadleaved trees" 1989 indicated by the EHSI



Enhanced attribute map of "broadleaved trees" 2000 indicated by the EHSI

bright areas: high "broadleaved trees" suitability
dark areas: less "broadleaved trees" suitability

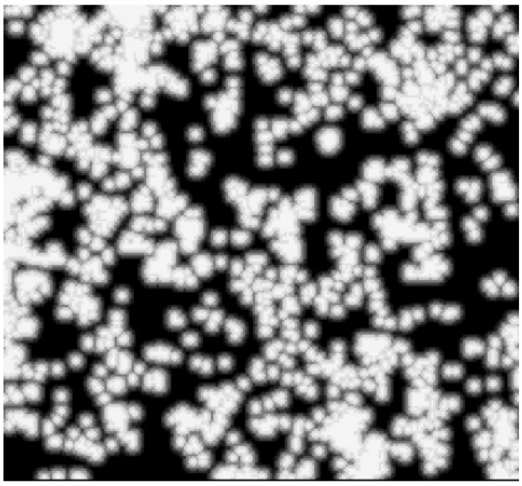


Change of attribute "broadleaved trees" for the Red Kite indicated by the EHSI

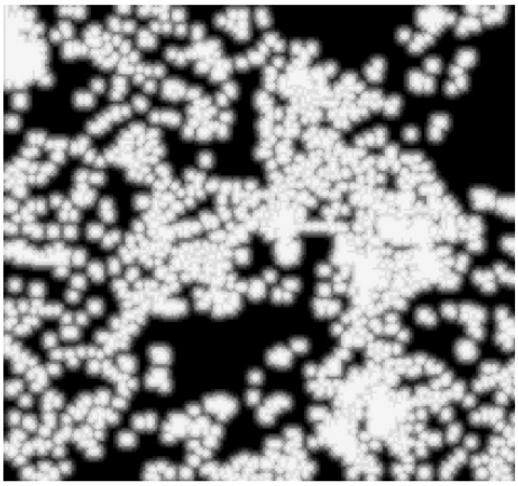
reddish colours: loss of "broadleaved trees"
greenish colours: increase of "broadleaved trees"
blue: no change of "broadleaved trees"
black: no "broadleaved trees" detected

Annex figure 5 EHSI result map of the attribute "broadleaved trees" for 1989 and 2000 and its changes

Forest$_{open}$

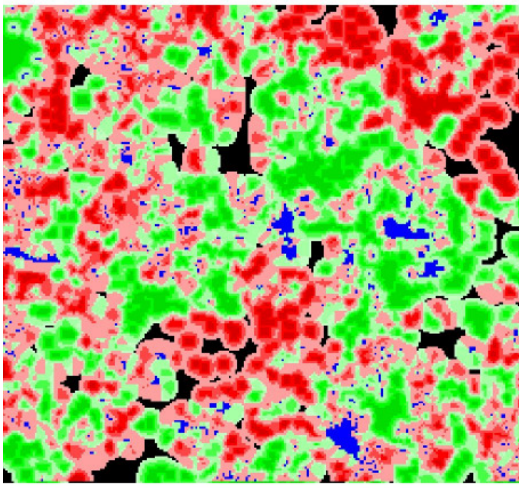


Enhanced attribute map of “open forest” in 1989 indicated by the EHSI



Enhanced attribute map of “open forest” in 2000 indicated by the EHSI

bright areas: high “open forest” suitability
dark areas: less “open forest” suitability

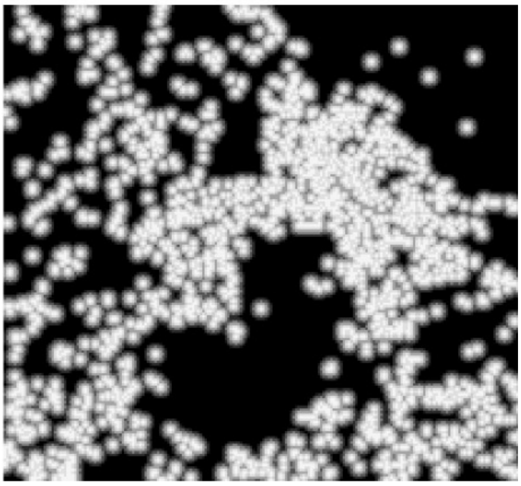


Change of the attribute “open forest” form 1989 to 2000 indicated by the EHSI

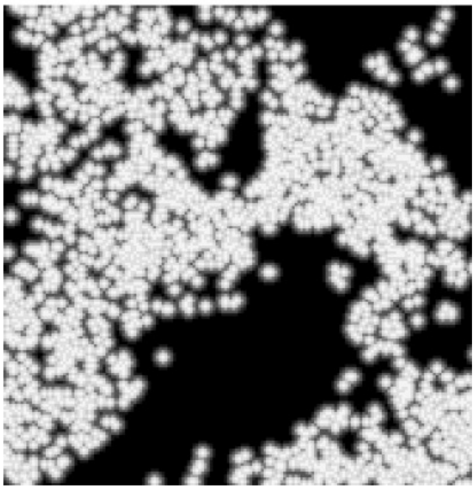
reddish colours: decrease of “open forest”
greenish colours: increase of “open forest”
blue: no changes of “open forest”
black: no “open forest” detected

Annex figure 6 EHSI result map of the attribute “open forest” for 1989 and 2000 and its changes

$\mathbf{Height}_{\mathbf{tree}}$

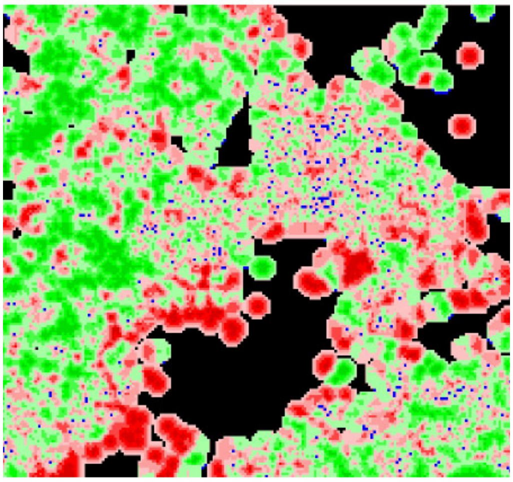


Enhanced attribute map of “tree height” in 1989 indicated by the EHSI



Enhanced attribute map of “tree height” in 2000 indicated by the EHSI

bright areas: high “tree height” suitability
dark areas: less “tree height” suitability



Change of the attribute “tree height” form 1989 to 2000 indicated by the EHSI

reddish colours: decrease of “tree height”
greenish colours: increase of “tree height”
blue: no changes of “tree height”
black: no “tree height” detected

Annex figure 7 EHSI result map of the attribute “tree height” for 1989 and 2000 and its changes

$\text{Dist}_{\text{water}}$ **$\text{Dist}_{\text{forest}}$**

Enhanced attribute map of distance to "water bodies" indicated by the EHSI

Enhanced attribute map of distance to "forest border" indicated by the EHSI

bright areas: high attribute suitability; dark areas: less attribute suitability

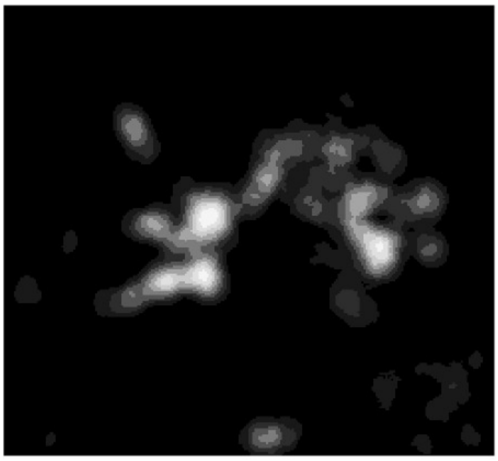
Annex figure 8 EHSI result map of buffers around the water bodies (1 km distance) and around the forest borders (0,5 km distance) in the test area

Annex table 2 Suitability of the EHSI attributes "water bodies" (1 km distance) and around the "forest border" (0,5 km distance) [% of the test site area]

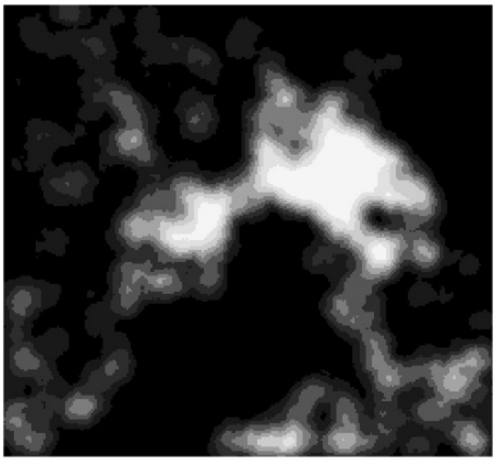
	$\text{Dis}_{\text{water}}$	**$\text{Dist}_{\text{forest}}$**
suitable	98,46%	71,98%
not suitable	1,54%	28,02%

HR-HSI Attribute Maps

Comp$_{tree}$

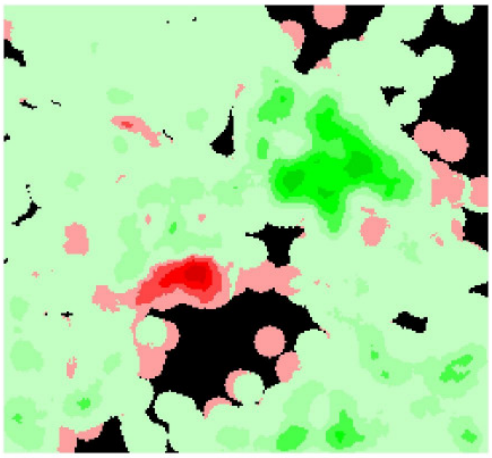


Continuous transition probabilities of the attribute “broadleaved trees” 1989 indicated by home range recalculation



Continuous transition probabilities of the attribute “broadleaved trees” 2000 indicated by home range recalculation

bright areas: high “broadleaved trees” suitability
dark areas: less “broadleaved trees” suitability

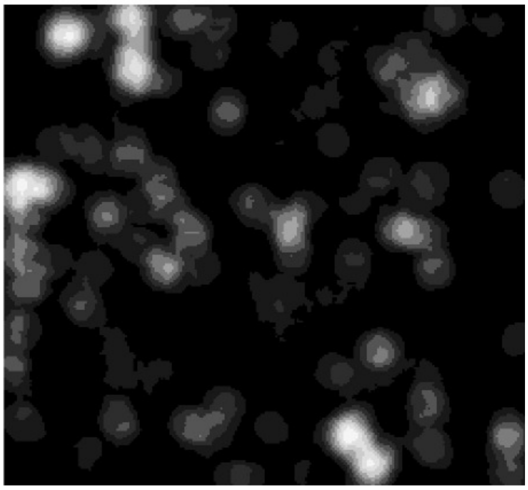


Change of the attribute “broadleaved trees” for the Red Kite indicated by home range recalculation

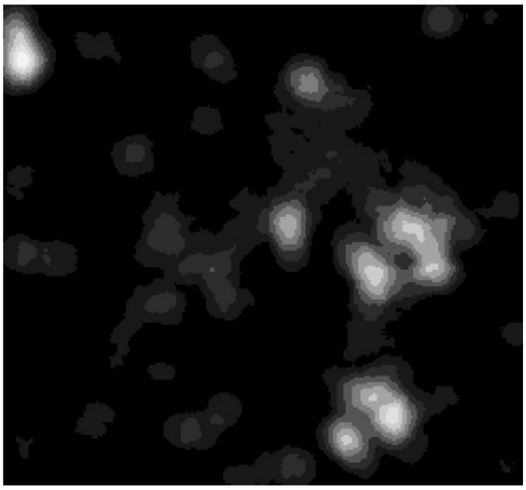
reddish colours: loss of “broadleaved trees”
greenish colours: increase of “broadleaved trees”
blue: no change of “broadleaved trees”
black: no “broadleaved trees” detected

Annex figure 9 HR-HSI result map of the attribute “broadleaved trees” for 1989 and 2000 and its changes

Forest$_{open}$

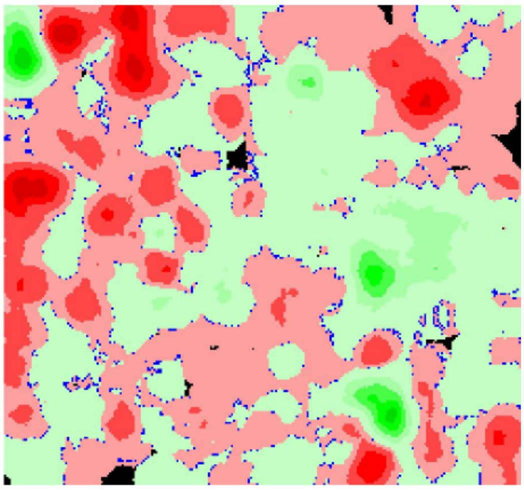


Continuous transition probabilities of the attribute “open forest” in 1989 indicated by home range recalculation



Continuous transition probabilities of the attribute “open forest” in 2000 indicated by home range recalculation

bright areas: high “open forest” suitability
dark areas: less “open forest” suitability

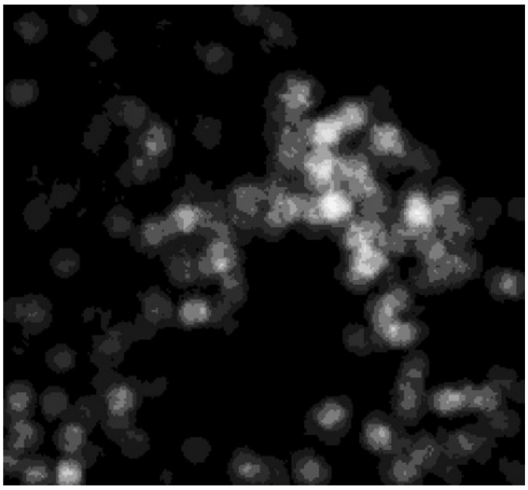


Change of the attribute “open forest” form 1989 to 2000 indicated by home range recalculation

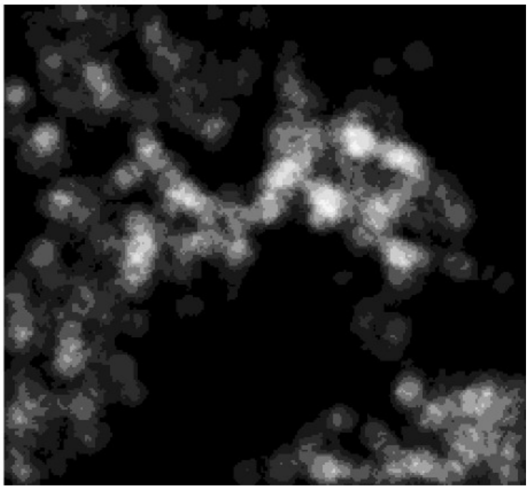
reddish colours: decrease of “open forest”
greenish colours: increase of “open forest”
blue: no changes of “open forest”
black: no “open forest” detected

Annex figure 10 HR-HSI result map of the attribute “open forest” for 1989 and 2000 and its changes

Height$_{tree}$

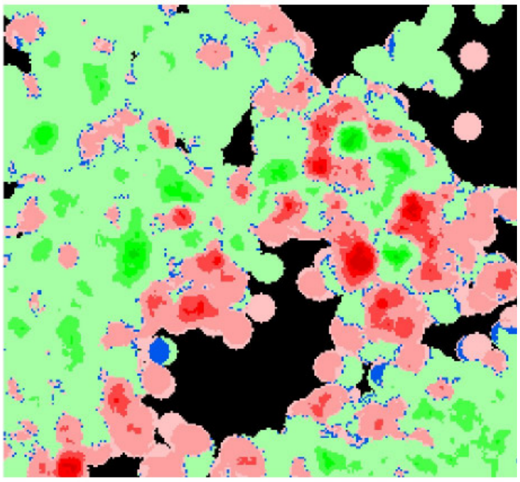


Continuous transition probabilities of the attribute “tree height” in 1989 indicated by home range recalculation



Continuous transition probabilities of the attribute “tree height” in 2000 indicated by home range recalculation

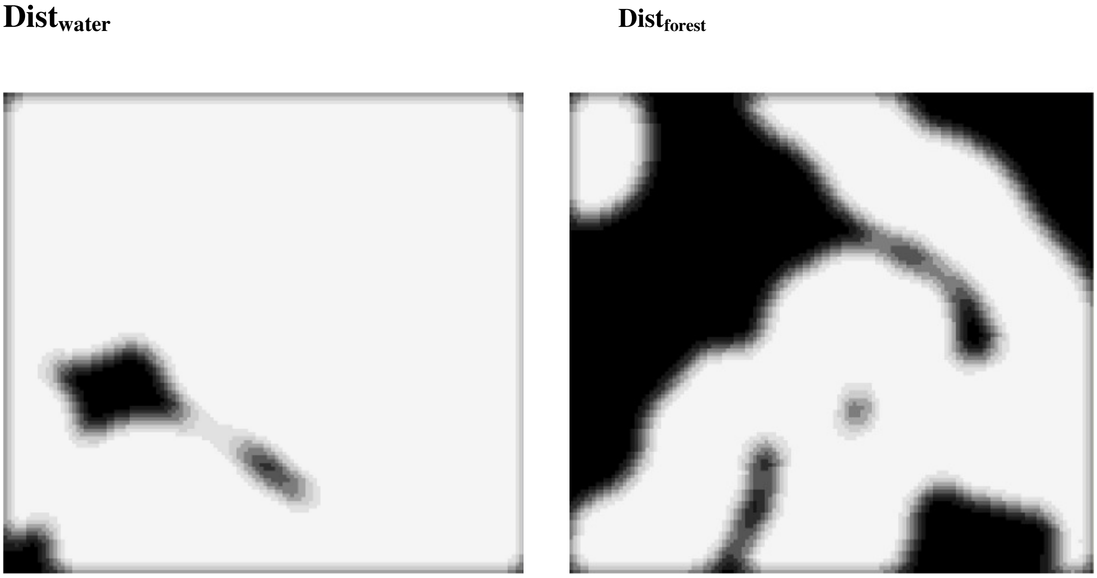
bright areas: high “tree height” suitability
dark areas: less “tree height” suitability



Change of the attribute “tree height” form 1989 to 2000 indicated by home range recalculation

reddish colours: decrease of “tree height”
greenish colours: increase of “tree height”
blue: no changes of “tree height”
black: no “tree height” detected

Annex figure 11 HR-HSI result map of the attribute “tree height” for 1989 and 2000 and its changes



Continuous transition probabilities of the attribute distance to “water bodies” indicated by home range recalculation

Continuous transition probabilities of the attribute distance to “forest border” indicated by home range recalculation

bright areas: high attribute suitability; dark areas: less attribute suitability

Annex figure 12 HR-HSI result map of buffers around the water bodies (1 km distance) and around the forest borders (0.5 km distance) in the test area

Annex table 3 Suitability of the HR-HSI attributes “water bodies” (1 km distance) and around the “forest border” (0,5 km distance) [% of the test site area]

	$\mathbf{Dis_{water}}$	$\mathbf{Dist_{forest}}$
suitable	99,62%	74,53%
not suitable	0,38%	25,47%

Development of the life requisite “food” according to the different HSI models

Annex table 4 Development of the HSI life requisite “food” from 1989 to 2000 [% of the test site area]

HSI – food

2000	1989	
	suitability of food	**no suitability of food**
suitability of food	88,75%	3,14%
no suitability of food	7,15%	0,96%

Σ 91,89%

Σ 95,90%

relative change of suitable area: **- 4,01 %**

Annex table 5 Development of the EHSI life requisite “food” from 1989 to 2000 [% of the test site area]

EHSI – food

2000	1989	
	suitability of food	**no suitability of food**
suitability of food	50,30%	13,21%
no suitability of food	36,47%	0,02%

Σ 63,50%

Σ 86,77%

relative change of suitable area: **- 23,26 %**

Annex table 6 Development of the HR-HSI life requisite "food" from 1989 to 2000 [% of the test site area]

HR-HSI – food

2000	1989		
	suitability of food	**no suitability of food**	
suitability of food	26,49%	23,79%	Σ 50,28%
no suitability of food	49,72%	0,00%	
	Σ 76,21%		

relative change of suitable area: **-25,92 %**

Development of the life requisite “nesting” according to the different HSI models

Annex table 7 Development of the HSI life requisite “nesting” from 1989 to 2000 [% of the test site area]

HSI - nesting

2000	**1989** **suitability of nesting**	**1989** **no suitability of nesting**	
suitability of nesting	3,18%	16,50%	Σ 19,68%
no suitability of nesting	13,78%	66,54%	
	Σ 16,96%		

relative change of suitable area: 2,72 %

Annex table 8 Development of the EHSI life requisite “nesting” from 1989 to 2000 [% of the test site area]

EHSI - nesting

2000	**1989** **suitability of nesting**	**1989** **no suitability of nesting**	
suitability of nesting	0,46%	60,42%	Σ 60,87%
no suitability of nesting	35,89%	3,23%	
	Σ 36,35%		

relative change of suitable area: 24,52 %

Annex table 9 Development of the HR-HSI life requisite “nesting” from 1989 to 2000 [% of the test site area]

HR-HSI - nesting

2000	**1989**		
	suitability of nesting	**no suitability of nesting**	
suitability of nesting	0,60%	55,16%	Σ 55,76%
no suitability of nesting	41,57%	2,67%	
	Σ 42,17%		

relative change of suitable area: 13,58 %

Development of the life requisite “safety” according to the different HSI models

Annex table 10 Development of the HSI life requisite “safety” from 1989 to 2000 [% of the test site area]

HSI - safety

2000	1989 suitability of safety	1989 no suitability of safety	
suitability of safety	2,28%	22,16%	Σ 24,44%
no suitability of safety	5,51%	70,05%	
	Σ 7,79%		

relative change of suitable area: 16,65 %

Annex table 11 Development of the EHSI life requisite “safety” from 1989 to 2000 [% of the test site area]

EHSI - safety

2000	1989 suitability of safety	1989 no suitability of safety	
suitability of safety	0,04%	60,66%	Σ 60,70%
no suitability of safety	24,87%	14,44%	
	Σ 24,91%		

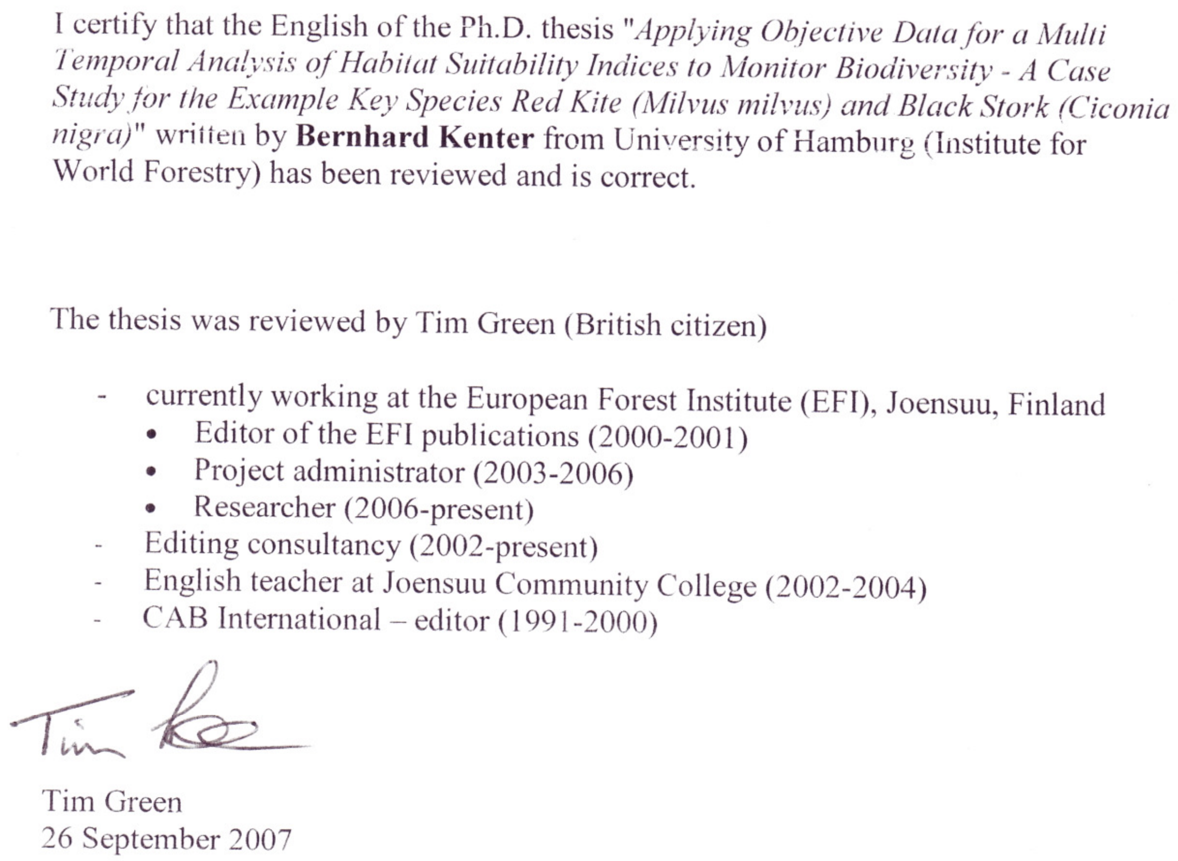
relative change of suitable area: 35,79 %

Annex table 12 Development of the HR-HSI life requisite "safety" from 1989 to 2000 [% of the test site area]

HR-HSI - safety

2000	1989		
	suitability of safety	**no suitability of safety**	
suitability of safety	1,08%	66,07%	Σ 67,15%
no suitability of safety	20,92%	11,92%	
	Σ 22,00%		

relative change of suitable area: 45,15 %



I certify that the English of the Ph.D. thesis "*Applying Objective Data for a Multi Temporal Analysis of Habitat Suitability Indices to Monitor Biodiversity - A Case Study for the Example Key Species Red Kite (Milvus milvus) and Black Stork (Ciconia nigra)*" written by **Bernhard Kenter** from University of Hamburg (Institute for World Forestry) has been reviewed and is correct.

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Tim

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26 September 2007