PhD Dissertation

Integrating GIS and Remote Sensing for Assessing the Impact of Disturbance on Habitat Diversity and Land Cover Change in a Post-Mining Landscape

A thesis approved by the Faculty of Environmental Science and Process Engineering at the Brandenburg University of Technology in Cottbus in partial fulfillment of the requirement for the award of an academic degree in Ph.D. Environmental and Resource Management.

By

Effah Kwabena ANTWI
M.Sc. Environmental and Resource Management
BSc. Biological Sciences

Place of Birth: Abetifi – GHANA

Supervisor:	Prof. Dr. rer. nat. habil. Gerhard Wiegleb
Supervisor:	Prof. Dr. rer. nat. habil., Dipl.-Math. Albrecht Gnauck
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Declarations

This doctoral dissertation "Integrating GIS and Remote Sensing for Assessing the Impact of Disturbance on Habitat Diversity and Land Cover Change in Post-Mining Landscape" was completed and written independently by me ANTWI Effah Kwabena. I hereby declare that:

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ANTWI Effah Kwabena
Lehrstuhl Allgemeine Ökologie
Brandenburg University of Technology Cottbus

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Dedication

This dissertation is dedicated to Mama Jane Kwao Sarbah, my wife Mary-Helina Effah Antwi, and our child who has just gone ahead of us to the father.

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List of Abbreviations

ED	Edge Density
ETM	Enhanced Thematic Mapper Plus
GIS	Geographic Information System
IR	Infrared
LC	Land Cover
LCC	Land Cover Change
LU	Land Use
LUC	Land Use Change
MPFD	Mean Patch Fractal Dimension
MPS	Mean Patch Size
MSI	Mean Shape Index
NIR	Near infrared
NDVI	Normalized Difference Vegetation Index
NUMP	Number of Patches
RS	Remote Sensing
SDI	Shannon Diversity Index
SEI	Shannon Evenness Index
SPOT	Systeme Pour l'Observation de la Terre
TM	Thematic Mapper
TPE	Total Patch Edge
UTM	Universal Transverse Mercator

Abstract

Human influence on the biosphere has transformed natural land cover (LC) into modified LC. Shifting focus from individual species study to large-scale assessment is therefore needed to restore the damaged ecosystem. The hypotheses were: (a) the post-mining landscapes are getting more diverse over time (b) GIS, remote sensing and patch analyst can generate LC information and landscape characterization statistics for assessing habitat diversity and monitoring land cover change (LCC) in a disturbance-dominated area (c) relationship exist between habitat diversity and field based species richness/LCC and environmental conditions/LCC and biodiversity losses. The general aims of this research were (a) to assess the impact of disturbance on LCC and habitat diversity (b) to identify how accurately patterns of habitat diversity, complexity, fragmentation, primary production and LCC can be assessed or predicted with GIS and remotely sensed data.

LC maps of 1988, 1991, 1995, 1998, 2000 and 2003 were produced from LANDSAT TM images of Schlabendorf Nord and Schlabendorf Süd. These images were used to survey the changing landscape. After classifying the images based on dominant land cover types, the area and perimeter of all patches were defined. Landscape characterization metrics were generated using patch analyst. LCC statistics were estimated for each LC map year. Change detection extension was used to identify changes among vegetation or land cover types into "negative change", "no change" and "positive change". DCA ordination technique (CANOCO) was used to study similarity among the distribution of land cover types. Other relevant analysis made include soil pH analysis and climate data evaluation.

The outcome of the research shows that the process of LCC takes place at the interface between environmental and human systems. Land cover transformations in most cases in Schlabendorf were as a result of progressive and reversed plant succession. Overall changes in both landscapes showed increased area of pine afforestation, deciduous trees afforestation, lake and mixed grassland with trees. The LCC s were predominantly caused by harvesting of afforested pine, restoration related construction activities or other land cover management practices, reverse succession, low soil pH especially along the path of the mine strip, loss of soil fertility, human decisions and policies.

There was increase in habitat richness, heterogeneity, fragmentation, and shape complexity due to decrease in habitat size, increased land use intensity etc. Lower habitat diversity in Schlabendorf Süd was due to the comparatively large landscape area, high patch number and higher habitat richness in most cases which confirms the claim that relationship between habitat diversity and habitat heterogeneity varies according to scale (Tews et al., 2004).
Increase in biomass accumulation particularly in Schlabendorf Süd contributed to the exchanges for greenhouse gases between the forest cover, soil and the atmosphere, hence changing the climatic condition on terrestrial ecosystems, biodiversity and LCC.
Unlike Schlabendorf Nord, Schlabendorf Süd still undergoes more active reclamation activities resulting in less similarity between the two post-mining landscapes over time. Within a given ecosystem, any change in habitat diversity can change the number of species in the resulting habitats types, in other words habitat diversity can be used to predict the species richness in a given ecosystem.

The approach to this work provides a beneficial trade off between expensive ground vegetation or LCC survey and low-priced image processing analysis. It requires less manpower and less time but greatly reliable for assessing LCC, habitat diversity/richness and heterogeneity in large inaccessible areas such as dunes in post-mining landscape.

Keywords: GIS, Remote Sensing, Landscape, Reclamation, Land Use/Land Cover Change, Disturbance, Habitat/Patch Diversity, Fragmentation, Richness, Complexity, Heterogeneity

1 Introduction

In landscape characterisation to identify disturbance, GIS and Remote Sensing have proved to be powerful tools in landscape ecology by means of mapping disturbance zones in ecosystem, quantifying its impact on the biodiversity and detecting land cover changes over a period of time. To understand the cause effect of disturbance on flora, a time series on land cover change is needed. Recent studies have shown that biodiversity of terrestrial ecosystem is expected to be mainly affected by land use changes within the next 100 years (Sala et al., 2000).

De Sherbinin (2002) addressed land cover change in the context of global environmental change. There has been a drastic and continuous change in the regional and global climate variables (e.g. cloud cover, precipitation, temperature, drought etc.) in recent past. But the question is how do the ongoing global changes affect the Earth's ecosystems, biodiversity, land cover changes and vice versa? According to de Sherbinin (2002), land cover changes are local and site specific yet their collective impact is one of the most important facet of global environmental change. Since the local ecosystems are linked to prevailing climatic conditions, any change in climate is expected to effect changes in the ecosystems. On the other hand, a change in the local or regional ecosystems can cause variations in the climatic condition, particularly with their role as carbon dioxide sink or their effect on greenhouse gasses. Turner (2001) ascertained that, humans are more and more regarded as dominant force behind global environmental change. According to Vitousek et al. (1997), "human use of land usurps as much as 40 % of the net primary production of the Earth, and changes in these may alter ecosystem service locally and globally".

In the Lower Lusatian region of northeastern Germany, lignite mining (brown coal) has been practiced extensively for almost 150 years. In such a disturbance-dominated landscape, patterns may fluctuate widely over time in response to the interplay between disturbance and succession processes that leads to change in biodiversity.

The extensive mining of coal in Lower Lusatia regions has permanently changed the ecosystem, land use potential and the attractiveness of the landscape. Furthermore, mining in this area has left behind damage stretching over large areas. It is therefore an important task of spatial planning to restore the damage to ecosystem and to open up new land use possibilities in this region (Federal Office for Building and Regional Planning, 2001). In order to manage the ecosystems, spatial and temporal understanding of the post mining landscape is required.

Pickett and White, 1985 ascertained that in Central Europe, primary succession is restricted to anthropogenically disturbed areas of post-mining landscapes but geographically explicit approach to disturbance has not been adequately integrated with temporal changes needed to represent the successional changes. Species diversity depends on spatio-temporal scales, but there is no simple scaling function available, and relations between diversity and environmental conditions, ecological processes and socio-economic factors are as well complex (Szaro, 1996). The post-mining landscape offers good study condition for modelling both temporal and spatial aspects of succession and biodiversity change.
Plant species richness is relatively simple to measure for a small area such as a sampling quadrat of a few square meters. Several methods exist for estimating the species richness of an assumed homogeneous, larger area (Bunge and Fitzpatrick, 1993; Colwell and Coddington, 1994; Palmer, 1995). During the late nineties however, Stohlgren et al., 1997a ascertained that assessing species richness of a complex landscape such the post mining landscape is still a problem.
This is because vegetation types cannot be regarded as homogeneous. They show an extremely different composition and often cannot be assigned to vegetation units described in the literature (e.g. Schubert et al., 1995). This is due to the small-scale heterogeneity and ongoing dynamics of the respective sites. Vegetation types occurring in the East German post-mining landscape are well described in Felinks and Wiegleb (1998), Felinks et al. (1999b) and Pietsch (1998). The brown coal opencast post-mining landscape in Lower Lusatian is a strongly disturbed landscape covering an area of 800 km^2 (Blumrich et al., 1998). Lower Lusatia is the largest brown coal mining area in the Federal Republic of Germany (Blumrich et al., 1998).

Approximately 15 percent of the terrestrial areas of Lusatia post-mining landscape are to be reserved for nature conservation (Wiegleb and Felinks, 2001b). Spoils in Lower Lusatia are characterized by high carbon content, low water capacity, low penetration possibility for roots, low nutrient content and lack of biological activity (Blumrich et al., 1998). The area also has a high evaporation rate with high surface temperatures, which leads to very dry habitat conditions. The area, characterized by lignite rich tertiary sand with extreme abaiotic soil condition has the potential of geogenic acidification.

In landscape analysis, indices of shape, richness and diversity provide additional evaluation of land cover spatial distribution within a particular landscape. It also provides an outline of the degree of disturbance and biodiversity change within a period of time (Roy and Joshi, 2002). In disturbance-dominated landscapes such as a post-mining area, patterns may fluctuate widely over time in response to the interplay between disturbance and succession processes that leads to change in biodiversity.

In conservation biology, focus has shifted from individual species study to assessment of entire biomes since the early nineties. This has motivated research into the applicability of effective assessment tools such as GIS and remote sensing that aid monitoring and assessment of terrestrial biodiversity at regional and community-ecosystem levels (Noss, 1990). Satellite remote sensing is a widely used technology to produce land use and land cover maps and to study vegetation cover. GIS provides information on the richness, dominance, fragmentation, porosity, patchiness, patch density, diversity, interspersion and juxtaposition in biodiversity management.

Ravan and Roy (1998) have proved the potential of GIS in landscape ecology by mapping disturbance zones in natural ecosystem and quantifying its impact on biodiversity. Landscape ecology considers vegetation as a mosaic of patches with unique landform, species composition and disturbance gradient (Ravan and Roy, 1998). Satellite images can be considered as a very convenient tool to measure landscape patterns since they provide a digital mosaic of the spatial arrangement of land covers (Chuvieco, 1999, Coulson et al., 1990).

Disturbance occurs in all ecosystems. It plays an important role in the dynamic equilibrium of vegetation development and the maintenance of biodiversity (White and Jentsch, 2001). Succession after disturbance generates a mosaic of patches in different successional stages. The effects of disturbance on patches vary with distance from patches and connectivity to other patches.

Detecting land cover change is needed in order to understand global environmental changes. Of particular interest is ecosystem fragmentation that varies with intensity and extent. Increase in fragmentation is either related to natural or human causes such as mining. Fragmentation may negatively influence the original biodiversity at the level of genes, species, and communities leading ultimately to the loss of biodiversity (Zuidema et al., 1996).

Having considered the background problems, the following objectives would be the concern of this research.

1. Develop methodology that can permit integration of land cover change processes and environmental changes into decision-making, with strategies in the context of conservation biology and sustainable forest management at the landscape/within community level.
2. Provide understanding regarding the relationship between land cover change and biodiversity losses in a post-mining landscape for future development decisions for users and stakeholders, including land owners
3. To generate land cover information and landscape characterization statistics that represents practical and time-efficient aspect of the spatial and temporal fluctuations at the post-mining area
4. Evaluate changes and similarities in land cover types and landscape characteristics in both post-mining landscapes subjected to different years of restoration activities
5. Identify the relationship between intensity of disturbance and the nature of fragmentation processes in the post-mining landscape.
6. Identify how accurately the patterns of biodiversity and land cover changes can be predicted on the basis of geographic and remotely sensed information.
7. To understand the impact of land use and land cover change on biodiversity and biomass accumulation in post-mining landscapes subjected to different years of restoration activities
8. To understand the relationship between land cover change and environmental conditions

The general aim of this research is to assess the impact of disturbance on land cover change and habitat diversity.

Considering the research aims, the following would be the research questions.

1. Does relationship exist between GIS and remote sensing generated landscape characterization statistics (species diversity) and environmental conditions?
2. How can GIS and remote sensing help generate land cover information and landscape characterization statistics for biodiversity change assessment in a disturbance-dominated area?
3. How is spatial and temporal change in habitat diversity related to field based (or ground data) species richness?
4. Are the post-mining landscapes getting more diverse over time?

2 Theoretical Background

2.1 Patch Dynamics and Perturbation

Generally, disturbances result in heterogeneous and patchy effects but then the state of the community in secondary succession plays a vital role. Furthermore the consequences of a particular disturbance are strongly determined by variety of biotic and physical factors.

The description of patch dynamics used in this work was based on that of Pickett and Thompson (1978) as follows.

- 'Patch' implies a relatively discrete spatial pattern, but does not establish any constraint on upper limit of patch size, internal homogeneity, or discreteness
- 'Patch' implies a relationship of one patch to another in space and to the surrounding, unaffected or less affected
- 'Patch dynamics' emphasizes patch change

Most researchers have used 'disturbance' and 'perturbation' synonymously but these terms still possess particular meanings in the work of others. The use of 'perturbation' has particularly got to do with a whole system orientation in the sense of any change in a parameter that defines the system (Loucks, 1975). The challenge concerning the application of perturbation to natural systems is the difficulty to separate it from the background variance in system parameters. "Perturbation" therefore is very useful in three comparatively narrow contexts, namely (a) when the parameters or behaviour that define systems have been explicitly defined, (b) when a given disturbance is known to be new to the system at hand (e.g. some kinds of human disturbances) and (c) when the disturbance is under direct experimental control. In these cases, a perturbation is a departure (explicitly defined) from a normal state or behaviour (Pickett and White, 1985). What is normal is the usually recognised response of ecosystems to disturbance event.

2.2 Disturbance

A disturbance is a discrete event by both internal and external forces in space and time that alters the structure of populations, communities and ecosystems. It does so by changing the density, the biomass or spatial distribution of biota, by affecting the availability and distribution of resource and substrate, or by otherwise altering the physical environment (Pickett and White, 1985). It often results in the creation of patches and the modification of spatial heterogeneity. Considering the socio-economic aspects, this alteration of the environmental structure also changes the living condition, the economic opportunities and the utility of people living in and around disturbed landscape (Walker and Willig, 1999). Two general kinds of disturbance can be distinguished: destructive events also considered as disturbance in strict sense by Jaime (1979) and environmental fluctuation. Thus the definition of disturbance includes environmental fluctuations and destructive events, whether or not these are perceived as normal for a particular system. This definition must be applicable in a wide variety of systems; it must allow for the fact that disturbance is relative to the spatial and temporal dimensions of the system at hand. For instance disturbance to bryophyte communities on streamside boulders can occur on a spatial (e.g. 10^{-4} m^2) and temporal scale (e.g. annual) that is irrelevant to the disturbance regime of the forest community growing on the same site (Pickett and White, 1985).

There is no doubt that disturbance is an important and widespread phenomenon in nature. In some of the early work done on disturbance, it is regarded as a mechanism in ecology resetting the inexorable march toward equilibrium (Clements, 1916). Disturbance in isolation was not recognised much in theory of community and ecosystem dynamics until recently though early workers did observe the effects of disturbance in various communities. It may be significant that Clements less influenced researches than others, either because they wrote before his major publications or because they worked in Europe. The independent thinkers who worked particularly in dynamic systems (Egler, 1977) opened the way for the study of disturbance itself as an ecologically significant phenomenon. Those who have followed their lead have often concluded that disturbance is important.

At landscape level, disturbance is related to patch structure and spatial arrangement determines the fate of patches, their size and duration. Severe disturbance or even a prolonged absence of disturbance generally has depressing effect on biodiversity, but intermediate disturbance seems to enhance diversity in a system (Pickett and White, 1985). Disturbance often result in open space, such as gaps in otherwise continuous forest, and they often alter level of resources such as light and nutrients. By creating these open spaces, disturbance creates patchiness in a landscape.

The concepts of disturbance regime and of patch dynamics form a basic framework in which comparative and quantitative studies of disturbance should be couched. Nevertheless the most important concepts of disturbance are embodied in the definition. There are several additional features of disturbance that must be taken into account in understanding it and comparing its role in a variety of situations. Disturbance is often patchy. It may create discrete opening of gaps in either or both of the above or below substrate components of a system. Patches themselves are characterized by sized, shape, dispersion and internal heterogeneity. It is particularly important to state how patches or gaps are defined i.e. what constitutes the lateral border; what constitutes the depth; what minimum and maximum size recognized without such explicit definition, comparison between systems and time will be unproductive (Pickett and White, 1985). In summary, the concept of disturbance can be seen as follows.

a. Disturbance is common to many different systems. It functions or has functioned at all temporal and spatial scales and levels of organization
b. The key processes common to all disturbances are alterations of resource availability and system structure
c. Although an understanding of disturbances is of crucial importance in ecology, no coherent theory exists to further its study. Two major generalisations, one concerning intermediate disturbance intensity and the other the rate of competitive exclusion relative to disturbance frequency (Pickett and White, 1985).

An explicit statement of the parameters that respond to disturbance, the variable that determine the impact of disturbance and consideration of the contest and constraints of disturbance can form the basis of a theory of disturbance.

Pickett and White (1985) enphsized the role of disturbance in ecosystems and landscapes, they found out that ecosystems are influenced by “natural” disturbances: Such influences are expressed as per below.

- Natural disturbances perform critical functions that maintain ecosystem structure and processes.
- All ecosystems have a “natural” disturbance regime to which they are adapted evolutionarily and, in certain cases, can maintain integrity despite rather dramatic large-scale disturbance events.
- Disturbance plays a key role in ecosystem and landscape dynamics specifically, in initiating secondary succession and maintaining ecosystems in a constant state of flux.
- In many landscapes, coarse-scale disturbances generate the patch mosaic structure that constitutes the dominant patterns in the distribution of vegetation. Such disturbance-dominated landscapes have a patch mosaic structure and patch dynamics that governs the abundance and distribution of many species and communities (Pickett and White, 1985).

The intermediate disturbance hypothesis regards disturbance regimes to have a dramatic effect on ecological diversity by creating heterogeneity in the physical environment and interfering with biotic interactions. Disturbance creates conditions that support the greatest diversity of species. This observation has been formalized into what is referred to as the ‘intermediate disturbance hypothesis’, which has the following postulates:

- Species richness will be greatest in communities experiencing some intermediate level of disturbance. This implies that biodiversity will be greatest in ecosystems experiencing intermediate levels of disturbance.
- This relationship is based on the fact that disturbances alter the availability of resources (physical, chemical, and biological) and are the source of multiple levels of environmental heterogeneity, and thus produce the diverse environments that form the basis for resource partitioning among coexisting species.

- At low and high disturbance levels, environments tend toward homogenisation and competitive relationships lead to selection for fewer species that are best adapted to the predominant environment that is produced.

Whenever an intermediate level of disturbance is reached, maximum environmental heterogeneity is maintained. Maximum niche differentiation and maximum opportunities for coexistence of competing species take effect at this stage (Pickett and White, 1985).

2.3 Landscape Fragmentation

In the context of this research, habitat fragmentation shall be defined as the "breaking up of habitat, ecosystem or land cover types into smaller parcels" (Forman, 1995). These smaller fragments of land are referred to as habitat patches. Habitat fragmentation has a major impact on the regional survival of plant species (Saunders et al., 1991; Tilman et al., 1994; Ney-Nifle and Mangel, 2000), and is one of the most important causes of worldwide loss of biodiversity (Vitousek et al., 1997). Habitat fragmentation almost always goes together with habitat loss. With fewer habitats available, less individuals of a particular species restricted to that habitat can survive. Furthermore habitat fragmentation reduces the area of individual habitat patches. A decrease in the area of habitat patches affects the survival probability of the populations in these patches. When the area of habitat patches is reduced, there is a high vulnerability of the conditions in the patches to external influences (Saunders et al., 1991). This means that smaller patches have larger contact zone with their environment, relative to their inner area, as compared to larger patches.

At certain instance higher species diversity may be due to patchiness (Pickett and Rogers, 1995). As a result of increased fragmentation, patch size and edge effect is reduced, this in turn reduces the species richness. Bahera (2001) attempted to validate the findings and observed that fragmentation has got significant impact on species diversity. When fragmentation is increased as a result of urban development it poses threat to biodiversity, increases the amount of habitat edge (effectively reducing interior habitat) and alters the regional biota to varying degrees (Saunders et al., 1991; Vogelmann, 1995; Riitters et al., 2000).

Disturbance and fragmentation are two related processes with strong relationships and it is difficult to distinguish the role and rate of the interactions. Being driven by many factors, disturbance interacts with other processes such as fragmentation, acting in a more restricted situation. Fragmentation has a strong influence on the dynamics and fate of material and energy moving across a landscape. The disturbance regimes can be measured by using different indices i.e., degree of fragmentation, fractal dimension, contagion, juxtaposition, evenness and patchiness (Li and Reynolds, 1994). Attempts have been made to develop disturbance indices in the landscape (Anon, 2001).

Among other factors that could lead to fragmentation are natural disturbance such as fire, windthrows or change in the land use and habitat loss. Activities that could cause habitat loss are clearing of natural vegetation for agriculture or road construction. As a result of fragmentation, fluxes of radiation, wind, water and nutrients across the landscape are altered significantly. Larger remnants and remnants, which are close to other remnants, are less affected by the fragmentation process.

The extent to which habitat fragmentation affects species is more dependent on the extent of the habitat connectivity. In other words, knowledge on the effect of fragmentation on connectivity is needed to access the consequences of habitat fragmentation for species survival.

Small fragments of habitat can mainly support smaller species populations, which tend to be vulnerable to extinction. Additionally, small fragments of habitat do not contain interior habitat. Habitat along the edge of a fragment has a different climate and favours different species to the interior. This implies small fragments are unfavourable for those species with a preference for interior habitat. This situation could result in extinction of those species. Fragmentation has a greater effect on species, which are specialized to particular habitats, and those, which have weak dispersal ability more than those with good dispersal ability i.e. generalist species.

The threat posed by forest loss and fragmentations to local biodiversity has been popularized for nearly two decades (Harris and Miller, 1984). Although spatial heterogeneity is a natural phenomenon, human activity are altering natural landscape by changing the abundance and spatial pattern of habitat. The two most significant effects of fragmentation are a decrease in population size and reduction of species diversity (Zuidema et al., 1996).

Four general types of fragmentation indices, suggested by Dale and Pearson (1997) to describe spatial pattern in habitat maps are: patch or habitat area, frequency distribution of patch size, measure of patch shape, and length of edge between different habitat types.

2.4 Landscape Heterogeneity

Even casual observation reveals that most landscapes are composed of various components. For instance a characteristic rural landscape could have several agricultural cropland, pasture, woodlands, streams, farmstead and roads. Such a landscape is considered heterogeneous thus, it depicts dissimilarity or diversity in its components or elements. Coupled with a noticeable spatial heterogeneity, landscape is temporally heterogeneous.

By definition, landscape is an area having a common geomorphology, climate and disturbance regime encompassing all types, frequencies and intensities of disturbance through time (Mooney and Godron, 1983; Forman and Godron, 1986). Disturbance has been more and more recognised by ecologists as a natural process and source of heterogeneity within ecological communities, revealing a real change in perception during the latter half of the 20 th century from an equilibrial or non-equilibrial view of the natural world (Wu and Louks, 1995).

A complex relationship exists between disturbance and heterogeneity in a landscape. The extent of this relationship depends on the disturbance scale and significant underlying environmental factors. Many studies of disturbance are at too fine scale for practical application. To gain a more complete hierarchical understanding of disturbance, we need to understand these processes at the larger scale. Disturbance may either increase or decrease heterogeneity (Denslow, 1985), whereas landscape heterogeneity may enhance or inhibit the spread of disturbance (Risser et al., 1984).

The type, effect and spatial and temporal scales of disturbance are exceedingly complex. The role of disturbance in ecosystem has received much attention in recent times although little research has been conducted on disturbance at the landscape level; though many environmental problems are managed at landscape level. This confirms the fact that landscape ecology cannot escape dealing with spatial analysis, spatial scale and scale-change effects. A landscape may look heterogeneous at a given scale but rather homogeneous at another scale. As summarized by Risser et al. (1984), homogeneity is often thought to enhance the spread of disturbance. Heterogeneity, on the other hand, may either enhance the spread of disturbance or retard the spread of disturbance if it occurs within the same cover type. Further, the effects of disturbance many increase heterogeneity of the environment and alter the impact of a later disturbance of the same magnitude. Heterogeneity, thus may act as a stabilizing factor (e.g. by spreading the risk) and in fostering disturbance. Important objective of landscape ecology include determination of the interacting effects of heterogeneity and disturbance and the proper management of the interactive effect.

At the landscape level, it is necessary to deal with heterogeneous systems. Previous studies have shown that response to disturbance in homogeneous environment is complex and at the landscape level this complexity increases. However the dynamics of heterogeneous environment have been largely ignored in the mid eighties by the ecological sciences (Risser et al., 1984).

Ecosystem processes vary spatially in response to many factors. For instance temperature gradients, precipitation patterns, and topographic variation produce differences in the rates of processes such as productivity, decomposition, and nitrogen cycling across landscapes.

2.5 Land Use/Land Cover Change Related to Mining

Land cover and land use describe the characteristics of the earth's surface. They reflect the operation of natural as well as anthropogenic processes, and are fluid in time and space. Two major driving forces of land use and land cover change are well documented, natural and anthropogenic (Mannion, 1997; Goudie, 2000). The latter is as well referred to as socio-economic change. Our biosphere is predominantly dominated by human mediated activities and natural events working together to change the natural land cover. Natural changes result from ongoing natural events uninterrupted by human factors. Climate change is one of the most important driving forces of the natural processes creating land use land cover changes (Mannion, 1997; Goudie, 2000). Environmental processes such as desertification and soil erosion are very influential in changing land use and land cover changes even though they do not work in isolation from human mediated factors.

Human influence on the biosphere has also led to the transformation of natural land cover into modified land cover or land use. Anthropogenic factors that cause lands cover and land use change are dynamic. A stimulus of change at a point in time may not be important subsequently. Anthropogenic changes in land cover and land use have occurred much more rapidly than natural process (Mannion, 1997; Goudie, 2000). Such changes have been generated through a range of socio-economic factors such as growth in population, wealth generation, political policies etc.

Whatever the method and whatever the resource, extraction will cause land cover changes at the site of extraction. Coal can be mined in a variety of ways: by deep, opencast, drift or strip mining. In deep mineral mines, land cover alteration may be at a relatively small-scale compared to strip or surface mining where alteration may stretch over wide range of hectares (Urbanska et al., 1997; Fox, et al., 1998; Haigh, 2000). Land cover changes are not only located to the site of extraction. Other mining related factors that result in change in land cover are construction of mining camp, road and tracks, pollution, contamination and reduction of groundwater. The major difference between natural changes and anthropogenic driven changes is a matter of scale, especially temporal scale. The former operate at global as well as regional scale, while the latter is particularly evident at local and, to some extent, regional scales.

Although restoration and reclamation of a mine-damaged land is feasible, they may either be a slow or comparatively fast process. Just as land cover change could be by natural process, reclamation may as well be by natural process (SER, 2004). Recovery by natural process of vegetation succession is slow and could take hundreds of years for full recovery or never recovering at all in some cases. Alternatively, a reclamation scheme could be adapted to a mine-damaged land and subject it to a clear after use. This may be rapid, lasting for approximately two decades.

Mining can have direct impact land use and land cover chang. As stated above, the exact type and extent of land cover alteration that occurs where minerals are extracted depends on the type of mineral and the type of mining. Strip mining is a particularly disruptive method of surface mining because it affects a larger surface area than quarrying of deep mining. In the United States, for example, there has been a big increase in the surface mining of coal and a shift to coalfields west of Mississipi since 1970. Some of the main reasons are increased for surface in western state, concern about safety as surface mining is less hazardous, increased number of power plants near the deposit etc. (Urbanska et al., 1997; Fox, al., 1998; Haigh, 2000).

Mining activities and construction of plant for ore processing frequently have an impact that extends well beyond the mined area. High acidity and high concentration of aluminums are also responsible for the loss of vegetation cover of 3 ha along the eastern edge of the coal outcrop (Bell et al., 2001). This is a problem commonly found in coal-mining areas (Urbanska et al., 1997; Fox, et al., 1998; Haigh, 2000). In addition to high water pH, discharges of heavy metals from mines also have negative impact on the aquatic and littoral lives. Tailings from mines discharged into rivers and lakes cause increased in sediment deposition.

2.6 The Rehabilitation of Mine Damaged Land

Extractions of mineral have a considerable and direct impact on landscape in the form of excavations, tailings ponds and spoil heaps. Furthermore, Knoche et al. (2000) conclude from their monitoring of drainage water characteristic in Lower Lusatian region, Germany, that the ecosystem gradually shift from a state of geochemical-dominated process to a mode of increasing biological control. Restoration schemes to mine-damaged landscape have been used successfully in different parts of the world.

The United Kingdom for instance has established numerous reclamation schemes on mine-damaged land that enjoy a clear after use with reasonable economic returns. Reclamation schemes though successful, have some significant problems to overcome. Unstable substrates, poor nutrient availability especially nitrogen, and lack of a source of appropriate plant species are the major problems to overcome in this region (Bradshaw, 1999).

Schultz and Wiegleb (2000) also documented reclamation scheme in Lower Lusatian region of northeastern Germany where lignite mining (brown coal) has been practiced extensively for almost 150 years. Though 17 mining sites ceased operation preceding reclamation process in 1989, the mining affected landscape area of 800 km2 as a result of lowering of groundwater level. Approximately 85 % of the region is being reclaimed for agriculture and forestry, with the remaining 15 % being given over to nature development.

They reported that one of the major problems to overcome is the presence of mine spoils, which are acidic and sulphurous. Drainage from these spoils contaminates wide range of land leading to high acidity and rapid leaching of nutrient such as calcium, some cations and magnesium. To overcome this problem, substance rich in calcium and magnesium, such as limestone and pulverized fuel ash from power plants were added to the soil in some areas. Addition of nitrogen, phosphate and potassium fertilizer is also important to provide essential plant nutrients. In another development, Bradshaw (1999) ascertained that provision of topsoil is one of the techniques used in reclamation of land damaged by coal though this practice may be pricey.

Heterogeneity that characterizes the Earth’s surface can be described in terms of land cover and land use. The reason why land cover and land use change occurs are often more varied than the changes themselves. Different stimuli lead to similar change in an area; conversely, similar stimuli may generate heterogeneous changes in a given area. As deduced from above, the driving forces of land cover and land use change are many and varied. Natural factors such as climate, soil and geology conspire to produce distinctive type of land cover manifest mostly as natural communities of plant and animals or ecosystems.

2.7 Biodiversity Conservation

Since the convention on Biodiversity was agreed upon Rio in 1992, conservation of biological diversity has attracted the attention of the international community and policy makers in diverse ways. Focus has since been shifted from protection of individual reserve to management of entire landscape. This is because failure to consider biodiversity at a larger scale (ecosystem level) results in risk of negative impacts on important life-support functions, risk of overlooking ecosystem services and failure to understand variation in time and space (TBAG, 2000).

Biodiversity by definition is the variety of life in all its forms, levels and combinations, encompassing genetic diversity, species diversity and ecosystem diversity (FAO). Considering ecosystem diversity of an area, Franklin et al. (1981) recognized three very important interconnected attributes that interact to determine the biological diversity of an area. These attributes are composition, structure and function. Composition embodies range of component present in an ecosystem, structure concerns spatial arrangement of ecosystem component parts and function refers to how different ecological process such as disturbance, nutrient cycling etc. are accomplished and how often are they accomplished.

Genetic diversity is totality of different genes found within population of a particular species and pattern of variation found in different population of same species. Species diversity refers to variety of living species. Ecosystem/habitat diversity relates to various habitat forms, biotic communities and ecological process at work in a particular ecosystem. A very vital element in ecosystem consideration is the natural state; thus the facts that it covers ecological processes such as energy flow and water cycle.

In some literature, habitat diversity is considered a more useful term than ecosystem diversity because habitat has clear boundaries. According to UNEP (1992), ecosystem diversity is the most difficult to measure as compared to genetic and species diversity. In other words, indicators of community diversity put forward by Reid et al. (1993) are fewer in number and basically less developed than species indicators.

In landscape analysis, indices of shape, richness and diversity provide additional evaluation of spatial distribution of land cover within a particular landscape. Landscape analysis also provides outlines of the degree of disturbance and biodiversity change within a period of time (Roy and Joshi, 2002). In disturbance-dominated landscapes such as a post-mining area, patterns may fluctuate widely over time in response to the interplay between disturbance and succession processes that leads to change in biodiversity.

Habitat fragmentation has a major impact on the regional survival of plant species and is one of the most important causes of worldwide loss of biodiversity (Vitousek et al., 1997). The threat posed by forest loss and fragmentations to local biodiversity has been popularised for nearly two decades (Harris and Miller, 1984). Although spatial heterogeneity is a natural phenomenon, human activities are altering natural landscape by changing the abundance and spatial pattern of habitat. The two most significant effects of forest fragmentation are a decrease in population size and reduction of diversity (Zuidema et al., 1996).

2.8 The Use of GIS and Remote Sensing in Landscape Ecology

Depleting biodiversity is a point of focus today because of its enormous importance as a natural reservoir and economic potentials. Spots which represent homes to endangered flora and fauna species, medicinal plants etc. needs to be identified while taking into account the land cover type and human activities around the reservoir.
Research has made it possible to depict an assemblage of dominant growth forms of plant species with a common habitat (vegetation type) through field-based observations. Remote sensing based observation can help identify vegetation and land cover units which were actually missing during field survey as a result of limitation in sampling technique.
This has made remote sensing technique well accepted. GIS gave more dimension to the application of remote sensing based vegetation type map for example, landscape ecology has benefited most from the availability of spatial GIS analysis.

Remote-sensing systems typically produce imagery that averages information over a large location but research is working to advances the spatial and spectral resolutions of sensors which will make direct remote sensing of certain aspects of biodiversity increasingly feasible; for example, distinguishing species assemblages or even identifying species of individual trees (Turner et al., 2003).

As documented by Ravan and Roy (1998), landscape ecology considers vegetation as a mosaic of patches with unique landform, species composition and disturbance gradient. Ravan and Roy (1998) again used GIS for mapping out disturbance zones in natural ecosystem to investigate the impact of such disturbed zones on primary production and biodiversity. Cohen and Goward (2004) also showed how records of LANDSAT data are used with GIS for mapping land and vegetation change and using the derived surfaces as inputs in ecological models. Edenius et al. (2003) used GIS to map the discontinuous distribution of cover types over different spatial scales which proved to be a determinant of range quality for reindeer.

Kerr and Ostrovsky (2003) provide an overview of the use of remote sensing and GIS for predicting the distribution of species and the variability in species richness. Kerr et al. (2001) again demonstrated that habitat heterogeneity, as measured by remotely sensed land cover change could be used to explain Canadian Butterfly richness better than any energy-related variable across spatial scales. Lassau et al. (2005) use high-resolution multi-spectral imagery in GIS to estimate habitat complexity and predict ant species richness in forests around Sydney. Gould (2000) uses remote sensing to detect patterns of vegetation and variations in biodiversity at the mesoscale. Turner et al. (2003) give a clear overview of the challenges and opportunities of using remote sensing in the field of biodiversity and conservation management.
The use of a variability of statistical measures (also called metrics) that describe landscape composition and configuration has aided quantification of land cover structure and its changes over time. The metrics at the level of landscape considers all patch types in landscape and reflect aggregate property of the patch mosaic (McGarigal and Marks, 1995).

GIS would be used in this study to quantify patch sizes, shapes, and patchiness of vegetation types in Schlabendorf. This would help for the estimation of vital landscape characterisation indices such as habitat richness, habitat diversity, heterogeneity, fragmentation and shape complexity. Further benefit from such estimation is the answer to the question “how related is spatial habitat diversity to a field or ground base species diversity”?

The following definitions as applied to landscape ecology are worth noting to enhance understanding of their usage. They are, abitat diversity; this is the mix of habitats; or size variety; or numbers of layers present; or number of types; or evenness of stand sizes and shapes by type. Also relative rarity. Not always lack of similarity. Occasionally differences in an area observed over time (instability). Habitat richness is a measure the number of habitat types present; it is not affected by the relative abundance of each habitat type or the spatial arrangement of habitats. Heterogeneity is the amount of diversity within a selected area or the uneven, non-random distribution of objects - opposite of homogeneity.

2.9 Human and Environmental Impacts on Landscape Dynamics

Progress in landscape ecology research emphasizes the connection between spatial pattern and ecological processes. Temporal transformation in ecosystems coupled with human mediated impact has undoubtedly led to a major variability in most natural landscapes. Naturally, dynamics in landscape processes are still influenced by variation in climatic factors. Thus landscape processes are related to spatial and temporal dynamics in landscapes and are required to be observed and measured. According to Turner and Ruscher (1988), temporal changes in landscapes consist of attributes such as number of patches, patch size and spread of disturbance.

Landscape management is undergoing changes with regard to complexity of viewpoints from generation to generation. A major aspect of these changes is the interaction between human system and ecological system. As confirmed by Holling et al. (1998), interdisciplinary means of inquiry that makes available enough information that unites systems of human and nature is needed. Though spatial heterogeneity is a natural occurrence, human process or activities change natural landscapes by altering the abundance and spatial pattern of habitat. Thus interaction between biological and social complexity makes biodiversity management a formidable challenge.

Human interaction on natural landscape may reduce the trend and extent of natural disturbance. It affects the complexity and connectivity among land cover types in landscape. Human interaction hinders natural processes that favour diversity.
A significant impact of human activity on the environment in recent year has been the impact on landscape dynamics and pattern through natural disturbance regime. A

typical example is the impact of forest management. Such impacts in a natural disturbance regime may be instantaneous or later an ecosystems.

Human activities such as, agriculture and mining have changed natural landscape on a global scale but little is known about the interaction existing between human activities and land cover change, diversity, ecosystem structure and functioning. Even a possible feedback mechanism between them still remains fuzzy. An example is the fuzzy relationship regarding how land use affects spatial distribution, habitat loss and fragmentation.

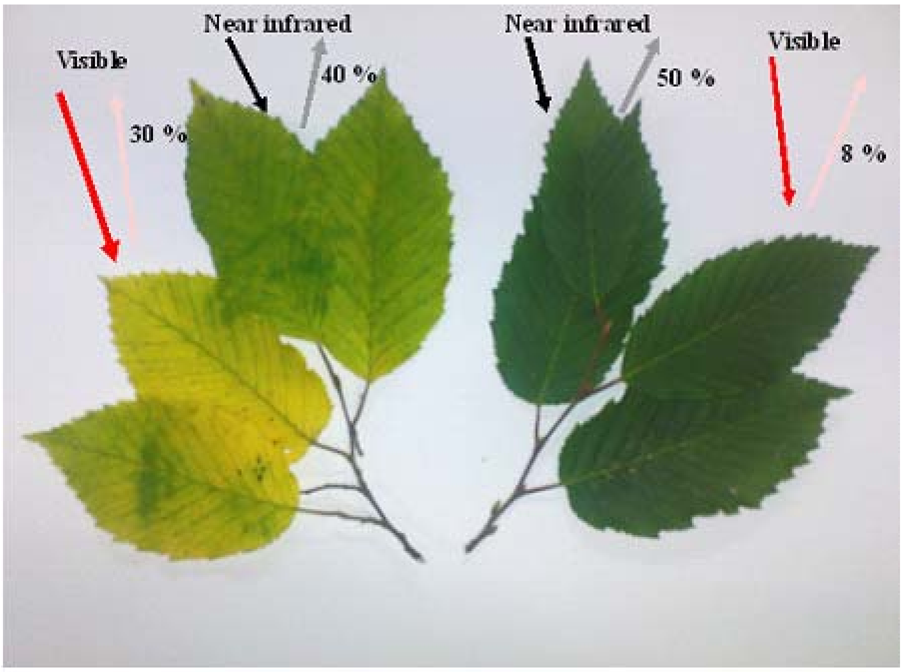
Human activities often result in fragmentation (breaking up of habitats and into smaller parcel). Indicators of human disturbance include logging of plants, road construction; construction or levelling of will be lakes, grazing i.e. higher livestock populations, surface compaction through footpath, and agriculture activity (cultivated land patches).

2.10 Indicators of Primary Production – Biomass Accumulation

The advent of remote sensing has given ecologist a tremendous insight into the spatial and temporal changes of net primary production. According to Running (1988), Young and Harris (2005) launching of the Landsat sensor in 1972, aided the application of remote sensing for the estimation of terrestrial plant production. Ecologist used daily image of the Earth at 1.1m resolutions (produced by the advanced very high resolution radiation satellite) to produce vegetation map of the globe (Justice et al., 1985). The map produced was based on the ratio of the difference between near-infrared and red portion of the spectrum (formula 1). This dimensionless ratio also referred to as normalized difference vegetation index (NDVI), is directly related to photosynthetic activity and provides indirect measure of ecosystem health (Jensen, 1996). Thus the NDVI provides a quantitative measure that indicates vegetation density in an ecosystem.

$$NDVI = (NIR - R)/(NIR+R) \qquad \text{...(1)}$$

When NDVI values of desert landscape and forest landscape were measured, the forest landscape had higher mean NDVI than desert land. Spatial heterogeneity is said to be greater for landscape with intermediate values of the index. Thus the higher the NDVI, the greener vegetations in the habitat are. Riera et al. (1998) realised that heterogeneity measured by NDVI increased as topographic complexity increases. It should be mentioned that, though NDVI is a good measurable indicator, good measurements are best collected in summer and rainy seasons. Figure 1 shows healthy or dense vegetation that absorbs most visible light and reflects most near-infrared light radiations. Unhealthy vegetation, desert and sparse reflect more visible but less near infrared.



$$\frac{(0.40 - 0.30)}{(0.40 + 0.30)} = 0.14 \qquad \frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$$

Figure 1 Absorption of Visible Light and Near-Infrared Radiations by Healthy and Unhealthy Vegetation.

By way of observing the distinct wavelength of sunlight reflected by plants (i.e. visible and near infrared light), researchers are able to determine the density of green in a particular patch of land. The green colouring matter in plant, chlorophyll, at a wavelength of 0.4 to 0.7 mm, strongly absorbs visible light for the synthesis of its food whiles the plant leave cell structure reflect near-infrared at a wavelength of 0.7 to 1.1 mm. If vegetation in a particular land patch reflects radiations in such a way that a significant level of radiation is reflected in the near-infrared wavelength (0.7 to 1.1

mm) than the visible light at 0.4 to 0.7 mm, then the vegetation is said to be dense vegetation such as forest. On the other hand, if the difference in absorption intensity of visible and near infrared is not high, the vegetation is said to be less dense. Example of this vegetation is sparse vegetation or desert.

2.11 Use of Organic Phosphate, Nitrate, Ammonia and pH as Indicators

Plant growth relies significantly on how much phosphorus is available for uptake by the plant. Uptake of phosphorus by plant is in the form of PO_4^{3-} of which three kinds exist. They are orthophosphate, metaphosphate and organic phosphate. Organic phosphate is formed from decaying organic matter or phosphate containing pesticides. Phosphorus is readily absorbed by plant primarily as monovalent ($H_2PO_4^-$) phosphate anion and less rapidly as the divalent anion (HPO_4^{2-}). PO_4 exist in particulate, solution, and loose fragmented forms. Since the early 1990s, phosphate application has proved to be essential for vegetation growth (Stirling-Maxwell, 1907).

According to Sample et al. (1980) low-level phosphorus in the soil is a primary limitation to vegetation growth. This is because phosphorus is usually bound to soil constituent and prevent it availability for plant uptake. Resulting to the use of concentrated phosphorus fertilizer has been used as a means of dealing with low phosphorus availability in the soil (Netzer, 1987).

Early research work has shown that significant relationship exists between level of soil nutrient and species composition in an ecosystem (Tilman, 1994). Phosphorus and nitrogen are nutrient that limit vegetation growth. Salisbury and Ross (1991) realised that, the availability of phosphorus depends on the pH of the soil medium hence making the interaction of phosphorus-pH gradient effective to affect species composition in an ecosystem. On the other hand, phosphorus uptake and precipitation also affect pH of the soil.

Another element needed in substantial quantity in the soil is nitrate (NO_3^-). Nitrate plays a major role in plant growth and health. In the soil, nitrogen may be available in a cation form as NH_4^+ or in an anion form, NO_3^-. Most plants absorb either NH_4^+ or NO_3^- or in some case both. The proportion of these nutrients in the soil can result in a major shift in the soil pH.

The role played by major soil nutrient such as NO_3^- or NH_4^- and PO_4^{3-} coupled with soil pH reflects the structure, composition and health of vegetation in an ecosystem. In other words these nutrients contribute to primary production and may affect dynamics in landscape succession. Consequently, the level of soil nutrient is an influential factor in ecosystem disturbance leading to the extent of diversity observed in an ecosystem under consideration.

Having realised that causes of ecosystem disturbance is either through anthropogenic or natural process, effort to identify which of these processes is the leading cause of an ongoing disturbance is needed to mitigate the extent that may lead to loss of diversity. Most often than not, the interaction between natural and anthropogenic processes is the cause of disturbance. In circumstances like this, being able to visualise the extent of influence and their relationship, would put to rest most speculations regarding the fuzzy nature natural-anthropogenic influence in an ecosystem. A vector layer of points made up of the various soil nutrients, moisture and pH would serve as natural factor dataset. NDVI layer (vector layer) of the study area would serve as biomass accumulation dataset (natural factor). Landscape metrics values depicting land cover characteristics such as diversity and land cover change due to post mining activities can reveal the anthropogenic processes in the post mining landscape.

2.12 Use of Landscape Metrics for Disturbance and Biodiversity Studies

Landscape metrics are regarded as having connection with the actively changing ecological processes such connection still remains unclear. Land cover maps extracted from satellite imagery or aerial photograph are used for computing landscape metrics. The mathematical formulation of landscape metrics has been intensively researched, mostly using artificial raster data or coarse-grain satellite information (Hargis et al., 1998). Patch Analyst offers a comprehensive choice of landscape metrics at the patch, class and landscape levels. It calculates spatial statistics on both polygon files (vector format such as shape files) and raster files (e.g. Arc/Info grids). It provides a number of basic landscape metrics depending on the format of the input map, vector or raster. The grid version provides more metrics as compared to the vector. Table 1 shows a summary of landscape metrics, range of metrics, indication and description of individual metrics type.

In landscape analysis, indices of shape, richness and diversity provide additional evaluation of land cover spatial distribution within a particular landscape. In surface mined areas, profound and rapid alterations occur in the landscape. Thus post-mining areas are best suitable for landscape transformation monitoring research aimed at assessing spatial and temporal changes in landscape pattern.

Table 1 Description of Landscape Metrics Showing Various Types of Metrics, their Indication and Ranges of Acceptance

Ecological Feature	Metrics Indicators	Description	Range
Habitat Richness/ Number of Patches Fragmentation	Number of Patches NP	It is a measure of the extent of subdivision or fragmentation of the habitat type NP = 1 when the landscape or class consists of a single patch	NP ≥ 1, without limit
	Edge Density ED	It measures habitat length in a landscape. ED = 0 when the entire landscape and landscape border, if present, consists of the corresponding patch type.	ED ≥ 0, without limit
Patch /Habitat Size	Mean Patch Size (MPS)	The range in MPS is limited by the grain and extent of the image and the minimum patch size in the same manner as patch area.	MPS > 0, without limit.
	Mean Shape Index (MSI)	It measures the average patch shape or perimeter-to-area ratio, for a patch type or patches in the landscape. MSI = 1 when all patches of the corresponding patch type are circular (vector). It increases without limit as the patch shapes become more irregular.	MSI ≥ 1 without limit.
Evenness Habitat Heterogeneity	Shannon Evenness Index (SEI)	It measures distribution of area among patch types SEI = 0 when the landscape contains only 1 patch (i.e., no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven. SEI = 1 when distribution of area among patch types is perfectly even (i.e., proportional abundances are the same).	0 ≤ SEI ≤ 1
Habitat Diversity	Shannon Diversity Index (SDI)	It is a measure of diversity in community ecology SDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SDI increases as the number of different patch types (patch richness, PR) increases.	SDI ≥ 0, without limit

Furthermore assessment of diversity, habitat richness, heterogeneity etc. in post-mining areas is sometimes inaccessible due to security reasons. Landscape metrics therefore offers a relatively easy and reliable means of landscape monitoring through remote sensing technique. It generally describes the form, configuration, and composition of landscape pattern and covers principal aspects of structural landscape assessment of crucial ecological meaningfulness (Lang and Tiede, 2005). The metrics are good analytical tools for monitoring diversity and fragmentation of habitat over time and expresses landscape diversity by means of patch richness. The metrics indicators in Table 1 represent which ecological features are being investigated.

The metrics generate quantitative measurement of the environmental condition or vulnerability of an ecological region. The generation of landscape metrics is sometimes complex and lengthy requiring substantial GIS expertise.

3 Materials and Methods

3.1 Descriptive Methodology Aspect

3.1.1 Data Acquisition and Spatial Database

Spatial data by definition is anything having a location in a given global space with zero size (point) or non-zero size (Benson and Zick, 1991). Spatial data are divided into location data (part of GIS indicating location of an object) and attribute data (indicates information about spatial object excluding its location). In other words, spatial data refers to combination of location and attribute data. Storage of spatial data in GIS is both vector or raster format, indicating that, acquisition of data to build a comprehensive database would require creation of vector and raster (cell-based) GIS database from various input sources. For purpose of spatial analysis or relations, either topology from vector environment or cell-by-cell model of the raster environment was used. To extract features from imagery in order to analyse area, perimeter etc., the vector format was useful. In order to make spatial data comparable, standard coordinate system and same resolution were kept throughout the work. An extensive spatial database was established to aid change detection, feature extraction, and feature classification and also help the integration of new data in the dataset.

Quantifying the land cover structure, its change over time and associated diversity change requires the use of a variability of statistical measures also known as metrics. Area, patch density & size, edge, shape and diversity metrics have been used greatly in this respect. These metrics describe landscape composition and configuration. These metrics can be used as quantifiable standard and indicator for biodiversity (Antwi and Wiegleb, 2008).

Hargis and Bissonette (1998) examined the behaviour of landscape metrics by generating artificial landscapes that mimicked fragmentation processes while controlling the size, shape, and placement of disturbance patches. They created nine series of increasingly fragmented landscapes that differed in the patch size or shape used to represent disturbance and used these landscapes to investigate patch edge density, perimeter-area and diversity.

The Patch Analyst calculates spatial statistics on both polygon files (vector format such as shape files) and raster files (e.g. Arc/Info grids). It offers a comprehensive choice of landscape metrics at various levels. At the level of patch, individual patches were considered and metrics at the patch level characterises spatial and context of patches. At the class level, the metrics are considered for all patches of a particular patch type. The metrics at the level of landscape considered all patch types in the entire landscape and reflect aggregated property of the patch mosaic (McGarigal and Marks, 1995). By definition, a 'patch' is each individual occurrence of a particular land cover type in the landscape. A 'class' is the occurrence of a particular cover type in a landscape (Graves and Bourne, 2001). In Table 2, a complete overview of the landscape metrics used is given. All metrics used in this study are applicable on both shape and grid theme.

Table 2 Summary of Relevant Landscape Metrics used for the Study, their Abbreviations and Unit of Measurement.

Selected Landscape Metrics	**Abbreviation**	**Unit**
Area Metrics		
Total Landscape Area	TLA	ha
Patch Density & Size Metrics		
Number of Patches	NUMP	
Mean Patch Size	MPS	ha
Patch Size Standard Deviation	PSSD	ha
Edge Metrics		
Edge Density	ED	m/ha
Shape Metrics		
Mean Shape Index	MSI	
Mean Patch Fractal Dimension	MPFD	
Diversity Metrics		
Shannon's Diversity Index*	SDI	
Shannon's Evenness Index*	SEI	

* Denotes applicable only at the landscape level.

Selection of metrics in Table 2 was based on their applicability to vegetation and landscape analysis at a landscape level, their suitability to the format of the dataset (vector) and their ability to provide needed explanation to landscape characteristics such as area, patch density & size, edge, shape and diversity.

Spatial statistics of the landscape generated as described by Riitters et al. (1995) are as follows. Area and perimeter fields and values were added to the attribute table with the 'Add Area/Perimeter' tab. To generate result in desirable units, the map units were set from the view properties dialog box. Every patch in the dataset had a unique record in the attribute table and boundaries of adjacent patches that belong to the same themes were dissolved. In order to analyse interior of patches, core area theme was created. From the spatial analysis dialog box, request to generate landscape metrics were made and the appropriate theme and analysis level were selected. Outcome of the computations was displayed in an output statistical table. Figure 2 shows all the stages involve in computing the landscape metrics from raster and vector data sources. In this research, vector format was used.

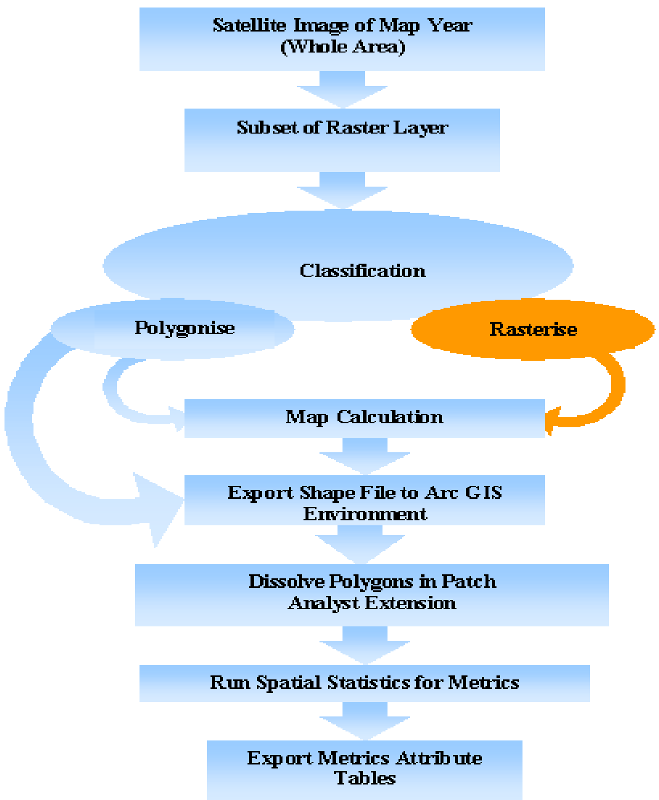


Figure 2 Diagrammatic Illustration of Landscape Metrics Computation From Raster and Vector Dataset.

3.1.2 Overview of Field Data Collections and Measurements

Landsat TM satellite images of the various map years were used to identify habitat types (mosaic of patches) in the area. Supervised and unsupervised classification methods were used for classification of the images. Information on diversity change, fragmentation and indication of disturbance were provided by Patch Analyst, which displays landscape characteristics of the area. The simple random sampling design aided by GPS was used to collect field sampling data points (Kent and Coker, 1992). Other data on location of soil and environment were acquired by the use of GPS.

Vagarious raster data sets of the area were generated to provide understanding to the influence of individual prevailing natural factors and the land cover changes. Among them is NDVI raster data set, which provided detail information on biomass accumulation. Raster layer of soil parameters provided detailed accounts of the acidity or nutrient status of land cover types indicating the influence of natural factor on land cover changes.

Other data types used are annual temperature reading, annual rainfall, soil parameters etc. Land cover map provided needed account of land cover change values and land cover characteristic over the study period. Most of the analysis done in this work required continuous data collection which was a major set back due to the absence of same data set or data that does not cover the entire study area.

Location of points such as geolocation of soil samples (point data) were done by using the Garmin GPS 12 (global positioning system) device. The data was collected in the Universal Transverse Marketer (UTM) coordinate system (Zone 33N. projection). Georeferecing was based on the WGS 1984 UTM. This was to conform to already georeferenced satellite images.

3.1.3 Image Classification, Change Detection and Accuracy

The Image Segmentation and Object-oriented method used employs software called eCognition9. The eCognition9 cements multispectoral images into homogeneous object or regions based on spectral and spatial properties of neighbouring pixel rather than using recognition algorithms which functions by using pixel-by-pixel. Figure 3 shows steps involved in the image segmentation and object-oriented classification process used.

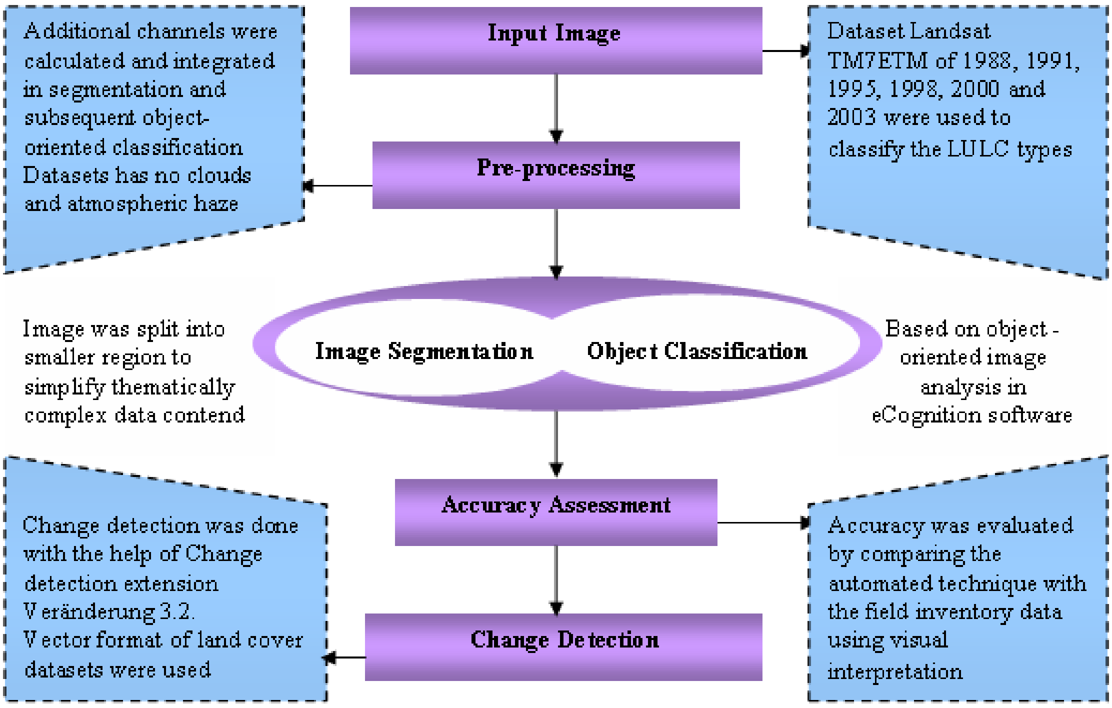


Figure 3 Diagrammatic Illustration of the Image Segmentation and Object-oriented Classification Methodology.

Image segmentation (subdivision of an image into separated regions) must be done before classification. Image object (from segmentation) serves as information carriers and building blocks for further classification or other segmentation. Generalization of objects was done through adjustable homogeneity criteria such as colour shape, and texture. The classification is based on standard nearest neighbour approach. Nearest neighbour is a classifier used to classify image - objects based on a given sample objects within a defined feature space (eCognition User Guide, 2002). The classified data was used as input image for change detection, using the change detection statistics tool, Veränderung 3.2.

According Richards (1993), knowledge-based (supervised) image classification involves expert knowledge to classify the image. Our knowledge from spectral characteristics played a major role. Differences in vegetation reflectance at the near-infra red band and the visual part of the electromagnetic spectrum also referred to as NDVI ranges from –1 to +1 was used to support classification of the images.

Classification accuracy of remotely sensed data is best represented by means of an error matrix also referred to as confusion matrix (Congalton, 1991). In remote sensing, accuracy of any classification is for the purpose of finding out how well selected reference data or ground truth conforms to classified data. A confusion matrix represents map data points on rows while ground truth data points are represented by columns. To acquire high accuracy in classification depends on how much training data is available.

3.1.4 Conceptual Model of Disturbance, LCC and Prevailing Factors

The conceptualised model in Figure 4 was formulated base on the definition, causes and effect of disturbance. The underlining concept of this research is the idea that disturbance has inhibitory effect on primary production or biomass accumulation in a landscape. This is due to the direct removal of flora and destruction of stable ecosystems. Disturbance is also thought to have indirect effect on habitat diversity in an ecosystem. This is because disturbance is patchy and patches formed are characterized by varying size, shape, dispersion and internal heterogeneity.

The question is, are the ongoing land cover changes in post-mining landscape due to anthropogenic causes, natural causes or the interactive effect of the two? Anthropogenic factors that cause lands cover change are dynamic and occur much more rapidly than natural processes.

Natural changes result from ongoing natural events uninterrupted by human factors. These include change in temperature and rainfall etc. Climate change is one of the most important driving forces of the natural processes creating land use land cover changes (Turner et al., 1993).

Another background of the model is the finding that mining in Schlabendorf has left behind nutrient deficient soil that eventually cannot support plant growth. Low soil pH from lignite mining also affects or inhibits primary production since some plants cannot thrive in acidic conditions (Figure 18, page 66).

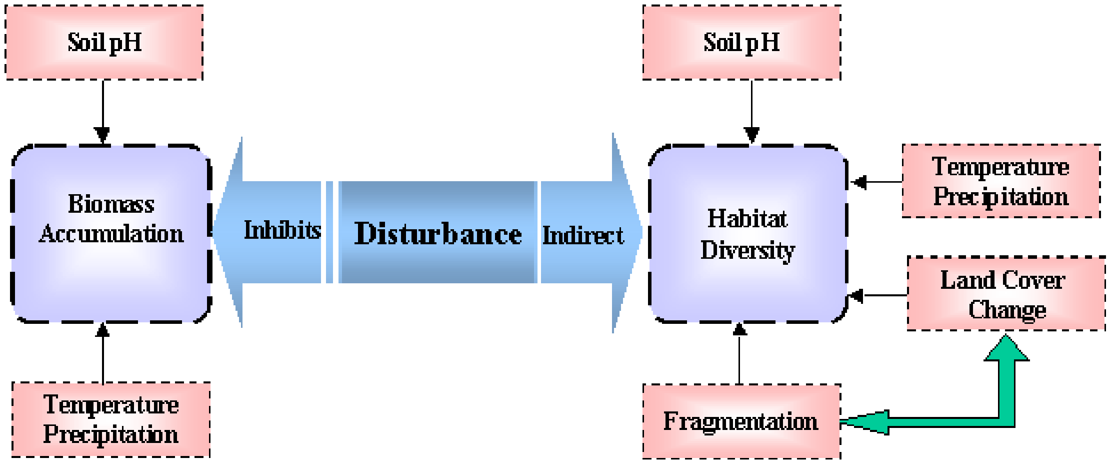


Figure 4 Conceptual Model Showing the Relationship among Disturbance and Natural Events or Anthropogenic Events.

Fragmentation and land cover change are also thought to contribute to disturbance in an ecosystem. Disturbance regimes can be measured by using different indices such as the degree of fragmentation, fractal dimension, evenness and patchiness (Li and Reynolds, 1994).

The impacts of the interactions among the above factors on disturbance in the post-mining landscape are the main concept of this research.

3.2 Study Area

The post-mining area, Schlabendorf, regarded as an extremely disturbed area in Lower Lusatia region, Germany, was selected as the study area. It is located at the southeastern border of north German lowland. Geographical coordinates of the Schlabendorf village (UTM: V14 in decimal degrees) are latitude 51.817 and longitude 13.817. Schlabendorf village is located between the study area (Figure 5 of page 50) dividing it to Nord (North) and Süd (South). Mining activity in this area started in 1975 to 1991 where the last mining activity occurred. Schlabendorf Süd covers an area of 3,035 hectares (ha) and 16 years of age since dumping.

Schlabendorf Nord on the other hand is 2,585 ha in area an 32 years of age since damping. The region experiences continental climate with annual temperature from 1988 to 2003 averaged 8.9 ^{o}C. The mean annual precipitation from 1988 to 2003 is 470 mm (Deutscher Wetterdienst).

Wiegleb (1996), Blumrich et al. (1998), and Wiegleb and Felinks (2001a,b) gave detailed account on the ecological and socioeconomic problems in the area. Information about dominant vegetation types and ages are given by Weichelt et al. (1997), Felinks et al. (1999a), Wiegleb and Felinks (2001a, b). The dominant land use type in the non-mining area is forestry. It covers approximately 70 % of the total area. Some habitat types found in the area are sparse vegetation, bare sand, grassland etc. Land cover types and description of dominant vegetation in Schlabendorf during the study period are shown in Tables 2 of page 43 and 3 of page 51, Figures 6 to 17 of pages 53 - 59. Common herbivores species found in the area include roe deer, wild boar, hare, red deer etc.

Schlabendorf is characterised by sandy spoils on lignite rich tertiary sediments with extreme abiotic condition due to low soil pH. The dumped mine spoils were ameliorated in some areas with nitrate, phosphate, and potassium base fertilizer as well as ashes from plants. The substrate has dry habitat condition due to low water retention capacity, high evaporating rate, high surface temperature etc. Not withstanding the influence of these factors (poor soil nutrient), farm yield in the region is not affected since agriculture is traditionally of minor importance in the area (Mrzljak and Wiegleb, 2000).

Human impacts on biodiversity operate differently at different spatial scales and have resulted in changes over time within-habitat (local), habitat-mosaic (landscape) and macro-scale (‘regional’) diversity (Weber et al., 2004). For the purpose of meeting the objectives of this research, the scale of assessment was based on diversity within habitat types in the landscape (habitat-mosaic). The boundaries of Schlabendorf Nord and Schlabendorf Süd are as shown in Figure 5. The area is considered suitable for this study due to the following reasons (Wiegleb, 2001a).

a. The landscape has the potential of forming extremely large man made lakes with high concentration of acid (down to pH 2.1) that affects water bodies, other plants and animal lives (e.g. seasonal migratory birds) in the ecosystem.
b. The need to restore the damaged ecosystem and open up new land use possibilities in the region (Federal Office for Building and Regional Planning, 2001).

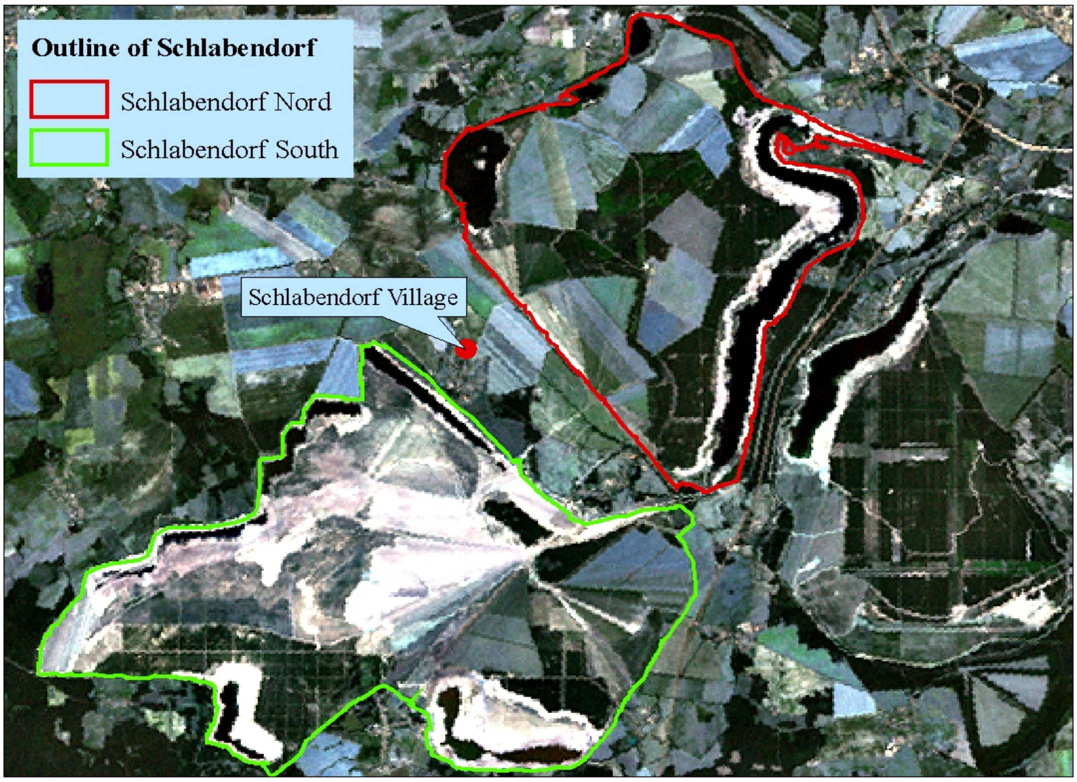


Figure 5 Outlines of Schlabendorf Nord and Schlabendorf Süd on a LANDSAT TM Image of 2000.

In Table 3, description of dominant vegetation types found in the land cover types are shown. The description of dominant vegetations in Table 3 focuses on component species in the LC classes rather than a more generalised comparative description of biotopes in section 3.6.2 (See Table 6 of page 63) based on field and remote sensing data. The total number of land cover types in both areas was eleven. Table 4 (page 52) indicates wetland was not present during 1988, 1991, 1998 and 2000 in Schlabendorf Nord. Afforestation of pine trees, afforestation of deciduous trees and afforestation were not present in Schlabendorf Süd during the study in 1988, 1988 and 2003 respectively (Table 4 of page 52).

Table 3 Description of Dominant Vegetation Cover in the Land Cover Types in 1988, 1991, 1995, 1998, 2000 and 2003. (Antwi and Wiegleb, 2008)

Type of land use	Description of vegetation types (dominant species)
Afforestation of Pine Trees	Pine afforestation from Pinus sylvestris and Pinus nigra.
Mixed Grassland and Trees	Mosaic of pine trees, deciduous trees and grassland species.
Afforestation (mixed forest)	Mosaic of mixed pine and deciduous trees some of which were from natural succession and afforestation.
Afforestation of Deciduous Trees	Indigenous Quercus petraea, Betula pendula and Salix spec Introduced species of Quercus rubra, indigenous trees like Tilia cordata, Betula pendula and Quercus petraea.
Agriculture Land	Cultivated area of wheat, maize, barley, alfalfa, grassland, meadow, quiescence, mixture of wheat and rye; and rape.
Sparse Pioneer Grassland	Sparse vegetation (on bare sand) consisting Corynephorus canescens, Deschampsia flexuosa.
Dry Vegetation	Psammophytic grassland, Festuca rubra, Festuca ovina agg. Corynephorus canescens, Helichrysum arenarium, Jasione montana, Conyza canadensis, Rumex acetosella, Hieracium pilosella, Calamagrostis epigejos.
Open Sand	Vegetation free area and lakeshore free of vegetation.
Dry Grassland	Dry sparse sown grassland (seeded grassland) and dense sown grassland of Cirsium arvense, Calamagrostis epigejos stand, Daucus carota, Epilobium angustifolium, Epilobium ciliatum, Epilobium tetragonum, Hypericum perforatum, Festuca rubra, Festuca ovina agg.
Lake	Body of acidic water (of considerable size) usually surrounded by open sand.
Wetland	Reeds and grass species usually on waterlog surface or bare sand.

The presence or absence of a particular class was indicated in Table 4; with an '*' representing land cover types present and '–' representing land cover type absent.

Table 4 Dominant Land Cover Types found in Schlabendorf Nord and Schlabendorf Süd in 1988, 1991, 1995, 1998, 2000 and 2003

No.	Land Cover Type	Present											
		1988		1991		1995		1998		2000		2003	
		N	S	N	S	N	S	N	S	N	S	N	S
1	Afforestation of Pine Trees	*	-	*	*	*	*	*	*	*	*	*	*
2	Afforestation	*	*	*	*	*	*	*	*	*	*	*	-
3	Afforestation of Deciduous Trees	*	-	*	*	*	*	*	*	*	*	*	*
4	Dry Vegetation	*	*	*	*	*	*	*	*	*	*	*	*
5	Agriculture Land	*	*	*	*	*	*	*	*	*	*	*	*
6	Mixed Grassland and Trees	*	*	*	*	*	*	*	*	*	*	*	*
7	Sparse Pioneer Grassland	*	*	*	*	*	*	*	*	*	*	*	*
8	Dry Grassland	*	*	*	*	*	*	*	*	*	*	*	*
9	Open Sand	*	*	*	*	*	*	*	*	*	*	*	*
10	Wetland	-	*	-	*	*	*	-	*	-	*	*	*
11	Lake	*	*	*	*	*	*	*	*	*	*	*	*

'*' represents land cover type present in a particular period

'–' represents land cover type not found in a particular year

'N' represents Schlabendorf Nord and

'S' represents Schlabendorf Süd

Coal mining in Lusatia has directly devastated an area of 800 km^2, of which 2.500 km^2 was affected by lowering of ground water. According to Schultz and Wiegleb (2000), the post mining landscape is rather diverse with respect to age and technique use in mining. The state of the post-mining landscape in 2000 showed:

a. Quasi-natural areas, incl. fracture cavities in the old underground mining areas, small mining pits, and areas of 70 years natural succession,
b. Recultivated areas (ca. 50 %) of the former GDR with more or less intensive land cover such as forestry and agriculture
c. Recently abandoned mines with large rest-holes and dangerous areas (incl. both steep slopes, with the danger of sudden settlement of sandy dumps, and large vegetation free plain areas, with the danger of wind erosion)

The study is part of the SUBICON (Fkz01LC0018), a sub-project of BMBF BIOLOG EUROPE collaborative research project on successional change and biodiversity conservation being investigated at the department of ecology, BTU Cottbus. SUBICON project looks into the mechanism of changes and maintenance of biodiversity of selected functional groups in red oak ecosystem.

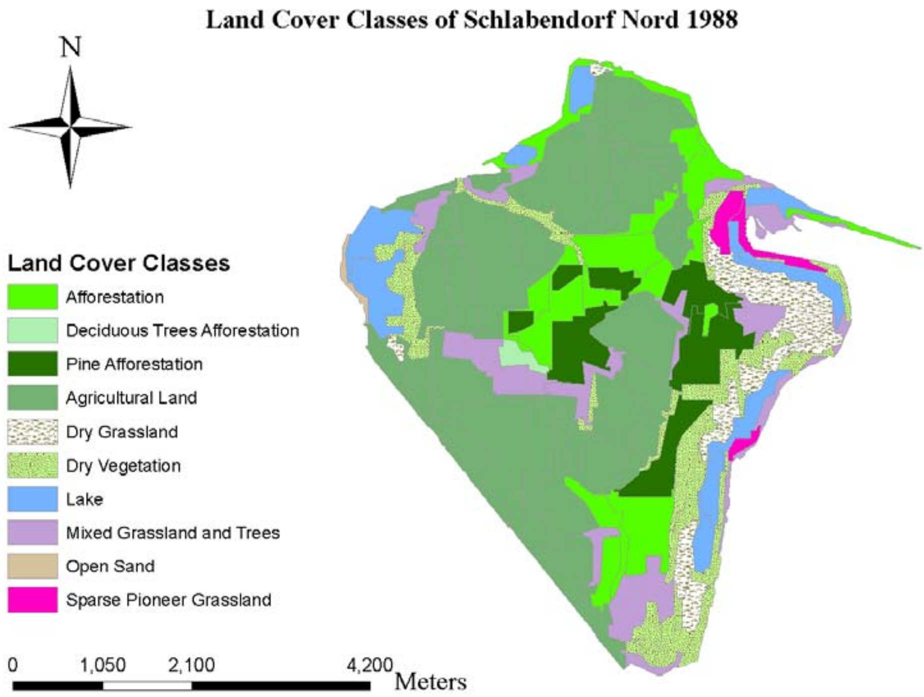


Figure 6 Final Classification of Land Cover Types in Schlabendorf Nord 1988 showing Land Cover Classes without Wetland.

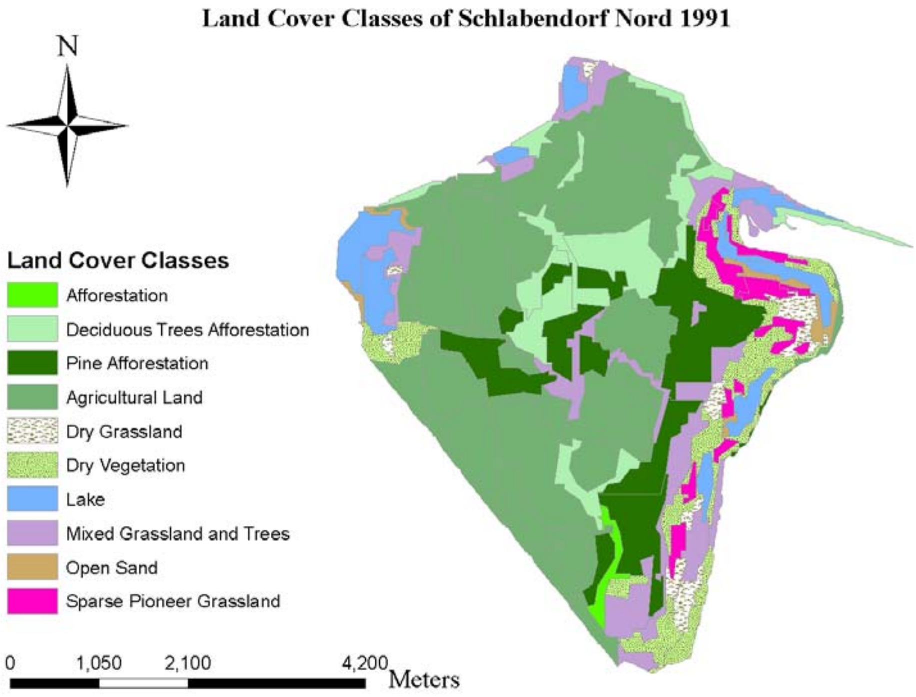


Figure 7 Final Classification of Land Cover Types in Schlabendorf Nord 1991 showing Land Cover Classes without Wetland.

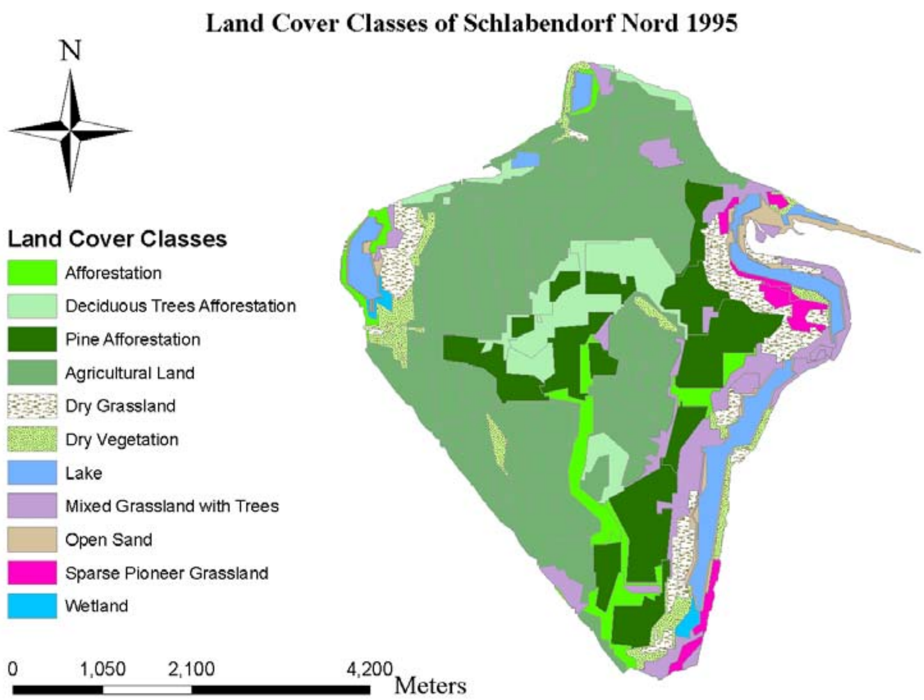


Figure 8 Final Classification of Land Cover Types in Schlabendorf Nord 1995 showing Land Cover Classes together with Wetland.

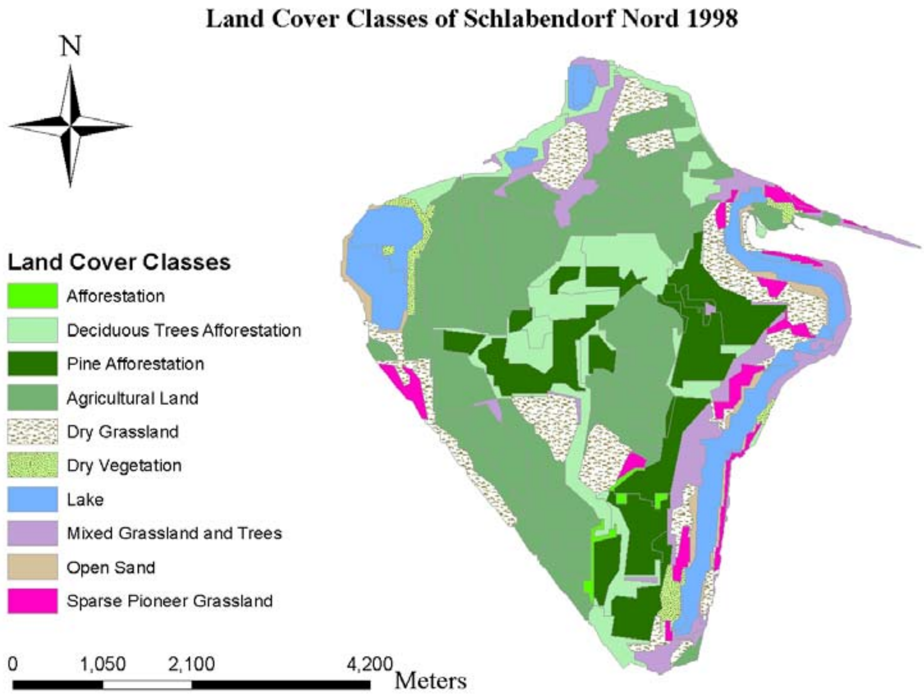


Figure 9 Final Classification of Land Cover Types in Schlabendorf Nord 1998 showing Land Cover Classes without Wetland.

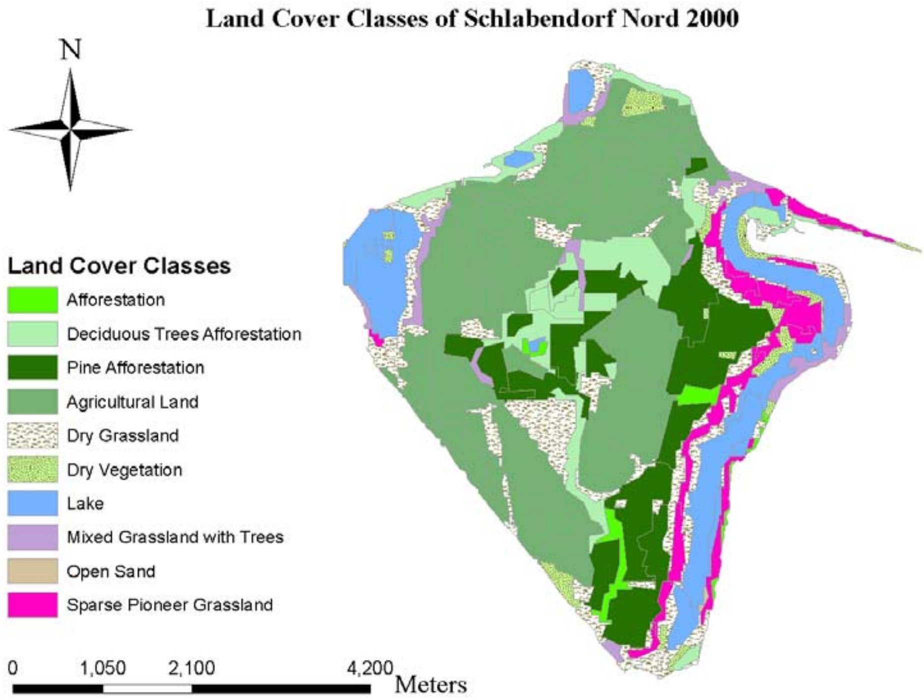


Figure 10 Final Classification of Land Cover Types in Schlabendorf Nord 2000 showing Land Cover Classes without Wetland.

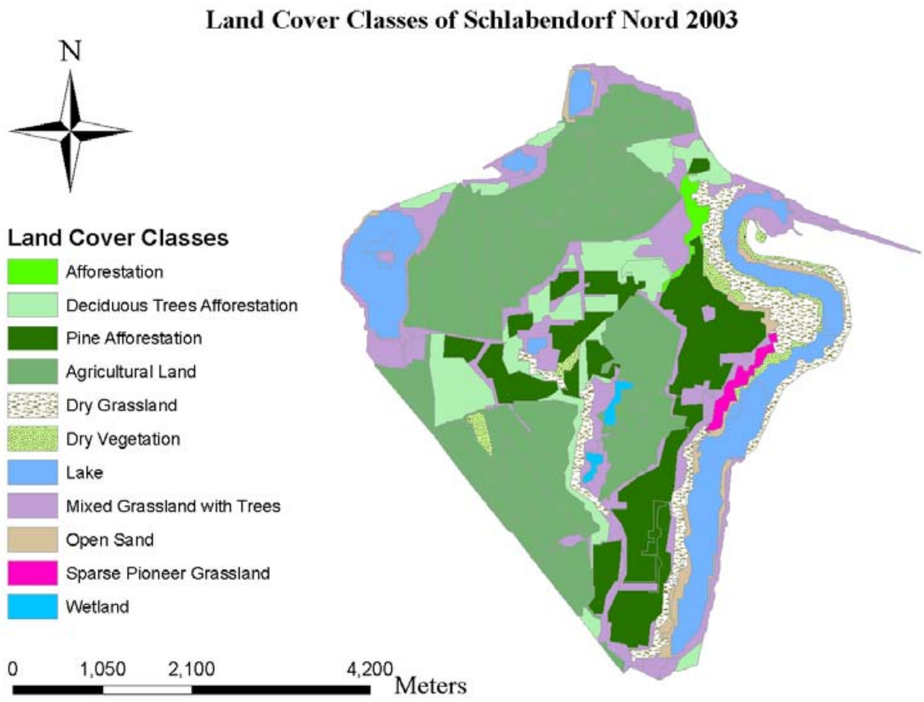


Figure 11 Final Classification of Land Cover Types in Schlabendorf Nord 2003 showing Land Cover Classes together with Wetland.

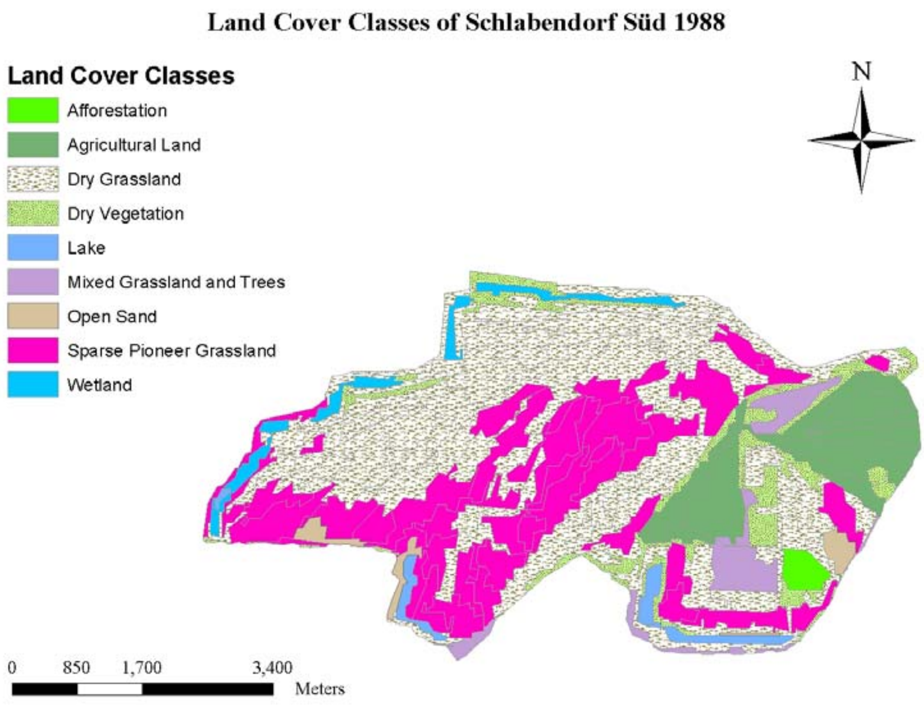


Figure 12 Final Classification of Land Cover Types in Schlabendorf Süd 1988 showing Land Cover Classes with Wetland. Missing area was not mined in 1988.

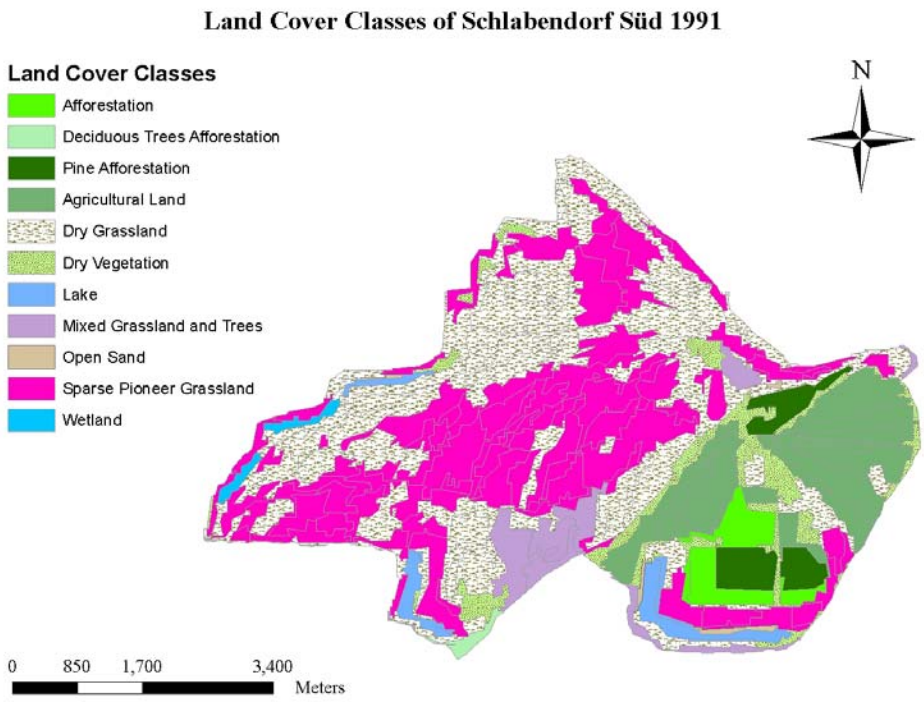


Figure 13 Final Classification of Land Cover Types in Schlabendorf Süd 1991 showing Land Cover Classes with Wetland.

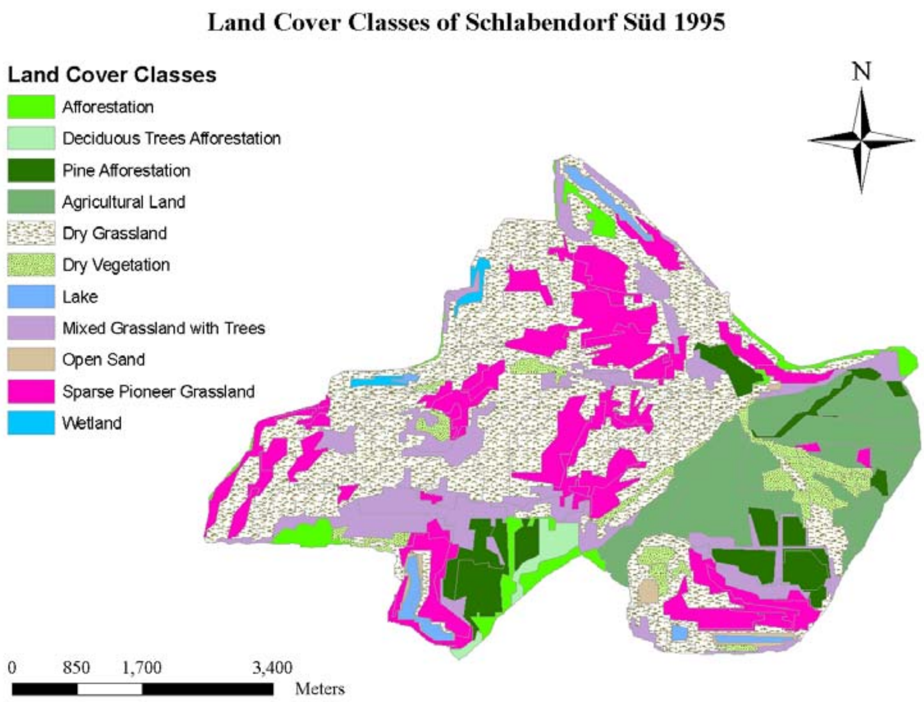


Figure 14 Final Classification of Land Cover Types in Schlabendorf Süd 1995 showing Land Cover Classes with Wetland.

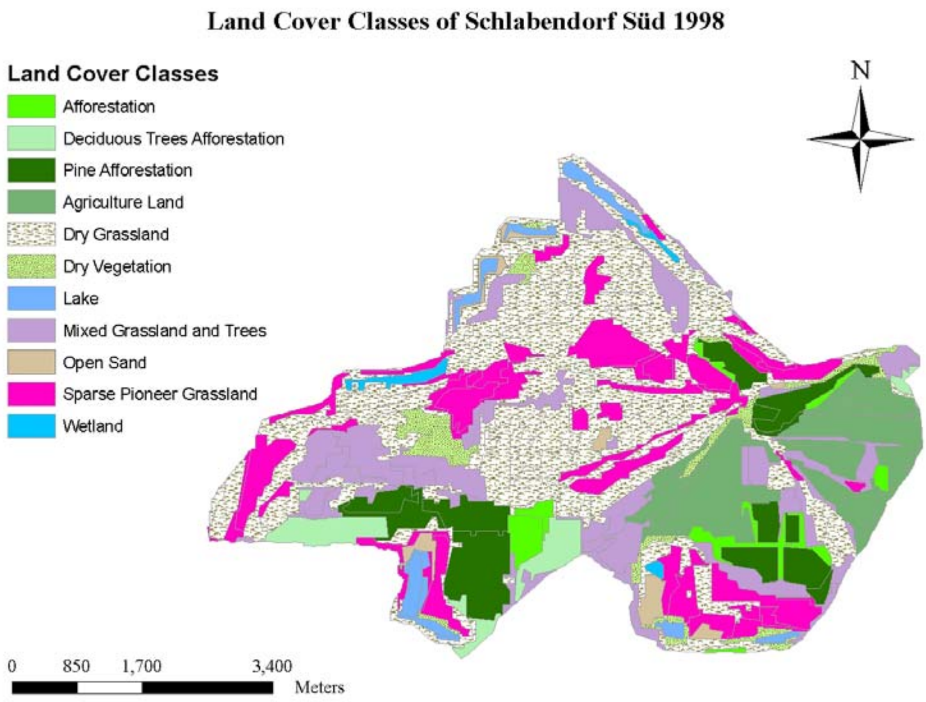


Figure 15 Final Classification of Land Cover Types in Schlabendorf Süd 1998 showing Land Cover Classes with Wetland.

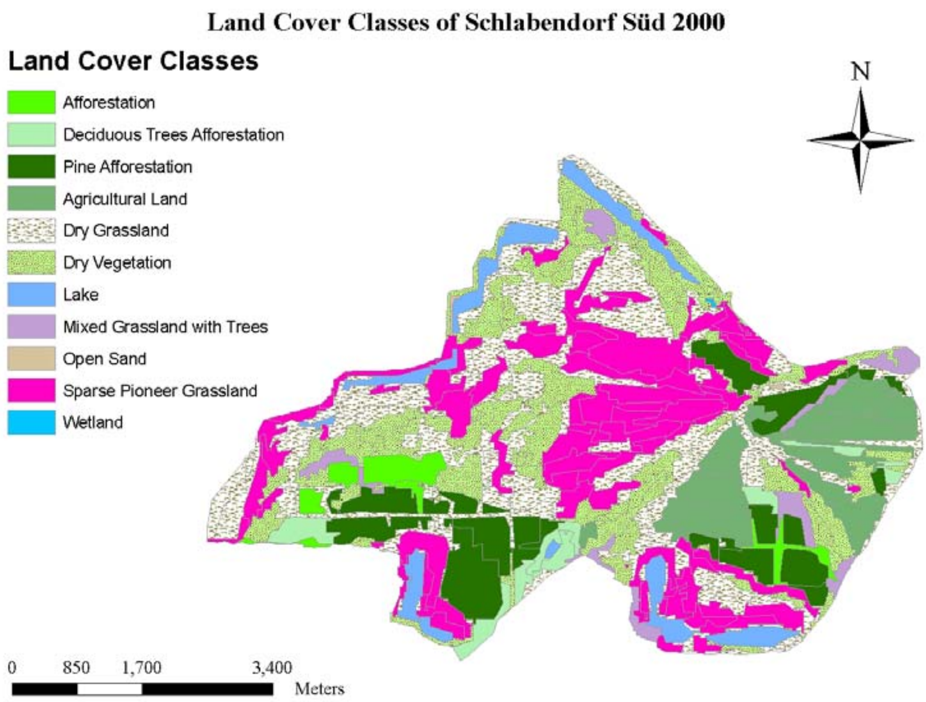


Figure 16 Final Classification of Land Cover Types in Schlabendorf Süd 2000 showing Land Cover Classes with Wetland.

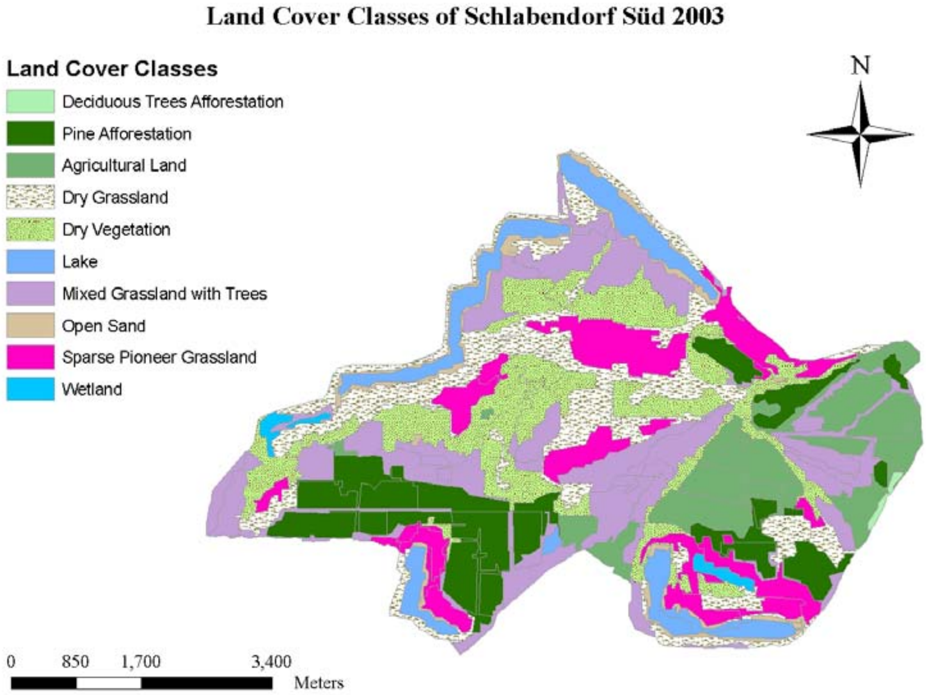


Figure 17 Final Classification of Land Cover Types in Schlabendorf Süd 2003 showing Land Cover Classes with Wetland.

3.3 Data Acquisition and Spatial Database

Satellite imagery (LANDSAT TM and SPOT) of the post-mining area in the years 1988, 1991, 1995, 1998, 2000 and 2003 were used to survey the changing landscape. Land cover maps were formed from these images. The land cover types were classified based on the dominant vegetation type present at the area during the study period (See Figures 6 - 17 of pages 53 - 59). Land cover types were aggregated into 11 vegetation classes (land cover types) represented by aggregation code.

Descriptions of landscape metrics computation from patch analyst often require expert knowledge. For each land cover map year; 1988, 1991, 1995, 1998, 2000 and 2003 in both study areas, land cover statistics were calculated and landscape metrics were computed using Patch Analyst version 3.1, for the entire study area including individual vegetation classes.

3.4 Field Data Collections and Measurements

3.4.1 Soil Samples Collection

1000 g of soil samples were taken from the topsoil layer at a depth of 0 - 10 cm (AG soil 1994). The samples were kept in airtight plastic bags and kept at a low temperature in an ice chest to avoid further biotic activities. When brought to the lab, the soil samples were sieved to remove stones debris and other large particle in it. The sieved samples were kept under freezing condition for further tests to be conducted. The soil samples were taken during the vegetation period, thus frost protected period.

3.4.2 Climate Data (Temperature and Precipitation) Measurements

Effects of climatic factors particularly precipitation and temperature on soil moisture is very influential for biotic communities in sandy soils (Jucevica and Melecis, 2002; Petersen et al., 2004). The average monthly temperature variation from 1988, 1991, 1995, 1998, 2000 and 2003 were used as the input data for assessing the role of temperature in the landscape transformation. Regarding precipitation dataset, average monthly precipitation data from 1988, 1991, 1995, 1998, 2000 and 2003 were used for monitoring the effect of rainfall on the changing landscape.

Precipitation and temperature data from the meteorological station in Cottbus (Deutscher Wetterdienst) were used. The station located among Schlabendorf Nord, Schlabendorf Süd and Seese West was deemed to record temperature and precipitation data reflective of the study area.

3.5 Determination of the pH-value from Soil Samples

Determination of soil pH (i.e. hydrogen ion) is aimed at studying the influence of soil pH on primary production, availability of nutrient and diversity of microbial population. Equipments used are pH-meter with one-stick measuring chain, PE- bottle (100 ml) and overhead shaker. Chemicals used are 0.01 molar solution of Calcium chloride $CaCl_2$ - (1.47 g of $CaCl_2$ * $2H_2O$/l) dissolved in demineralised water.

A 10g soil duplicate samples were weighed for each of the soil samples, sieved through a 2 mm mesh, homogenised and air-dried in a 100 ml PE bottle. In the first bottle containing the 10 g soil sample, 25 ml of Calcium chloride ($CaCl_2$ = 0.01 mol/l) was added. 25 ml of distilled water was added to the second bottle also containing the other 10 g soil sample. The first and second bottles were closed and placed in the overhead shaker for 5 minutes of strong shaking. The content of both bottles were allowed to settle for about 1 hour.

After a careful calibration of the pH meter, pH(s) of soil samples collected were determined (on the basis of both calcium chloride and water). During the pH measurements the diaphragm was dipped completely into the solution and readings were made only after reading on pH meter was stabilised.

3.6 Image Classification, Change Detection and Accuracy

3.6.1 Spatial and Remote Sensing Accuracy Issues

Overall accuracy was computed by dividing total number of correctly mapped data point (or sample data point) by total number of points. It indicated the probability that a randomly selected point on the map is correctly classified (Table 5). The more training data (sampled points) is available, the more accurate the classified data.

Various sampling designs are available but the most important issue is that sample taken should be representative. The field sample design used is the simplest sample design referred to as simple random sampling. In this method each element has equal chance of being sampled. Though it is representative, many points were needed for each sampling. The number of point used for sampling were 861 points in 1988, 1067 points in 1991, 1108 points in 1995, 1160 points in 1998, 1293 points in 2000 and 1130 point in 2003. The sample points differed with sizes of landscape and the number patches available. These sample points belong to classification made for Schlabendorf Nord and Schlabendorf Süd together.

In the context of land cover studies, the recommended sampling method is the simple random sample stratified sampling (where area is allocated into sub-population with each sub-population randomly sampled independently) (ITC, 1999).

Table 5 Overall Kappa Statistics and Overall Accuracy for the Classifications

Year	Overall Accuracy (%)	Overall Kappa Statistics (%)
2003	97.35	97.04
2000	98.22	98.01
1998	96.90	96.53
1995	97.92	97.69
1991	96.16	95.76
1988	95.70	95.23

To ensure classification output is not as a result of chances, Kappa, the coefficient of agreement was used. The overall Kappa calculated for all classes together is a determinant of below average map quality, equal or above a random agreement and also give quantitative value of this agreement. Table 5 shows the overall Kappa statistics for all the classifications. The following are the Kappa values and what they represent. The two extremes are -1 to 1 (or -100 to 100) represents map that does not correspond to ground truth. 1 implies map has the same attributes as validation data 0 means random agreement (ITC, 1999).

3.6.2 Field-based and RS-based Biotopes in Schlabendorf

Biotope by definition is an area of uniform environmental condition that provide living place for specific assemblage of plant and animals. Table 6 provides comparative descriptions between nomenclatures of field supported biotope type and remote sensing-based biotope collections.

Table 6 Overview of Field Biotope and Remote Sensing based Biotope in Schlabendorf

Biotope Type	Field-Based Biotope	RS-Based Biotope
Grass and Herbs	Wild Grassland	Sparse Grass and Herbs
	Cultivated Grasses	Moderately Dense Grass and Herbs
	Dense Grassland Calamagrostis	Dense Grassland and Herbs
Site Without Vegetation	Bare Soil	Bare Sand
Water and Reeds	Lake	Lake
	Reeds	Reeds
		Mosaic of Shrubs and Reed
Wooden Forest	Young Forest on Dry Site	Pioneer Forest
	Afforestation	Afforestation
	Hedges and Heath land	Shrubs and Bushes
	Deciduous Forest	Deciduous Forest
	Coniferous Forest	Pine Forest
	Mixed Forest	Mixed Forest
Agricultural Land	Agriculture Land	Agriculture Land
	Meadow	Meadow
Mosaic of Open Land		Bare Sand and Herbs
		Mosaic of Grass and Shrubs; Herbs and Scattered Threes
		Mosaic of Shrub, Grass, Bare Land and Herbs

3.7 Change Detection with the Extension "Veränderung"(version 3)

Change detection is the process of identifying changes in land cover over time. With the help of change detection extension, changes from one vegetation type to another were detected by producing a land cover change map that characterises land cover change into “negative change”, “no change” and “positive change”. For example, “negative change” means land cover area reduction; “positive change” is land cover area increase and “no change”, land cover area maintained.

All changes calculated were done in an Arc View GIS environment. Before the change calculations land cover maps were converted into shape file and imported to Arc GIS environment for change detection since the extension works only on polygon files. This extension "Veränderung", determines changes between two polygons themes that represent feature of the same area. A typical example is land cover change of a particular land cover type say, afforestation in Schlabendorf Süd 1995 and Schlabendorf Süd 2000.

In order to detect changes in a vector dataset, at least, two polygon themes are required in view. The theme to use as input is specified. The older polygon theme is selected as the first impute theme followed by the new theme.

A new shape file is created on disk after the filename and location for the new shape file are provided. The two shape files intersect and form a union, which is the output shape file. Non–intersection shape adages are selected out as well as remaining record within shapes that are intersected by union. All records within the input shape file field are selected. If the input shape file field is outside the union it is still added as part of the output shape as an increased area or on the contrary, reduced area. The input shapes outside union polygon entirely are considered in this case. From the attribute table of the output theme with the detected changes, further analyses are made.

3.8 Estimation Procedure for Biomass Accumulation

The normalised difference vegetation index has been one of the earliest estimates of plant parameter (e.g. plant biomass) based on spectral properties (Rouse, 1973). It is a reliable way to capture biomass accumulation in a particular land or habitat. High value of NDVI (whiter area) is an indication of dense or healthy vegetation whiles low NDVI value (dark area), represents sparse or unhealthy vegetation. In other words the NDVI is an indicator of surface disturbance. It has been applied in various fields of studies such as crop production monitoring, land cover classification and determination of stress in crops.

Imagery of both selected study areas were obtained from LANDSAT TM and SPOT images of the years 1988, 1991, 1995, 1998, 2000 and 2003 during peak vegetation periods. They were masked in ERDAS imagine 6.8 environment. The masked layer contains amongst other bands, the TM band 4 or SPOT band 3 and TM band 3 or SPOT band 2. The extracted bands were imported into Arc GIS environment where the raster calculator from spatial analyst extension aided the computation of net NDVI values. Thus NDVI was calculated using the near infrared (TM band 4, SPOT band 3) and red (TM band 3, SPOT band 2) as shown in formula (1) of page 36.

With the LANDSAT TM images, band 3 (red) was subtracted from band 4 (near infrared). The resulting layer was multiplied by 100. Band 4 (near infrared) was added to band 3 (red). Both layers were made permanent. The (band 4 – band 3) was divided by (band 4 + band 3) and the resulting layer was made permanent. In case that SPOT image was used, TM band 4 was replaced by SPOT band 3 and TM band 3 was replaced by SPOT band 2.

The net NDVI values for each map year were estimated from the attribute tables. Attribute table from the 'band 4 – band 3 was divided by band 4 + band 3' (or (SPOT band 3 - SPOT band 2)/ SPOT band 3 + SPOT band 2) layer was exported into Microsoft excel compatible format (dBase4). The exported attribute table had an ID field, NDVI value field and count fields which indicated the total number of each NDVI value. Net primary production values were then estimated from the attribute tables as shown in formula (2) below.

Net primary production (NDVI) = Sum (count x value) / Sum (count). ……………(2)

The output NDVI layer now has values ranging from –1 to +1. Higher NDVI values represent a more active growth and primary production. NDVI values below 0 represent vegetation free surface to less active vegetation growth.

3.9 Determining the Effect of Soil pH on Land Cover Change - Pseudo Slash (Ŧ) Approach

One important question that immerged during this research was why did some areas cultivated earlier turn to open sand. Example of such area was found in the pine afforestation. Those failed afforested areas were areas along the path of strip mine (Figure 18). It was thought that these failed afforested areas should have lower soil pH that cannot support plant growth (Antwi and Krawczynski, in process).

To investigate this assumption, a pseudo slash (Ŧ) shape line transect was designed to cover areas with successful pine growth and failed pine growth presumed to have low soil pH (Figure 19). Transect comprises two horizontal arms (long and short) and a 10 m long vertical arm. The longer horizontal arm is 15 m long and the short, 5 m. The longer horizontal arms run parallel to the short horizontal arm. Crossing the horizontal arms is the vertical arm which begins from the short horizontal arm but crosses the longer horizontal arm.

Figure 18 Path along Strip Mine where Pine Afforestation did not thrive due to Low Soil pH. Background Image on LANDSAT TM image of 2002.

The lengths along both vertical and horizontal arms were graduated into units with each unit measuring 0.5 m from each other (Figure 19). The long horizontal arm was graduated into 30 units and place along the open sand area where the pine afforestation was not successful. The short horizontal arm was graduated into 10 units and placed in the pine forest while the vertical arm had 20 units but begins from the pine forest through the open sand area and ends inside the pine forest on the other side (Figure 19).

Soil samples were taken at each unit along the transect for soil acidity analysis. Thirty soil samples were collected along the long horizontal arm, 10 soil samples along the short horizontal arm and 20 soil samples along the long vertical arm. Method used for collecting soil sample is described in section 3.4.1 of page 60. Soil pH was measured in every sample taken with the method described in section 3.5 of page 60.

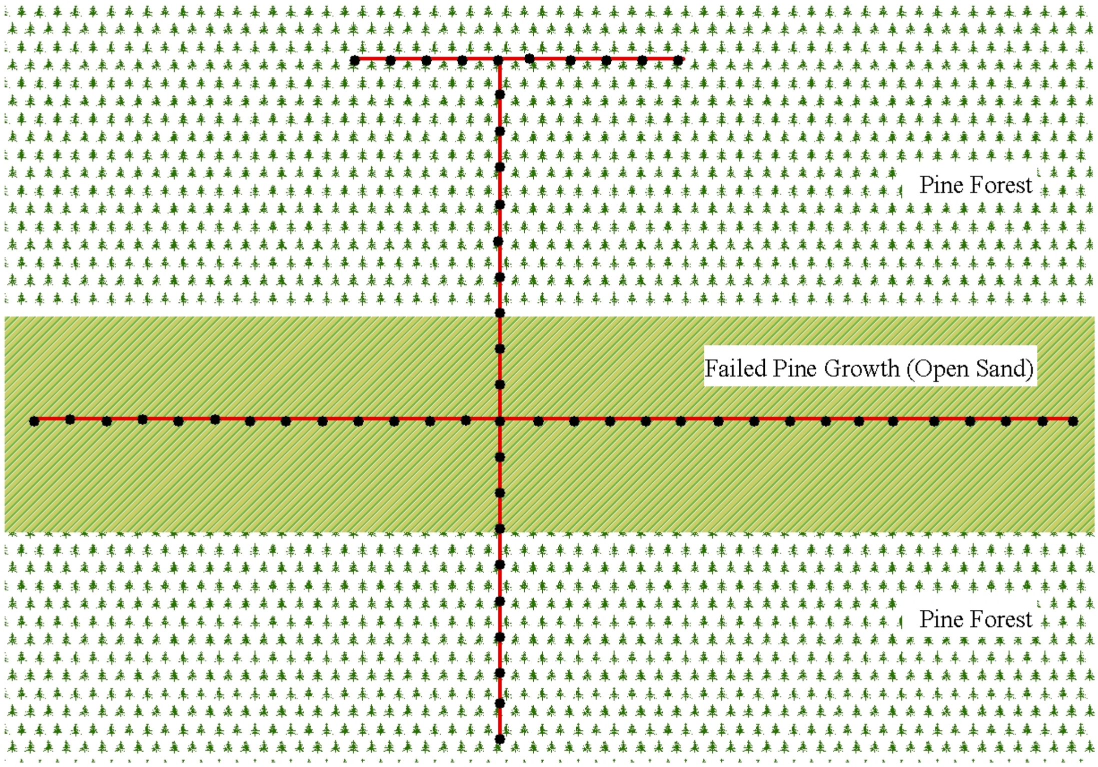


Figure 19 The 'Pseudo Slash - (Ŧ)' Transect Designed to Collect Soil Sample in Both Failed Pine Growth Areas and Successful Pine Growth Area.

3.10 Relationship among Land Cover Types from DCA Ordination Analysis

Detrended correspondence analysis (DCA) is popular among field ecologist because it provides effective approximation solution to ordination problem. It was considered for this analysis due to its best performance among all tested ordination techniques and the fact that it gives difficult but most interpretable results. DCA results are better with added advantage such as greater freedom from involutions on axes and better scaling.

The DCA is a modified correspondence analysis (CA), designed by Hill and Gauch (1980) to correct the arch effect (artifact in ordination diagram where the second ordination axis is an arch function of the first ordination axis) and the often-compressed ends of axes relative to the axes middle. The arch effect is a mathematical artifact that corresponds to no real structure in the data. Hill and Gauch (1980) resolved the arch effect through detrending. Thus ensuring that at any point along the first axis, the mean value of the site scores on the subsequent axes is about zero. Nonlinearly rescaling of the axis for practically equal curve width was done to solve the problem of compressed axis ends relative to its middle.

Hill and Gauch (1980) defined the length of the ordination axis as the range of site scores measured in multiples of the standard deviation (s.d.). Sites that differ by 4 s.d. in scores have no species in common. Ter Braak (1996) found out that in DCA sites are represented by points and each site is located at the center of gravity of the species that occurs there. Locations of species on the edge are often unusual (species). Their location is either due to the fact that they have extreme pattern/condition or they happen to occur by chance under such extreme condition in which case additional data might be helpful for further clarification (ter Braak, 1996).

CanoDraw CANOCO program (version 4.5) was used to plot the ordination diagram (ter Braak and Smilauer, 2002). The analyses were performed for Schlabendorf Süd and Schlabendorf Nord to display the similarities among land cover distributions during the period study. The DCA plots for land cover distribution in Schlabendorf Süd and Schlabendorf Nord are given in Figure 26, page 95. Based on the position of the six study years on the axis 1, the first DCA ordination axis correlates with gradient of increasing year (time) of land cover from 1988 to 2003. The second axis increases with increasing land cover distribution area. The first two ordination axes explain 60.5 % and 67.6 % variance of the species data of the plot in Schlabendorf Süd and Schlabendorf Nord respectively, and they are both significant (Table 17 page 94).

4 Results

4.1 Land Cover Characteristics Deduced from Landscape Metrics

4.1.1 Habitat Area Characteristics of Schlabendorf Nord and Schlabendorf Süd

Mean Patch Size at Schlabendorf Nord:- Mean patch size (MPS) is an indicator of grain of landscape. Considering the 15-year duration of study, mean patch size generally decreased. The highest MPS values were in 1988 and 1991 respectively. Unlike the second and last segment of the study, where mean patch size increased significantly, the first segment rather showed no significant changes (Figure 20, Table 7 of page 73). Trend of mean patch size in Schlabendorf Nord shows that the post-mining landscapes between the periods of 1988 to 1991 has become more fragmented. Fragment formations in the second and third segment of the study reduced significantly, which support results from number of patches in Figure 21 in page 71. The landscape was more fragmented in 2000 than any other time of study. Generally habitat fragmentation increased in Schlabendorf Nord (Figure 20).

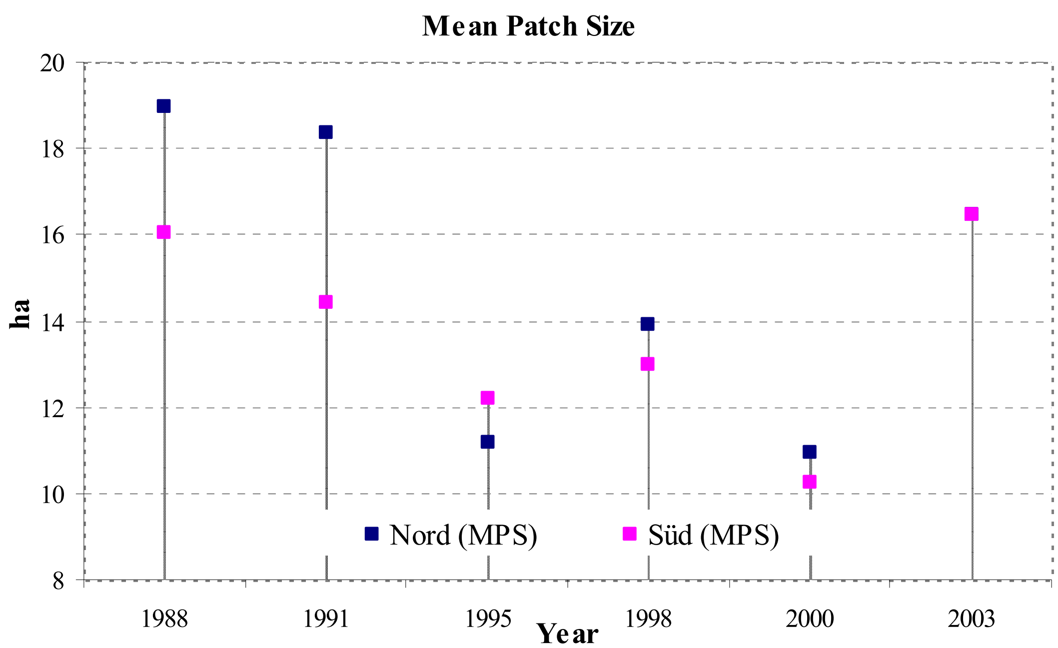


Figure 20 Graphical Description of Mean Patch Size in Schlabendorf Nord and Schlabendorf Süd.

Mean Patch Size at Schlabendorf Süd:- The largest mean patch size at Schlabendorf Süd was at end of the study in 2003 (MPS = 16.48 ha). At the beginning of the study, mean patch size was high (i.e. 16.07 ha in 1988) but decreased generally in the subsequent map years until the year 2003 where the largest mean patch size was measured (Table 8). Since lower values of mean patch size represent higher fragmentation, the post-mining landscape in this area can be said to have become more fragmented from 1988 to the year 2003 where level of habitat fragmentation decreased (Figure 20). MPS had similar pattern in both study areas. The smallest hence the most fragmented areas (MPS) were both observed at the period of 2000 (Figure 20).

Number of Patches at Schlabendorf Nord (NUMP):- The number of patches in the first segment increased from 126 in 1988 to 130 in 1991. The second and last segment rather had a significant decrease in the number of patches with the lowest NUMP in the last section. The decrease was the reason for loss of 42 patches in second segment and 72 patches at the last segment (Table 7 of page 73). Though the number of patches decreased in the later two segment of the study, they generally increased over the study period with the highest number of patches in 2000 and 1995 respectively (Table 7). Trend of fragmentation therefore implies the post-mining landscape between the periods of 1988 to 1991 became fragmented. Fragment formation in the second and third segment of the study reduces significantly (Figure 21). Nevertheless, fragmentation over the entire study period showed an increase in this index. Fragmentation in this context means breaking up of habitat, ecosystem or land cover types into smaller parcels (Forman, 1995). Since larger patches tend to be more complex than smaller patches, this has the effect of determining patch complexity independent of its size.

Number of Patches at Schlabendorf Süd:- The number of patches was at its highest value, 322, in the year 2000. Schlabendorf Süd earlier in 1988 had the least number of patches (188) of all map years. Until 1998, there was a continues increase in the number of patches (Figure 21, Table 8 of page 73). Generally, the post-mining landscape in Schlabendorf Süd over the 15-year period increased in number of patches.

Since number of patches is directly related to habitat richness (the higher the number of patches, the higher habitat richness) Schlabendorf Süd generally has higher habitat numbers (habitat richness) than Schlabendorf Nord.

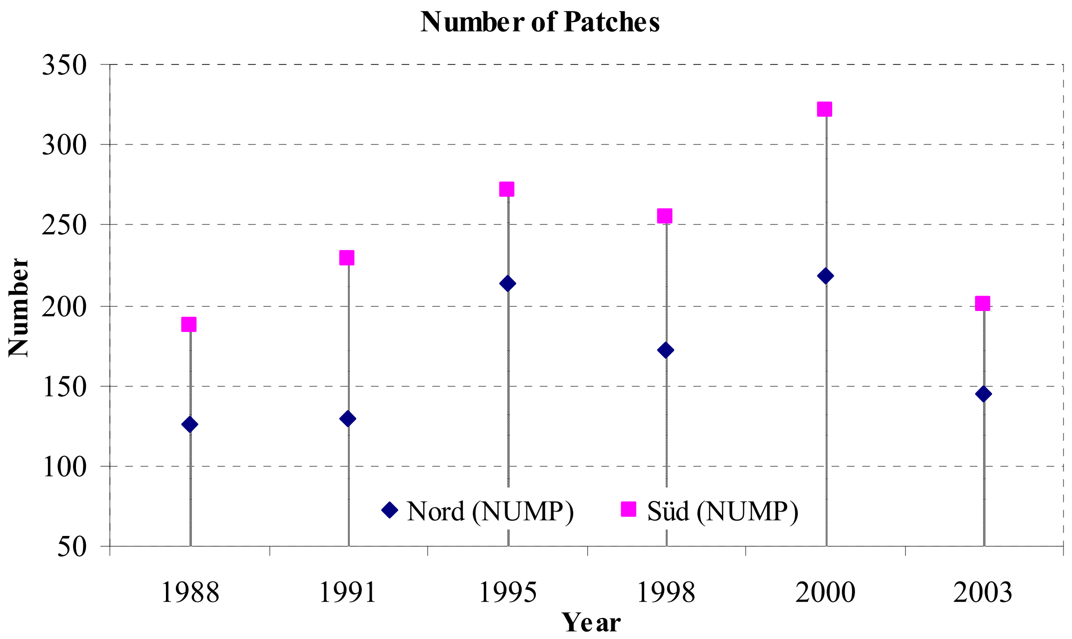


Figure 21 Graphical Description of Number of Patches in Schlabendorf Nord and Schlabendorf Süd.

The highest and lowest numbers of patches in both study areas were observed in 2000 and 1988 respectively.

4.1.2 Edge Density Metrics of Schlabendorf Nord and Schlabendorf Süd

Edge Density of Schlabendorf Nord:- Edge Density ED is 0 when there is no edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of a single patch and the user specifies that none of the landscape boundary and background edge be treated as edge. Earlier in the studies, edge density was basically at the same level with an insignificant decrease between the period of 1988 and 1991 (144.91 ha and 144.63 ha respectively).

The highest edge density value, 179.34 ha at Schlabendorf Nord was recorded in the year 1995 (Figure 22, Table 7 of page 73). Though decrease in edge density occurred in 1998, the subsequent years relatively showed a stable and insignificant increase in edge density. Generally however, edge density values in the 15-year period of study at Schlabendorf Nord, increased considerably (Figure 22).

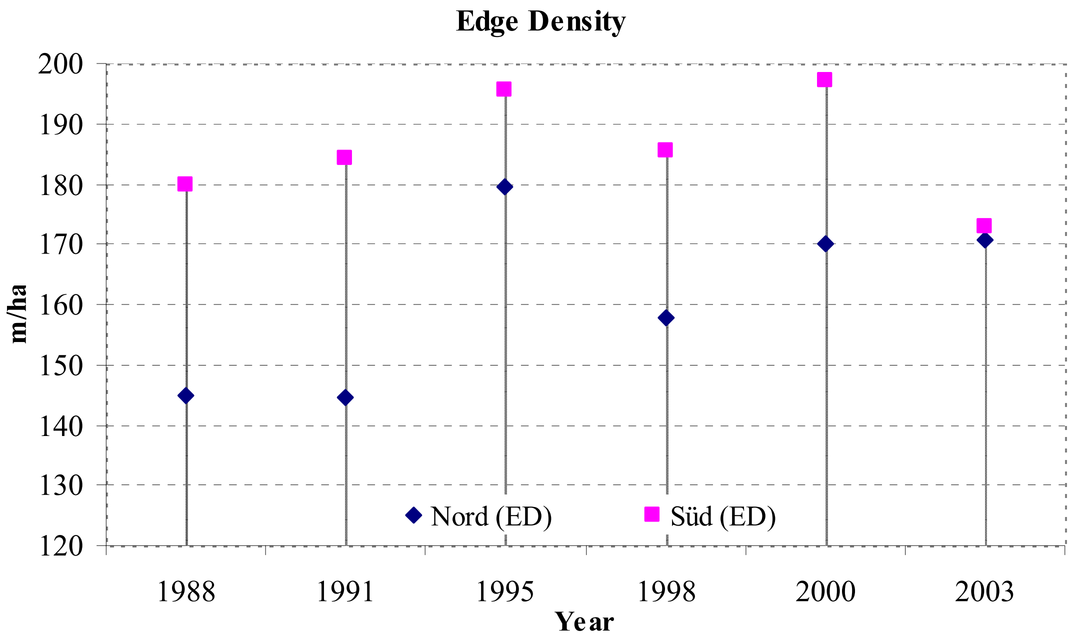


Figure 22 Graphical Description of Edge Density in Schlabendorf Nord and Schlabendorf Süd.

Edge Density of Schlabendorf Süd:- Edge density during 2000 was the highest of all the map years in Schlabendorf Süd. It reduced to its minimum value in the year 2003 (Figure 22). Over the study period, edge density had a continues rise basically from 1988 to 2000 though ED in 1998 was lower than the year before and after (Figure 22, Table 8 of page 73). Generally ED in Schlabendorf Süd was greater than Schlabendorf Nord though it fluctuated in both landscapes throughout the study period.

Table 7 Landscape Metrics at Schlabendorf Nord from 1988 to 2003

Study Period Table MN.	NUMP	MPS (ha)	ED (m/ha)	TPE	MSI	MPFD	SDI	SEI
Schlabendorf Nord 1988	126	18.97	144.91	34.63	2.01	1.37	1.89	0.82
Schlabendorf Nord 1991	130	18.38	144.63	34.56	1.97	1.33	1.99	0.86
Change	4	-0.59	-0.28		-0.04	-0.04	0.1	0.04
Schlabendorf Nord 1995	214	11.2	179.38	42.99	2.16	1.39	2.1	0.87
Schlabendorf Nord 1998	172	13.91	157.77	37.75	1.97	1.35	2.06	0.89
Change	-42	2.71	-21.61		-0.19	-0.04	-0.04	0.02
Schlabendorf Nord 2000	218	10.97	170.18	40.70	1.87	1.36	1.99	0.87
Schlabendorf Nord 2003	145	16.49	170.81	40.84	2.22	1.35	1.96	0.82
Change	-73	5.52	0.63		0.35	-0.01	-0.03	-0.05

Table 8 Landscape Metrics at Schlabendorf Süd from 1988 to 2003

Study Period Table MS	NUMP	MPS (ha)	ED (m/ha)	TPE	MSI	MPFD	SDI	SEI
Schlabendorf Süd 1988	188	16.07	179.81	54.31	2.23	1.38	1.56	0.71
Schlabendorf Süd 1991	229	14.42	184.27	60.87	2.17	1.37	1.67	0.69
Change	41	-1.65	4.46		-0.06	-0.01	0.11	-0.02
Schlabendorf Süd 1995	272	12.21	195.71	64.99	2.19	1.37	1.87	0.78
Schlabendorf Süd 1998	255	13	185.55	61.52	2.07	1.35	1.9	0.79
Change	-17	0.79	-10.16		-0.12	-0.02	0.03	0.01
Schlabendorf Süd 2000	322	13.01	197.15	65.33	1.93	1.35	1.85	0.77
Schlabendorf Süd 2003	201	16.48	172.89	57.29	2.25	1.36	2.05	0.89
Change	-121	3.47	-24.26		0.32	0.01	0.2	0.12

4.1.3 Shape Metrics of Schlabendorf Nord and Schlabendorf Süd

Mean Shape Index (MSI) of Schlabendorf Nord:- Mean shape index (MSI) is 1 when all patches (polygons) are circular with polygons, or square in the case of grids. Decreasing MSI indicates habitat shape has becomes simpler, and increasing, otherwise. The least complex and for that matter the landscape with simplest habitat shapes, was Schlabendorf Nord 2000 (Figure 23). Habitat shapes in 2003 had higher complexity than the other map years. The first segment basically had the same level of habitat complexity i.e. 2.01 in 1988 and 1.97 in 1991 (Figure 23 and Table 7). Habitat shape complexity declined slightly during 1995 to 1998 but increased considerably between 2000 and 2003. Generally, habitat shapes in the early part of the study were relatively complex with high levels of complexity recorded in 1995 and 2003 (Figure 23).

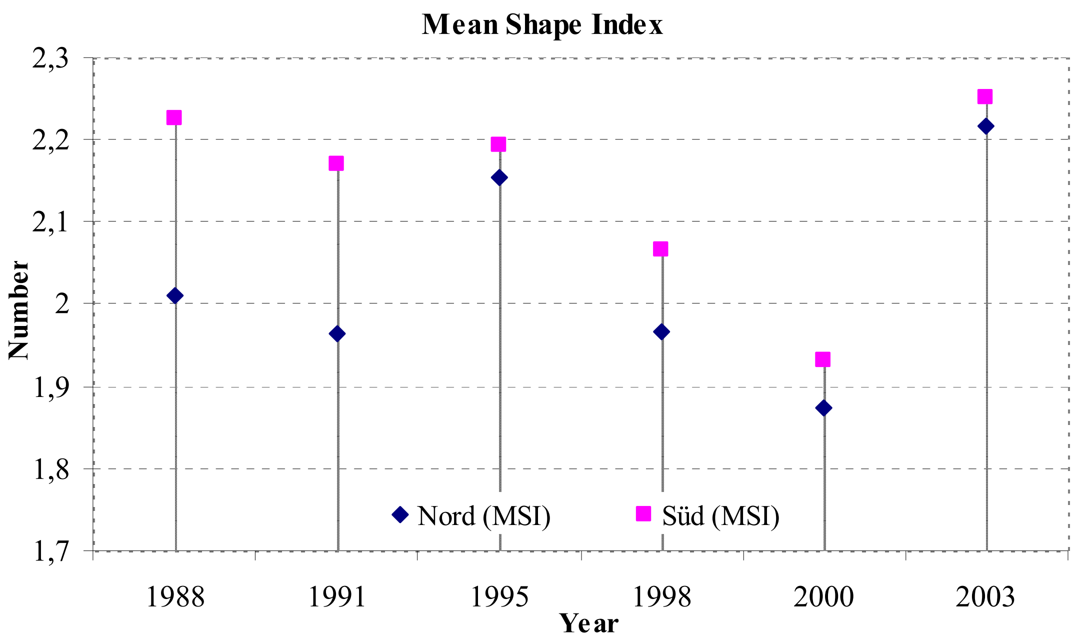


Figure 23 Graphical Description of Mean Shape Index in Schlabendorf Nord and Schlabendorf Süd.

Mean Shape Index (MSI) of Schlabendorf Süd:- Similar to Schlabendorf Nord, the least complex of all map years with regard to habitat shape was that of Schlabendorf Süd 2000 though its MSI is higher than that of Schlabendorf Nord (Figure 23 and Table 8). The post-mining landscape had higher habitat complexity by the end of the study period in 2003. The very beginning of the project in 1988 had high habitat complexity but decreases slightly over the years until 2003 where a considerable increase in habit shape complexity was recorded (Figure 23, Table 8 of page 73). Schlabendorf Süd has experienced a slight decrease to stable habitat shape complexity over the 15-year period with a considerable increase in complexity at the end of the study. Mean shape index from 1988 to 1995 largely decreased in Schlabendorf Süd but increased in Schlabendorf Nord (Figure 23). It continued with a similar pattern in both areas to 2003 where the highest habitat shape complexity (MSI) throughout the study was observed. Thus comparatively, the post-mining landscape in Schlabendorf Süd has higher habitat shape complexity than Schlabendorf Nord (Figure 23 above).

Mean Patch Fractal Dimension of Schlabendorf Nord:- Mean patch fractal dimension (MPFD) is 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 when shapes are more complex. MPFD ranging from 1.33 to 1.39 at Schlabendorf Nord indicate simple habitat shape complexity (Figure 24, Table 7 of page 73). MPFD in both landscapes rose and fell but remained in between the range of 1.36 and 1.35 from 1998 to 2003.

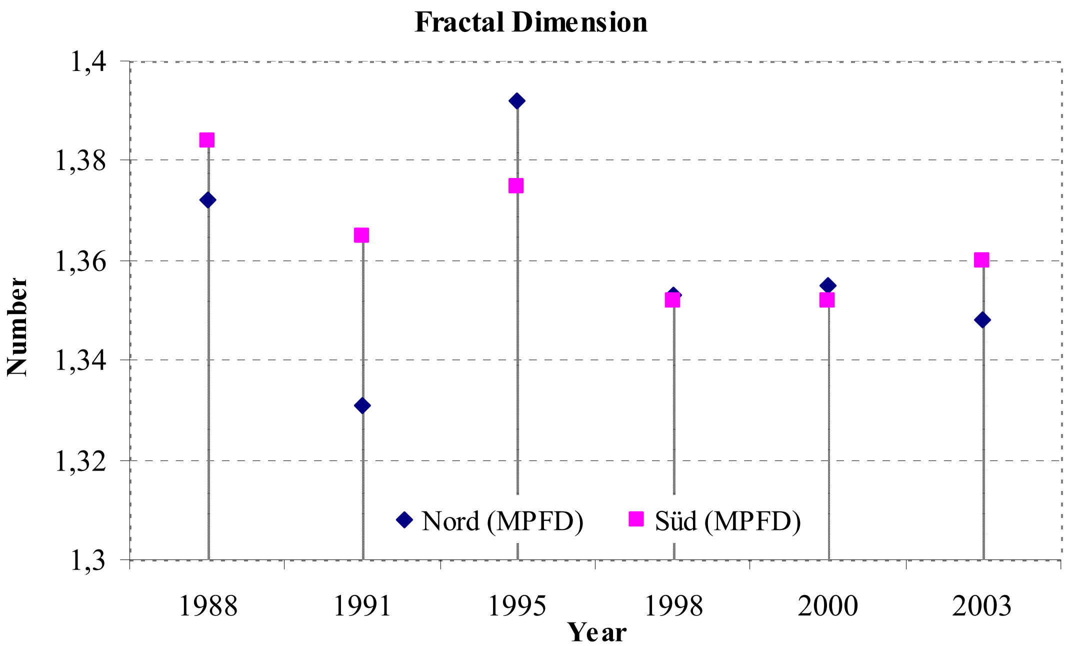


Figure 24 Graphical Description of Mean Patch Fractal Dimension in Schlabendorf Nord and Schlabendorf Süd.

Though all the map years can be said to be simple, slight increase in complexity occurred in those map years that appear between the two extremes. These are 1.37 in 1988, 1.36 in 2000, 1.35 in 2003 and 1.35 in 1998 in order of increasing MPFD values. It can be observed that MPFD basically remained the same from 1998 to the end of the study period (Figure 24).

Mean Patch Fractal Dimension of Schlabendorf Süd:- The highest MPFD in Schlabendorf Süd was in 1988. The lowest MPFD was in 1998 and 2000 at MPFD value of 3.35. Generally, the very first three map years basically had the same mean patch fractal dimension values (between 1.37 and 1.38) as in the case of the remaining map years (i.e. between 1.36 and 1.35) Table 8. Schlabendorf Süd over the study period had a slight decrease but relatively stable fractal dimension (Figure 24).

4.1.4 Diversity Metrics of Schlabendorf Nord and Schlabendorf Süd

Shannon's Diversity and Evenness Index Schlabendorf Nord:- Shannon's diversity and evenness index (SDI and SEI) are popular measures of diversity in community ecology. SDI is 0 when the landscape contains only 1 patch. SDI increases as the number of different patch types (i.e., patch or habitat richness) increases and/or the proportional distribution of area among patch types become more uneven.

The lowest habitat diversity was 1.89 in the beginning of the analysis in 1988. Schlabendorf Nord in 1995 had the highest habitat diversity with an SDI value of 2.1 (Table 7). The period between 1988 and 1991 had a slight increase in diversity. The area in 1998 had relatively less habitat diversity compared to the highest diversity value in 1995. Similar to the period between 1995 and 1998, Schlabendorf Nord between 2000 and 2003 recorded a slight decrease (0.04) in diversity (Figure 25 and Table 7). Considering the general trend of habitat diversities over the 15 year study period, habitat diversities have comparatively increased since beginning of the reclamation (Figure 25).

Shannon's Diversity and Evenness Index Schlabendorf Süd:- Shannon diversity index from Figure 25 shows that the habitat diversity was highest in 2003; SDI = 2.05 (Table 8). The least habitat diversity in Schlabendorf Süd like Schlabendorf Nord was recorded at the very beginning of the study in 1988 (Figure 25). Considering the trend of habitat diversity, there was relatively continues rise in diversity from SDI value of 1.56 in 1988 to the highest SDI value (2.05) in 2003 though the post-mining area deviated from this trend with a slight decline in habitat diversity in 2000. Habitat diversity over the 15-year period of the study has increased in Schlabendorf Süd (Figure 25).

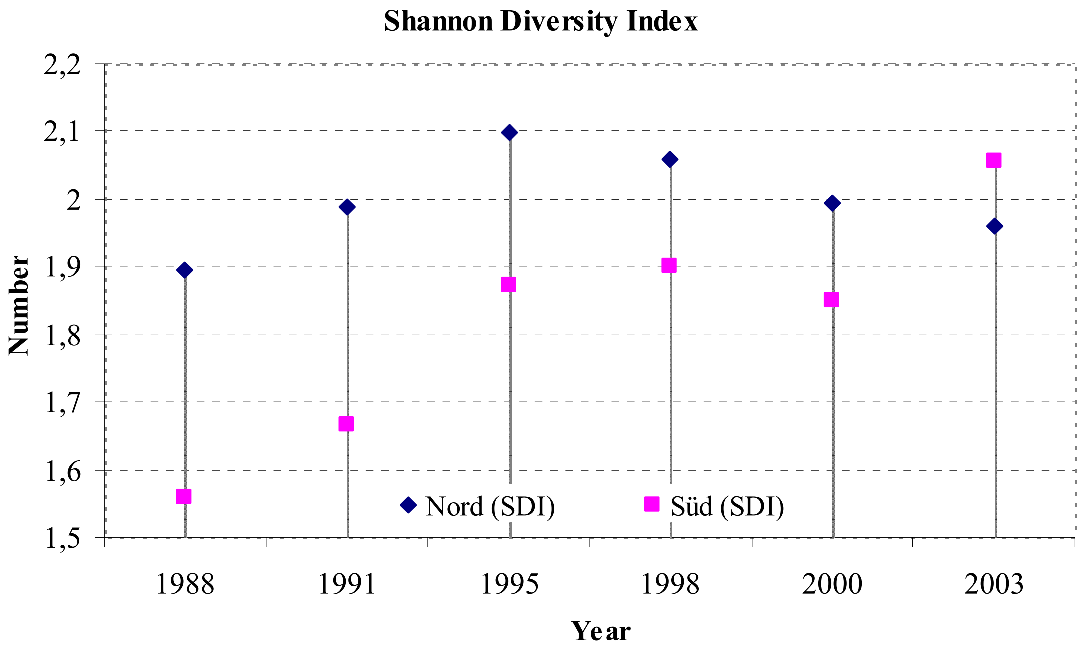


Figure 25 Graphical Description of Shannon Diversity Index in Schlabendorf Nord and Schlabendorf Süd.

Both areas had increased diversity from 1988 to 1995. SDI continued decreasing in Schlabendorf Nord till 2003 as diversity in Schlabendorf Süd fluctuated to a final increase in 2003.

4.1.5 Total Patch Edge of Schlabendorf Nord and Schlabendorf Süd

Total Patch Edge (TPE) of Schlabendorf Nord:- The sum of all perimeters within a landscape (landscape level) is known as total patch edge. At the landscape level, total amount of edge is directly related to the degree of spatial heterogeneity in the landscape (McGarigal and Marks, 1994).

Total patch edge of patches in 1988 and 1991 were basically the same. A significant increase in total patch edge was observed in 1995 (TPE = 42.99). Considerable decrease in total patch edge occurred during 1998 to a TPE value of 37.75 though the subsequent years had increasing but comparatively stable total patch edge values (Table 7). The post-mining area at Schlabendorf Nord has become more heterogeneous over the 15 year period with the most heterogeneous landscape being that of 1995. Similar to 1988 and 1991 with relatively stable heterogeneity, the year 2000 and 2003 also had stable heterogeneity (Table 7 of page 73).

Total Patch Edge of Schlabendorf Süd:- Total patch edge in the very beginning of the project was the least of all the TPE values recorded over the study period. It increased significantly to 60.87 in 1991, 64.99 in 1995, 61.52 in 1998, 65.33 in 2000 and 57.29 in 2003 (Table 8). Though a significant rise in total patch edge occurred over the study period, slight deviation from the increasing trend (decline) occurred in 1998 (61.52) and 2003 (57.29). Since total patch edge at landscape level directly relate to the degree of spatial heterogeneity (McGarigal and Marks, 1994), Schlabendorf Süd has since 1988 become more heterogeneous. The area in 1998 had reduced in heterogeneity but further increase in the year 2000 and finally declined to value higher than the initial value in 1988. The most heterogeneous landscape was that of 2000.

4.2 An Overview of Land Cover Distribution Study at the Period of 1988 and 2003 in both Study Areas

4.2.1 Land Cover Distribution at Schlabendorf Nord - 1988 to 2003

Mixed grassland with trees area in Schlabendorf Nord gained 128.01 ha of the other land cover types during the 15-year period (Table 9). The area covered with mixed grassland with trees at the end of 2003 was 14.6 % of the study area. Initially in 1988, mixed grassland with trees covered only 221.16 ha being 9.25 % of the entire study area (Table 9).

Dry grassland in 1988 covered an area of 146.74 ha being 6.14 % of the study area (Table 9). During the study period, it increased comparatively by relatively small margin (6.8 ha) to 153.54 ha in 2003. This was the least of all increase in land cover types recorded in Schlabendorf Nord during the study. Dry grassland in other words comparatively did not undergo changes in its cover type within in the 15 years of study (Table 9).

Table 9 Land Cover Changes at Schlabendorf Nord from 1988 to 2003

Land Cover Type	Agg.	Year 2003 Area/ha	%	Year 1988 Area/ha	%	Change/ha
Afforestation	2	16.74	0.7	302.98	12.68	-286.24
Deciduous Trees Afforestation	3	215.99	9.03	11.48	0.48	204.51
Afforestation of Pine Trees	1	364.18	15.23	200.03	8.37	164.15
Agricultural Land	5	872.3	36.48	1038.58	43.46	-166.28
Dry Grassland	8	153.54	6.42	146.74	6.14	6.8
Dry Vegetation	4	44.64	1.87	244.64	10.24	-200
Lake	11	298.96	12.5	183.11	7.66	115.85
Mixed Grassland with Trees	6	349.17	14.6	221.16	9.25	128.01
Open Sand	9	46.71	1.95	6.91	0.29	39.8
Sparse Pioneer Grassland	7	17.56	0.73	34.05	1.42	-16.49
Wetland	10	11.16	0.47	0	0	11.16
Total		2390.95		2389.68		1.27

Open sand area in Schlabendorf Nord gained 39.8 ha of other land cover types. Total area that became free of vegetation cover in 2003 was about 2 % of the study area (Table 9). Areas of Schlabendorf Nord which is now free of vegetation cover has intend increased more than 7 times its initial 6.91 ha area covered in 1988.

Afforestation of pine trees among all the three afforestation classes in Schlabendorf Nord had the highest cover (364.18 ha). Initially in 1988, 200.03ha being 8.37 % of the area was afforestation of pine trees cover (Table 9). The pine afforestation extended its area significantly to other land cover types, leading to the 164.15 ha increase in pine afforestation area in 2003 (Table 9).

Land cover map of 1988 had 7.66 % of study area covered by lake. As the study progresses, lake extended its area to 12.5 % in 2003 (Table 9). This implies that a total of 115.85 ha of the other land cover types in Schlabendorf Nord during the 15 year duration have became flooded with water. The rate at which lake is encroaching on neighbouring and non-neighbouring land cover types is about 7.7 ha per year

(115.85/15). In other words about 7.7 ha of the study area in Schlabendorf Nord is changed to lake every year (Table 9).

Afforestation was the highest of all the three afforestation types found in Schlabendorf Nord 1988. It covered an area of 302.98 ha or 12.68 % of the study area. Area of afforestation decreased drastically to 16.74 ha or 0.7 % in the year 2003 (Table 9). Thus the 15 year period of change monitoring showed afforestation area has lost -286.24 ha to other land cover types or reduces in size 24 times it initial size in 1988.

The area of afforestation of deciduous trees at Schlabendorf Nord in 1988 covered only 0.48 % of the entire landscape but increased drastically to 9.03 % of study area in the year 2003. Areas that have now become afforestation of deciduous trees are 204.51 ha. Thus afforestation of deciduous trees over the 15 year period has increase about twenty times its initial cover in 1988 (Table 9).

The land cover type wetland was absent in the land cover map of 1988. The year 2003 on the other hand showed that wetland had an area of 11.16 ha. It must be said that increase in wetland area was due to the absence of wetland in 1988 (Table 9).

Sparse pioneer grassland occupied 34.05 ha of Schlabendorf Nord when the studies began in 1988. This area declined considerably at the end of the study period in 2003 to 17.56 ha. Sparse pioneer vegetation over the 15-year period declined by margin of 16.49 ha of the study area (Table 9).

Dry vegetation had one of the highest lost of land cover types in Schlabendorf Nord during the study. Earlier in 1988, 10.24 % of the study area being 244.64 ha had dry vegetation cover. 2003 on the other hand recorded a considerable decrease in dry vegetation cover to 44.64 ha or 1.87 % (Table 9).

Considering land cover change estimation from 1988 to 2003, agricultural land decreased by -6.98 % / 164.15 ha. The land cover area used for agriculture in 1988 was 1038.58 ha or 43.46 % of the study area. Agricultural area decreased to 872.3 ha in 2003 (Table 9).

4.2.2 Land Cover Distribution at Schlabendorf Süd - 1988 to 2003

All the analysis made in Schlabendorf Süd takes into consideration the fact that land cover map of the post-mining landscape was 293.47 ha smaller than that of the other land covers maps (Table 10).

Dry vegetation in Schlabendorf Süd gained 324.69 ha of other land cover types during the 15-year period of the study. It covered an area of 218.11 ha or 7.22 % of the post-mining landscape as of 1988. At the end of the study period in 2003, dry vegetation increased to 542.8 ha of the study area (Table 10).

Mixed grassland with trees had the highest increase of all the land cover types in Schlabendorf Süd (Table 10). Earlier in the study in 1988, 114.63 ha or 3.8 % had mixed grassland with trees cover. The year 2003 however had a considerable increase in mixed grassland with trees cover (671.3 ha or 20.26 %). This implies that 556.67 ha of other land cover types changed to mix grassland with trees cover (Table 10).

Afforestation of deciduous trees as of 1988 had no vegetation cover in Schlabendorf Süd. At the end of the study period in 2003 its total cover was only 6.27 ha of the study area. Within the 15-year period of study, afforestation of deciduous trees was the least of all land cover types present in Schlabendorf Süd (Table 10).

Open sand area in Schlabendorf Süd gained 37.28 ha being 1 % of other land cover types during the 15-year period of the study. Total area that became free of vegetation cover at the end of 2003 formed about 2.49 % of the study area (Table 10). Areas of Schlabendorf Süd which has newly become free of vegetation cover has in turn increased twice its initial 45.34 ha or 1.5 % area covered in 1988 (Table 10).

Results in Table 10 shows that a total of 321.97 ha being 10.66 % of the study area was used for agricultural purpose in 1988 (Table 10). The land cover map in 2003 showed there was an increase in agricultural land to 396.79 ha. Over the 15 years study period, agricultural land gained a comparatively large portion (74.82 ha) of other land cover types in the area (Table 10).

Table 10 Land Cover Changes at Schlabendorf Süd from 1988 to 2003

		Year 2003		Year 1988		
Land Cover Type	**Agg.**	**Area/ha**	**%**	**Area/ha**	**%**	**Change/ha**
Afforestation	2	0	0	25.47	0.84	-25.47
Deciduous Trees Afforestation	3	6.27	0.19	0	0	6.27
Afforestation of Pine Trees	1	467.54	14.11	0	0	467.54
Agricultural Land	5	396.79	11.97	321.97	10.66	74.82
Dry Grassland	8	505.81	15.26	1299.55	43.03	-793.74
Dry Vegetation	4	542.8	16.38	218.11	7.22	324.69
Lake	11	232.18	7.01	53.6	1.77	178.58
Mixed Grassland with Trees	6	671.3	20.26	114.63	3.8	556.67
Open Sand	9	82.62	2.49	45.34	1.5	37.28
Sparse Pioneer Grassland	7	381.13	11.5	868.65	28.76	-487.52
Wetland	10	27.34	0.83	72.99	2.42	-45.65
Total		3313.78		3020.31		293.47

Sparse pioneer grassland at Schlabendorf Süd covered 868.65 ha or 28.76 % of the study area in 1988. It was the second largest land cover type recorded during the 15 years of study in this area. It declined significantly in area by a margin of -487.52 ha to an area of 381.13 ha or 11.5 % at the end of the study period in 2003 (Table 10). Sparse pioneer vegetation in effect had 487.52 ha of its area taken up by other land cover types.

The wetland area from 1988 to 2003 had its area reduced considerably by a margin of -45.65 ha or 1.6 % to other land cover types. Early part of the study showed wetland covered a larger area of 72.99 ha or 2.42 % (Table 10). Nevertheless, wetland area reduced to 27.34 ha or 0.83 % of the area. The rate of reduction in wetland area at Schlabendorf Süd is 3.03 ha per year.

At early stages of the study in 1988, only 1.77 % of the area was covered by lake. Land cover map in 2003 rather recorded a significant increase in the size of lake to 7.01 % (Table 10). Schlabendorf Süd within the 15-year period of study experienced as sizable portion of its area (178.58 ha) belonging to different land cover types, changed to lake. Lake in this case has increased more than 4 times its initial area in 1988. The rate at which other land cover types (neighbouring and non-neighbouring) change into lake is 12 ha per year (Table 10).

Afforestation of mixed forest was the only afforestation type present at the beginning of the study. It covered a total of 25.47 ha being only 0.84 % of the study area in 1988. At the end of 2003, afforestation of mixed forest had no cover at the post mining landscape (Table 10).

The largest afforestation type in Schlabendorf Süd between the periods of 1988 to 2003 was afforestation of pine trees. In 1988, the land cover map revealed there was no afforestation of pine trees in post-mining landscape (Table 10). Nevertheless, land cover map of the same area in 2003 recorded 467.54 ha of newly afforested area (Table 10). Some of the areas had newly planted pine trees in 1988 which was not visible in the satellite image though large pine afforestation also occurred after 1988.

Land cover distribution monitoring shows that 43.03 % of the post-mining area in Schlabendorf Süd in 1988 was covered with dry grassland (Table 10). Dry grassland was the highest land cover type ever recorded over the 15-year period of study (Table 10). Its area in 2003 (505.81 ha) was drastically reduced to other land cover types. Thus dry grassland lost a total of 793.74 ha of the study area.

4.3 Detailed Land Cover Distributions and Change Analysis at Three Different Segments (1988-1991, 1995-1998, 2000-2003) in Schlabendorf Süd

4.3.1 Land Cover Change Estimation at Schlabendorf Süd from 1988 to 1991 – First Segment

The period between 1988 and 1991 (dabbed first segment) at Schlabendorf Süd experienced the highest loss of land cover in the dry grassland (-214.84 ha) (Table 11). Other recognisable losses were that of wetland, open sand and dry vegetation. Most of the areas lost in the dry grassland were mainly used for afforestation purpose, lake and open sand. On the other hand, dry grassland took a considerable proportion of dry vegetation (Appendix Table 1). Agricultural land and mixed grassland and trees also contributed to the decline in dry grassland area.

Table 11 Land Cover Changes at Schlabendorf Süd from 1988 to 1991

Land Cover Class	Agg.	Year 1991 Area/ha	Year 1991 %	Year 1988 Area/ha	Year 1988 %	Change/ha
Afforestation	2	96.89	2.93	25.47	0.84	71.42
Deciduous Trees Afforestation	3	12.67	0.38	0	0	12.67
Afforestation of Pine Trees	1	108.14	3.27	0	0	108.14
Agricultural Land	5	399.18	12.08	321.97	10.66	77.21
Dry Grassland	8	1084.71	32.84	1299.55	43.03	-214.84
Dry Vegetation	4	191.03	5.78	218.11	7.22	-27.08
Lake	11	80.15	2.43	53.60	1.77	26.55
Mixed Grassland and Trees	6	143.26	4.34	114.63	3.80	28.63
Open Sand	9	12.38	0.37	45.34	1.50	-32.96
Sparse Pioneer Grassland	7	1155.21	34.97	868.65	28.76	286.56
Wetland	10	19.71	0.60	72.99	2.42	-53.28
Total		3303.33		3020.31		283.02

The first segment at Schlabendorf Süd also recorded a significant increase in the sparse pioneer grassland (286.56 ha). A considerable increase also occurred in afforestation and agricultural land but afforestation of deciduous trees and mixed grassland and trees did not actually gain much of other land cover types comparatively (Table 11). As reported in the above paragraph, sparse pioneer grassland gained a considerable proportion of the lost dry grassland area. Also contributing to increased area of sparse pioneer grassland were open sand, dry vegetation and open sand (Appendix Table 1).

The first segment had the least increase in lake size (26.55 ha of the entire area) as compare to the other segments (Table 11). The 26.55 ha increase in lake size was largely taken from dry vegetation, sparse pioneer grassland, dry grassland and wetland. 72.69 ha of lake size was maintained (Appendix Table 1).

Generally in Schlabendorf Süd, lake size has since 1988 increased four times its area (53.6 ha). The most significant increase occurred between the years 2000 and 2003 (Table 13). About 29.8 ha being 73 % of lake size in Schlabendorf Süd was maintained (Appendix Table 1). A consistent increase was observed in lake size throughout the study period except the year 1995 where it decreased to a level lower than its initial size in 1988 (Table 12).

Of the entire three segments, only the first segment had reduction in wetland area. As stated above, increase in lake size contributed to the reduced wetland area. Gain in dry grassland and sparse pioneer grassland also contributed to lost in the wetland area (Appendix Table 1).

In addition to area gained by sparse pioneer grassland, 67.11 % of it was maintained (Appendix Table 1). Though dry grassland lost such large area to other land cover types, almost 50 % of its area did not undergo any change.

4.3.2 Land Cover Distribution and Change Analysis from 1995 to 1998 in Schlabendorf Süd – Second Segment

The period between 1995 and 1998 (dabbed second segment) at Schlabendorf Süd recorded changes in land cover types, which were not acute as those, observed between 2000 and 2003. The highest loss of land cover type was -101.64 ha reduction in the sparse pioneer grassland. Other considerable losses were agriculture land -71.58 ha and dry grassland -68.04 ha (Table 12).

Increase in area of afforestation of pine trees, 82.53 ha, afforestation of deciduous trees, 73.42 ha, mixed grassland and trees, 76.31 ha were all individual increases greater than 2 % of the area (Table 12). Open sand in this segment unlike the last segment increased by a small magnitude. Please see Appendix Table 2 for details of the above changes.

The size of wetland and lake increased by 7.17 ha and 28.76 ha respectively (Table 12). Detail change detection results showed that 35.27 % of the wetland area contributed to increase in lake size though 30.1 % of its area was maintained (Appendix Table 2). Increase in wetland area was predominantly taken from dry grassland, lake, dry vegetation, and sparse pioneer grassland. Regarding increase in lake size, areas such as open sand and dry grassland also contributed. It must be said that 35.22 ha being 74.97 % of lake size did not change to other land cover types between this periods (Appendix Table 2).

Table 12 Land Cover Changes at Schlabendorf Süd from 1995 to 1998

		Year 1998		Year 1995		
Land Cover Class	**Agg.**	**Area/ha**	**%**	**Area/ha**	**%**	**Change/ha**
Afforestation	2	84.79	2.56	105.02	3.16	-20.23
Deciduous Trees Afforestation	3	107.89	3.25	34.47	1.04	73.42
Afforestation of Pine Trees	1	315.03	9.50	232.50	7.00	82.53
Agriculture Land	5	370.60	11.18	442.18	13.32	-71.58
Dry Grassland	8	1154.39	34.81	1222.43	36.82	-68.04
Dry Vegetation	4	111.77	3.37	142.73	4.30	-30.96
Lake	11	76.37	2.30	47.61	1.43	28.76
Mixed Grassland and Trees	6	488.22	14.72	411.91	12.41	76.31
Open Sand	9	49.32	1.49	29.66	0.89	19.66
Sparse Pioneer Grassland	7	532.73	16.07	634.37	19.11	-101.64
Wetland	10	24.71	0.75	17.54	0.53	7.17
Total		3315.82		3320.42		-4.60

4.3.3 Land Cover Distribution and Change Analysis from 2000 to 2003 in Schlabendorf Süd –Third Segment

The highest loss of land cover type at Schlabendorf Süd between the period of 2000 and 2003 (dabbed third segment) was predominantly found in the sparse pioneer grassland (-393.97 ha) and dry grassland (-270.47 ha). Afforestation, afforestation of deciduous trees and dry vegetation all lost more than 80ha of their cover to other land cover types (Table 13).

Decrease in area of sparse pioneer grassland was predominantly lost to dry grassland, dry vegetation and mixed grassland with trees (Appendix Table 3). Reduced area in the dry grassland was distributed to other land cover types such as afforestation of pine trees, open sand and mixed grassland with trees.

Table 13 Land Cover Changes at Schlabendorf Süd from 2000 to 2003

Land Cover Class	Agg.	Year 2003 Area/ha	%	Year 2000 Area/ha	%	Change/ha
Afforestation	2	0	0	87.64	2.64	-87.64
Deciduous Trees Afforestation	3	6.27	0.19	97.77	2.95	-91.5
Afforestation of Pine Trees	1	467.54	14.11	373.32	11.27	94.22
Agricultural Land	5	396.79	11.97	316.80	9.56	79.99
Dry Grassland	8	505.81	15.26	776.28	23.42	-270.47
Dry Vegetation	4	542.80	16.38	624.18	18.83	-81.38
Lake	11	232.18	7.01	169.02	5.10	63.16
Mixed Grassland with Trees	6	671.30	20.26	89.89	2.71	581.41
Open Sand	9	82.62	2.49	3.02	0.09	79.6
Sparse Pioneer Grassland	7	381.13	11.50	775.10	23.39	-393.97
Wetland	10	27.34	0.83	0.95	0.03	26.39
Total		3313.78		3313.97		-0.19

Mixed grassland with trees increased to 581.41 ha between the year 2000 and 2003 (Table 13). This increase was largely taken from dry grassland, agricultural land, sparse pioneer grassland, pine afforestation, lake, afforestation and deciduous tree afforestation (Appendix Table 3). Other increase in land cover types observed were 94.22 ha afforestation of pine trees, 79.99 ha agricultural land and 79.6 ha open sand; all of which increased about 80 ha or more than 80 ha (Table 13).

The size of lake and wetland also recorded the highest increase at this period with the lake gaining 63.16 ha of other land cover types. Wetland gained 26.39 ha of other land cover types (Appendix Table 3). Increase in lake size was due to 30.87 ha of dry vegetation, 20.35 ha of sparse pioneer grassland, 24.80 ha of dry grassland or 65.61 % of the wetland (0.62 ha) changing to lake (Appendix Table 3). Wetland area gained 10.31 ha of sparse pioneer grassland and 11.98 ha dry grassland. Approximately 90 % of lake size being 150.83 ha was maintained at Schlabendorf Süd between 2000 and 2003 (Appendix Table 3).

4.4 Detailed Land Cover Distributions and Change Analysis at Three Different Segments (1988-1991, 1995-1998, 2000-2003) in Schlabendorf Nord

4.4.1 Land Cover Change Estimation at Schlabendorf Nord from 1988 to 1991 – First Segment

Results from land cover distribution and changes in Schlabendorf Nord shows interesting interaction among land cover types in the first segment. There was 286.19 ha decrease in afforestation area. Dry grassland and dry vegetation also lost a considerable part of their area to other land cover type (Table 14).

Reduction in afforestation area was mainly due to increase in agricultural land and afforestation of deciduous trees area (Appendix Table 4). Thus most of the trees planted at this period were predominantly deciduous tress. Afforestation of pine trees emerged as one of the dominant land cover types that took most of the afforestation area. Other land cover types that contributed to reduced area of afforestation is the agricultural land that also increased its area in the second segment (Appendix Table 4).

Decreasing area of dry grassland was largely the effect of increased area of sparse pioneer grassland. Dry vegetation also gained portions of dry grassland though the size of dry vegetation decreased by margin of 55 ha (Table 14 and Appendix Table 4). Change detection analysis reveals that only 32.16 % of the dry grassland area was maintained.

About 215 ha of the study area was changed to afforestation of deciduous trees (Table 14). In 1988 afforestation of deciduous trees covered 11.48 ha of the study area. This was increased significantly to 225.11 ha in 1991 resulting in a 213.63 ha increase in size. The increase in afforestation of deciduous trees indicates increase in tree planting activity. In another development, afforestation of pine trees also increase from 200.03 ha in 1988 to 334.20 ha in 1991 (Table 14). Other increase area observed was in agricultural land (27.26 ha).

Table 14 Land Cover Changes at Schlabendorf Nord from 1988 to 1991

Land Cover Class	Agg.	Year 1991 Area/ha	%	Year 1988 Area/ha	%	Change/ha
Afforestation	2	16.79	0.70	302.98	12.68	-286.19
Deciduous Trees Afforestation	3	225.11	9.42	11.48	0.48	213.63
Afforestation of Pine Trees	1	334.20	13.98	200.03	8.37	134.17
Agricultural Land	5	1065.84	44.60	1038.58	43.46	27.26
Dry Grassland	8	60.71	2.54	146.74	6.14	-86.03
Dry Vegetation	4	189.64	7.94	244.64	10.24	-55
Lake	11	154.29	6.46	183.11	7.66	-28.82
Mixed Grassland and Trees	6	238.56	9.98	221.16	9.25	17.4
Open Sand	9	24.65	1.03	6.91	0.29	17.74
Sparse Pioneer Grassland	7	80.12	3.35	34.05	1.42	46.07
Total		2389.91		2389.68		0.23

The 213.63 ha increase in area of afforestation of deciduous trees was due to contributions from afforestation. Thus deciduous tree part of afforestation became noticeable enough and its borders with afforestation of deciduous trees became distinct. In another development, afforestation of deciduous tress extended its cover to a considerable portion of agricultural land though agriculture land maintained more than 90 % of its area (Appendix Table 4).

The period 1988 to 1991 in Schlabendorf Nord did not have wetland cover at Schlabendorf Nord. Lake size reduced from 183.11 ha in to 154.29 ha (Table 14). The decreasing lake size is attributed to portion of the lake becoming open sand and mixed grassland and trees. About 70 % of lake size was maintained (Appendix Table 4).

Generally in Schlabendorf Nord lake area increased two times its original size in 1988 over the study period (Table 14). There was a steady decrease from 1988 to 1995. Nevertheless, it increased sharply from 1995 through to the year 2003, 18139.73 ha to 298.96 ha (Table 15 to 16).

4.4.2 Land Cover Change Estimation at Schlabendorf Nord from 1995 to 1998 – Second Segment

Land cover distribution and changes in Schlabendorf Nord from 1995 to 1998 are shown in Table 15. The second segment had a significant reduction in the size of afforestation (-102.21 ha) and agricultural land (-194.05 ha) at Schlabendorf Nord 1995 to 1998. Substantial reduction of area also occurred in dry vegetation cover.

Decreasing size of afforestation was as a result of it mainly changing to afforestation of pine trees and afforestation of deciduous trees (Appendix Table 5).
Of all the reduction in land cover areas observed in the second segment, agricultural land had the highest lost (Table 15). Changes detection analysis showed that 47.84 ha of the agricultural land was used for afforestation of deciduous trees while part of it was as well left to become mixed grassland and trees and dry grassland. Though about 195 ha of the agricultural land was lost from 1995 to 1998 in Schlabendorf Nord, 65.54 % being 622.02 ha of its area did not undergo any change (Appendix Table 5).

Table 15 Land Cover Changes at Schlabendorf Nord from 1995 to 1998

Land Cover Class	Agg.	Year 1998		Year 1995		Change/ha
		Area/ha	%	Area/ha	%	
Afforestation	2	12.33	0.52	114.54	4.78	-102.21
Deciduous Trees Afforestation	3	306.11	12.79	180.25	7.52	125.86
Afforestation of Pine Trees	1	363.15	15.18	372.74	15.55	-9.59
Agricultural Land	5	856.00	35.77	1050.05	43.81	-194.05
Dry Grassland	8	272.23	11.38	141.66	5.91	130.57
Dry Vegetation	4	40.10	1.68	100.58	4.20	-60.48
Lake	11	249.61	10.43	139.73	5.83	109.88
Mixed Grassland and Trees	6	178.17	7.45	182.94	7.63	-4.77
Open Sand	9	36.70	1.53	57.28	2.39	-20.58
Sparse Pioneer Grassland	7	78.37	3.28	45.02	1.88	33.35
Wetland	10	0	0	11.89	0.50	-11.89
Total		2392.77		2396.68		-3.91

Afforestation of deciduous trees increased from 180.25 ha in 1995 to 306.11 ha in 1998 (Table 15). Dry grassland in 1995 covered 141.66 ha of the study area, however in 1998, dry grassland area increased up to 272.23 ha (Table 15). The increase in dry grassland represents 130.57 ha of the study area. Sparse pioneer grassland also increased by a margin of 33.35 ha at the end of the second segment (Table 15).

Deciduous trees afforestation increasing in size was as a result of part of agricultural land being used for planting deciduous trees from 1995 to 1998 (Appendix Table 5). Significant portions of afforestation area also changed to afforestation of deciduous trees though 74.89 % of afforestation of deciduous trees was maintained (Appendix Table 5). Portions of sparse pioneer grassland in this segment also dried up to contribute to the increased area of dry grassland.

In 1995, 139.73 ha of the study area were covered by lake. Lake in 1988 however increased by margin of 109.88 ha (Table 15). Change detection analysis results (Appendix Table 5) show that significant part of this increase was taken from dry grassland and open sand. It must be said that 90.99 % of lake area was maintained. A detailed look at changes that occurred in the wetland also shows that 88.25 % of the wetland area also contributed to the increased size of lake (Appendix Table 5).

4.4.3 Land Cover Change Estimation at Schlabendorf Nord from 2000 to 2003 – Third Segment

The changes in land cover types monitored between the periods of 2000 to 2003 at Schlabendorf Nord showed that mixed grassland with trees had the greatest increase in area 279.83 ha (Table 16). 45.36 ha from other land cover types changed to open sand. Relatively small portion of other land cover types change to the afforestation of deciduous trees (Appendix Table 6). Areas that contributed to increase in mixed grassland with trees were those that were lost from dry vegetation, afforestation of deciduous trees, agricultural land, afforestation and lake (Appendix Table 6).

Table 16 Land Cover Changes at Schlabendorf Nord from 2000 to 2003

Land Cover Class	Agg.	Year 2003 Area/ha	%	Year 2000 Area/ha	%	Change/ha
Afforestation	2	16.74	0.70	34.12	1.43	-17.38
Deciduous Trees Afforestation	3	215.99	9.03	199.11	8.33	16.88
Afforestation of Pine Trees	1	364.18	15.23	386.55	16.17	-22.37
Agricultural Land	5	872.30	36.48	935.47	39.12	-63.17
Dry Grassland	8	153.54	6.42	280.80	11.74	-127.26
Dry Vegetation	4	44.64	1.87	63.28	2.65	-18.64
Lake	11	298.96	12.50	285.33	11.93	13.63
Mixed Grassland with Trees	6	349.17	14.60	69.34	2.90	279.83
Open Sand	9	46.71	1.95	1.35	0.06	45.36
Sparse Pioneer Grassland	7	17.56	0.73	135.90	5.68	-118.34
Wetland	10	11.16	0.47	0	0	11.16
Total		2390.95		2391.25		-0.3

Dry grassland decreased in area from 280.80 ha in 2000 to 153.54 ha in 2003 (Table 16). This is a decrease by margin of 127.26 ha of the entire area. Similarly, the area covered by sparse pioneer grassland decrease by -118.34 ha of the entire area. Other substantial reductions in size were observed in the agricultural land (63.17 ha) and afforestation of pine trees (22.37 ha) (Table 16). Reduction in dry grassland cover was due to portions of its cover changing to agricultural land, mixed grassland with trees, lake and open sand (Appendix Table 6). Portion of sparse pioneer grassland becoming smaller in size can partly be attributed to the mixed grassland with trees extending its cover to dry grassland (Appendix Table 6). Other areas that also contributed to the reduced size of sparse pioneer grassland were lake and dry grassland.

Though there was increase in the size of wetland and lake at the third segment, the increase was relatively small. 92.8 % of lake size was basically maintained. Other land cover types contributing to increase in lake size were sparse pioneer grassland, mixed grassland and trees and dry vegetation (Appendix Table 6).

4.5 Detrended Correspondence Analysis - DCA

Though DCA gives difficult but most interpretable results, there are still some limitations that make the inclusion of additional environmental condition and ecological insight necessary (Hill and Gauch, 1980). Pielou (1984) warned that DCA is “overzealous” in correcting the defect in CA, and may sometimes lead to the unwitting destruction of ecologically meaningful information. The first two ordination axes explain total of 60.5 % variance of the species data of the plot in Schlabendorf Süd and 67.6 % of the plot in Schlabendorf Nord (Table 17). These are both significant. The results of DCA plot for land cover distribution at Schlabendorf Nord and Schlabendorf Süd are as shown in Figure 26, page 95.

4.5.1 Detrended Correspondence Analysis Results at Schlabendorf Süd

Results from the ordination plot at Schlabendorf Süd are described in Figure 26 of page 95 and Table 17. Similarities were visible in both sides of the ordination diagram. Vegetation types located at the left side of the second axis generally decreased in area at the end of the study period (Figure 26 of page 95). On the other hand however, vegetation type’s distribution and lake at the right side of ordination axis 2 increased their areas at the end of the study period.

In general, higher eigenvalue are related to higher beta diversities but there are numerous exceptions to this pattern (http://ordination.okstate.edu/DCA.htm). On both axes, the minimum sample score is zero. Of all the land cover distributions over the study period, land cover distribution in 1995 and 1998 were more similar in Schlabendorf Süd (Figure 26 of page 95). Though there were fluctuations in the land cover areas, gradient of dissimilarity transformation increased along both axes.

In Schlabendorf Süd, similarities were visible in the group of pine afforestation, lake and mixed grassland, which are arranged together in ordination diagram. Afforestation of pine trees and lake both had parallel trend of land cover transformation throughout the period of study (Figure 26 of page 95 and Appendix Table 8). In a similar way, mixed grassland experienced largely comparable land cover transformation as afforestation of pine trees and lake for most part of the study period except in the year 2000 where there was a deviation from the transformation trend (Appendix Table 8). On the same side of the diagram, just below ordination axis 1 lays another interesting observation (Figure 26 of page 95).

Table 17 Ordination Statistics showing Eigenvalues and how the Variance explain the Distribution of Land Cover Types along the Primary Axes of DCA at Schlabendorf Süd and Schlabendorf Nord

	Schlabendorf Süd		**Schlabendorf Nord**	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**
Eigenvalues	0.121	0.008	0.097	0.009
Variance explained (%)	56.9	60.5	61.6	67.6
Lengths of gradient	0.981	0.394	0.793	0.513

Dry grassland cover experienced a reverse of the parallel transformation observed among pine afforestation, lake and mixed grassland throughout the study period (Appendix Table 8). Agricultural land and deciduous tree afforestation both encountered similar land cover distribution for most part of the study period with some variation in both vegetation types at 1998 and 2003.

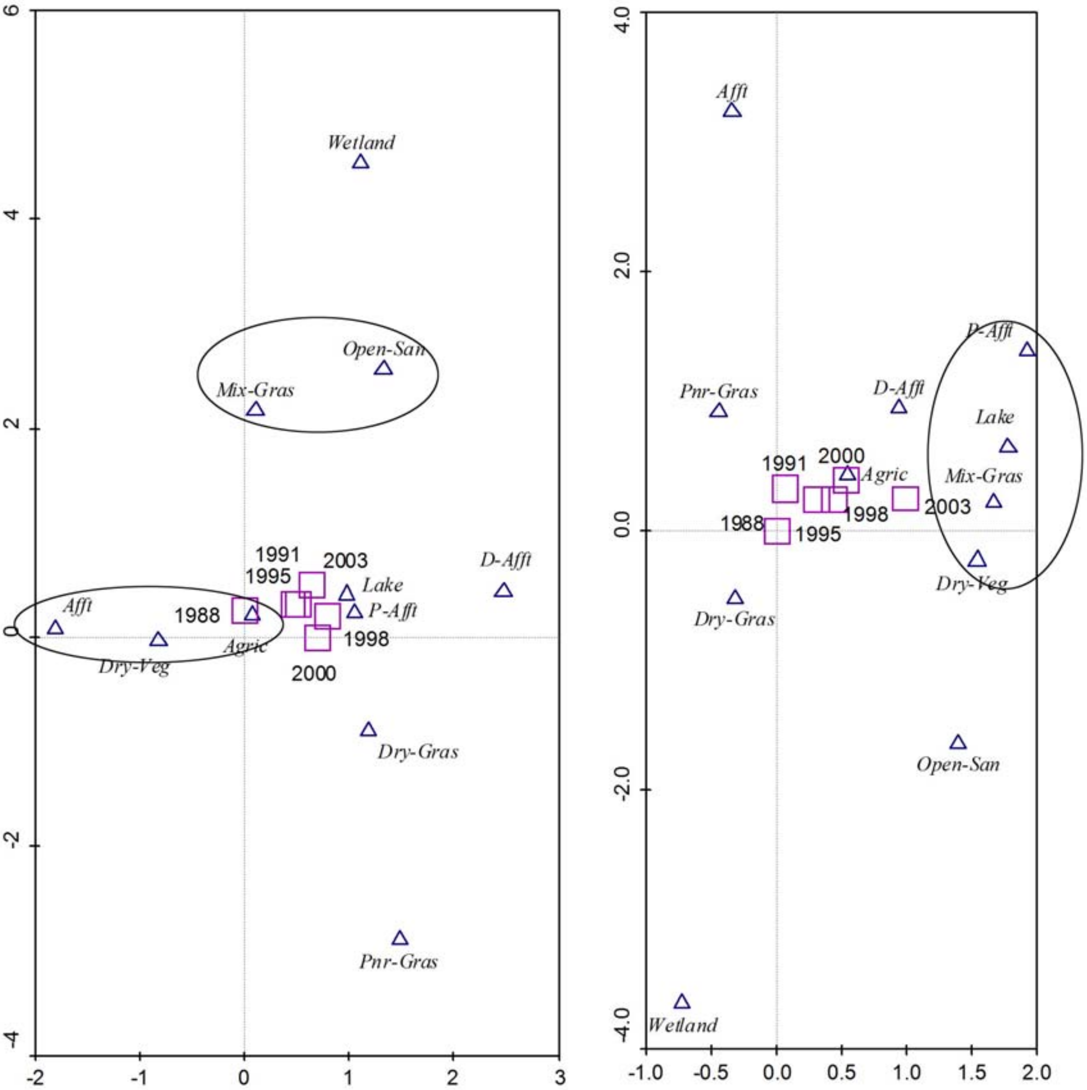
The distributions of the remaining land cover types in ordination diagram are further apart from each other and therefore emphasize the degree of dissimilarities in their distributions (Figure 26).

4.5.2 Detrended Correspondence Analysis Results at Schlabendorf Nord

Afforestation and deciduous tree afforestation both had continues dissimilarity in vegetation cover in the entire period of study (Appendix Table 7). This is why they are located further apart at both ends of the ordination axis 1. Any increase in vegetation cover corresponded to decreased vegetation in the same land cover year. This dissimilarity as well existed between afforestation of deciduous trees and dry vegetation though both vegetation types decreased in 1998 (Appendix Table 7).

Afforestation and dry vegetation are grouped together due to the parallel trend of distribution observed between them (Figure 26). An increase in afforestation attracted a parallel increase in the dry vegetation cover except in 1998 where deviation (reduction) occurred in dry vegetation cover (Appendix Table 7).

Mixed grassland and open sand largely had similar land cover distribution for most part of the study except in 1991 where variation occurred.



DCA ordination plot for LC distribution at Schlabendorf Nord with untransformed data

DCA ordination plot for LC distribution at Schlabendorf Süd with untransformed data

Figure 26 DCA Ordination Plot for Land Cover Distribution at Schlabendorf South and Schlabendorf Süd with Untransformed Data.

Legend: P-Afft. represents afforestation of pine trees, Afft. - afforestation, D-Afft. - deciduous trees afforestation, Dry-Veg. - dry vegetation, Agric. - agriculture land, Mix-Grass. - mixed grassland and trees, Pnr-Grass. - sparse pioneer grassland, Dry-Grass - dry grassland, Open-Sand. - open sand, Wetland. - wetland, Lake. - lake.

The further apart the land cover types are from both ordination axes, the lesser the similarity in their distribution in the landscape. Pioneer grassland is located further from mixed grassland, open sand and wetland (Figure 26). Correlation results show there is a strong negative relationship between pioneer grassland and mixed grassland, wetland and open sand. Generally, mixed grassland and open sand increased their vegetation cover at the end of the study period as pioneer grassland increased (Appendix Table 7). Though pine afforestation and lake lay closer to each other in the ordination plane, they do not represent any visible similarity in land cover distribution (Figure 26).

4.5.3 DCA Results at Schlabendorf Nord and Schlabendorf Süd Compared

The first DCA ordination axis correlates with gradient of increasing year (time) of land cover from 1988 to 2003. As indicated earlier, the first two ordination axes explain 60.5 % and 67.6 % variance of the species data of the plot in Schlabendorf Süd and Schlabendorf Nord respectively (they are both significant). The second axis increases with increasing land cover distribution area. Land cover types close to the center of both ordination axes, are those that did not undergo much transformation in area over time. For instance, Agricultural land in Schlabendorf Nord did not undergo significant changes from 1988, 1991 and 1995 (Figure 26, 27 and Appendix Table 8). It remains basically stable with gentle decline even after a significant decrease in 1998. Similarly in Schlabendorf Süd, agriculture land was the most stable land cover type. Other stable land cover types are those that had low standard deviation values. Figure 27 below illustrates gradual changes in agricultural land cover area in Schlabendorf Süd and Schlabendorf Nord

Comparing the land cover distribution in the two ordination plots, visible variability was observed in Schlabendorf Nord and Schlabendorf Süd (Figure 26). Thus the diagram can be used to visualize the similarity in the same landscape or their trend in the two post-mining landscapes. Unlike Schlabendorf Nord, the land cover distributions in Schlabendorf Süd correspond with gradient of time (Figure 26).

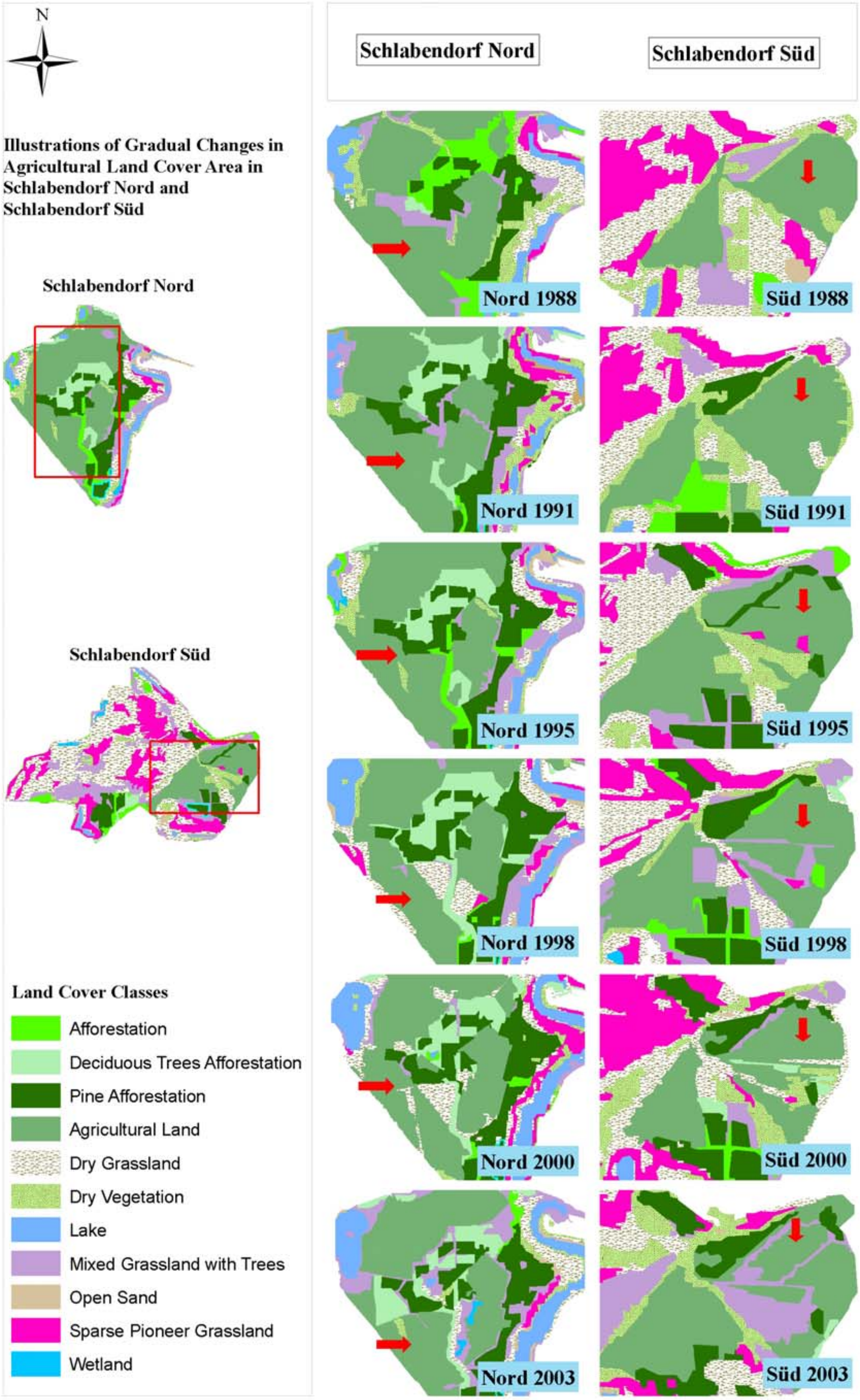
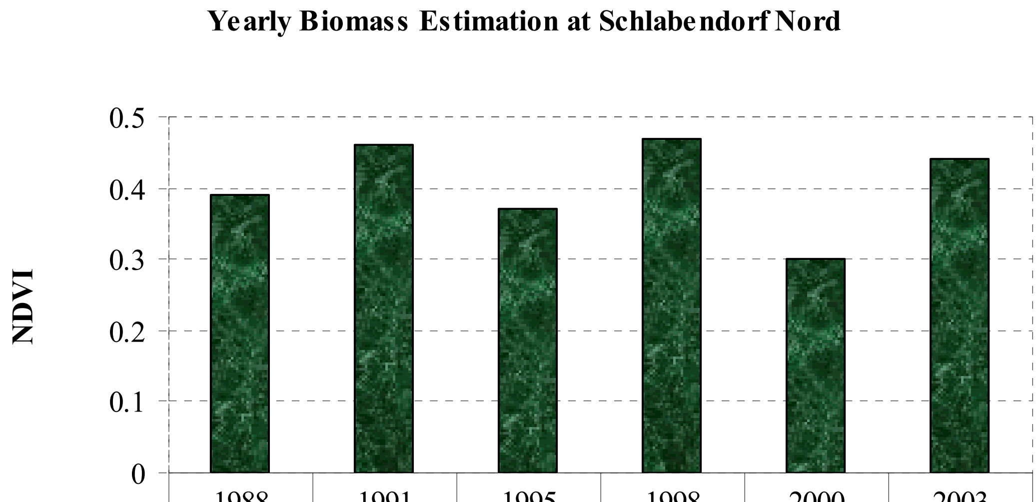


Figure 27 Gradual Change in Agricultural Land Cover Area

Most land cover types in Schlabendorf Süd (4 out of the 11) were located at the left side of the first ordination axis as compared to 2 out of 11 land cover types in Schlabendorf Nord. The location of afforestation, pioneer grassland and dry grassland at Schlabendorf Süd implies decreasing land cover area over the study period that favours reverse succession. Greater part of the sown grassland failed. Change detection results reveal that greater part of area that was lost in pioneer grassland became open sand. Thus reverse succession occurred in much more in Schlabendorf Süd as compared to Schlabendorf Nord. It must be said that afforestation was found in both side of the study area.

4.6 Estimation of Primary Production from Normalized Difference Vegetation Index

NDVI values in Schlabendorf Nord showed greater variation in primary production from 1988 to 2003. The highest NDVI value was in 1998 and 2003 respectively (Figure 28). The year 2000 had the lowest value of NDVI in Schlabendorf Nord. Unlike Schlabendorf Süd with largely consistent increase NDVI value, Schlabendorf Nord had fluctuating NDVI values where an increased NDVI in one year is followed by decreased NDVI and vice versa.



	1988	1991	1995	1998	2000	2003
NDVI	0.39	0.46	0.37	0.47	0.3	0.44

Figure 28 Estimated Biomass for Schlabendorf Nord 1988, 1991, 1995, 1998, 2000 and 2003.

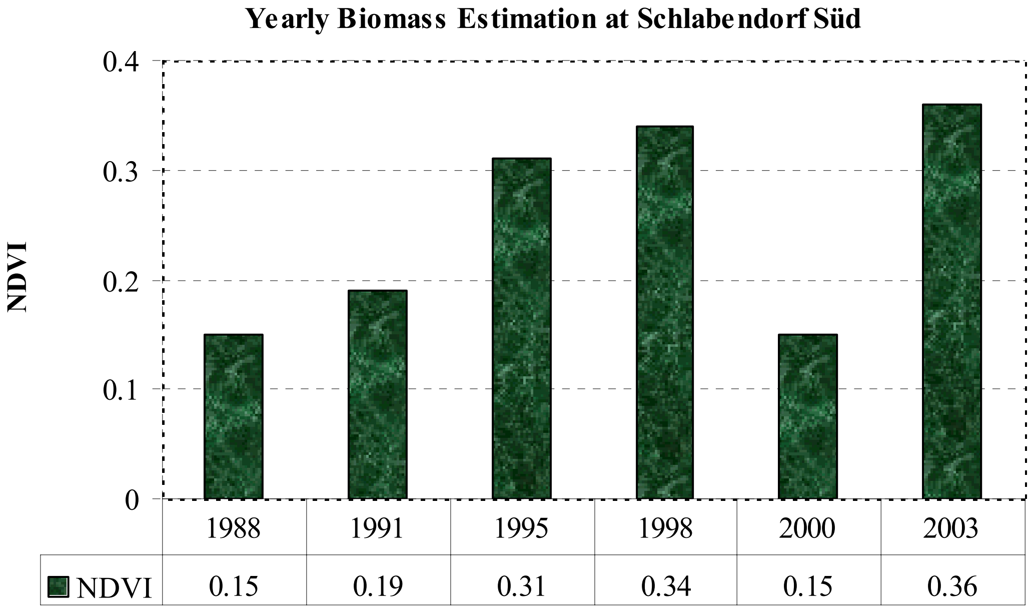


Figure 29 Estimated Biomass for Schlabendorf Süd 1988, 1991, 1995, 1998, 2000 and 2003.

NDVI values ranges from -1 to +1 but vegetation values typically fall within 0 and +1 with higher index values representing more active growth and primary production.

All study periods in Schlabendorf Nord had greater NDVI value than the same period in Schlabendorf Süd. In both study areas, the least primary production was observed in 2000. Generally there is a consistent trend in the estimated primary production in Schlabendorf Süd over the study period except in 2000. There was a general increase in net biomass during the first ten years of the study (Figure 29).

Though primary production decreased in 2000 to its initial value in 1988, there was a sharp increase in 2003 where the highest NDVI value was recorded. The highest NDVI value was in 2003. Both 1988 and 2000 recorded the least primary production.

4.7 Effect of Soil pH on Vegetation Growth and Land Cover Change

Soil pH taken along and near the failed pine afforestation area (mining strip/belt), which could not support vegetation growth, were generally low (Figure 30). Soil pHs from the pine forest across the open sand areas were high at both sides of the pine forest but decreased in the open sand area.

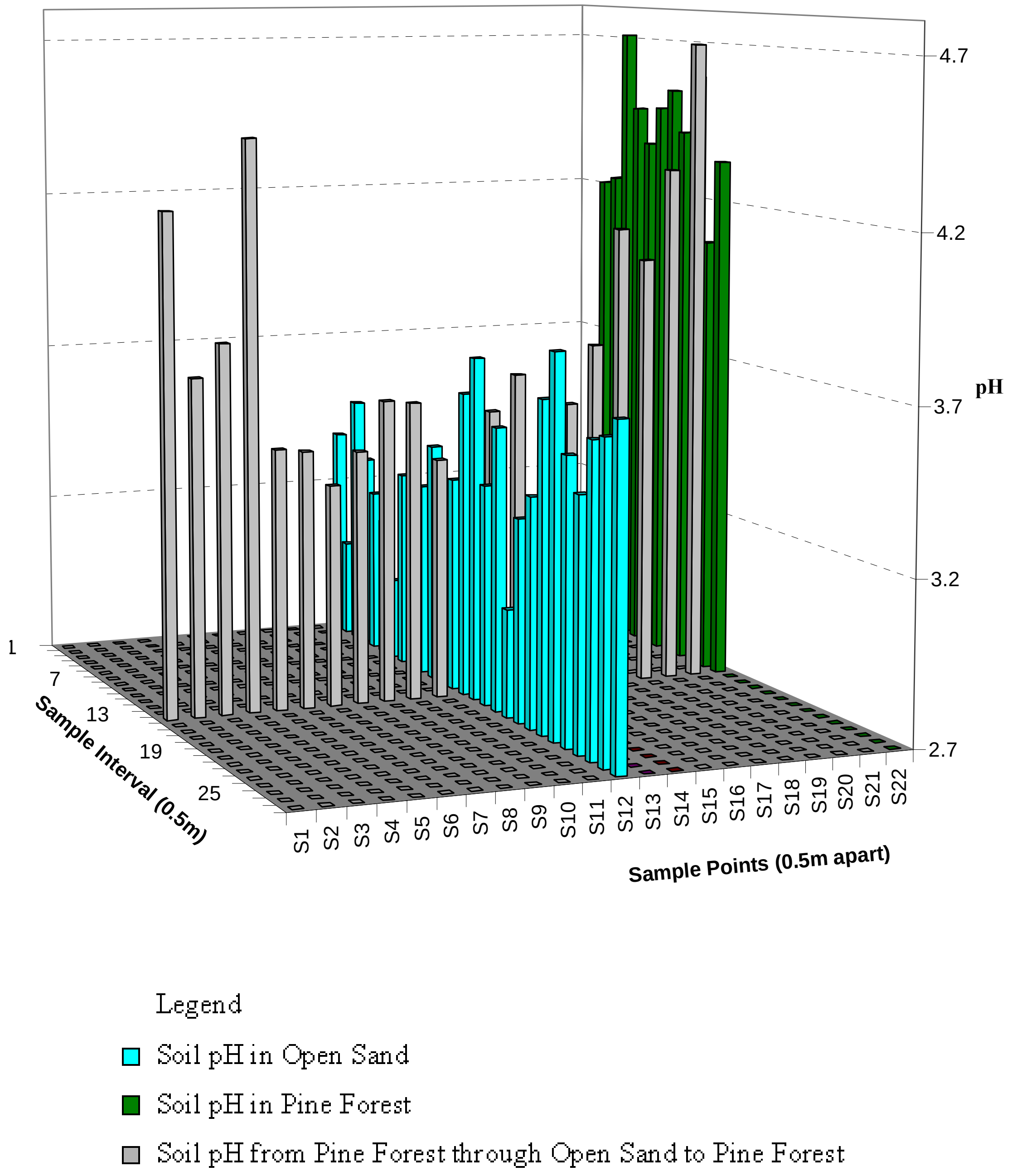


Figure 30 Soil pH taken from failed Pine Afforestation Area (open sand) and Successful Pine Afforestation (Antwi and Krawczynski, in process).

The failed pine afforestation area is one of several bare sand areas along mining strip, which were initially afforested but could not support the vegetation growth after some years.

Soil sample taken strictly from the pine forest also has comparably high pH values (Figure 30). Thus areas that failed to support vegetation growth had much lower soil pH than the pine forest (Figure 30).

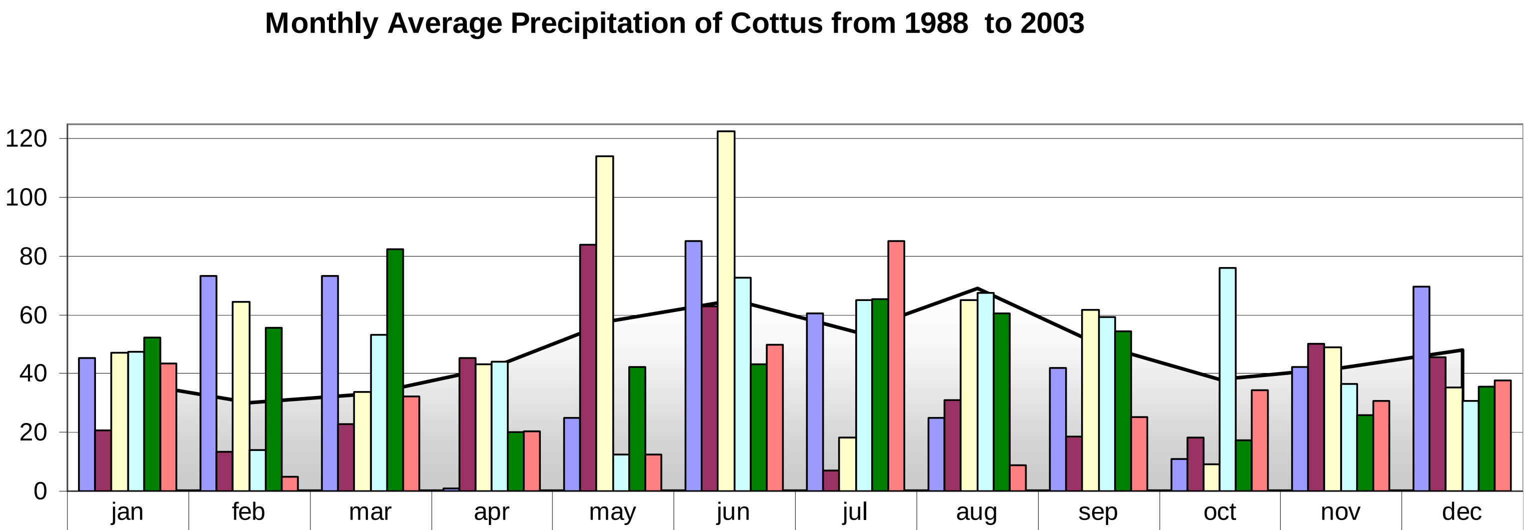
4.8 Average Behaviour Function of Climate Factors in Schlabendorf

The annual mean precipitation for the study period 1988, 1991, 1995, 1998, 2000 and 2003 were 553.7 mm, 419.8 mm, 663.5 mm, 578.9 mm, 555.4 mm, and 385.1 mm respectively. Compared to the 566 mm mean precipitation from 1961 and 1991, the years 1991 and 2003 were the driest of all the study periods (Figure 31, page 102). The wettest of all the years of assessment was 1995. Annual precipitation measured in 1988, 1998, and 2000 were closely related to the mean precipitation from 1961 to 1991 (566 mm).

The monthly temperature of February 1998 to 2000; March 2000; April 2000; May 1991; June 1991 and 1995; July 1998 and 2000; September 1988 and 1995; October 1988; 1991 and 2003; November 1988, 1991, 1995 and 1998; and December 1991 and 1995 were below the mean temperature (Figure 32, page 103). Most of the temperatures recorded were above the average values. In August where most of the analyses were carried out, every land cover year had the temperature at or above the average value.

The annual precipitation measured in 1993, 1994, 1995, and 2002 were significantly above the mean precipitation values (Figure 33, page 104). Most of the annual precipitation fell below the mean annual value of 1961 to 1990. Regarding the various years of study, 2003 and 1991 were the driest periods. The wettest period during the study was in 1995. Rainfall recorded during 1988, 1998 and 2000 were largely close to the mean value (Figure 33).

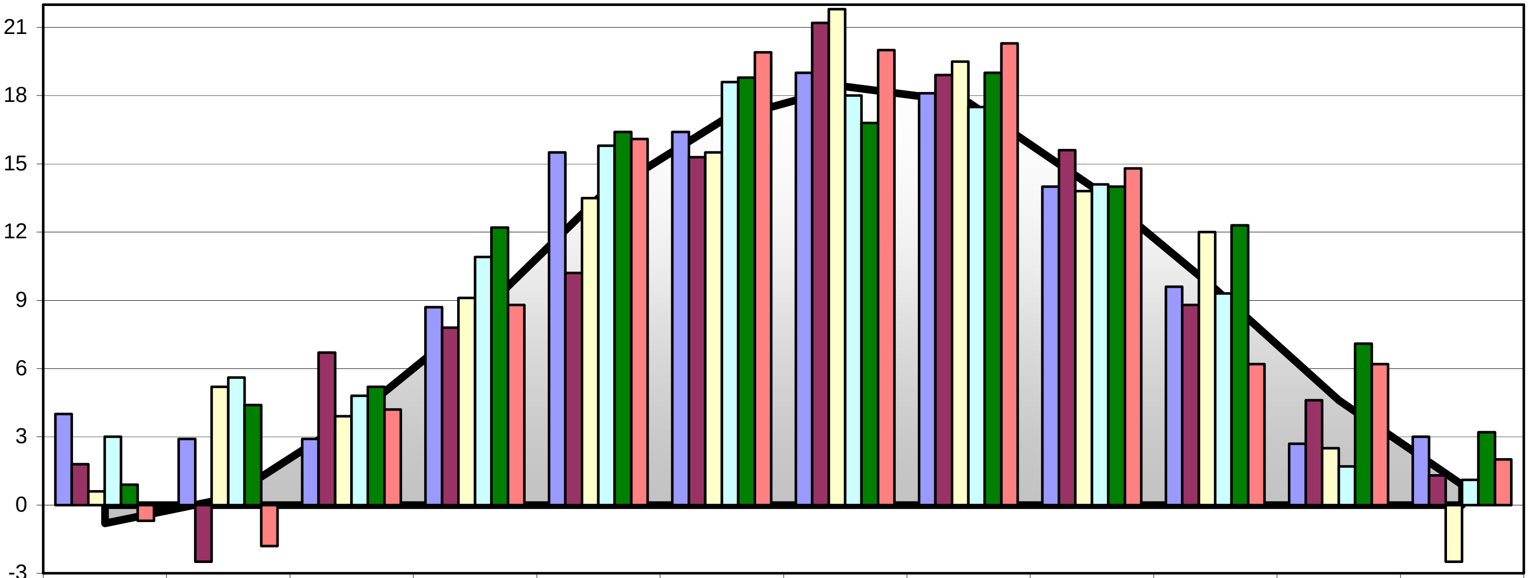
All the annual temperatures were above the mean value except annual temperature of 1996 which was the coldest throughout the years (Figure 34, page 105). Temperature recorded during 1991, 1993 1995 and 1997 were close to the mean value. During the study however, all the annual temperature recorded were above the mean value.



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Mean 1961-1990	37	30	33	42	58	65	54	69	50	38	42	48
2003	43.6	5	32.2	20.3	12.4	50	85.1	8.7	25.1	34.4	30.7	37.6
2000	52.3	55.7	82.3	20.2	42.4	43.3	65.4	60.5	54.5	17.2	25.9	35.7
1998	47.5	13.9	53.3	44.2	12.6	72.6	65	67.5	59.2	76	36.4	30.7
1995	47.1	64.5	33.9	43.2	114.2	122.5	18.2	65	61.7	9	49	35.2
1991	20.8	13.4	22.8	45.3	83.9	63	7.1	31	18.6	18.1	50.1	45.7
1988	45.4	73.2	73.2	1	25	85.3	60.5	25	42.1	11.1	42.2	69.7

Figure 31 Monthly Average Precipitation of Cottbus During the Period of 1988 to 2003 Compared with the Average Precipitation from 1961 to 1990.

Monthly Average Temperature of Cottus for the Study Periods 1988, 1991, 1995, 1998, 2000 and 2003



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Mean 1961-1990	-0.8	0.3	3.8	8.2	13.5	16.9	18.4	17.7	14	9.5	4.6	0.9
2003	-0.7	-1.8	4.2	8.8	16.1	19.9	20	20.3	14.8	6.2	6.2	2
2000	0.9	4.4	5.2	12.2	16.4	18.8	16.8	19	14	12.3	7.1	3.2
1998	3	5.6	4.8	10.9	15.8	18.6	18	17.5	14.1	9.3	1.7	1.1
1995	0.6	5.2	3.9	9.1	13.5	15.5	21.8	19.5	13.8	12	2.5	-2.5
1991	1.8	-2.5	6.7	7.8	10.2	15.3	21.2	18.9	15.6	8.8	4.6	1.3
1988	4	2.9	2.9	8.7	15.5	16.4	19	18.1	14	9.6	2.7	3

Figure 32 Monthly Average Temperature of Cottbus During the Period of 1988 to 2003 Compared with the Average Temperature from 1961 to 1990.

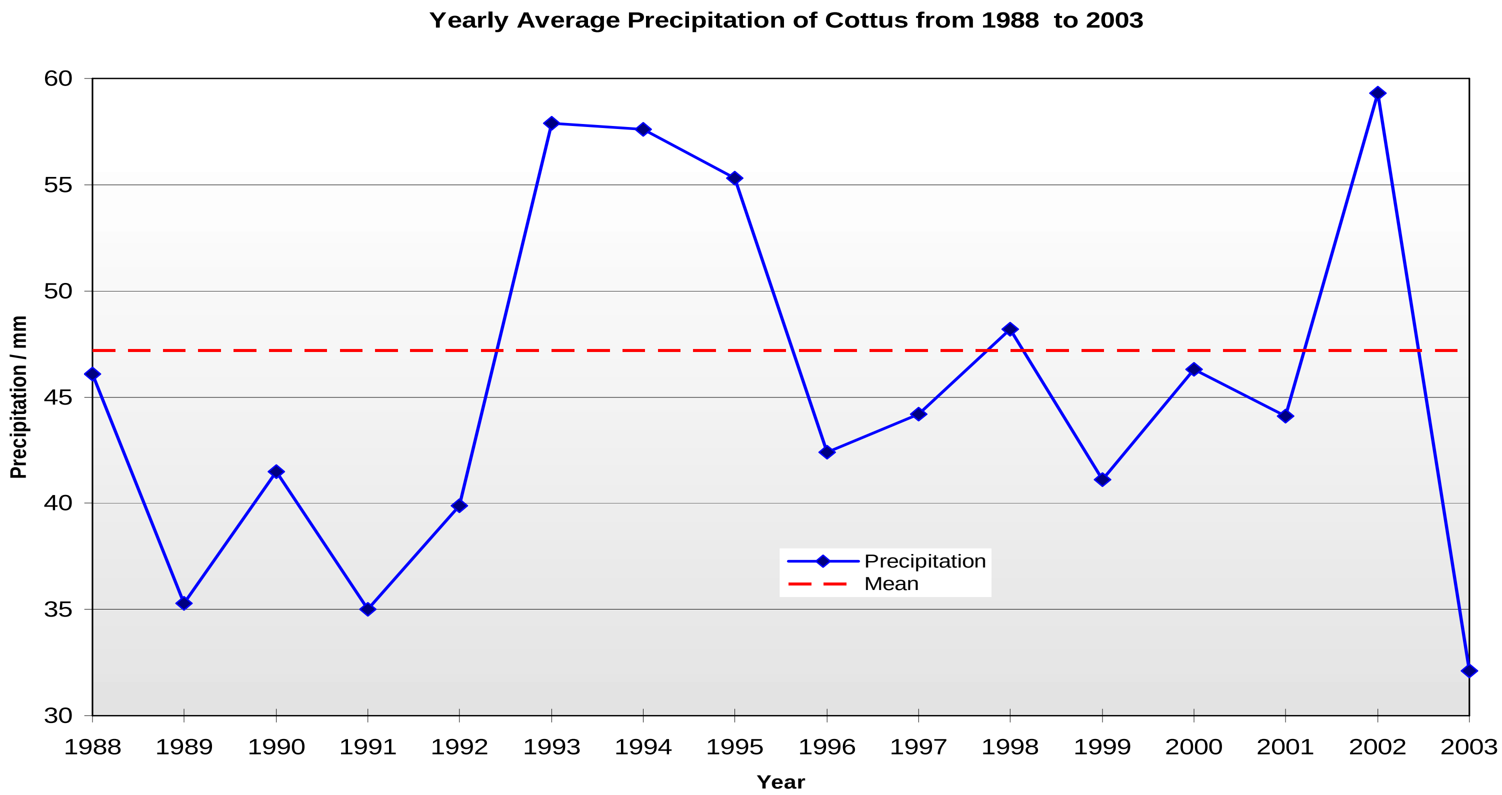


Figure 33 Yearly Average Precipitations of Cottbus from 1988 to 2003 Compared with the Mean Precipitation from 1961 to 1990. The Mean Precipitation Value from 1961 to 1990 was at 47.2 mm.

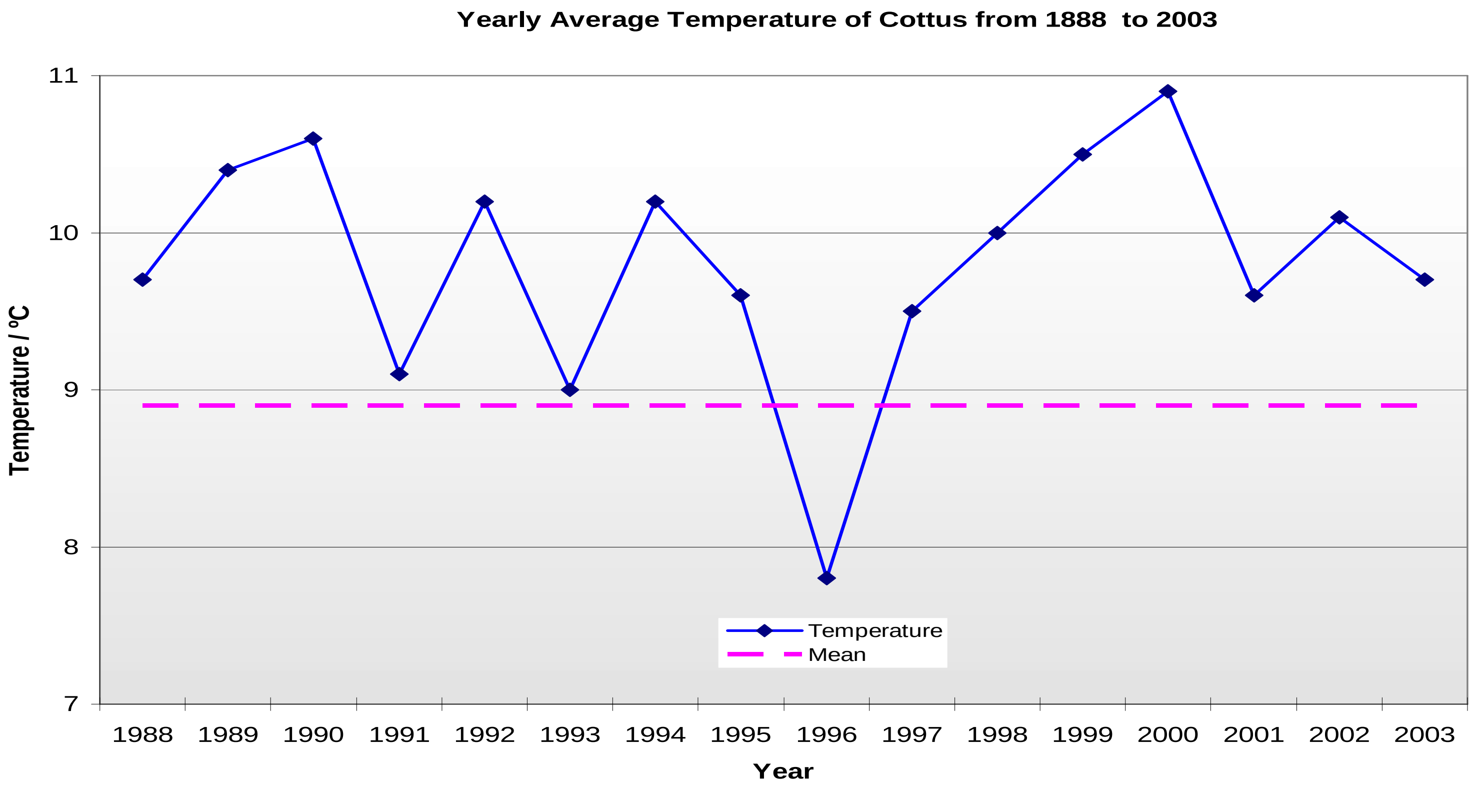


Figure 34 Yearly Average Temperatures of Cottbus from 1988 to 2003 Compared with the Mean Precipitation from 1961 to 1990. The Mean Temperature Value from 1961 to 1990 was 8.9 ºC.

5 Discussions

5.1 Estimation of Habitat Richness, Habitat Size and Habitat Fragmentation from Patch Area Metrics in Schlabendorf Nord and Schlabendorf Süd

One of the four general types of fragmentation indices suggested by Dale and Pearson (1997) to describe spatial pattern in habitat maps is patch or habitat area. The others are frequency distribution of patch size, measure of patch shape, and length of edge between different habitat types. In the context of this research, habitat fragmentation shall be defined as the 'breaking up of habitat, ecosystem or land cover types into smaller parcels' (Forman, 1995).

Formation of more patches leading to high degree of fragmentation in the post-mining landscape could be the result of the reclamation or "afforestation" or the result of plant succession. In other words, fragment formations in these areas could be due to natural and anthropogenic causes or the interactive effect of the two as found usually in plant succession. Some of the anthropogenic causes of landscape fragmentation in the post-mining landscapes are cutting out afforested areas and construction in potential lake areas.

The most recognisable natural cause of fragmentation is lack of soil nutrient and low soil pH in certain areas of the post-mining landscape. These areas are usually cultivated either with trees or seeded grasses but eventually lose their vegetation cover to become open sand hence, breaking habitats that were once large into smaller patches (Forman, 1995). Thus, the above factors have led to the formation of high number of patches with comparatively smaller mean patch sizes (See Section 4.7 of page 99 for the effect of soil pH on vegetation growth). The post-mining landscape also has high population of wild boars, which occasionally destroy large vegetation areas in search of food.

Number of patches is related to habitat richness. High number of patches indicates high habitat richness (McGarigal and Marks, 1994). Habitat richness in both study areas was generally high due to general increase in number of patches.

Similar to Schlabendorf Nord, habitat fragmentation in Schlabendorf Süd generally increased over the period of study due to high number of patches and decreased mean patch sizes (Figures 35 and 36). Both areas were least fragmented during the beginning of the project in 1988 though they still emerged the most fragmented landscapes in 2000 (Figures 35 and 36). Generally the trend of fragmentation in both study areas followed a similar pattern.

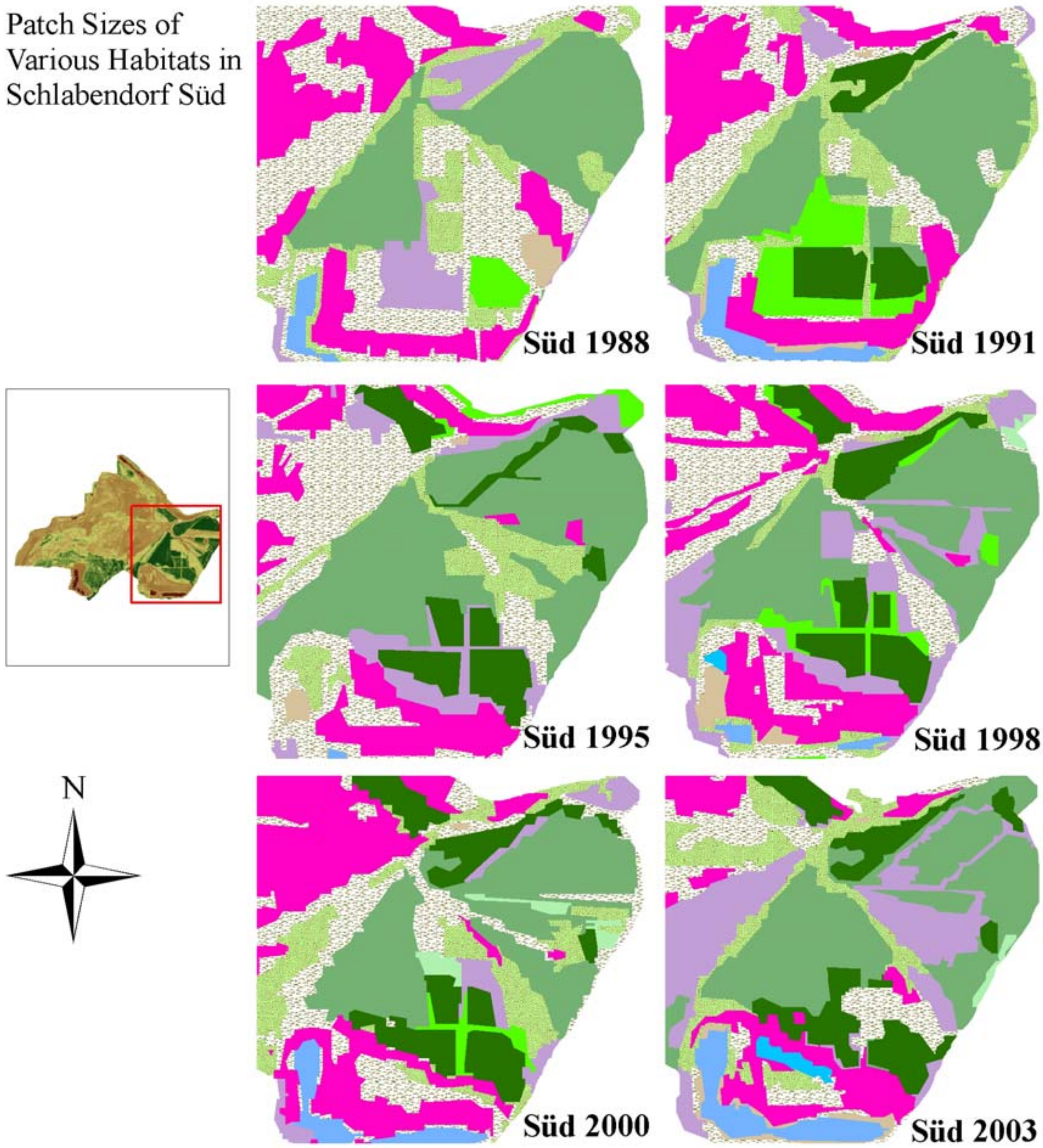


Figure 35 Diagrammatic Illustration of Changing Number of Patches and Mean Patch Sizes in Schlabendorf Süd.

Saunders et al. (1991) observed that when areas of habitat patches are reduced, there is increase in the vulnerability of the conditions in the patches to external influences. Following this observation, habitat conditions in both areas are now more affected by external influences than they were earlier on. Thus conditions in individual habitat have become more susceptible to external influence over the years with the highest or most probable susceptibility in 2000.

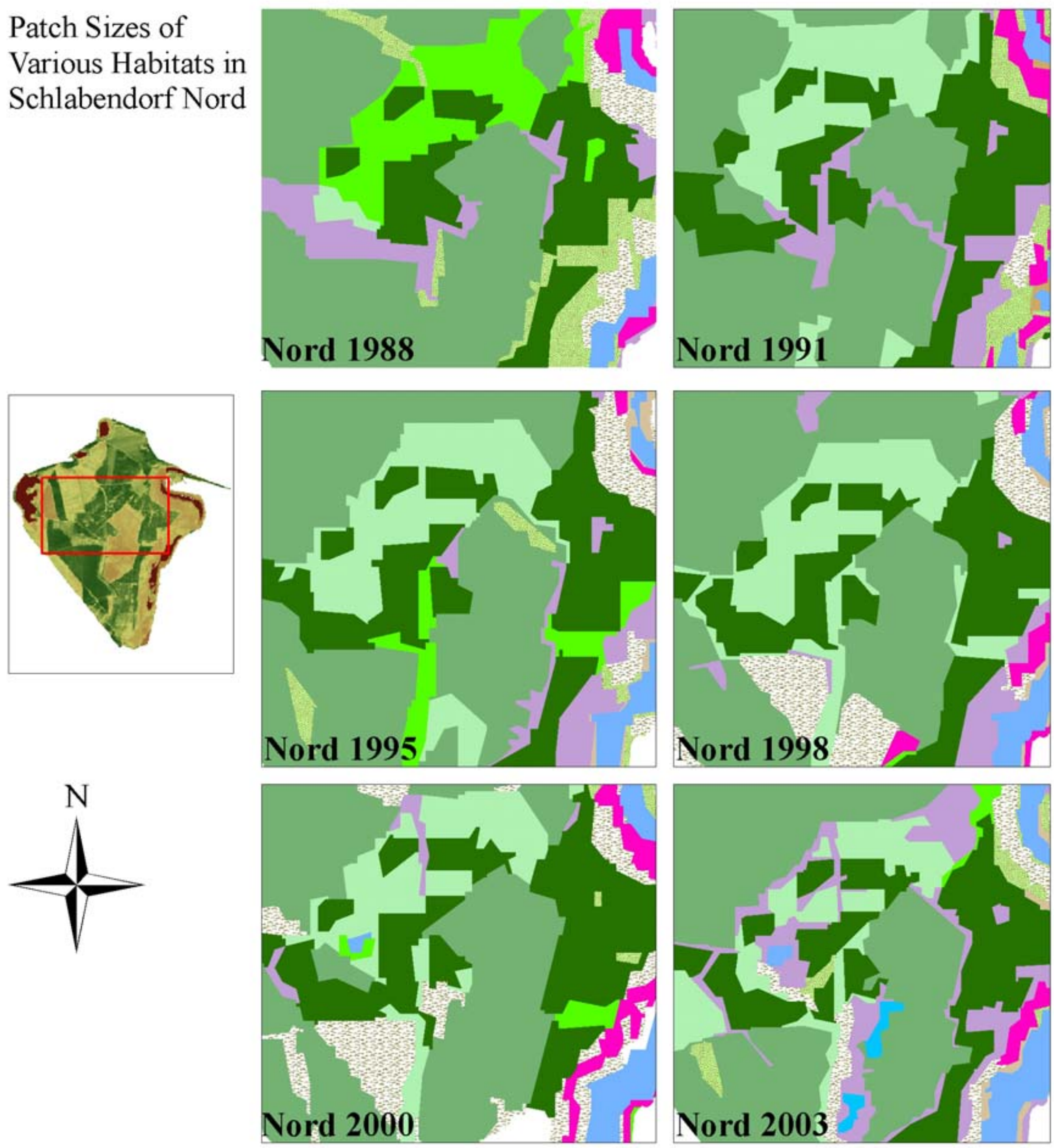


Figure 36 Diagrammatic Illustration of Changing Number of Patches and Mean Patch Sizes in Schlabendorf Nord.

The two most significant effect of habitat fragmentation are a decrease in habitat size and reduction in species diversity (Zuidema et al., 1996). Having observed a considerable decrease in mean patch sizes in both study areas, the results of habitat diversity (increased or reduced) could be one of the determining factors supporting the intermediate disturbance hypothesis or the fragmentation hypothesis.

The intermediate disturbance hypothesis has received a widespread application in explaining pattern of local and regional biodiversity. It states that severe disturbance or even a prolonged absence of disturbance generally has depressing effect on biodiversity, but intermediate disturbance seems to enhance diversity in a system (Pickett and White, 1985; Collins 1989, 1992).

Since habitat fragmentation has a major impact on the regional survival of plant species (Saunders et al., 1991; Tilman et al., 1994; Ney-Nifle and Mangel, 2000), and it is said to be one of the most important causes of worldwide loss of biodiversity (Vitousek et al., 1997) factors in Schlabendorf Nord and Süd such as poor soil nutrient, low soil pH and cutting out trees in the landscapes should be checked. As concluded by Zuidema et al. (1996), habitat fragmentation almost always goes together with habitat loss and decrease in population. With large patches becoming smaller in both study areas, survival possibility of specialized species and generalised species could be affected since large patches in those areas are becoming smaller. Thus less and less individuals of a particular species restricted to that habitat could survive.

According to Pickett and Rogers (1995), patchiness occasionally results in higher species diversity. Increase in the number of patches over the years supports the idea that species diversity in Schlabendorf could increase. In 1988, Schlabendorf Süd had 9 habitat types compared to 10 habitat types in Schlabendorf Nord. Habitat types in Schlabendorf Süd 2003 were also one less than that of Schlabendorf Nord 2003. But habitat types in most period of study were more in Schlabendorf Süd than Schlabendorf Nord. The land cover type wetland was not formed during greater part of the study in Schlabendorf Nord (i.e. in 1988, 1991, 1998, and 2000) except in 1995 and 2003 where it existed but it basically had the same size. Thus habitat richness was considerably high in Schlabendorf Süd than Schlabendorf Nord.

5.2 Detecting Habitat Shape Complexity in Schlabendorf from Shape Metrics

The mean shape index (MSI) has been published and widely used in landscape ecology to describe geometric characteristics of habitat shapes in landscapes. MSI measurement is not affected by patch scale and does not depend on resolution. Couple with other advantages, MSI was preferred to a resolution dependent mean patch fractal dimension which is an equally good measure of habitat shape complexity. MSI is 1 when all patches (polygons) are circular with polygons or square in the case of grids (McGarigal and Marks, 1995). Decreasing MSI indicates shape has become simpler, and increasing, otherwise.

In both landscapes habitats with larger mean patch sizes were found to have high shape complexity. This can be attributed to the fact that large habitats sometimes show irregular shapes (Moser et al., 2002).

Habitat shape complexity in beginning was relatively high in both Schlabendorf Nord and Süd but decreased in 1991. During 1991 and 1995, habitats shape became more complex in both landscapes though complexity was more visible in Schlabendorf Nord than Schlabendorf Süd (Figures 35 and 36). Habitat shape complexity eventually became lower and lower in both areas as the study progressed from 1995 to 2000. In fact, habitat shapes in 2000 became one of the simplest of all the periods studied with the lowest MSI values. Considering the above observations, Dramstad et al. (1998) assertion that when patches join to become larger, they do not necessarily become simple is confirmed. This is also in agreement with the fact that large habitats occasionally show irregular shapes (Moser et al., 2002). The mean shape index in 2003 again indicates habitat shapes became more complex and closer in magnitude to each other even more than they have ever been throughout the study.

It must be said that at every year studied, habitat types were more complex in Schlabendorf Süd than Schlabendorf Nord. Schlabendorf Nord being 14 years older than Schlabendorf Süd was afforested earlier and is expected that habitat types in the Nord have become more stable in shape and form since this area sees less intensive afforestation or land use intensity. Increasing land use intensity has been found to have a depressing effect on landscape shape complexity (Moser et al., 2002). Though pattern of habitat shape complexity was largely similar in the old site (Schlabendorf

Nord) despite the sharp rise in MSI, higher MSI in the younger study site (Schlabendorf Süd) indicates variability in habitat structure and form are conspicuous. Factors such as variability in soil condition, and human influences as noted earlier could be having effect on the varying habitat structure.

Moser et al. (2002) noted that other several driving factors are responsible for decreasing landscape complexity with increasing land use intensity. Most landscape elements (such as afforested areas, agricultural land etc.) in areas such as the post-mining area are usually designed to be straight with distinct boundaries. Hulshoff (1995) also realised that outer edges of semi-natural patches get straightened by neighbouring afforested area or cultivated areas therefore decreasing the complexity of patch shapes as in the case of 2000 in both landscapes. Thus increasing land use intensity is accompanied by a decrease semi-natural area (Mander et al., 1999) and decrease in curvy patch edges.

Many small patches or simple patches do not offer the same habitat opportunity as a single larger patch, especially for organisms that require interior habitat. Therefore formation of more simple or fractal patches in year 2000 in both areas indicated variability in habitat opportunity. Habitat conditions therefore became more heterogeneous in year 2000.

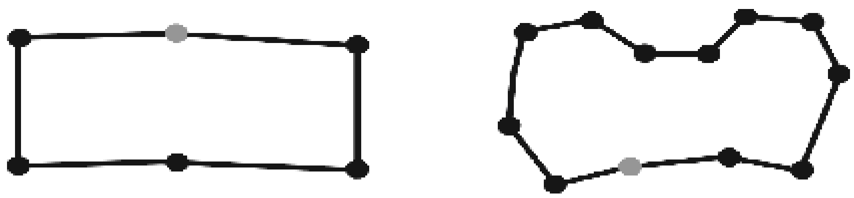


Figure 37 Diagrammatic Illustration of MSI in a Hypothetical Landscape Compared.

Patch shape complexity (simple or complex habitats) can be illustrated in Figure 37. As defined by McGarigal (1995) simple habitat as in the case of rectangles usually requires few vertices or point to complete their polygon. Convoluted patches rather require much more vertices or points to complete their polygon. The illustration in Figure 37 provides structural comparisons among habitat shape complexity but it does not necessarily indicate how acute shape complexity in one landscape is compared to the other.

Nevertheless, shapes of habitat types in Schlabendorf Süd are more complex than Schlabendorf Nord due to increased land use intensity. Habitat shape complexity as shown above provides meaningful ecological understanding regarding how land use intensities relate to habitat shapes, why large habitats show irregular shapes and why certain plant and animal species prefer habitat edges condition to interior habitat condition.

5.3 Edge Density Metrics in Schlabendorf Nord and Schlabendorf Süd

Edge density basically is the amount of edge relative to the landscape area. Habitat edge is the outer band of habitat patch. Depending on the parameter under consideration, its area may vary in width. ED in this work was measured in hectares (ha). Edge Density (ED) ranges from 0 without limit. It is 0 when there is no edge in the landscape (McGarigal and Marks, 1995).

Edge density at landscape level is directly related to the degree of spatial heterogeneity (McGarigal and Marks, 1994). The post-mining landscape in Schlabendorf Süd is generally more heterogeneous than Schlabendorf Nord. This is because in all the period of assessment edged densities in Schlabendorf Süd were found to be higher. Furthermore graphical description shows values of edge densities at Schlabendorf Süd were relatively closer to each other than they were in Schlabendorf Nord, which also indicates that the degree of habitat heterogeneity was wide spread over the period of study. The above is due to the fact that Schlabendorf Süd is being subjected to more intensive reclamation activities. Habitat heterogeneity from 1988 to 1991 and 2000 to 2003 in Schlabendorf Nord were basically at the same level though they have differing magnitude. Thus despite the differing nature of heterogeneity in Schlabendorf Nord, periods of stable heterogeneity were found.

Straight patch edges offer fewer niche or habitat opportunities than curved edges. As indicated by MSI, habitat shapes are more complex in Schlabendorf Süd and even casual observation reveals that patch edges were as well curvier. Coupled with larger edge densities, patch edges in Schlabendorf Süd are expected to offer niches for plant and animal species with edge dwelling preferences. By providing habitat for edge dwelling species, edge density improves the biodiversity. Breaking up of large habitat into smaller ones (creating habitat edge), usually creates edge conditions from interior habitats, which may lead to net decrease of biodiversity on a large scale or loss of habitat. Thus habitat edge can have desirable or undesirable effect on biodiversity. Habitat edges in both study areas were larger in those study years with smaller mean patch sizes thus reducing interior habitat present in those years.

Krawczynski (2007) investigated variation in the species richness in Collembola at the same study site under different vegetation covers. The number of specimen per sample decreased from 44 per sample to 18.6 within 16 years. During this period, invasion of meadow species occurred in the samples after the disturbance by free cutting of adjacent habitat. Increase in specimen occurred after 20 year of afforestation but more importantly, 86 specimens were recorded after 34 years of afforestation. Krawczynski (2007) suggested that variation in the species number has site-specific effects. Its composition after succession would be affected by distance and direction to areas, dispersal rate of colonisers, microclimate and vegetation structure. Factors such as boundary characteristics or neighbourhood effect obviously contributed to the species richness variation (Dauber et al., 2003).

The use of edge density for addressing the above ecological questions requires a great deal of causation since different species require different habitat. Furthermore based on the size and mobility of species, habitat edge that serves as niche for one species would be small for other species.

More often than not, habitat conditions at the interior habitat are expected to differ from the edge especially with larger habitat edges. Furthermore environmental conditions adjacent to patches affect the patch edge in many ways. Some of these conditions include temperature, wind velocity and moisture content. In Schlabendorf Süd for instance, larger edge densities would be beneficial in protecting interior habitat against windstorm. It must also be said that larger habitat edge as stated above can as well affect an ecosystem greatly. For instance it can impede the dispersal of plant species hence affecting plant succession.

5.4 Estimation of Habitat Diversity in Schlabendorf Nord and Schlabendorf Süd

SDI is a relative index for comparing landscapes at different times (McGarigal and Marks, 1994). In both study areas, habitat diversity increased considerably from 1988 to 1995. Schlabendorf Nord gradually declined in diversity consistently till 2003. Between 1995 and 2000, habitat diversity decreased slightly in Schlabendorf Süd but increased finally in 2003 where it had its highest SDI value. Since higher SDI figures indicate higher diversity (McGarigal and Marks, 1994), there is all indication that habitat has increased though both areas have become more fragmented. As indicated earlier in 2003 habitat richness in Schlabendorf Süd were one less than that of Schlabendorf Nord even though habitat types in most cases were more in Schlabendorf Süd than Schlabendorf Nord. Thus habitat richness was considerably higher in Schlabendorf Süd than Schlabendorf Nord. The reason for this is as indicated earlier; Schlabendorf Nord was afforested 14 years earlier than Schlabendorf Süd. Habitat types in Schlabendorf Nord have become more stable since the area sees less intensive afforestation or land use intensity. Diversity was presumably not affected significantly by habitat richness in those years with fewer habitat types though some of them had reasonably less diversity. As Wagner (2001) observed, strong difference exist between habitat types in contributing to plant species richness. This view is subjected to the habitat type in question since the present or absent of a particular habitat type would not have any effect of the diversity. Duelli (1997) implied that natural, semi-natural or agriculture land or presumably less disturbed habitat contributes more per Meter Square to landscape species richness than frequently disturbed habitat. For instance, Wagner (2001) also realized that the elimination of a habitat, type say hedgerow, would most likely affect plant diversity more severely that the elimination of habitat type say road. These are all in support of the expectation that habitat diversity and disturbance are the most important factors for explaining patch species richness (Forman, 1995).

Severe disturbance or even a prolonged absence of disturbance generally has depressing effect on biodiversity, but intermediate disturbance seems to enhance diversity in a system (Pickett and White, 1985). With such severe disturbance followed by reclamation program over the past 16 years in Schlabendorf Süd and 30 years in Schlabendorf Nord, increase in diversity can certainly be attributed to an intermediate level of disturbance. The intermediate disturbance hypothesis predicts that intermediate disturbance leads to higher diversity (Johst and Huth, 2005). It is also obvious that increase in diversity at the post mining area was partly influenced by breaking up of large habitat into smaller habitat.

Schlabendorf Nord had comparatively small total landscape area, lesser number of patches and fewer land cover type in some cases. The proportion of habitat types in Schlabendorf Nord relative to the sum of habitats is higher than Schlabendorf Süd. Thus the results support the claim that relationship between habitat diversity and habitat heterogeneity varies according to scale (Tews et al., 2004).

5.5 Land Cover Distributions and Change in Schlabendorf

5.5.1 Overview

Land cover changes were analysed first for changes between 1988 and 2003 in both study areas. Secondly, changes were monitored at three different levels dabbed, segments. First segment includes changes from 1988 to 1991, second segment, 1995 to 1998 and third segment includes changes from 2000 to 2003. DCA ordination technique was used to study how similar the distribution of one land cover type relates to the others of the same area.

5.5.2 Land Cover Distribution and Change Analysis

In 1988 at Schlabendorf Nord, lake occupied 7.66 % of land. In 2003 however lake extended its area to 12.5 % of the entire area. At the same time interval, lake increased by a margin 178.58 ha in Schlabendorf Süd. The interesting thing is that the rate at which lake is encroaching on other land cover types is more than 4 ha per year faster at the young post-mining area (Schlabendorf Süd) than the old (Schlabendorf Nord). Furthermore, larger area of water was added at the young post-mining area (Figures 39, page 118 and 40 of page 119).

The obvious reason for the ongoing transformation is difference in balancing water table being arrived at in both areas. It is expected that about 555.3 ha of the land in the old post-mining area would become lake by 2010. Of this expected value, 298.96 ha have already become lake in 2003 (Figure 38). Figure 38 shows that a relative large area in Schlabendorf Süd would become lake by 2010. In the younger post-mining area however, out of about 658.84 ha of land expected to form lake, 232.18 ha in 2003 had already become lake whilst 426.66 ha is expected to become lake by 2003 (Der Braunkohlenausschuss Sanierungsplan, 1994).

Thus most of the areas in the old post-mining landscape expected to become lake are already occupied by water due to balance in the water table being attained. The unsettling water table in Schlabendorf Süd is still rising and would need a longer time to attain the balance attained in Schlabendorf Nord.

According to Grünewald (2001), 'greatest number of lakes in the Lusatian region will be filled in about 25 years time'. If this claim were true, roads used for reclamation activities that are close to lake would need relocation, which in itself leads to further fragmentation or habitat loss. Post-mining activities such as leveling of would-be-lakes and other construction work have possibly altered the landscape, resulting in reduced habitat sizes and species composition of the area.

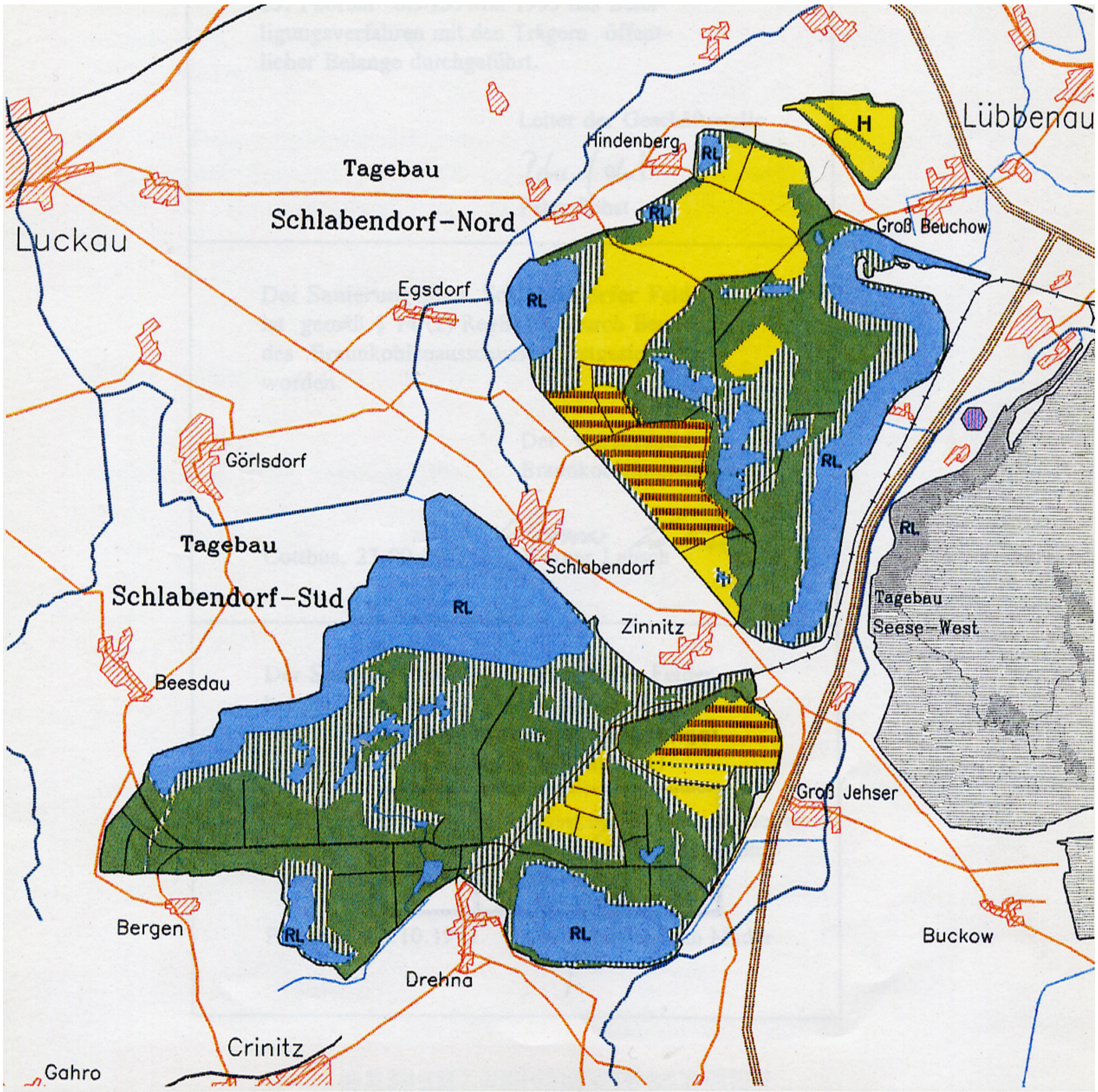


Figure 38 Area of Land Projected to form Lake by 2010 in Schlabendorf Nord and Süd. Expected Lake Area in Blue (Der Braunkohlenausschuss, Sanierungsplan, 1994).

Further habitat changes occurred due to activities such as soil compaction by explosives. In accordance with Grünewald's finding and our observation over the years, it is most likely that greater part of land cover types dry vegetation, sparse pioneer grassland, dry grassland, open sand, and wetland that are already changing to “lake” or share direct boundary with “lake” would likely be affected by the increasing size of “lake”.

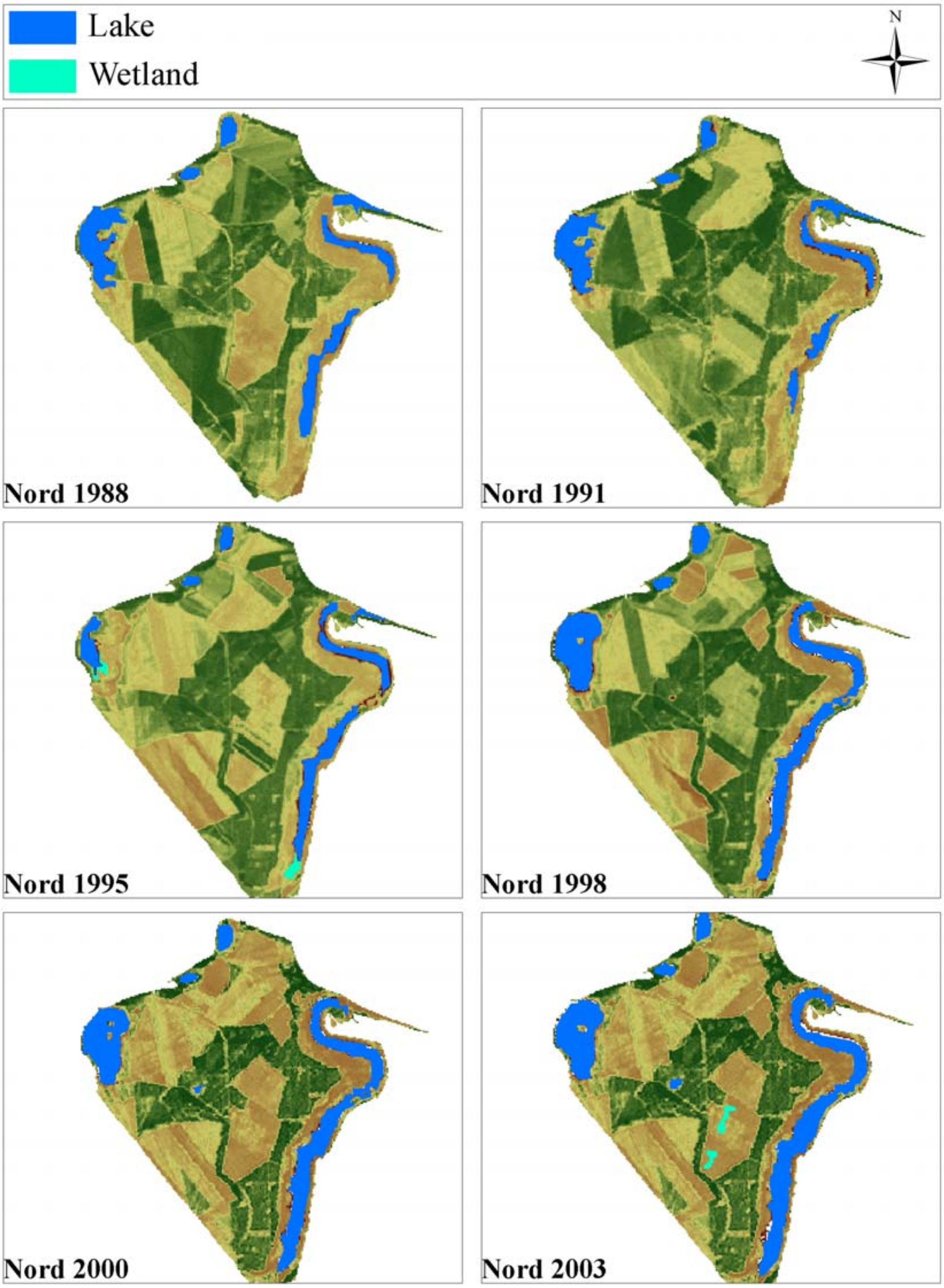


Figure 39 Area of Land Occupied by Lake in Schlabendorf Nord During 1988, 1991, 1995, 1998, 2000 and 2003.

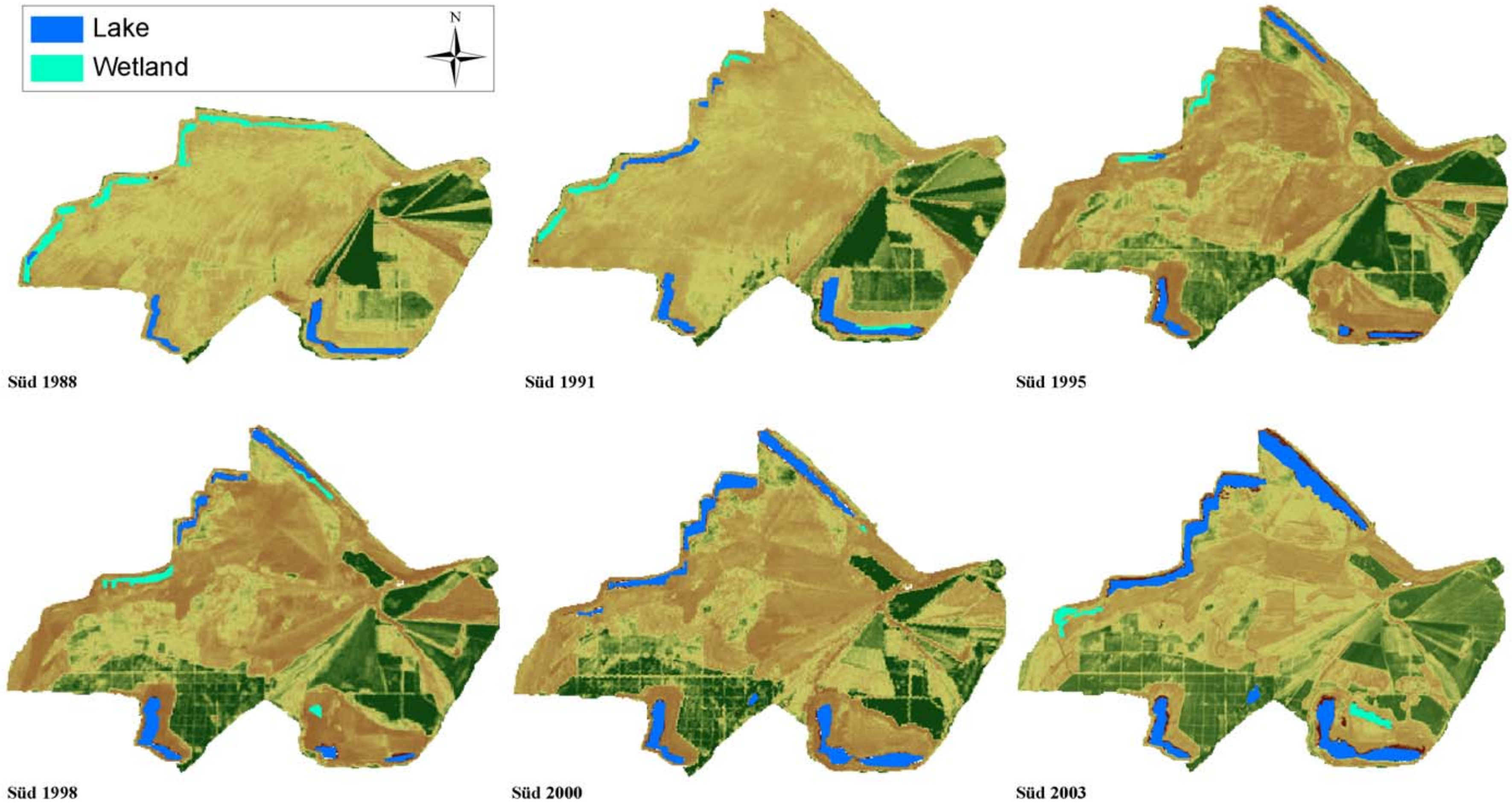


Figure 40 Area of Land Occupied by Lake in Schlabendorf Süd During 1988, 1991, 1995, 1998, 2000 and 2003.

Detail look at the yearly land cover transformations reveals that increase in lake was accompanied with interaction among other land cover types, hence disturbance habitat conditions in those land cover types (Figures 41 and 42). Most of the areas in Schlabendorf Süd that changed to lake were dry vegetation, sparse pioneer grassland, deciduous trees afforestation, dry grassland and wetland (Figure 41). Similarly, in Schlabendorf Nord, areas that became lake were dry vegetation, sparse pioneer grassland, dry grassland, open sand and mixed grassland and trees (Figure 42). What all these land cover types have in common is the presence of shallow fibrous root system or open sand without root system that can serve as bank protection. The roots of plants at the bank of lakes protect and hold the soil together therefore protecting the bank from rapid erosion. This can contribute to significant proportions of the above land cover types that share direct boundary with lake changing to lake.

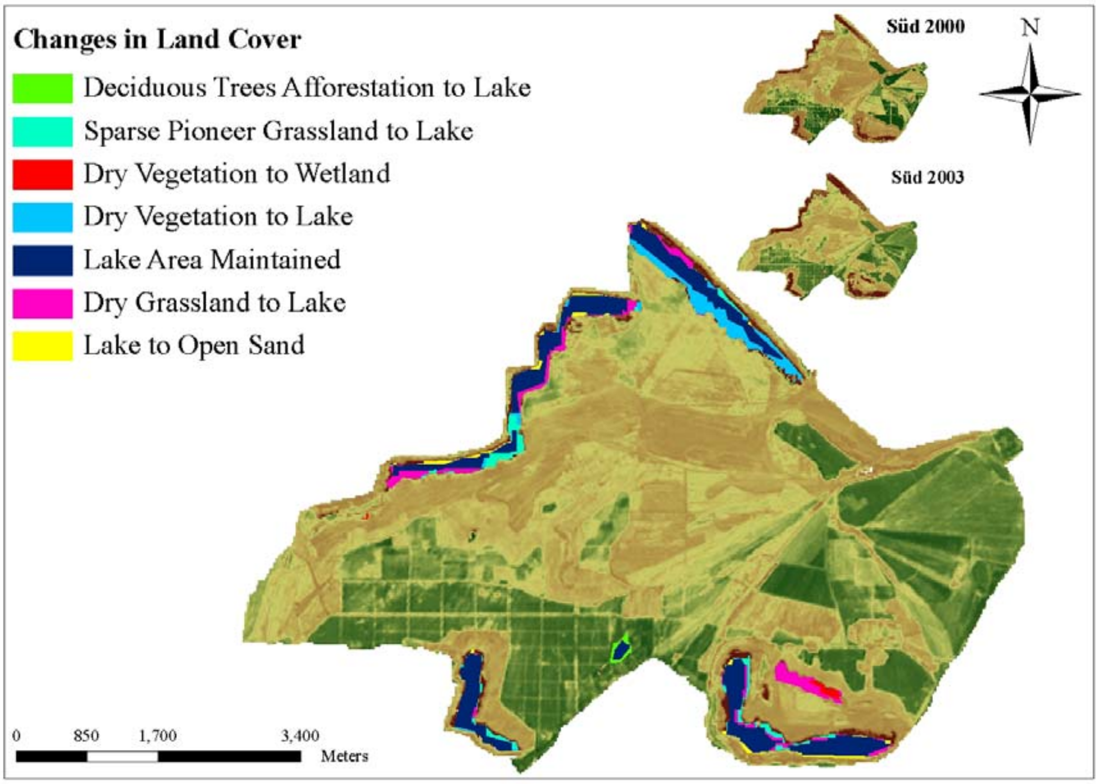


Figure 41 Land Cover Change Illustrations at Schlabendorf Süd from 2000 to 2003 on a Landsat TM image Background.

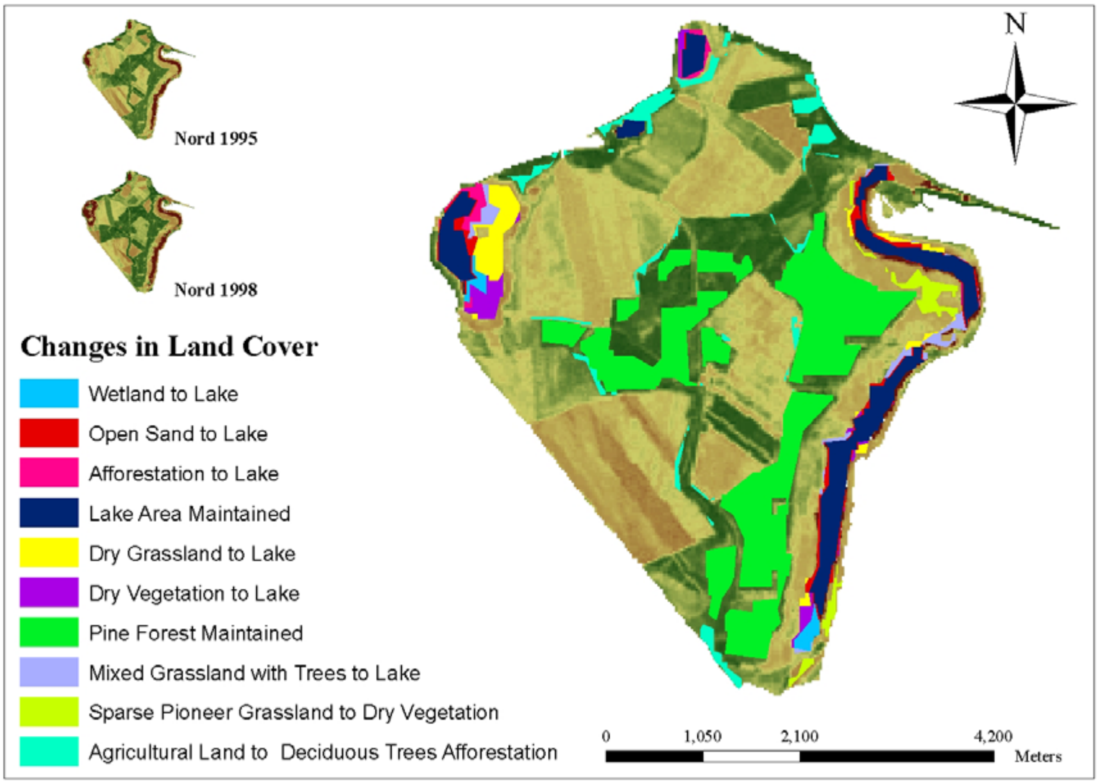


Figure 42 Land Cover Change Illustrations at Schlabendorf Nord from 1995 to 1998 on a Landsat TM image Background.

To operate the mining process, groundwater level of the open cast mine should be beneath the deepest working level. This is achieved through pumping out the groundwater (Grünewald, 2001). Since the mine closure in 1991, pumping rate has decreased from 31.8 m^3/s to a final value of 17 m^3/s in 2000 leading to rise in groundwater table (Grünewald, 2001). This accounts for the significant increase in the size of lake throughout the study period in both areas and more importantly the decreased land size in Schlabendorf Nord (from 1988 to 1995) and Schlabendorf Süd (in 1995).

It is usually expected that increase in precipitation and temperature should influence lake size. Couple with the initial pumping of large volume of water in early stages, low precipitation and high evaporation rate with high surface temperatures contributed to the early decrease in lake size. For instance, in middle of August 1995 where the Landsat TM image used for the analysis was acquired, the climate was dry and hot (Figures 31 of page 102 and 32 of page 103). The monthly average precipitation in August was below the mean precipitation value and also the immediate preceding month July was one of the driest periods of the study. Furthermore the month prior to August 1995 was the hottest summer month in the 15 years. Another proof to the above claim is the fact that the rate of pumping out water from lake was the same in both landscapes in 1993, 1994 and 1995 (Der Braunkohlenausschuss Sanierungsplan, 1994 page 27). Though most of the years of study had monthly average precipitation values below the mean value (Figure 31, page 102), significant reduction in pumped out water hence, increasing water table after 1995, is the main contributor to the increasing lake size.

Wetland revealed a remarkable difference in land cover existing in both study areas. Most years of study in Schlabendorf Nord were without wetland except 1995 and 2003 (Figure 39 of page 118). On the other hand, the different years investigated at Schlabendorf Süd have remarkable areas of wetland some of which were six times larger than the largest wetland in the old post-mining area (Figure 40 of page 119). Again the absence of wetland in mostly at the old post-mining area is as a result of the differences in age since dumping. Unlike Schlabendorf Süd with 16 years of reclamation, Schlabendorf Nord has undergone 32 years of reclamation program during which a balance in the water table has almost been arrived at and most of the areas expected to be flooded are already flooded. This is not the case in Schlabendorf Süd, which has undergone only 16 years of reclamation with large areas still expected to form lake. Thus the constant occurrence of wetland land in the younger landscape is due to an imbalance in the water table. This is an indication of greater variability in the land cover change process. From our observation, most of these wetland areas will eventually turn into lake (Figures 44, page 124 and 45, page 125).

Agricultural land generally decreased in the old mining area except the period between 1988 and 1991. Most of the areas that were initially used for cultivation in Schlabendorf Nord have eventually been abandoned to undergo natural succession in the form of dry grassland and mixed grassland with trees (Figures 42, and 46 of page 126). Areas of the agricultural land were also planted with deciduous trees as part of the deciduous trees afforestation. In every year, about 80 % of the existing agricultural land was maintained. Like the old post-mining area, some of the agricultural land in Schlabendorf Süd was left to undergo natural succession in the form of mixed grassland with trees. Part of the agricultural land was also used for pine afforestation and mixed forest. Though significant area of cultivated areas has been abandoned for natural succession and afforestation, the existing agricultural land and the afforested areas still have negative influences on habitat heterogeneity. This is because most of these landscape elements in the post-mining landscape are designed as rectangles with straight and distinct boundaries (O'Neill et al., 1988a). As indicated earlier by MSI, these straight patch edges offer few niche possibilities, hence effecting biological diversity and reducing habitat heterogeneity.

Most land cover transformations in both old and new post-mining areas were obviously due to plant succession. This includes dramatic changes from dry grassland, agricultural land and mixed grassland and trees to pine afforestation and deciduous tree afforestation. Also contributing to plant succession was parts of open sand that turned to sparse pioneer grassland. Agricultural land and sparse pioneer grassland turning mixed grassland with trees for instance favours plant succession (Figures 41 to 47). For conservation success, these transformations are very desirable in the post mining area.

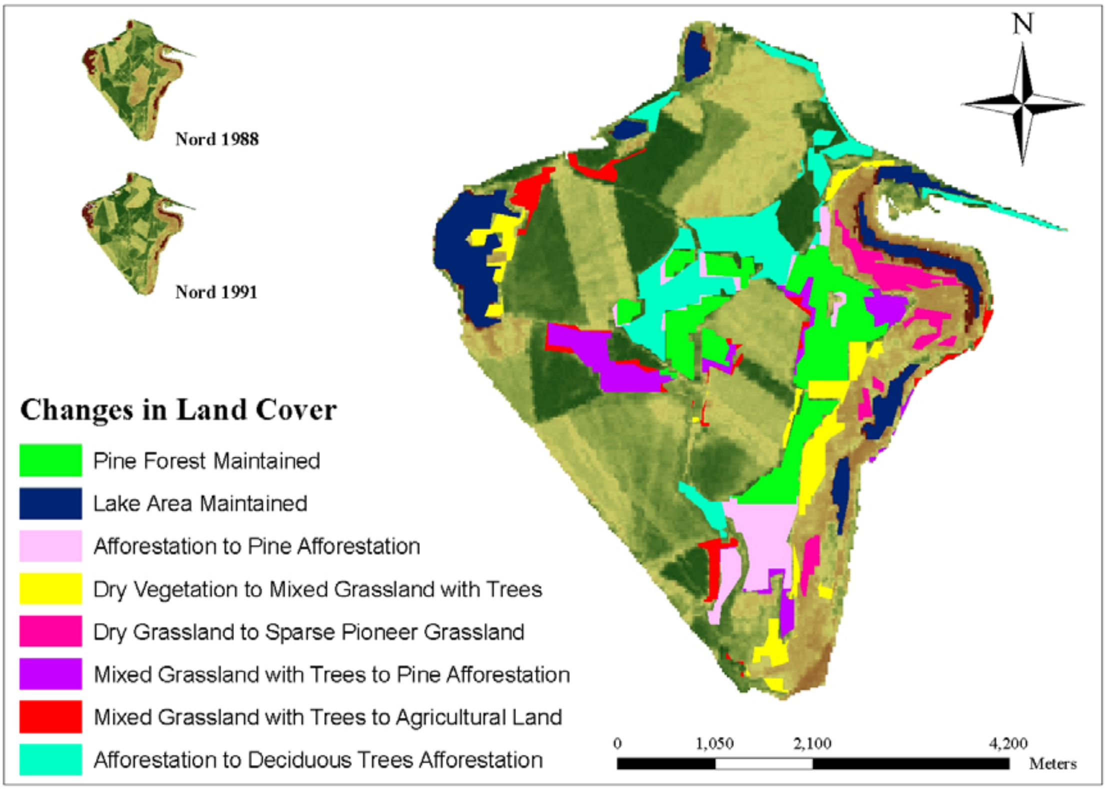


Figure 43 Land Cover Change Illustrations at Schlabendorf Nord from 1988 to 1991 on a Landsat TM image Background.

Increase in sparse pioneer grassland was due to planting a relatively large area of land with grass cover (seeded grassland). Though planting of grass decreased over the years, seeded grassland area was larger in Schlabendorf Süd than Schlabendorf Nord because in Schlabendorf Süd the seeded grassland have until recently been used as primary colonizers in the mine reclamation.

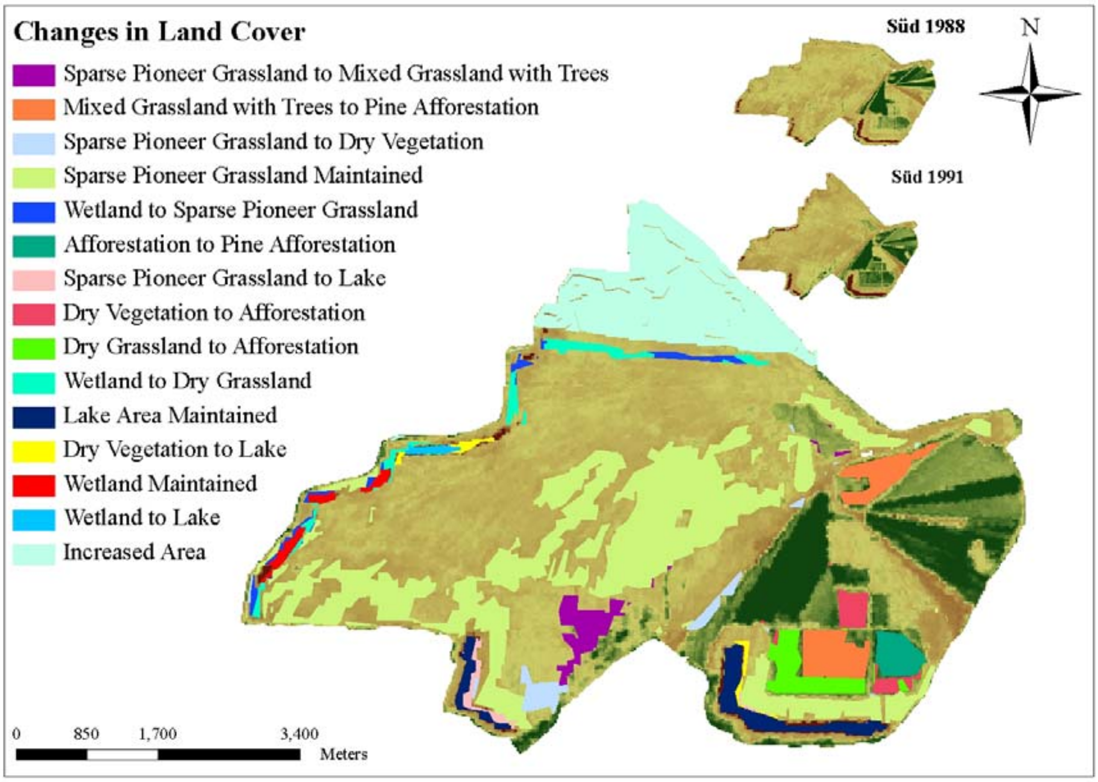


Figure 44 Land Cover Change Illustrations at Schlabendorf Süd from 1988 to 1991 on a Landsat TM image Background.

On the contrary reverse succession occurred in both areas of the post-mining landscape. Reverse succession in this context is define as change from a particular land cover type after a period of vegetation growth back to the initial or a characteristically comparable land cover type via natural or artificial processes. This includes areas where changes from open sand, mixed grassland with trees, dry vegetation and dry grassland to lake occurred (Figures 41 to 47). Changes from dry grassland to open sand, and afforestation of deciduous trees to mixed grassland and trees are also examples of usually undesirable transformation from plant succession perspective (Figures 41 to 47). The above is supported by Felinks (2000) who also described plant succession in a post-mining landscape as having stages of stochastic regression instead of web-like stages of succession.

The reverse succession is as a result of factors such as nutrient deficient soil to support plant growth, prolonged seasonal fluctuations in the microclimate, low soil pH and harvesting of afforested areas as occurred in Schlabendorf Süd (Figure 47) in 2003.

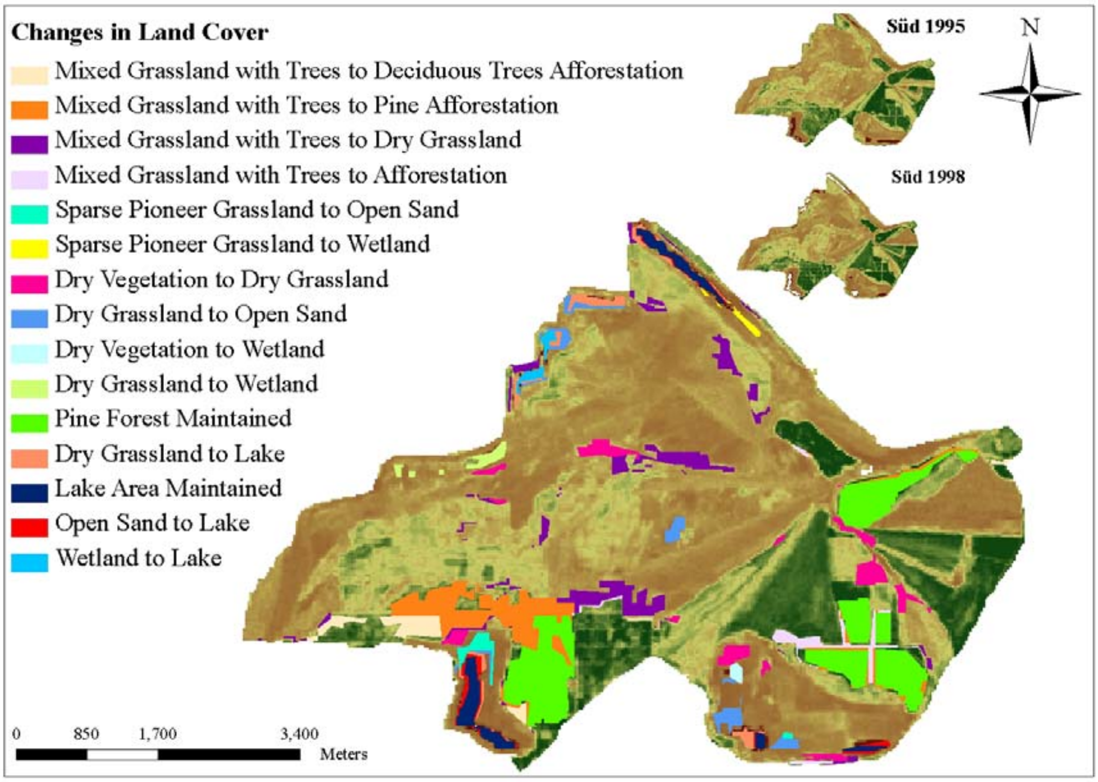


Figure 45 Land Cover Change Illustrations at Schlabendorf Süd from 1995 to 1998 on a Landsat TM image Background.

An interesting trend of reverse succession in the post-mining landscape was the frequent changing of dry vegetation/dry grassland/sparse pioneer grassland to open sand, open sand to wetland, and finally wetland to lake. Considering conditions in the mine-damaged areas, such trend of reverse succession is highly probable to occur in other post-mining landscape.

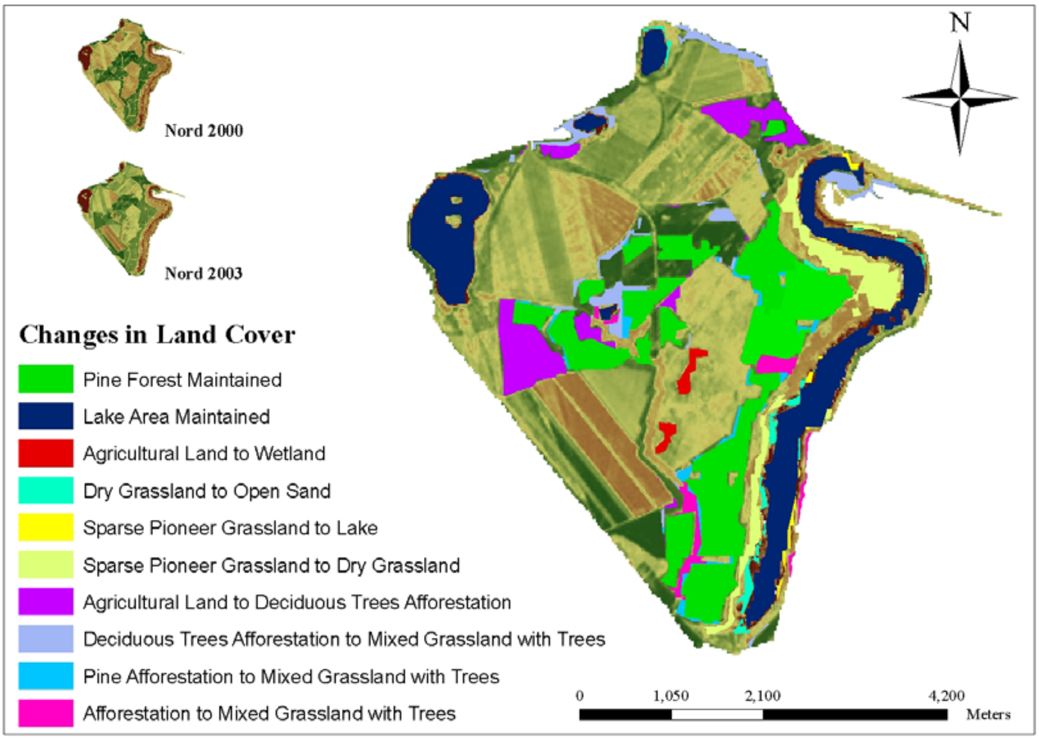


Figure 46 Land Cover Change Illustrations at Schlabendorf Nord from 2000 to 2003 on a Landsat TM image Background.

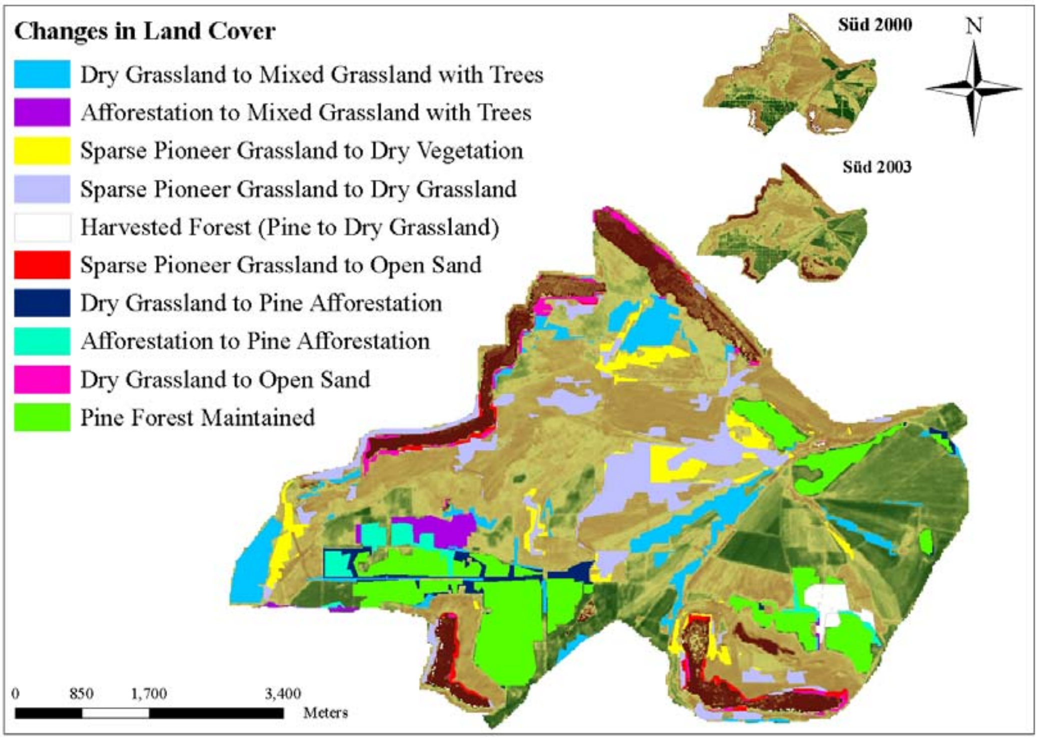


Figure 47 Land Cover Change Illustrations at Schlabendorf Süd from 2000 to 2003 on a Landsat TM image Background.

5.6 Biomass Accumulation (Primary Production) in Schlabendorf

The afforested area increased steadily in Schlabendorf Nord. By the end of 2003 about 25 % of the entire area had been planted with pine and deciduous trees. Furthermore most of the pine afforestation areas were maintained (Figures 42 to 47). This is as partially reflected in the 44 % net primary production. Figures 48 and 49 show the estimation of primary production from normalized difference vegetation index in Schlabendorf Nord and Schlabendorf Süd. Significant increase in mixed grassland also contributed greatly to the net biomass accumulated. The fluctuating net biomass accumulated year after year was possibly due to changing size of dry grassland, dry vegetation, lake and open sand. Like Schlabendorf Nord, Schlabendorf Süd had a significant and continues increase in the pine forest. Furthermore increase in mixed grassland with trees also contributed to the succession success in this area. This is reflected in the progressive increase in net primary production.

Figures 48 and 49 show primary production (NDVI) estimate in Schlabendorf Nord and Schlabendorf Süd. NDVI values ranges from -1 to +1 but vegetation values typically fall within 0 to +1 with higher (greener) index values representing more active growth and primary production.

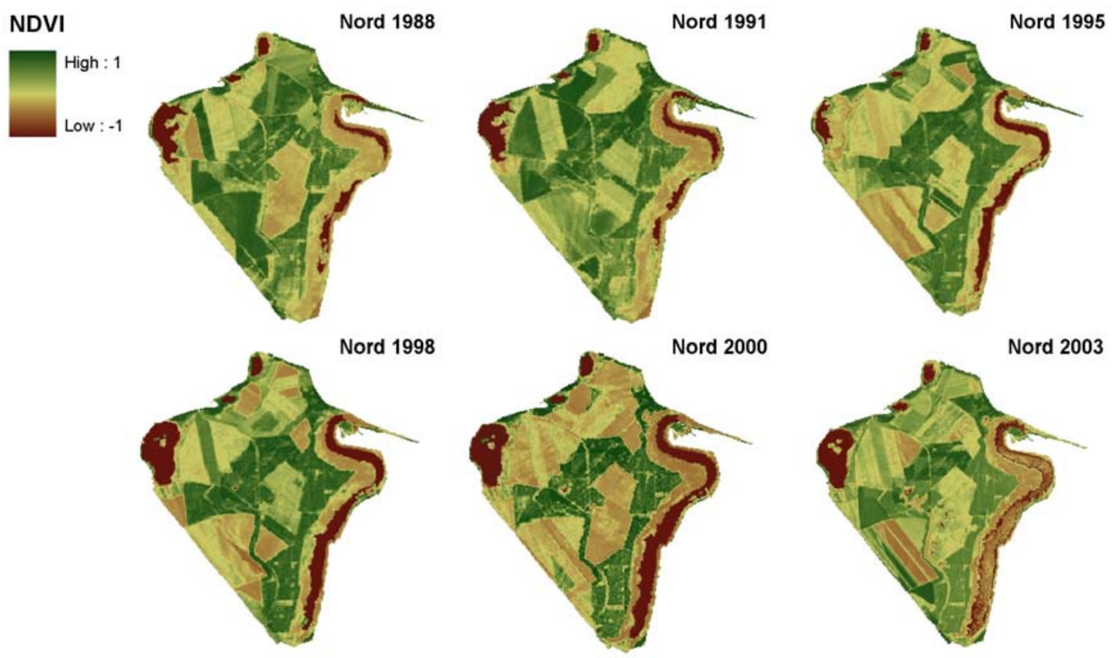


Figure 48 Estimation of Primary Production from Normalized Difference Vegetation Index in Schlabendorf Nord.

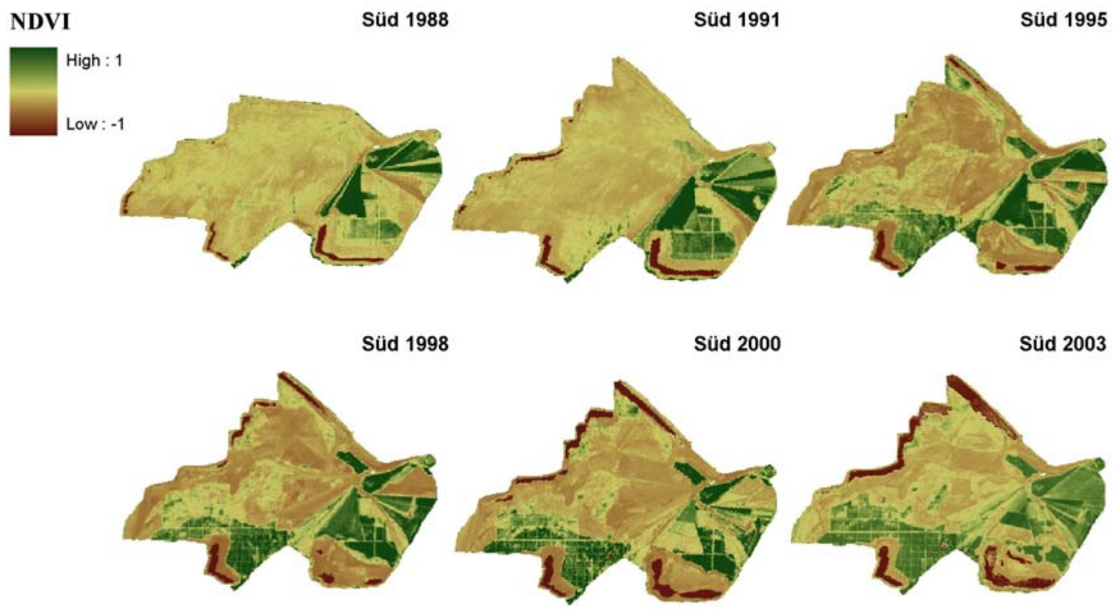


Figure 49 Estimation of Primary Production from Normalized Difference Vegetation Index in Schlabendorf Süd.

5.7 Relationships among Land Cover Changes Determine from DCA Plot

Land covers distributions pattern among pine afforestation, lake and mixed grassland in Schlabendorf Süd were mostly similar though this similarity does not indicate any ecological interdependence or process. They lie close to each other in the same side of the ordination plane because they generally increased in size during the study (Figure 26 and Table 17 of section 5.4). Particularly pine forest and mixed grassland represent significant restorations success (in areas intended for recultivation) and contributed greatly to the increasing net primary production in most periods of assessment. On the contrary, the increased size of lake impedes net biomass.

As mentioned earlier, most of the pine afforested areas are man made landscape elements with straight patch edges. This can lead to habitat shapes becoming less and less complex. The mixed grassland area could increase habitat heterogeneity since the area is predominantly left to undergo natural succession.

Dry grassland cover experienced reverse of the parallel transformation observed among pine afforestation, lake and mixed grassland throughout the study period (Figure 26 Table 17 of section 5.4). This is a typical case where reverse succession occurred in the landscape at Schlabendorf Süd (Figure 50). Most of the land cover types at the right side of the ordination diagram contributed to the increasing size of for example pine afforestation, lake and mixed grassland etc. Figure 50 indicates that a significant area of the pine forest was cut during 2003, leaving the area to form new habitat types (open sand and seeded grassland). Seeded grasses in 1988 and 1991 were replaced with pine afforestation. Lake (in brown) size changed throughout the 15-year period.

For most periods studied in Schlabendorf Süd, land cover distribution pattern of agricultural land and deciduous tree afforestation were similar though some variation occurred in both vegetation types in 1998 and 2003. Increase in one corresponded to an increase in the other (Figure 26 and Table 17 of section 5.4). Here portion of deciduous trees in a naturally growing area with pine trees was replaced with pine afforestation and in others also emerge as mixed grassland with trees in 2003. Agricultural land did not change significantly from each other.

In Schlabendorf Nord, decrease in afforestation area corresponded with decrease in afforestation of deciduous trees (Figure 26 and Table 17 of section 5.4). The dissimilarity in distribution pattern of afforestation and deciduous tree afforestation land cover types is due to the fact that afforestation was made up of mosaic of free growing pine and deciduous trees (mixed forest), which was gradually cultivated predominantly with deciduous trees. This is visible from the continuously increasing size of afforestation of deciduous trees and decreasing size of afforestation. Such dissimilarity existed in the distribution pattern of dry vegetation and afforestation of deciduous trees to a greater extent.

It is fair to say that pattern of distribution in afforestation was similar to dry vegetation in most period of study (Figure 26 and Table 17 of section 5.4). But since afforestation generally decreased at the end of 2003, increase in the dry vegetation in this case support reverse succession. This inference is made from the general increase in dry vegetation area and not strictly linked to decreased size of afforestation.

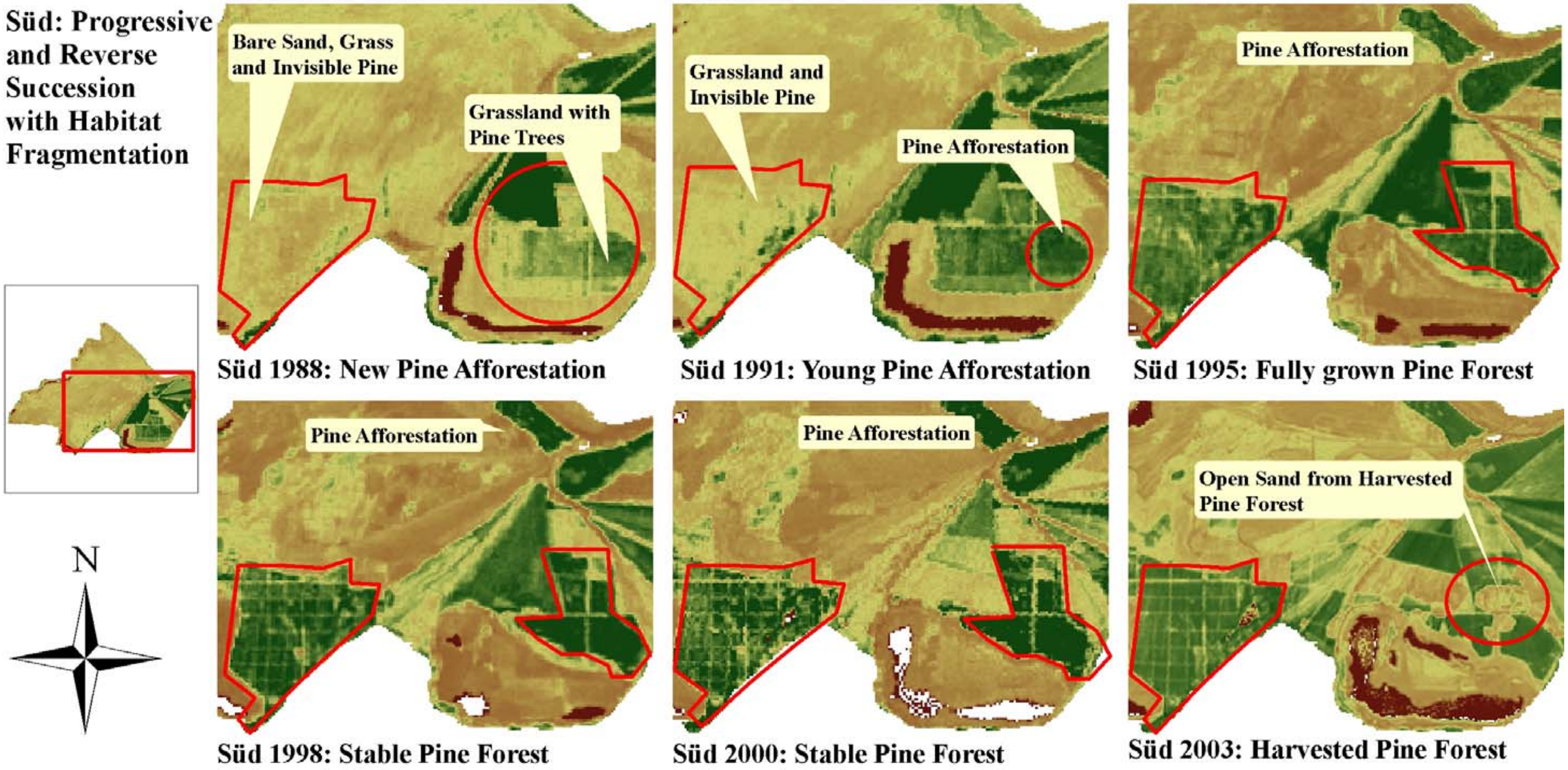


Figure 50 Progressive and Reverse Succession in Schlabendorf.

Some land cover distribution patterns were similar to others or are close to each other but are not dependent on each other. An example in Schlabendorf Nord is where mixed grassland and open sand largely had similar land cover distribution for most part of the study except the variation in 1991 (Figure 26 and Table 17). Another example is pine afforestation and lake located closer to each other in the ordination plane but have no visible similarity in land cover distribution.

As land cover types spread apart from each other in the ordination axes, similarity in their distribution pattern diminishes. For instance, the location of pioneer grassland further from mixed grassland, open sand and wetland reveals a strong negative relationship between these land cover types (Figure 26). As mixed grassland and open sand increased their vegetation cover at the end of the study period, pioneer grassland decreased.

Hill and Gauch (1980) defined the length of the ordination axis to be the range of site scores measured in multiples of the standard deviation (s.d.). Sites that differ 4 s.d. in scores have no species in common. Ter Braak (1996) found out that in DCA sites are represented by points and each site is located at the center of gravity of the species that occurs there. Locations of species on the edge are often unusual (species). Their location is either due to the fact that they have extreme pattern/condition or they happen to occur by chance in such extreme condition in which case additional data might be helpful for further clarification (ter Braak, 1996).

5.8 Ecological Significance of the Land Cover Changes

It would be difficult to understand how significant land cover change is to an ecological system without an improved knowledge of the land use. This is because naturally land use practices have direct influence on ecological processes and systems (Turner et al., 1993).
The post-mining landscape has undergone a considerable period of restoration (afforestation) after disturbance that has modified the ecosystems. Thus land cover change has influenced the ecological system negatively and positively. For instance, tertiary substrates with a high potential for pyrite oxidation in the area were allowed to form major part of the upper substrate layer instead of applying the topsoil to re-establish soil fertility. Coupled with rising groundwater level, a remarkable area of the

landscape has formed acidic lake and acidic condition in the terrestrial habitat (Schultz and Wiegleb, 2000).

Considering some ecosystems in the post-mining landscape, land cover change had the following effects on them:

- substantial increase in pine and deciduous tree afforestation from 1988 to 2003.
- increase in wetlands especially in the young post-mining area
- decrease in open sand area
- maintained land cover types (no change) such as lake, pine afforestation
- significant increase in the lake size taken from open sand, mixed grassland with trees, dry vegetation and dry grassland

Since impact of land cover changes from surface mining are not only located to the site of extraction, other sites were destroyed for constructing mining camps, roads, foot paths etc. The neighbourhood of the mined areas are usually polluted by dust, or contaminated (e.g. contamination of the Spree river by iron and groundwater by acid).

Gaps formed from the absence of vegetation cover such as open sand in Schlabendorf, are usually undesirable reclamation successes. Nevertheless, gaps in patches can prevent the spread of some kinds of disturbance such as wild fire.

5.9 Reclamation of Mine Damage Areas in Schlabendorf

Parts of the post mining landscape with greatly impoverished soils could be restored through some sort of human intervention. Such intervention would help greatly to achieve conservation successes. Nevertheless, reclamation of mine-damaged land is generally complex, often expensive and comes with specific problems based on the type of mining. In Schlabendorf, an estimated 300 million Euros has gone into the reclamation program (Der Braunkohlenausschuss Sanierungsplan, 1994).

Certain features related to removal of topsoil and aftercare may be common to all mine-damaged land. But as Bradshaw (1999) realised, reclamation schemes must focus on providing some sort of human intervention since succession may take a longer period.

Here in Schlabendorf, such human intervention that could accelerate succession is the enrichment of the soil with nutrient before recultivation especially in nutrient deficient areas that initially lost their vegetation cover to open sand because replacement of the topsoil to re-establish soil fertility was not carried out (Schultz and Wiegleb, 2000). In such areas, enriching the topsoil through the application of selected diaspore enriched-heymulch could significant facilitate primary succession. The addition of aches (potassium) to the acidic soil to improve its pH for plant growth is as well another vital step towards plant succession. It must be said that this intervention measure should be desirable in cases where reclamation aim is to get closed vegetation cover (e.g. towards protection from wind erosion) otherwise, treatment should be restricted to areas which requires them.

One of the most successful and recommendable reclamation schemes to support human intervention in succession is that of Western Australia where the mining company Alcoa, stored topsoil from areas selected for bauxite extraction (i.e. soil reclamation) and reused it to re-cover the area after mining (Bradshaw, 1999). The replaced topsoil was then seeded with native nitrogen fixing shrubs, which were subsequently followed by annuals, and biennials that are not typical of indigenous vegetation type. This stabilized the soil and provided suitable conditions for native species such as jarrah forest to thrive. Thus it accelerated the process of succession. After about 8.5 years after reclamation, soil on the reclaimed area had nitrogen content and pH similar to the soil below unmined jarrah forest (Bradshaw, 1999).
In order to maintain lake size, pumping out of water from “lake” should be undertaken.

5.10 Causes of Land Cover Changes in Schlabendorf

According to Geist et al. (2006) causes of land cover changes can be grouped into direct (how and why human influence changes a local land cover type or an ecosystem) and indirect causes (the primary force behind the local changes). Nevertheless a complex interaction between these two causes also lead to land cover changes though these causes may vary with time and space. Temperature, precipitation and soil condition can influence the type of land cover in an area. In Schlabendorf, biophysical (Geist et al., 2006) driving forces such as drought and high temperature in the months of June to August in 1995 were some of the reasons for the decreased size of lake though the same volume of water were pumped out of lake at the same velocity (Der Braunkohlenausschuss Sanierungsplan, 1994). Loss of soil fertility as a result of turning of the upper topsoil has left behind nutrient deficient soil, which cannot support vegetation growth (Schultz and Wiegleb, 2000). Other local driving forces of land cover change in the post-mining landscape are low soil pH especially along the path of the strip mine and open sand area. Cutting out of afforestation areas (Figure 50, page 130) and other restoration related construction activities are some of the main contributors to land cover transformations in the post mining area (Bröring and Wiegleb, 2005). According to Turner et al. (1993) the interactive effects of these biophysical factors and human influences obviously changes vegetation cover though the process is difficult to identify.

In Schlabendorf Süd, human decisions and policies also affected land cover changes. The decision to stop pumping water from lakes was one of the major causes of increasing size of lake and formation of wetlands especially in Schlabendorf Süd (Figure 40 in page 119). Since pumping out of water from lake ceased in 2000, water table has risen significantly resulting in flooding out of large areas such as open sand, wetland dry grassland etc. (Figures 41 to 47). Human decisions also interact with other environmental changes that eventually result in land cover change. This is probably because most of the temperatures recorded during the study were above the mean temperature from 1961 to 1990 (Figure 32). For instance, in August where most of the analyses were carried out, every LC year had the temperature at or above the average value (Figure 32). Thus process of land cover change takes place at the interface between environmental and human systems, interrelating with both systems and with each other in a feedback and other process in other systems (Geist et al., 2006).

5.11 Habitat Diversity and Species Diversity in Schlabendorf

Having estimated changes in spatial habitat diversity in the post-mining area, it is still important to know how habitat diversity is related to species diversity from field or ground data. Two aspects of the post-mining landscape namely open land and afforested sites were considered. Species diversity in this context is defined as the number of different species in a particular area (http://cnx.org/content/m12174/latest/, last assessed 14.02.08).

In a research aim at studying terrestrial Heteroptera distribution and abundance in the open land, Bröring and Wiegleb (2005) used site classification based on general features of habitats described by Felinks (2000). In Schlabendorf, four of the seventeen habitat types were reference sites (undisturbed habitats) located outside the post-mining landscape. They were used for comparisons purposes. Collection of terrestrial Heteroptera was by sweepnet and pitfall traps. They used principal component analysis to analyse details of habitat structure and CANOCO for eigenvector ordinations analysis (Ter Braak and Smilauer, 2002). Their results are as shown in Table 18 and Figure 51 below.

In Schlabendorf, a total of 110 species of Heteroptera were found (Bröring and Wiegleb, 1999). Areas that were 20 years old since dumping in Schlabendorf Nord had 93 species compared to 75 species in a 5 – 10 year old Schlabendorf Süd. After habitat classification based on general features of habitat type i.e. patterns of the vegetation structure, principal component analysis aimed at relating species to habitat preference was carried out. Seeded grassland, tall grass stands, heath, sparse vegetation with Corynephorus stands, ruderal stands and grass vegetation with mosses emerge but most Heteroptera species constantly occurred at the seeded grassland site though some species were frequent at tall grass stand, Corynephorus stands, heath and sparse vegetation (Figure 51). Species number decreased with decreasing vegetation height (axis 1) but increased as vegetation density increases on axis 2 (Figure 1). The first two axes explain 69.2 % of variance of the species data. Sum of all unconstrained eigenvalue is 2.504. Names of Heteroptera species are abbreviated.

It became clear from the investigation that habitat diversity in the open land areas of Schlabendorf is related to species diversity of Heteroptera. Furthermore, habitat types also had a strong relationship with community pattern of Heteroptera.

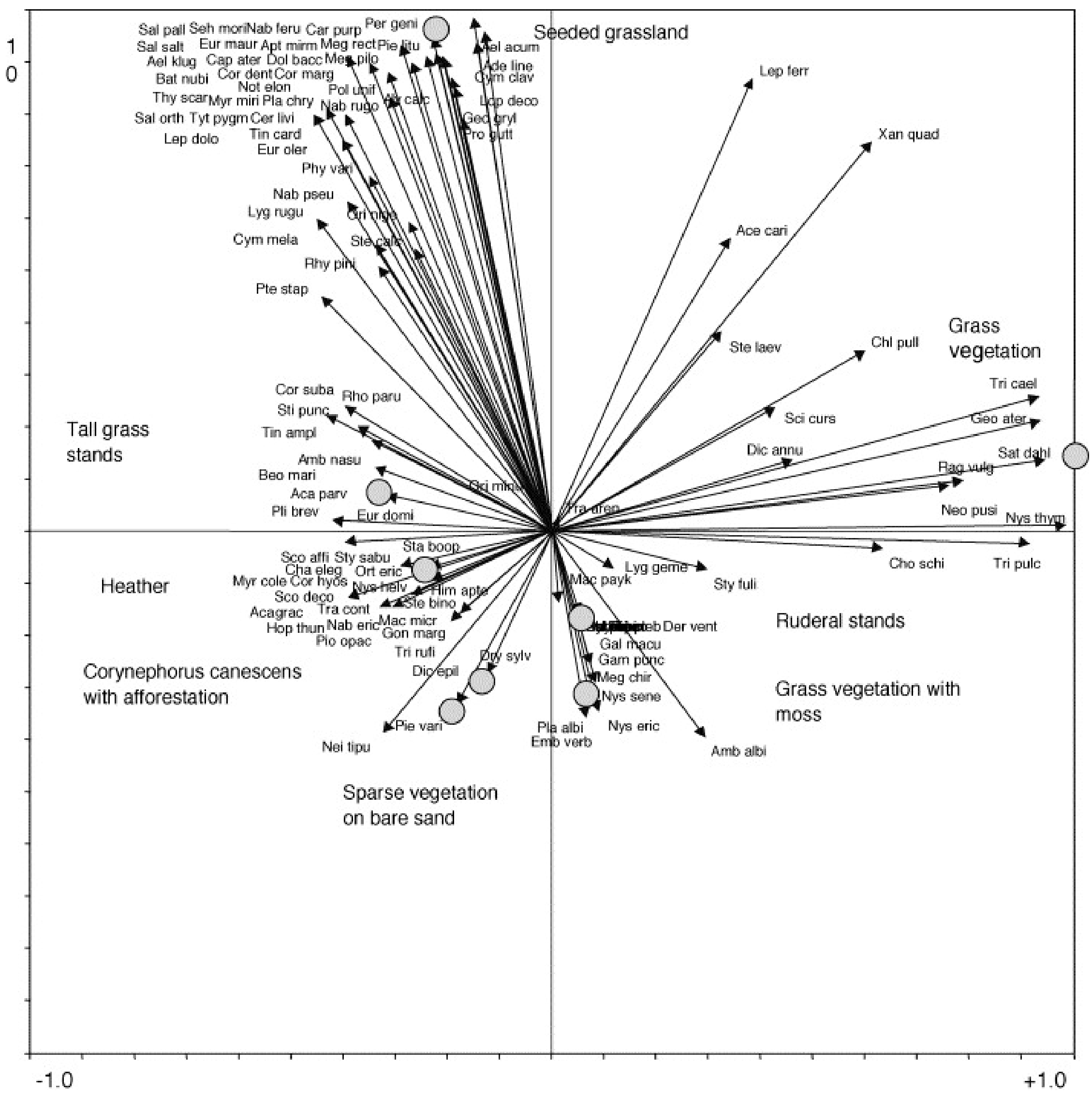


Figure 51 Ordination Diagram of Heteroptera Species and Habitat Types in an Open Landscape of the Post-mining Area after Principal Component Analysis (from Bröring and Wiegleb 2005).

Bröring and Wiegleb (2005) observed that assemblages of Heteroptera species strongly depend on the species pool of the surrounding area and their colonisation is the result of temporal variation of vegetation structure. They also concluded that the ages of habitats are generally less important in explaining species diversity and species composition in the post-mining landscape. This is because few years after mining, high numbers of species could be found in different habitat of the open post-mining area. Communities in disturbed sites were similar to those in undisturbed sites few years after damping Table 18.

Table 18 Dominant Vegetations, Age of the Sample Sites, Number of Heteropteran Species and Sampling. Classification of Habitat by Felinks (2000)

Mining site	Vegetation resp. habitat type	Age	Species	Sampling
Schlabendorf-Nord*	Calamagrostis epigejos stand	Undist.	20	SW, PT
Schlabendorf-Nord*	Dwarf shrub heath	Undist.	33	SW, PT
Schlabendorf-Nord	Psammophytic grassland	20 years	11	SW, PT
Schlabendorf-Nord	Dense sown grassland	20 years	6	SW, PT
Schlabendorf-Nord	Dense sown grassland	20 years	35	SW, PT
Schlabendorf-Nord	Sparse vegetation on bare sand	20 years	23	SW, PT
Schlabendorf-Nord	Species-rich psammophytic grassland	20 years	47	SW, PT
Schlabendorf-Nord	Calamagrostis epigejos stand	20 years	24	SW, PT
Schlabendorf-Nord	Moss-rich psammophytic grassland	20 years	26	SW, PT
Schlabendorf-Süd*	Calamagrostis epigejos stand	Undist.	41	SW, PT
Schlabendorf-Süd*	Calamagrostis epigejos stand	Undist.	34	SW, PT
Schlabendorf-Süd	Sparse vegetation on bare sand	6 years	25	SW, PT
Schlabendorf-Süd	Sparse sown grassland	7 years	21	SW, PT
Schlabendorf-Süd	Failed pine afforestation	7 years	10	SW, PT
Schlabendorf-Süd	Dense sown grassland	5 years	31	SW, PT
Schlabendorf-Süd	Free of vegetation	15 years	4	PT
Schlabendorf-Süd	Scarce Corynephorus canescens stand	10 years	22	SW, PT

Asterisk (*) represents undisturbed land, PT = pitfall trap, SW = sweepnet sampling, S = sampling site.

In another research aimed at documenting succession of different ecological groups of Collembola and dominant species on acidic reclaimed land, Krawczynski (2007) sampled afforested areas of the post-mining landscape in Schlabendorf, Koyne and Plassa.

During the same number of years in Schlabendorf (23 years), Krawczynski (2007) found that the number of Collembola species in the pine forest was higher (17) than the red oak forest (14) (Figure 52). Different results were obtained for different sites at different age group. He also observed that if reference sites (habitats) area were included, Spearman Rho shows a significantly high correlation between stand and age and increase in species ($r = 0.65$, $p < 0.022$). It became clear that habitat diversity in the afforested areas of Schlabendorf is strongly related to species diversity (Collembola in this case). We can therefore conclude that habitat diversity is related to species diversity of other organisms.

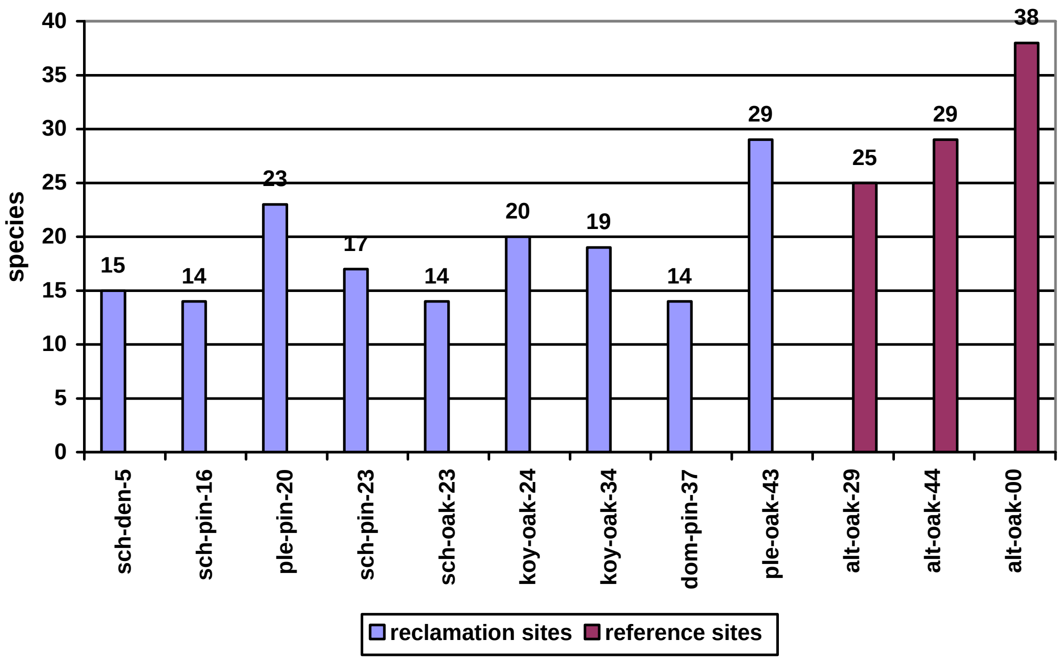


Figure 52 Numbers of Species in Afforested Sites (from Krawczynski, 2007).

Legend: Sch represents schlabendorf, koy = koyne, ple = plessa, pin = afforestation with Pinus sylvestris, oak = afforestation with Quercus rubra, Q. petraea, den = dense vegetation on meadow and wasteland, Calamagrostis epigejos-dominated grassland.

Changes in habitat diversity can be used to predict the species richness in an area. Because many organisms are associated with a single patch type, patch richness often correlates well with species richness (McGarigal and McComb, 1995). Within a given ecosystem, any change in habitat diversity can change the number of species in the resulting habitats types. The trend of habitat diversity in Schlabendorf Süd for instance indicates that number of species in Schlabendorf Süd would increase for the next seven to ten years after which a stable to slow decline would occur. Schlabendorf

Nord on the other hand should have a relatively stable number of species. But given the ongoing anthropogenic and natural influence on the land cover transformation, a shift to different vegetation type or in habitat structure can occur which would intend change the resulting number of species.

According to Roslin and Koivunen (2001) habitat preference of species affect their spatial population structure. They ascertained that generalist species are often distributed evenly within and between habitat types. Specialist species on the other hand are distributed into discrete habitats. This means that depending on the type of species (specialist or generalist) a helpful indication regarding how number of species relates to habitat diversity can be abstained.

The type of resource in a particular habitat is another useful indication needed for estimating the number of species from the trend of habitat diversity because related species using similar resources usually show similar distribution pattern (Wahlberg et al. 1996).

6 Conclusions, Outlook for Future Studies and Criticisms

6.1 Overall Conclusions

The outcome of the study revealed that the use of GIS and remote sensing for assessing the impact of disturbance on land cover change and habitat diversity can help (i) identify complex relationship existing between environmental parameters and land cover changes over time (ii) identify the interaction between human activities and environmental conditions that singly or interactively affect disturbance (iii) establish the relationship between habitat diversity and species richness when spatial data (habitat diversity) are related to ground data (species richness) and (iv) generate landscape characterization statistics for monitoring the impact of disturbance on biodiversity and land cover changes. Furthermore it became clear that images processed from remote sensing and GIS platform can provide useful information for monitoring present and future land cover and habitat diversity/ biodiversity changes.

Increase in habitat diversity recorded in both landscapes agrees with the presence of ecosystem disturbance and supports an intermediate level of disturbance. This is confirmed by the assertion that severe disturbance or prolonged absences of disturbance have depressing effect on biodiversity but intermediate disturbance enhance diversity (Pickett and White, 1985). Low habitat diversity in Schlabendorf Süd was due to comparatively large landscape area of Schlabendorf Süd, high number of patches and higher habitat richness in most cases. This supports the claim that relationships between habitat diversity and habitat heterogeneity vary according to scale (Tews et al., 2004). As it was also found that changes in habitat diversity can be used to predict the species richness in an area. This is because change in habitat diversity yielded change in the number of species in a particular habitat type.
As Weber et al. (2004) noted: “landscape diversity is the most important information for conservationists and landscape planners”. The observed landscape transformation therefore raises alarm concerning the urgent need for conservationist and landscape planners involved in the reclamation program to focus on measures that would not worsen the already deteriorating state of the landscape as they embark on recultivation of areas that could not support vegetation growth.

Given two post-mining landscapes subjected to different periods of reclamation activities, clear differences in primary production, habitat diversity, heterogeneity, complexity and sizes would occur. The two post-mining landscapes were getting more diverse over time. Nevertheless some of these differences are partly due to the land use intensity and other geophysical factors. For example, primary production in Schlabendorf Süd generally increased over the years due to the intense afforestation but fluctuated around a similar value in a more stable Schlabendorf Nord. The increased primary production has also contributed greatly to climate change by providing sink for green house gases and would as well improve local climatic conditions. Habitat richness as well as rate of increase in lake size was high in the younger site.

The study showed there has been distinct pattern of increase and decrease in lands cover types both study areas. Land cover transformations in most cases in Schlabendorf were as a result of progressive and reversed plant succession. Incidence of reversed succession include changes from open sand, mixed grassland with trees, dry vegetation and dry grassland to lake occurred. Trends of reverse succession in the post-mining landscape was the frequent change of dry vegetation/dry grassland/sparse pioneer grassland to open sand, open sand to wetland, wetland to lake, and afforestation of deciduous trees to mixed grassland and tree. Incidences of plant succession were; remarkable changes from dry grassland/agricultural land/mixed grassland and trees to pine, open sand to sparse pioneer grassland, agricultural land and sparse pioneer grassland to mixed grassland with trees. Haven come to the above knowledge, it has become obvious that natural processes of natural succession in the post-mining area should be aided by some sort human intervention in order to accelerate the reclamation of the area. Areas recommended for such intervention are areas originally intended for revegetation but have greatly impoverished soils that cannot support plant growth. The early use of nitrogen fixing shrubs followed by annuals and biennials typical or atypical of the indigenous vegetation types can be used as in the case of Western Australia above.

Process of land cover change takes place at the interface between environmental and human systems (Geist et al., 2006). In the post-mining landscape, biophysical driving forces such as drought and high temperature in the months of June to August in 1995 contributed to the decreased size of lake though the same volume of water were pumped out of lake at the same velocity (Der Braunkohlenausschuss Sanierungsplan, 1994). Furthermore low soil pH especially along the path of the mine strip (now changed to open sand area), harvesting of afforested (pine forest) areas and other restoration related construction activities (Bröring and Wiegleb, 2005) acted interactively or separately to bring about the land cover transformation, reverse succession and diversity in the post mining landscape. Loss of soil fertility as a result of turning of the upper topsoil has left behind nutrient deficient soil, which cannot support vegetation growth (Schultz and Wiegleb, 2000). In other words, the two post-mining landscapes were getting more diverse over time. Nevertheless some of these differences are partly due to the land use intensity and other geophysical factors.

The post-mining landscapes have undergone increase in habitat richness, heterogeneity, fragmentation, and shape complexity due to decrease in habitat size, increased land use intensity etc. The younger post-mining landscape, Schlabendorf Süd, confirmed the above claim with higher values of the above variable in most cases. Unlike Schlabendorf Nord, Schlabendorf Süd still undergoes more active reclamation activities. As Moser et al. (2002) found out, increasing land use intensity has been found to have a depressing effect on landscape shape complexity. Zuidema et. al. (1996), also established that decrease in habitat size is one of the most significant causes of landscape fragmentation.

6.2 Outlook for Future Studies

Reclamation programs in a diverged landscape (e.g. post-mining area) should be based on site-specific treatments rather than a generalized reclamation method. This is because soil conditions and other factors relevant for recultivation vary across the landscape and suitable treatment in an area may fail in another area. This is illustration by this research in section 4.7 of page 99.

The pseudo slash (Ŧ) transect designed for soil sampling was effective in post-mining landscape where soil patterns vary with short distances apart. The collection point along the transect should be allocated base on research needs and attributes of soil samples being studied should not be generalised over a wide area of land since the transect may not give full indication of field variability.

Demographic factors are one of the determinant of land use nevertheless little is known about their influence on LCC. Additional research would therefore be needed to understand how such factors (e.g. economic, ownership, values, political structure, level of affluence, population size and density) interact to determine land use and cause land use/land cover change. To do this, a multidisciplinary approach would be required.

Insufficient dataset was a setback in this study. Larger, coherent and cost efficient database on landscape structure and changes would be needed to study the ecological, environmental and human interactions at the post-mining landscape.

Having come to the understanding of this research, further studies would also be needed to (a) formulate model focusing on how well changes in spatial habitat diversity can be used to predict present/future species richness in an area (b) design an ecosystem modeling that would focus on the role of climate systems (environmental change) and anthropogenic activities on land cover change and biodiversity loss. To do this, a study regarding periodic inventory and regular monitoring is required. Such model would help improve knowledge on land use and provide insight into the future state of LULC with knowledge of factors that determine them (c) digital elevation model would be required to investigate how slope and aspect of the post-mining landscape affect distribution of land cover types and soil conditions.

Transferability of study: The approach used in this study provides a beneficial exchange between expensive ground vegetation sampling and low-priced image processing analysis. It is reliable for assessing LCC, landscape structure etc. or a research type project whenever the spatial data, attribute data and materials used are available.

6.3 Criticisms - Strengths and Weaknesses of Methodologies

6.3.1 Landscape Metrics for Disturbance and Land Cover Analysis

It has to be mentioned that, there are some limitations regarding the use of landscape metric for assessing dynamic ecological processes (Gustafson 1998a; Hargis et. al., 1998; Herzog and Lausch, 1999). Some of these limitations are

- Their dependency on the data model, be it raster or vector as well as further specification of data acquisition and processing.
- Fuzzy ecological understanding regarding the relationship between landscape metrics and ecological processes
- Landscape metrics vary significantly with varying grain and extent. Thus it is essential to ensure uniformity in the grain and extent of the input data format before computing landscape metrics change with time.

If landscape metrics are to be applied regularly for landscape monitoring and if they are to enter environmental indicator packages (Antwi and Wiegleb, 2008), this must be done on the bases of a homogeneous database and by observing some standards in data processing. It is also recommended that the choice of metrics clearly mirror some hypothesis about the observed landscape (Gustafson 1998a; Hargis et. al., 1998; Herzog and Lausch, 1999). Furthermore certain significant questions are worth answering in the use of landscape metrics. These questions include:

a. Does it correspond to composition of the landscape being considered or its configuration? Thus landscape metrics depict pattern of landscape, defining its extent, grain and patches is a necessary requirement.
b. Which way does the patch respond to landscape pattern variations? For instance, the extent of variation permitted within a patch might be due to the criteria used to defining the patch.
c. Which feature of composition or configuration does it represent? Metrics actually measure multiple aspects of landscape configuration or composition and most of them are related. In other words, metrics measures identical aspect of landscape pattern.

6.3.2 Soil Sampling Method

In using the pseudo slash (Ŧ) transect for soil sampling in a large area, the 0.5 m unit graduation should be increased to a wider graduation unit (say 2 m) in order to avoid collecting excess samples. The pseudo slash (Ŧ) transect also may not give full indication of field variability such as texture, pH, and other soil components if not measured. Nevertheless in post-mining landscape where soil patterns vary with short distances apart, the 0.5 m graduation is representative.

6.3.3 Change Detection

Results generated from change detection analyses are usually lengthy since any smaller change in area between two overlapping polygon themes that represent features of the same area (habitat) is calculated. Since borders of input themes are not real borders in the landscape but are defined by the user, changes detected in the attribute table of the output shapefile may sometimes corresponds to user defined changes and not necessarily changes that exist in the landscape. This weakness can be eliminated by ensuring high level of overall accuracy and overall Kappa statistics in the classification as shown in Table 5, page 60. The landscape boundaries from reference data or ground truth were made to conform to the classified data.

6.3.4 Spatial and Remote Sensing Accuracy Issues

More training data (sampled points) were used to ensure a more accurate classified data. The sample points taken were representative. An average of 1050 points were used for the 11 classes. Thus, about 90 point per class. The sample points used differed with sizes of landscape and the number of classes. As a rule of thumb, 30 points in each class can be used. The 90 points used per class is because, the more the points the better the classification accuracy and also more points help avoid risk of a biased sampling. Limitation with the accuracy methodology is that 90 point per class was chosen for each class leading to the possibility of having an overrepresentation of correctly mapped points. Thus there is the risk of accepting an unacceptable map (ITC, 1999).

6.3.5 DCA Ordination Analysis

As mentioned earlier, DCA provides the best performance among all tested ordination techniques but as Pielou (1984) warned, DCA is overzealous and its use can result in unwitting damaging of ecologically important information. On the other hand, one may not be able to deduce any ecologically important information from a DCA plot though patterns may exist in the ordination plot. For instance similar distribution patterns was observed among pine afforestation, lake and mixed grassland with trees in Schlabendorf Süd but this similarity does not indicate any ecological interdependence or process. This makes results from DCA plot difficult but very interpretable.

6.3.6 Fragmentation in the Post-mining Area

It is has been challenging to admit that incidence of fragmentation exist in the post-mining landscape but I must admit, the evidence are conspicuous. Figure 50 indicates that a significant area of the pine forest was cut during 2003, leaving the area to form new habitat types (open sand and seeded grassland). Seeded grasses in 1988 and 1991 were replaced with pine afforestation. Furthermore, areas of pine afforestation were not successful (hence turned to open sand) due to lack of soil nutrient or low soil pH. The emergence of wetlands, lake and open sand in areas formally covered with vegetation also contributed to the breaking up of large habitat into smaller ones.

Biomass accumulations in 2000 was lower than expected due to artifact introduced by the type of satellite image bands used for the estimation.

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8 Glossary

Accuracy - Degree of conformity with a standard, or the degree of correctness attained in a measurement.

Afforestation - The establishment of a forest or stand in areas where the preceding vegetation or land use was not forest.

Biota - All the organisms, including animals, plants, fungi and microorganisms in a given area.

Classification - The procedure of assigning the same or similar attribute types into groups or classes.

Ecosystem - An ecosystem is a dynamic and complex whole, interacting as an ecological unit. Some consider it is a basic unit in ecology, only a structured functional unit in equilibrium, characterised by energy and matter flows between the different elements that compose it. But others consider this vision or a self-standing unit with coherent and stable flows only to be a bit restrictive.

Edge Effect - Traditionally, this term has been used to describe the increased richness of flora and fauna found where two habitat types or communities meet. More recently, the term has also been used to refer to the increased predation and brood parasitism that often occurs near these boundaries.

Fragmentation - The breaking up of habitat, ecosystem or land cover types into smaller parcels (one of several processes in land transformation). It also refers to the reduction in connectivity among ecosystems within a landscape.

Geographic Information System (GIS) - A spatial database management system designed to allow users to collect, manage, and analyse volumes of geographically referenced and associated attribute data.

Habitat - The environment where an organism (plant, animal or micro-organism) lives for all or part of its life. It includes the territory needed to find food, water and shelter, and to reproduce.

Habitat Richness - Measures the number of habitat types present; it is not affected by the relative abundance of each habitat type or the spatial arrangement of habitats.

Heterogeneity - The amount of diversity within a selected area or the uneven, non-random distribution of objects - opposite of homogeneity.

Homogeneity - The degree to which attributes in a region are similar - opposite of heterogeneity.

Land cover - Land cover corresponds to a (bio)physical description of the earth's surface. It is that which overlays or currently covers the ground.

Landscape - An area of interacting and interconnected patterns of habitats (ecosystems) that are repeated because of the geology, landform, soil, climate, biota, and human influences throughout the area. A landscape is composed of watersheds and smaller ecosystems. Landscapes are usually defined for large areas, typically from 1000 to 100,000 ha in size.

Landscape Metrics - Group of indexes used to characterise composition and spatial configuration of landscape such as diversity, homogeneity, fragmentation, etc.

Landscape-level metrics - Metrics used in landscape ecology to measure the aggregate properties of an entire mosaic of landscape patches.

Mosaic - A pattern of vegetation in which two or more kinds of communities are interspersed in patches, such as clumps of shrubs with grassland between.

Number of Patches - A measure of the total number of patches found in the landscape if 'analyse by landscape' is selected or number of patches for each individual class if 'analyse by class' is selected.

Patch - Territorial unit, which represents an area covered by one single land cover class.

Patch Types - Discrete area of landscape with relatively homogeneous surface composition and environmental conditions.

Shannon Diversity Index - An algorithm for quantifying the diversity of a landscape based on two components: the number of different patch types and the proportional distribution of area among these patch types.

Succession - Succession involves the changes that occur in communities over time. Specifically, the presence of specific species may provide an environment that is conducive to the influx of other species.

Spatial Data - A GIS contains spatial data. The spatial data represents geographic features associated with real world locations.

Reverse succession - Change from a particular land cover type after a period of vegetation growth back to the initial or a characteristically similar land cover type via naturally or anthropogenically mediated processes.

Richness - A component of biodiversity; the number of species present in an area.

10 Appendix Tables

Appendix Table 1 Changes Detected in Schlabendorf Süd 1988 to 1991

Changes - 1988 to 1991 (Süd)	**Count**	**Whole Area/ha**	**Overall Change/%**	**Class Change/%**
The Area was 10 but is now 10	3	10.12	0.33	14.85
The Area was 10 but is now 11	1	5.31	0.17	7.80
The Area was 10 but is now 7	13	17.50	0.57	25.69
The Area was 11 but is now 10	1	1.63	0.05	3.97
The Area was 11 but is now 11	5	29.80	0.97	72.69
The Area was 4 but is now 11	5	11.81	0.38	6.18
The Area was 4 but is now 2	5	23.86	0.77	12.49
The Area was 4 but is now 8	42	55.39	1.79	29.00
The Area was 2 but is now 1	1	24.72	0.80	97.05
The Area was 5 but is now 2	2	18.50	0.60	6.51
The Area was 7 but is now 11	12	10.46	0.34	1.25
The Area was 7 but is now 4	17	29.54	0.96	3.52
The Area was 7 but is now 6	16	35.97	1.17	4.29
The Area was 7 but is now 7	134	562.61	18.23	67.11
The Area was 8 but is now 11	10	7.44	0.24	0.64
The Area was 8 but is now 2	7	41.29	1.34	3.54
The Area was 8 but is now 4	34	78.65	2.55	6.74
The Area was 8 but is now 5	19	36.92	1.20	3.16
The Area was 8 but is now 6	18	69.99	2.27	5.99
The Area was 8 but is now 9	5	7.78	0.25	0.67
The Area was 8 but is now 8	187	574.38	18.61	49.19
The Area was 9 but is now 11	3	2.73	0.09	6.26
The Area was 9 but is now 7	12	34.08	1.10	78.13

Appendix Table 2 Changes Detected in Schlabendorf Süd 1995 to 1998

Changes - 1995 to 1998 (Süd)	Count	Whole Area/ha	Overall Change/%	Class Change/%
The Area was 1 but is now 1	15	150.72	4.89	77.66
The Area was 10 but is now 10	5	5.27	0.17	30.05
The Area was 10 but is now 11	1	6.19	0.20	35.27
The Area was 11 but is now 10	2	3.36	0.11	7.14
The Area was 11 but is now 11	9	35.22	1.14	74.97
The Area was 11 but is now 4	4	4.30	0.14	9.15
The Area was 11 but is now 8	7	2.62	0.08	5.57
The Area was 4 but is now 10	2	2.86	0.09	2.23
The Area was 4 but is now 8	19	47.76	1.55	37.33
The Area was 5 but is now 1	5	37.46	1.21	11.72
The Area was 6 but is now 1	25	87.63	2.84	21.57
The Area was 6 but is now 3	6	25.98	0.84	6.40
The Area was 6 but is now 8	54	79.00	2.56	19.45
The Area was 7 but is now 10	1	3.56	0.12	0.57
The Area was 7 but is now 11	11	2.70	0.09	0.43
The Area was 7 but is now 9	5	9.12	0.30	1.46
The Area was 8 but is now 10	7	8.23	0.27	0.69
The Area was 8 but is now 11	15	20.47	0.66	1.73
The Area was 8 but is now 9	21	26.43	0.86	2.23
The Area was 9 but is now 11	32	10.72	0.35	38.14

Appendix Table 3 Changes Detected in Schlabendorf Süd 2000 to 2003

Changes - 2000 to 2003 (Süd)	**Count**	**Whole Area/ha**	**Overall Change/%**	**Class Change/%**
The Area was 1 but is now 1	38	324.05	9.60	86.84
The Area was 1 but is now 6	19	10.87	0.32	2.91
The Area was 10 but is now 11	1	0.62	0.02	65.61
The Area was 11 but is now 11	13	150.83	4.47	89.24
The Area was 11 but is now 6	2	0.87	0.03	0.52
The Area was 2 but is now 1	12	43.54	1.29	49.68
The Area was 2 but is now 6	11	33.62	1.00	38.36
The Area was 3 but is now 1	10	29.51	0.87	30.18
The Area was 3 but is now 6	13	33.98	1.01	34.76
The Area was 4 but is now 11	18	30.87	0.91	5.07
The Area was 4 but is now 9	27	15.40	0.46	2.53
The Area was 5 but is now 6	17	62.36	1.85	19.68
The Area was 6 but is now 1	6	14.16	0.42	15.79
The Area was 7 but is now 11	25	20.35	0.60	2.76
The Area was 7 but is now 4	60	120.52	3.57	16.33
The Area was 7 but is now 6	49	53.36	1.58	7.23
The Area was 7 but is now 8	89	233.43	6.91	31.62
The Area was 7 but is now 9	34	24.03	0.71	3.26
The Area was 7 but is now 10	9	10.31	0.31	1.40
The Area was 8 but is now 1	32	39.27	1.16	5.19
The Area was 8 but is now 11	36	24.80	0.73	3.28
The Area was 8 but is now 6	75	184.25	5.46	24.37
The Area was 8 but is now 9	45	28.96	0.86	3.83
The Area was 9 but is now 11	1	1.23	0.04	40.93

Appendix Table 4 Changes Detected in Schlabendorf Nord 1988 to 1991

Changes - 1988 to 1991 (Nord)	Count	Whole Area/ha	Overall Change/%	Class Change/%
The Area was 1 but is now 1	10	173.59	7.41	86.96
The Area was 11 but is now 11	14	117.44	5.02	69.17
The Area was 11 but is now 4	13	12.63	0.54	7.44
The Area was 11 but is now 6	10	23.22	0.99	13.68
The Area was 11 but is now 9	6	7.79	0.33	4.59
The Area was 2 but is now 1	15	70.45	3.01	23.81
The Area was 2 but is now 3	23	156.55	6.69	52.90
The Area was 2 but is now 5	23	33.16	1.42	11.21
The Area was 4 but is now 4	20	90.77	3.88	37.37
The Area was 4 but is now 5	21	30.88	1.32	12.71
The Area was 4 but is now 6	21	84.05	3.59	34.60
The Area was 5 but is now 3	21	45.64	1.95	4.55
The Area was 5 but is now 5	125	913.37	39.01	91.06
The Area was 6 but is now 1	11	53.11	2.27	26.78
The Area was 6 but is now 5	30	44.30	1.89	22.34
The Area was 6 but is now 6	11	68.81	2.94	34.71
The Area was 8 but is now 4	12	32.47	1.39	22.93
The Area was 8 but is now 7	14	48.32	2.06	34.13
The Area was 8 but is now 8	14	45.53	1.94	32.16

Appendix Table 5 Changes Detected in Schlabendorf Nord 1995 to 1998

Changes - 1995 to 1998 (Nord)	Count	Whole Area/ha	Overall Change/%	Class Change/%
The Area was 1 but is now 1	20	249.60	11.39	84.39
The Area was 10 but is now 11	3	10.49	0.48	88.25
The Area was 11 but is now 11	17	127.14	5.80	90.99
The Area was 11 but is now 6	9	2.66	0.12	1.90
The Area was 11 but is now 7	3	3.10	0.14	2.22
The Area was 11 but is now 9	11	3.09	0.14	2.21
The Area was 2 but is now 11	6	10.53	0.48	11.91
The Area was 2 but is now 1	14	13.87	0.63	15.69
The Area was 2 but is now 3	10	37.88	1.73	42.86
The Area was 3 but is now 3	20	134.99	6.16	74.89
The Area was 5 but is now 3	39	47.84	2.18	5.04
The Area was 5 but is now 6	21	51.77	2.36	5.46
The Area was 5 but is now 8	28	135.50	6.18	14.28
The Area was 6 but is now 1	13	10.10	0.46	5.79
The Area was 6 but is now 11	17	17.45	0.80	10.01
The Area was 6 but is now 5	12	31.03	1.42	17.79
The Area was 7 but is now 8	7	22.86	1.04	53.54
The Area was 8 but is now 11	21	35.23	1.61	25.80
The Area was 8 but is now 7	12	23.74	1.08	17.38
The Area was 9 but is now 11	63	24.92	1.14	45.82

Appendix Table 6 Changes Detected in Schlabendorf Nord 2000 to 2003

Changes - 2000 to 2003 (Nord)	Count	Whole Area/ha	Overall Change/%	Class Change/%
The Area was 1 but is now 1	21	271.69	11.36	86.67
The Area was 1 but is now 6	23	20.63	0.86	6.58
The Area was 2 but is now 6	9	24.49	1.02	72.65
The Area was 3 but is now 6	23	54.46	2.28	28.42
The Area was 4 but is now 5	7	22.72	0.95	37.19
The Area was 4 but is now 6	12	7.54	0.32	12.33
The Area was 4 but is now 11	11	4.61	0.19	7.54
The Area was 5 but is now 10	2	11.16	0.47	1.20
The Area was 5 but is now 3	28	94.02	3.93	10.13
The Area was 5 but is now 5	140	722.82	30.23	77.87
The Area was 6 but is now 11	5	3.93	0.16	5.78
The Area was 7 but is now 11	11	6.59	0.28	4.89
The Area was 7 but is now 6	17	29.56	1.24	21.93
The Area was 7 but is now 8	17	70.52	2.95	52.33
The Area was 8 but is now 5	36	88.34	3.69	32.04
The Area was 8 but is now 6	51	85.50	3.58	31.01
The Area was 8 but is now 9	20	17.13	0.72	6.21
The Area was 8 but is now 11	25	12.77	0.53	4.63
The Area was 11 but is now 11	18	256.96	10.75	92.80
The Area was 11 but is now 4	3	0.51	0.02	0.19
The Area was 11 but is now 6	16	5.20	0.22	1.88
The Area was 11 but is now 8	8	1.31	0.05	0.47
The Area was 11 but is now 9	12	12.92	0.54	4.66

Appendix Table 7 All land Cover Changes among Various Period of study at Schlabendorf Nord

Year Nord	Afft	D-Afft	P-Afft	Agric	Dry-Grass	Dry-Veg	Lake	Mix-Grass	Open-Sand	Pnr-Grass	Wetland
1991-1988	-286.19	213.63	134.17	27.26	-86.03	-55	-28.82	17.4	17.74	46.07	0
1995-1991	97.75	-44.86	38.54	-15.79	80.95	-89.06	-14.56	-55.62	32.63	-35.1	11.89
1998-1995	-102.21	125.86	-9.59	-194.05	130.57	-60.48	109.88	-4.77	-20.58	33.35	-11.89
2000-1998	21.79	-107	23.4	79.47	8.57	23.18	35.72	-108.83	-35.35	57.53	0
2003-2000	-17.38	16.88	-22.37	-63.14	-127.26	-18.64	13.63	279.83	45.36	-118.34	11.16
1995-1988	-188.44	168.77	172.71	11.47	-5.08	-144.06	-43.38	-38.22	50.37	10.97	11.89
1998-1991	-4.46	81	28.95	-209.84	211.52	-149.54	95.32	-60.39	12.05	-1.75	0
2000-1995	-80.42	18.86	13.81	-114.58	139.14	-37.3	145.6	-113.6	-55.93	90.88	-11.89
2003-1998	4.41	-90.12	1.03	16.33	-118.69	4.54	49.35	171	10.01	-60.81	11.16
1998-1988	-290.65	294.63	163.12	-182.58	125.49	-204.54	66.5	-42.99	29.79	44.32	0
2000-1991	17.33	-26	52.35	-130.37	220.09	-126.36	131.04	-169.22	-23.3	55.78	0
2003-1995	-97.8	35.74	-8.56	-177.72	11.88	-55.94	159.23	166.23	-10.57	-27.46	-0.73
2000-1988	-268.86	187.63	186.52	-103.11	134.06	-181.36	102.22	-151.82	-5.56	101.85	0
2003-1991	-0.05	-9.12	29.98	-193.51	92.83	-145	144.67	110.61	22.06	-62.56	11.16
2003-1988	-286.24	204.51	164.15	-166.25	6.8	-200	115.85	128.01	39.8	-16.49	11.16

P-Afft. represents afforestation of pine trees, Afft. = afforestation, D-Afft. = deciduous trees afforestation, Dry-Veg. = dry vegetation, Agric. = agriculture land, Mix-Grass. = mixed grassland and trees, Pnr-Grass. = sparse pioneer grassland, Dry-Grass = dry grassland, Open-Sand. = open sand, Wetland. = wetland, Lake. = lake.

Appendix Table 8 Land Cover Changes among Various Period of Study at Schlabendorf Süd

Year-Süd	Afft	D-Afft	P-Afft	Agric	Dry-Grass	Dry-Veg	Lake	Mix-Grass	Open-Sand	Pnr-Grass	Wetland
1991-1988	71.42	12.67	108.14	77.21	-214.84	-27.08	26.55	28.63	-32.96	286.56	-53.28
1995-1991	8.13	21.8	124.36	43	137.72	-48.3	-32.54	268.65	17.28	-520.84	-2.17
1998-1995	-20.23	73.42	82.53	-71.58	-68.04	-30.96	28.76	76.31	19.66	-101.64	7.17
2000-1998	2.85	-10.12	58.29	-53.8	-378.11	512.41	92.65	-398.33	-46.3	242.37	-23.76
2003-2000	-87.64	-91.5	94.22	79.99	-270.47	-81.38	63.16	581.41	79.6	-393.97	26.39
1995-1988	79.55	34.47	232.5	120.21	-77.12	-75.38	-5.99	297.28	-15.68	-234.28	-55.45
1998-1991	-12.1	95.22	206.89	-28.58	69.68	-79.26	-3.78	344.96	36.94	-622.48	5
2000-1995	-17.38	63.3	140.82	-125.38	-446.15	481.45	121.41	-322.02	-26.64	140.73	-16.59
2003-1998	-84.79	-101.62	152.51	26.19	-648.58	431.03	155.81	183.08	33.3	-151.6	2.63
1998-1988	59.32	107.89	315.03	48.63	-145.16	-106.34	22.77	373.59	3.98	-335.92	-48.28
2000-1991	-9.25	85.1	265.18	-82.38	-308.43	433.15	88.87	-53.37	-9.36	-380.11	-18.76
2003-1995	-105.02	-28.2	235.04	-45.39	-716.62	400.07	184.57	259.39	52.96	-253.24	9.8
2000-1988	62.17	97.77	373.32	-5.17	-523.27	406.07	115.42	-24.74	-42.32	-93.55	-72.04
2003-1991	-96.89	-6.4	359.4	-2.39	-578.9	351.77	152.03	528.04	70.24	-774.08	7.63
2003-1988	-25.47	6.27	467.54	74.82	-793.74	324.69	178.58	556.67	37.28	-487.52	-45.65

P-Afft. represents afforestation of pine trees, Afft. = afforestation, D-Afft. = deciduous trees afforestation, Dry-Veg. = dry vegetation, Agric. = agriculture land, Mix-Grass. = mixed grassland and trees, Pnr-Grass. = sparse pioneer grassland, Dry-Grass = dry grassland, Open-Sand. = open sand, Wetland. = wetland, Lake. = lake.

Appendix Table 9 Areas of Various Land Cover Types from 1988 to 2003 in Schlabendorf Nord

Year Nord	Afft	D-Afft	P-Afft	Agric	Dry-Grass	Dry-Veg	Lake	Mix-Grass	Open-Sand	Pnr-Grass	Wetland
1988	302.98	11.48	200.03	1038.58	146.74	244.64	183.11	221.16	6.91	34.05	0
1991	16.79	225.11	334.2	1065.84	60.71	189.64	154.29	238.56	24.65	80.12	0
1995	114.54	180.25	372.74	1050.05	141.66	100.58	139.73	182.94	57.28	45.02	11.89
1998	12.33	306.11	363.15	856	272.23	40.1	249.61	178.17	36.7	78.37	0
2000	34.12	199.11	386.55	935.47	280.8	63.28	285.33	69.34	1.35	135.9	0
2003	16.74	215.99	364.18	872.33	153.54	44.64	298.96	349.17	46.71	17.56	11.16

P-Afft. represents afforestation of pine trees, Afft. = afforestation, D-Afft. = deciduous trees afforestation, Dry-Veg. = dry vegetation, Agric. = agriculture land, Mix-Grass. = mixed grassland and trees, Pnr-Grass. = sparse pioneer grassland, Dry-Grass = dry grassland, Open-Sand. = open sand, Wetland. = wetland, Lake. = lake.

Appendix Table 10 Areas of Various Land Cover Types from 1988 to 2003 in Schlabendorf Süd

Year Süd	Afft	D-Afft	P-Afft	Agric	Dry-Grass	Dry-Veg	Lake	Mix-Grass	Open-Sand	Pnr-Grass	Wetland
1988	25.47	0	0	321.97	1299.55	218.11	53.6	114.63	45.34	868.65	72.99
1991	96.89	12.67	108.14	399.18	1084.71	191.03	80.15	143.26	12.38	1155.21	19.71
1995	105.02	34.47	232.5	442.18	1222.43	142.73	47.61	411.91	29.66	634.37	17.54
1998	84.79	107.89	315.03	370.6	1154.39	111.77	76.37	488.22	49.32	532.73	24.71
2000	87.64	97.77	373.32	316.8	776.28	624.18	169.02	89.89	3.02	775.1	0.95
2003	0	6.27	467.54	396.79	505.81	542.8	232.18	671.3	82.62	381.13	27.34

P-Afft. represents afforestation of pine trees, Afft. = afforestation, D-Afft. = deciduous trees afforestation, Dry-Veg. = dry vegetation, Agric. = agriculture land, Mix-Grass. = mixed grassland and trees, Pnr-Grass. = sparse pioneer grassland, Dry-Grass = dry grassland, Open-Sand. = open sand, Wetland. = wetland, Lake. = lake.