Long-distance dispersal in cultural landscapes – evidence from lignite mines

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Long-distance dispersal in cultural landscapes – evidence from coal mines
Conclusions

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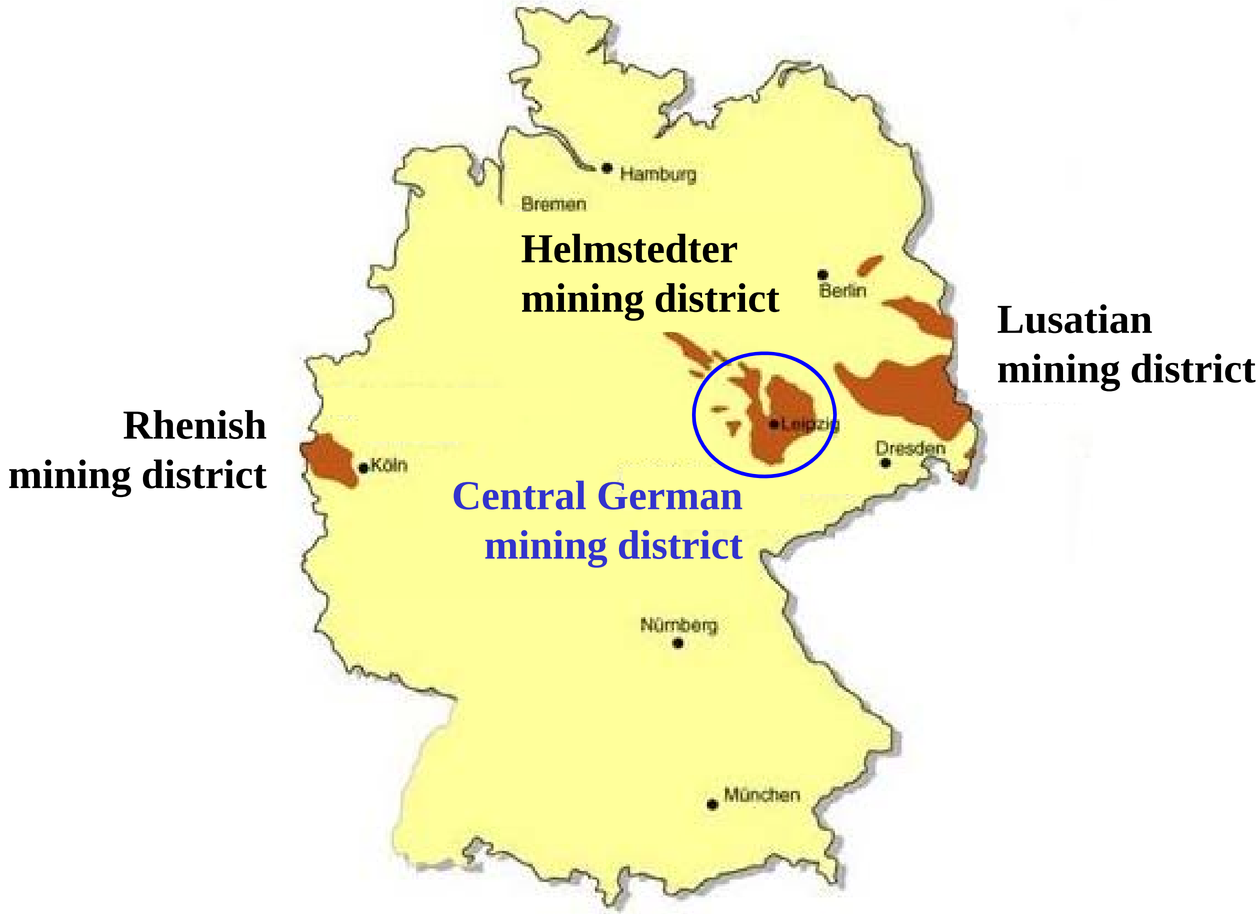
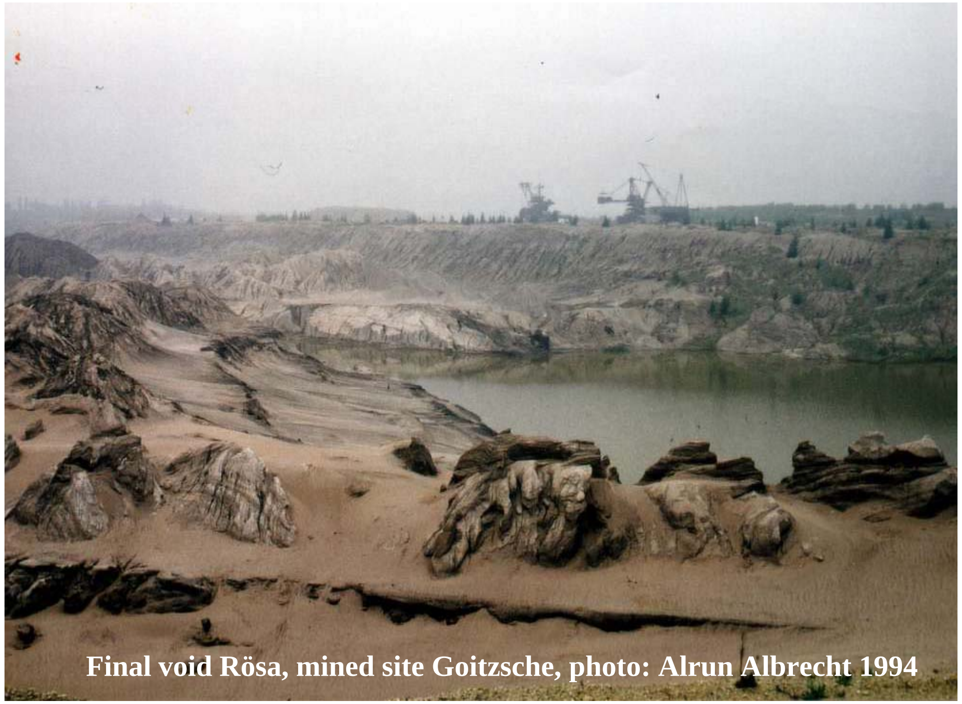
Mining districts in Germany



Post-mining landscapes in eastern Germany: situation 1989/90

- 215 final voids in 31 mining sites were shut down
- c. 1200 km² directly affected by surface mining of lignite
- c. 2000 km² affected by decrease of the groundwater table
- c. 12.7 Mrd. m³ water deficit
- Only 55 % of the mined area had been restored



Final void Rösa, mined site Goitzsche, photo: Alrun Albrecht 1994

High potentials of surface-mined land on landscape level

- large extension without barriers
- low disturbance after mining stopped
- raw soil with low nutrient content
- low competition
- high heterogeneity in terms of substrate, water regime, geomorphology
- high niche availability
- high dynamic of geomophological and biological processes

Mined site Mücheln 1997, photo: LMBV

Mahn & Tischew 1995, Henle et al. 1997, Wiedemann et al. 1998, LENAB 1998, Herbst & Mahn 1998, FBM 1999, Blumrich mdl., FLB 2003, Tischew et al. 2003, Tischew 2004, Tischew & Kirmer 2007

Post-glacial character of large-scale surface mines

In the last century, surface-mining of lignite exceeded the mass turnover of the last ice age in the German federal states of Brandenburg, Saxony and Saxony-Anhalt (Müller & Eissmann 1991).

Müller, A. & Eissmann, L. (1991) Die geologischen Bedingungen der Bergbaufolgelandschaft im Raum Leipzig. Abhandlungen Sächsische Akademie der Wissenschaften, Leipzig.

- no seed sources within the area
- no soil seed bank
- no soil biota
- no soil development

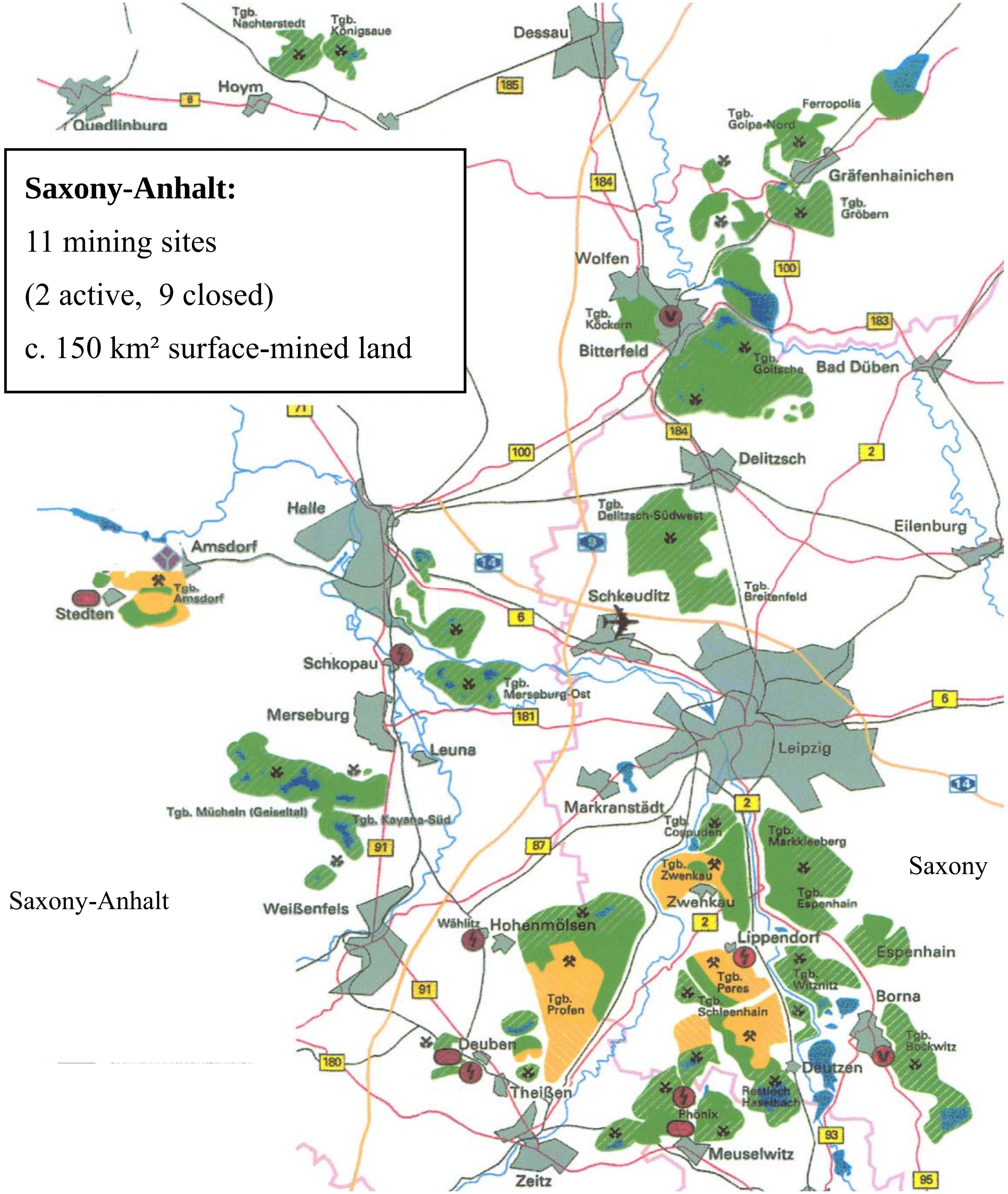
⇨ **primary succession**

Saxony-Anhalt:

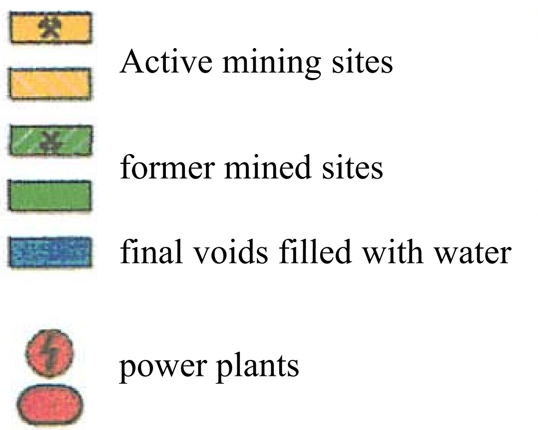
11 mining sites

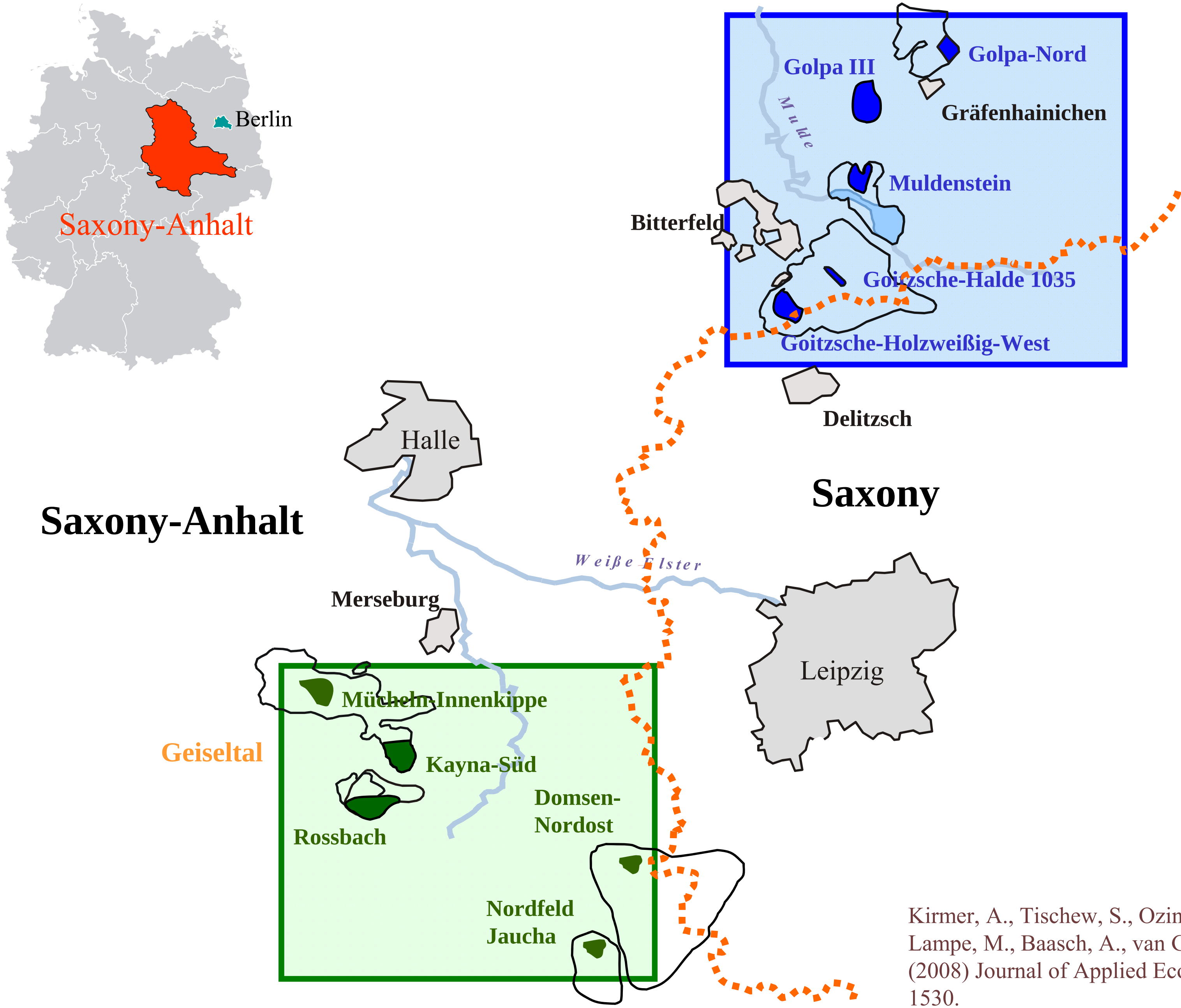
(2 active, 9 closed)

c. 150 km² surface-mined land



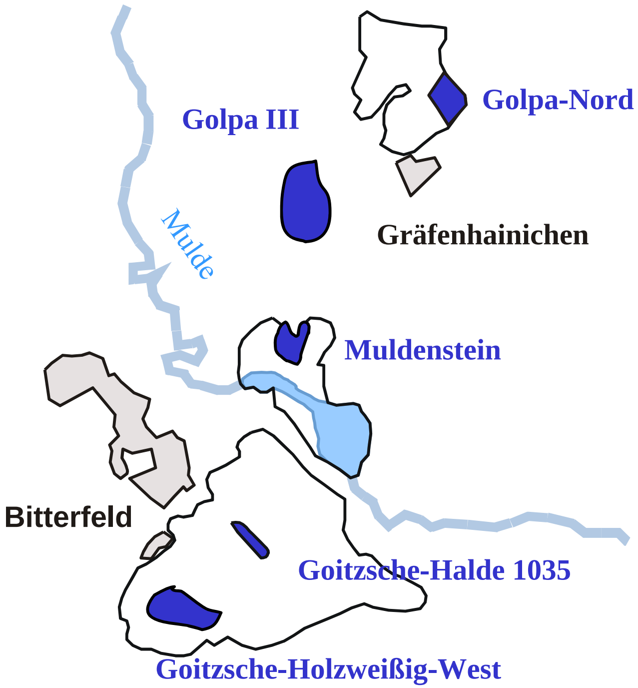
Central German lignite mining district





Kirmer, A., Tischew, S., Ozinga, W.A., von Lampe, M., Baasch, A., van Groenendael, J.M. (2008) Journal of Applied Ecology 45: 1523-1530.

Bitterfelder / Gräfenhainicher lignite mining district



mined site	approx. age	extension
Golpa-Nord, Bachaue	(2 -) 14 years	1 km²
Golpa III	(6 -) 50 years	2.5 km²
Muldenstein, Burgkemnitz	38 years	0.8 km²
Goitzsche, Halde 1035	(3 -) 40 years	0.6 km²
Goitzsche, Holzweißig-West	(4 -) 30 years	1.8 km²

All sites developed spontaneously (only small parts were recultivated) and contain only small areas with inhospitable tertiary substrate (pH <3)

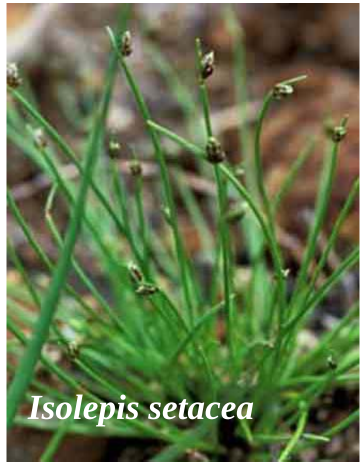
Mined site Muldenstein, nature reserve “Burgkemnitz”

Extension of the study site: 0.8 km²

regrading stopped in 1962

recultivation only at the edges (mostly planting of trees and shrubs)

dominance of moist and wet site conditions; in parts dry and sandy


Isolepis setacea

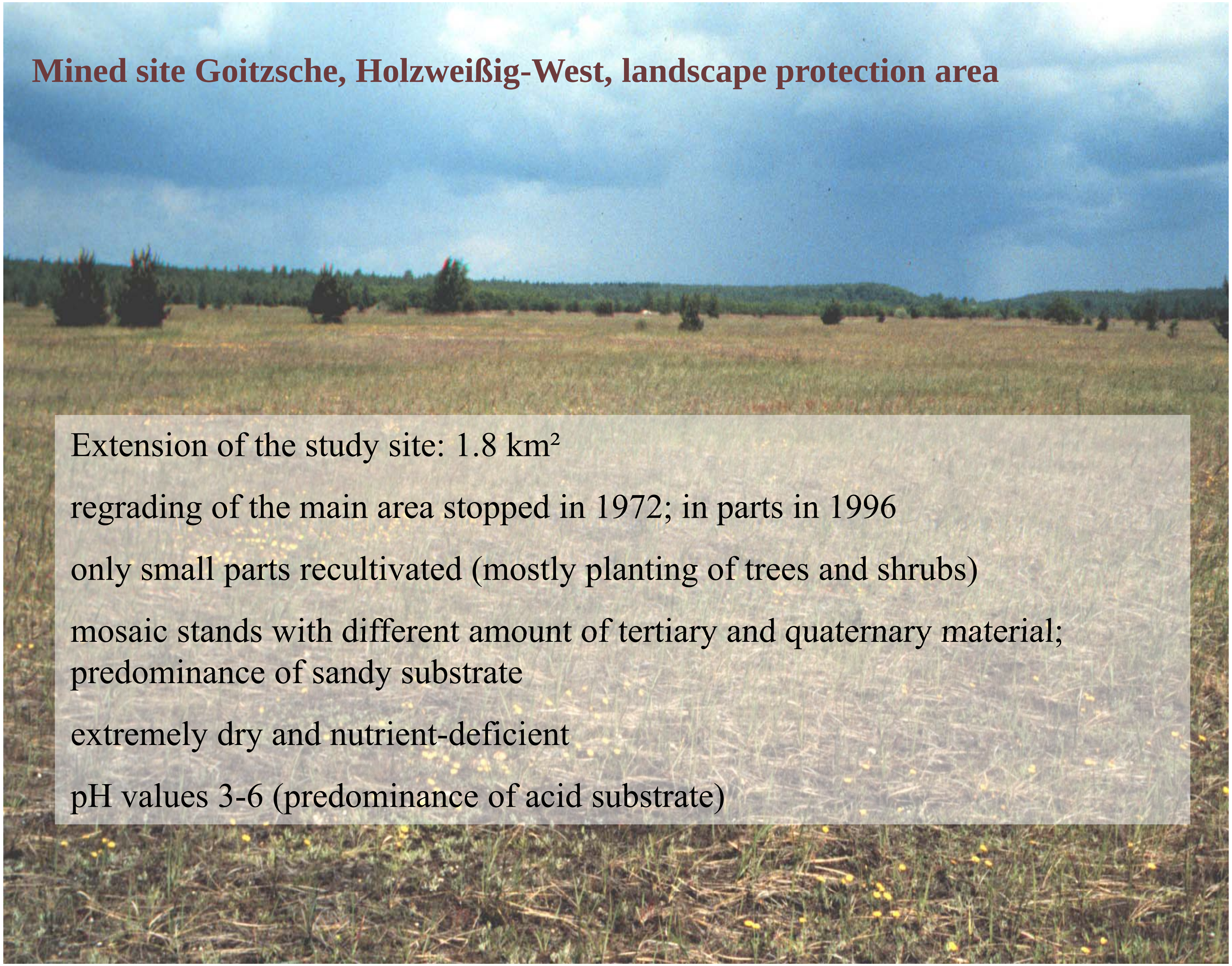

Dactylorhiza maculata


Centaurium pulchellum


Utricularia australis


Eriophorum angustifolium


Armeria maritima



Mined site Goitzsche, Holzweißig-West, landscape protection area

Extension of the study site: 1.8 km²

regrading of the main area stopped in 1972; in parts in 1996

only small parts recultivated (mostly planting of trees and shrubs)

mosaic stands with different amount of tertiary and quaternary material; predominance of sandy substrate

extremely dry and nutrient-deficient

pH values 3-6 (predominance of acid substrate)


Mined site Goitzsche, Holzweißig-West,
landscape protection area
208 plant species, 11 endangered


Dianthus deltoides


Corynephorus canescens


Jasione montana

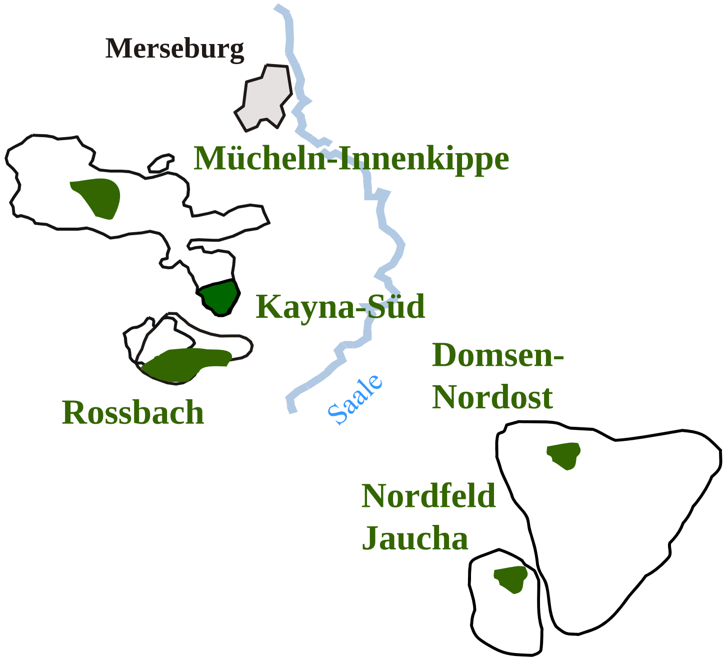

Filago arvensis


Centaurium erythraea


Saxifraga granulata


Helichrysum arenarium

Geiseltal / Profener lignite mining district

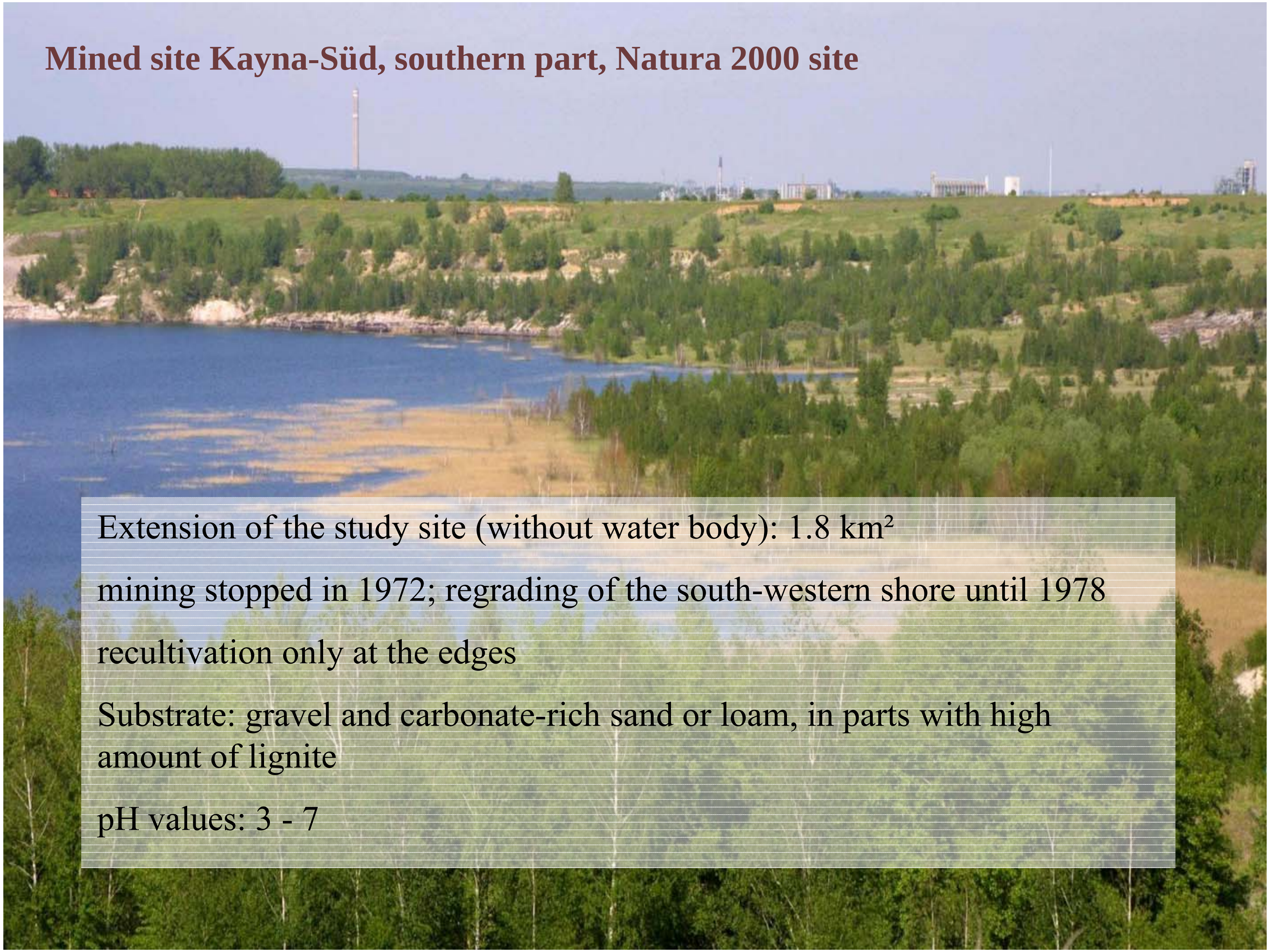


mined site	approx. age	extension
Mücheln/Innenkippe	(2 -) 41 years	2.6 km^2
Kayna-Süd	(3 -) 34 years	1.8 km^2
Roßbach	(1 -) 23 years	2.3 km^2
Domsen	27 - 41 years	1 km^2
Nordfeld Jaucha	26 - 55 years	1 km^2

All sites developed spontaneously (only small parts with recultivation) and contain only small areas with inhospitable tertiary material (pH <3)




Mined site Kayna-Süd, southern part, Natura 2000 site



Extension of the study site (without water body): 1.8 km²

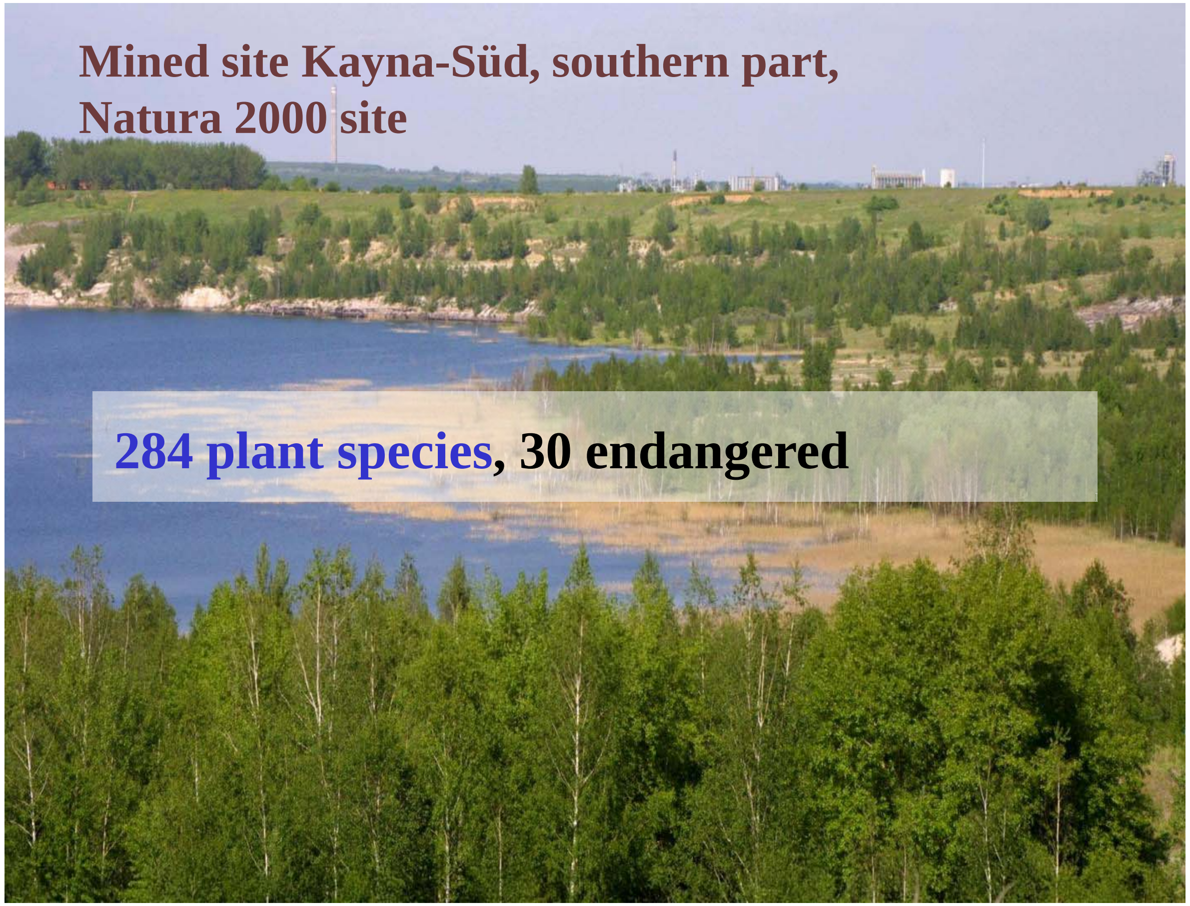
mining stopped in 1972; regrading of the south-western shore until 1978

recultivation only at the edges

Substrate: gravel and carbonate-rich sand or loam, in parts with high amount of lignite

pH values: 3 - 7

Mined site Kayna-Süd, southern part, Natura 2000 site



284 plant species, 30 endangered

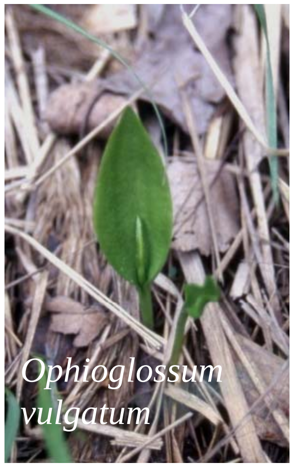
Pulicaria dystenterica

Ophrys apifera

Trifolium aureum

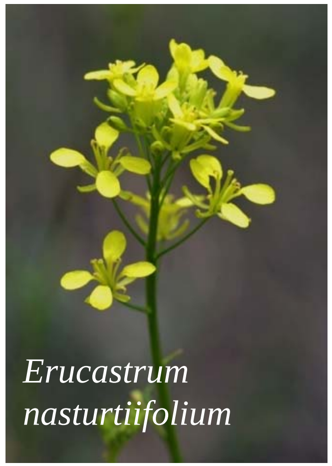
Achillea nobilis

Epipactis atrorubens

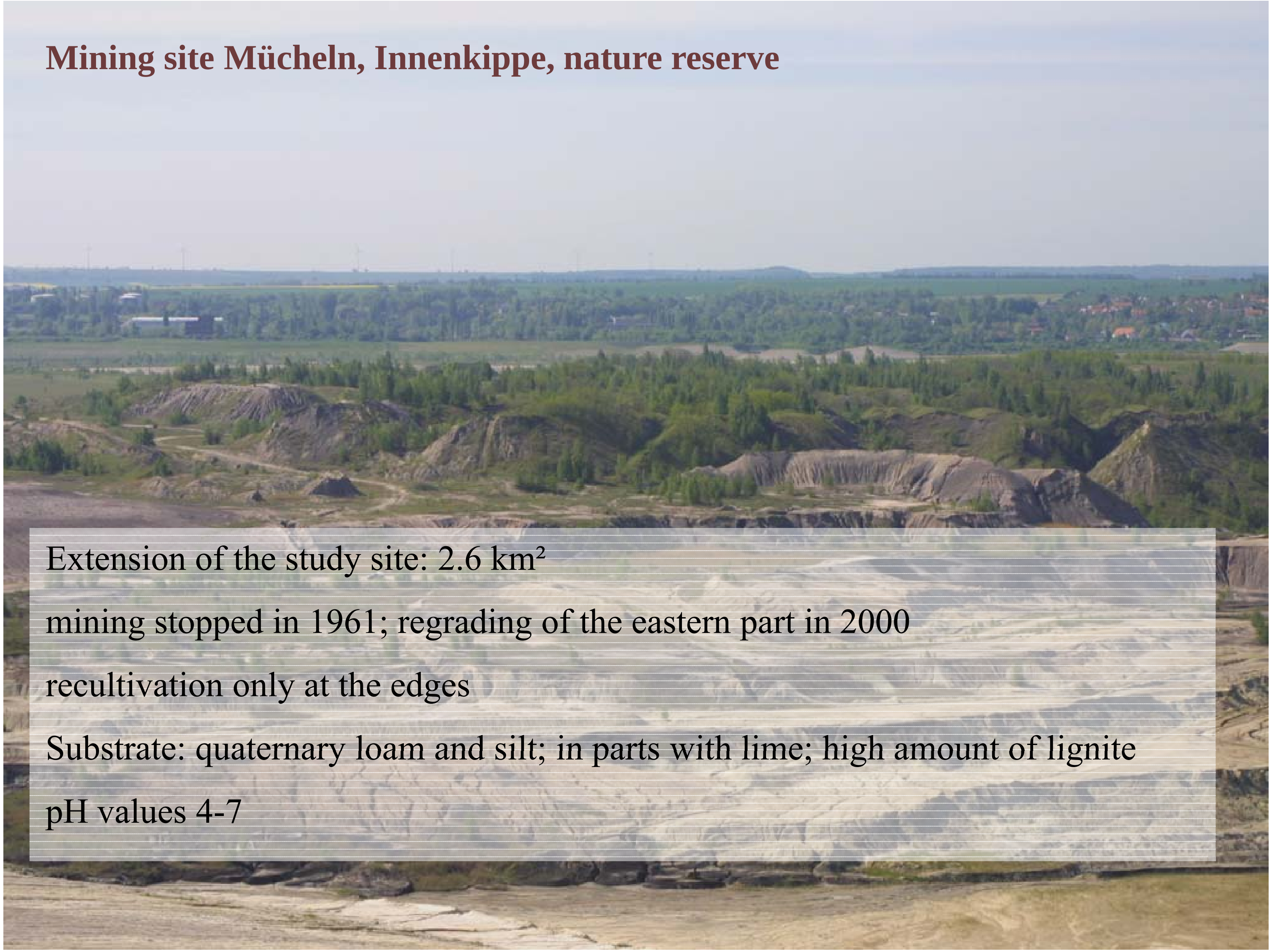


Ophioglossum vulgatum

Dactylorhiza incarnata



Erucastrum nasturtiifolium



Mining site Mücheln, Innenkippe, nature reserve

Extension of the study site: 2.6 km²

mining stopped in 1961; regrading of the eastern part in 2000

recultivation only at the edges

Substrate: quaternary loam and silt; in parts with lime; high amount of lignite

pH values 4-7





Anagallis foemina


Scorzonera laciniata


Dianthus carthusianorum


Epipactis palustris


Thymelaea passerina


Botrychium lunaria


Centaurea diffusa


Linum austriacum

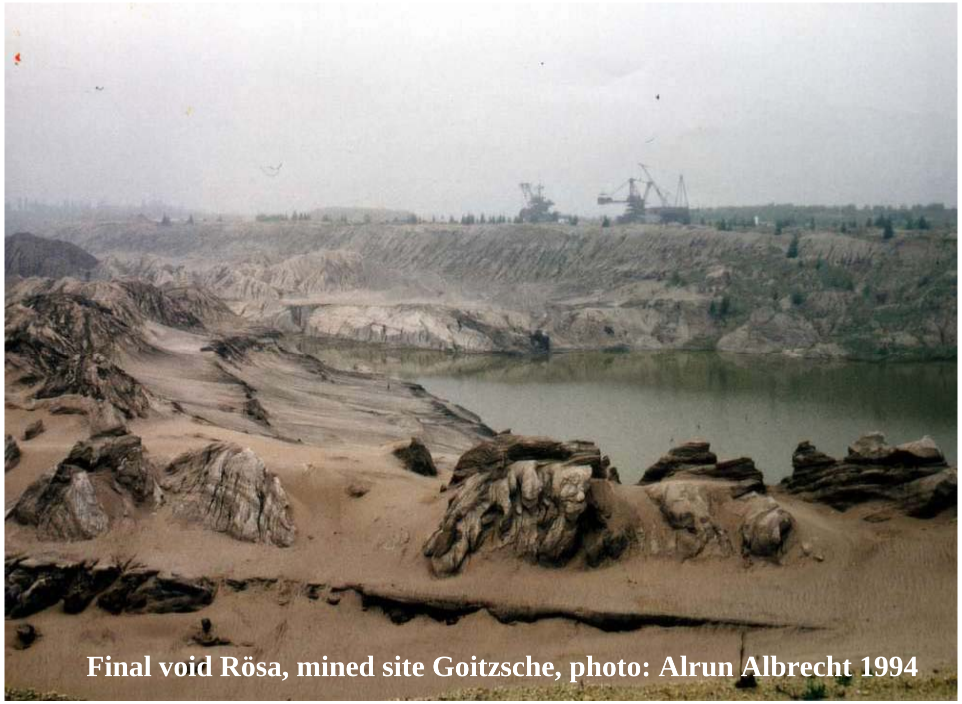
Special situation in post-mining landscapes in eastern Germany

During GDR times: mining sites were forbidden zones with limited access due to their economical importance

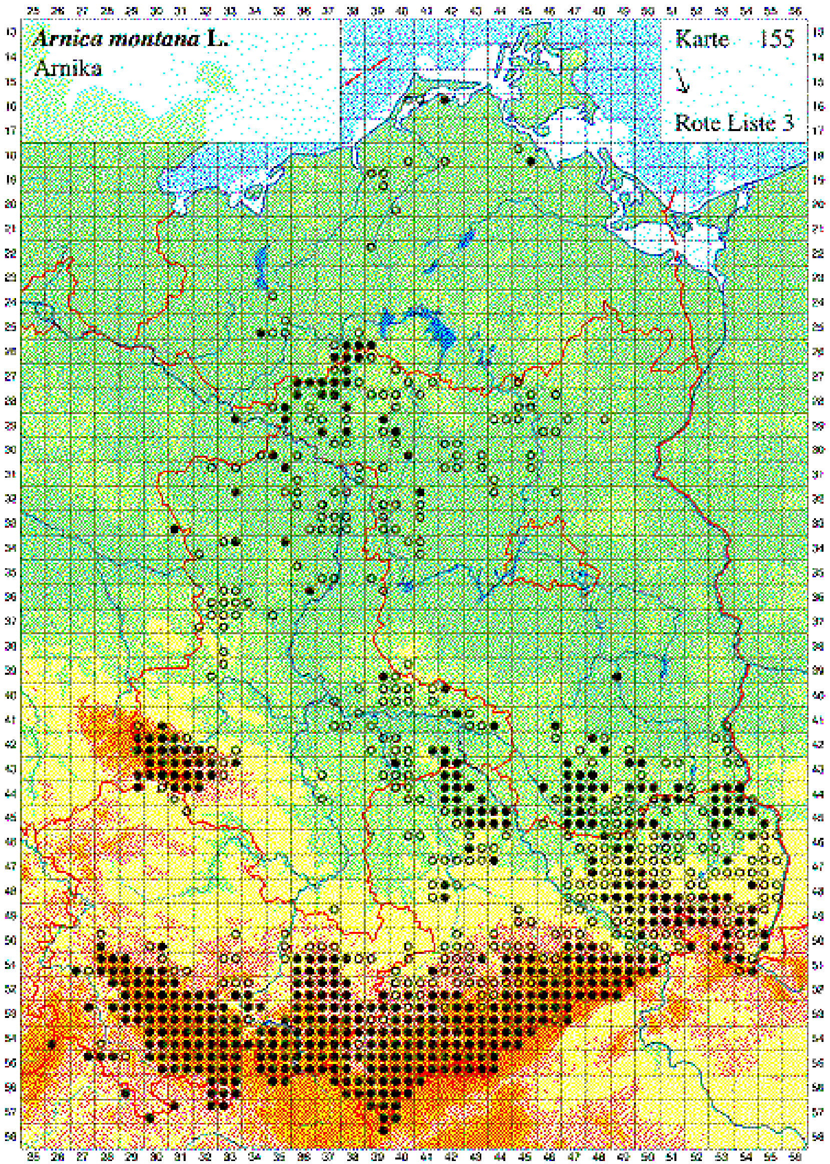
1949 - 1998: floristic mappings without implementation of mining areas

1994 - 2002: several research projects with thorough botanical assessments in mined areas

➔ **two data sets for analysis**



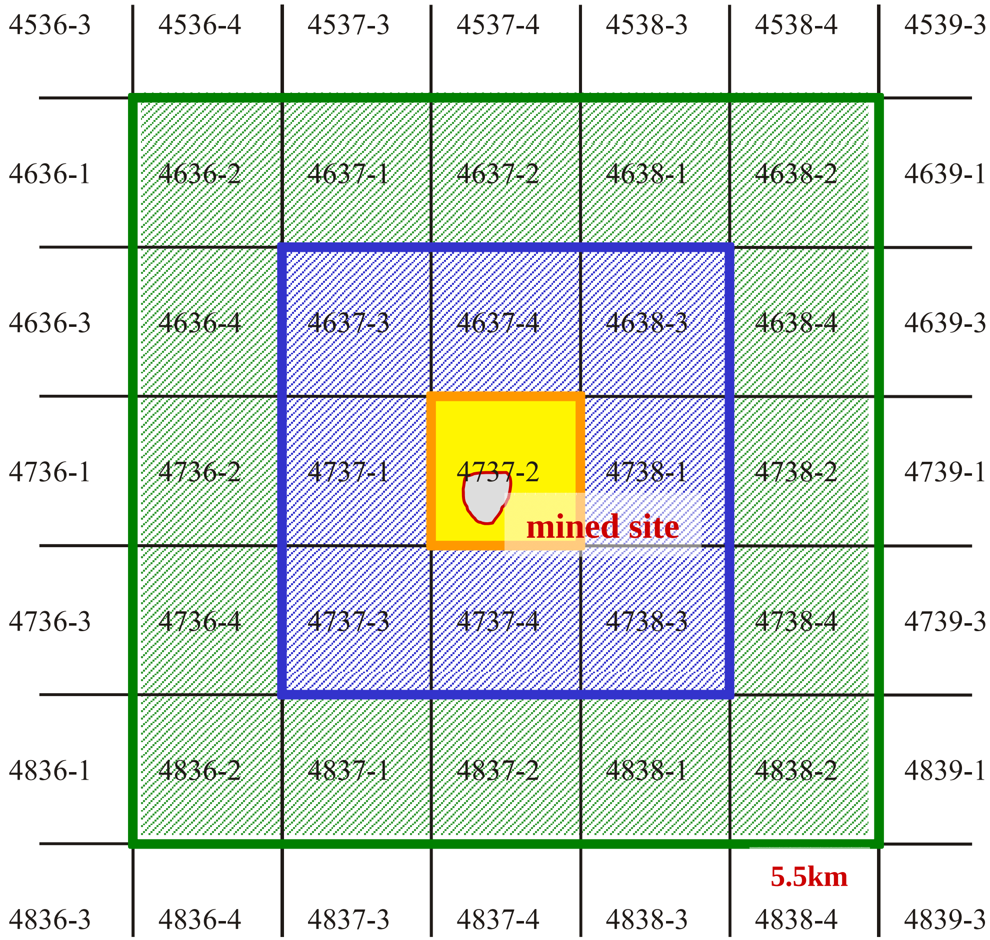
Final void Rösa, mined site Goitzsche, photo: Alrun Albrecht 1994



Floristic Mapping of higher plants in Germany

(Schönfelder, P. 1999: Mapping the flora of Germany. Acta Bot. Fennica 162: 43–53)

Mapping is based on grid cells with 5.5 km mesh size



mined sites: lists of plant species

surrounding area: data from the floristic mapping of the states Saxony-Anhalt and Saxony (after 1949)

categories

- <3km (1 grid cell)
- 3-10km (8 grid cells)
- 10-17km (16 grid cells)
- >17km

Kirmer, A., Tischew, S., Ozinga, W.A., von Lampe, M., Baasch, A., van Groenendael, J.M. (2008) Journal of Applied Ecology 45: 1523-1530.

Definition of species pools

Geographical Species Pool (GSP)

= species that are present in the whole region. The abundance of these species is expressed by the number of occupied 30.25 km² grid cells.

Species filter: Species able to grow under mining site conditions

Habitat Species Pool (HSP)

= species that are present in the whole region and have proved to be able to grow under mining site conditions. The abundance of these species is expressed by the number of occupied 30.25 km² grid cells (subset of GSP).

Environmental filter (specific site conditions in mined site)

Regional Species Pool 1 | **Regional Species Pool 2** | **Regional Species Pool n**

= species from the habitat species pool that occurred in 0-17 km distance of each mined site and are able to grow in the specific mined site. The abundance of these species is expressed by the number of occupied 30.25 km² grid cells (subset of HSP).

Actual Species Pool 1 | **Actual Species Pool 2** | **Actual Species Pool n**

= species that are already present in the examined mined sites.

Species traits used in analyses

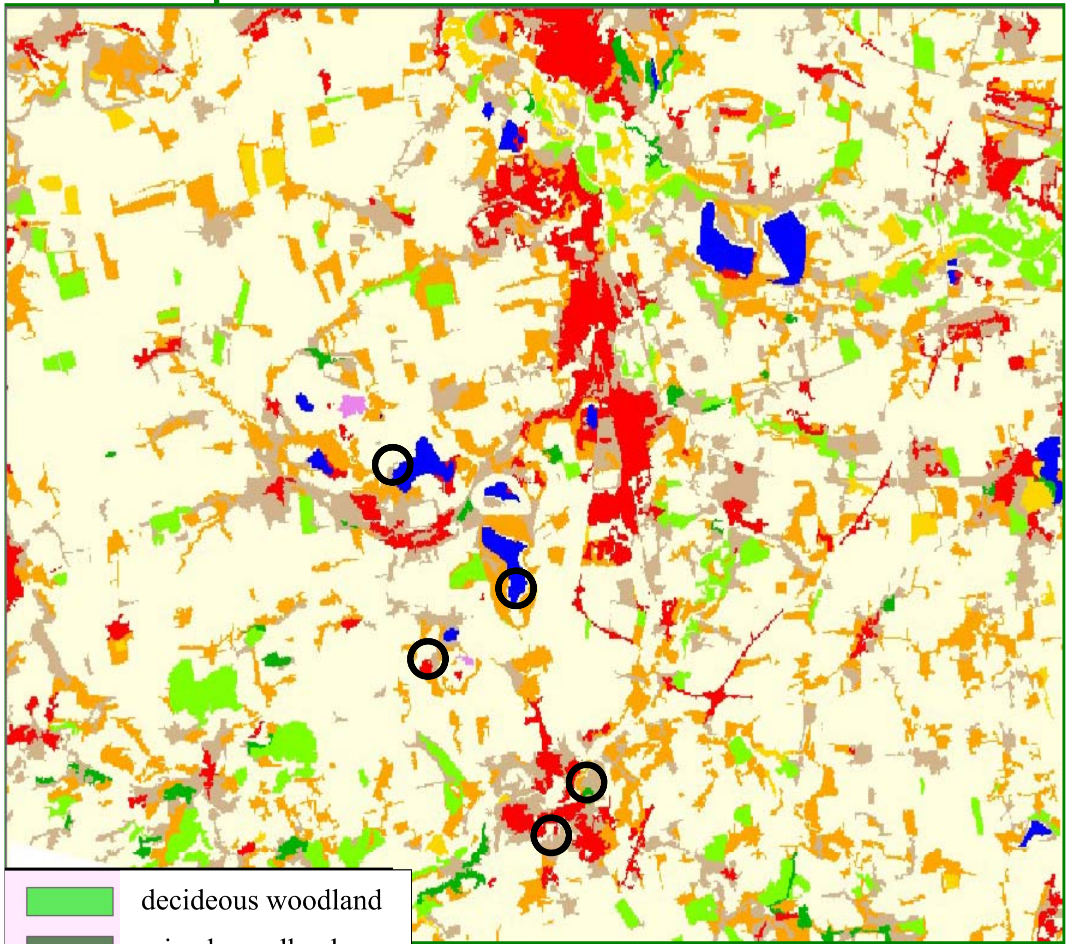
- **Distance** of the next seed source to the respective mined site
- Affiliation to the **northern or southern** mining region
- **Ellenberg indicator values**
  - light availability
  - moisture
  - nitrogen availability

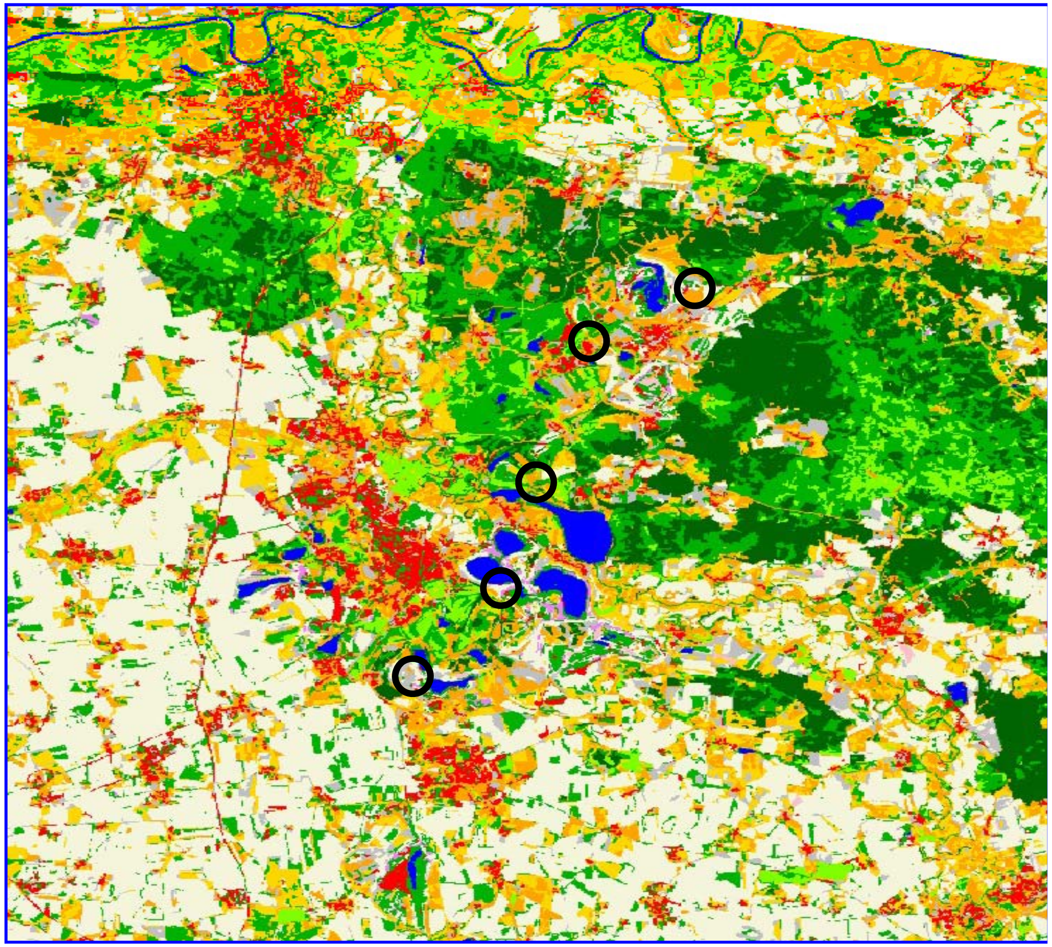
- **Seed weight** (mg)
- **Terminal velocity** of seeds (m/sec)
- **dispersal strategy type**
  - wind (anemochor)
  - birds (ornithochor)
  - fur (epizoochor)
  - ants (myrmekochor)
  - self (autochor)
  - water (hydrochor)

Data compiled from: Bioflor database (Frank et al. 1990), von Lampe (unpubl.), IRIS/LEDA database; database higher plants & selective biotope mapping in Saxony-Anhalt (Landesamt für Umweltschutz Sachsen-Anhalt, Halle) working status 1998; database higher plants in Saxony (Sächsisches Landesamt für Umwelt und Geologie, Dresden)

Question 1:

Do special features of the two mining regions affect the occurrence of plant species in the respective mined sites?





- decideous woodland
- mixed woodland
- coniferous woodland
- arable land
- grassland
- tall herb community
- dry grassland
- bare soil
- water
- settlements

Southern region ○ **Study sites** **Northern region**

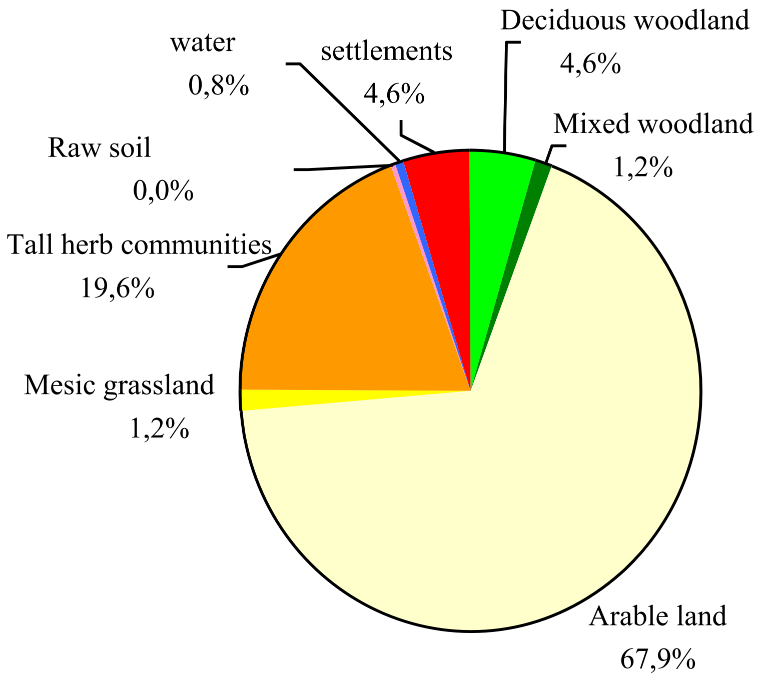
Landsat 7 ETM+ (14/08/2000); Digital segment based analysis
(University of Halle, Institute for Geography, Prof. Dr. Gläßer)

Proportion of different land use on 35 km x 40 km

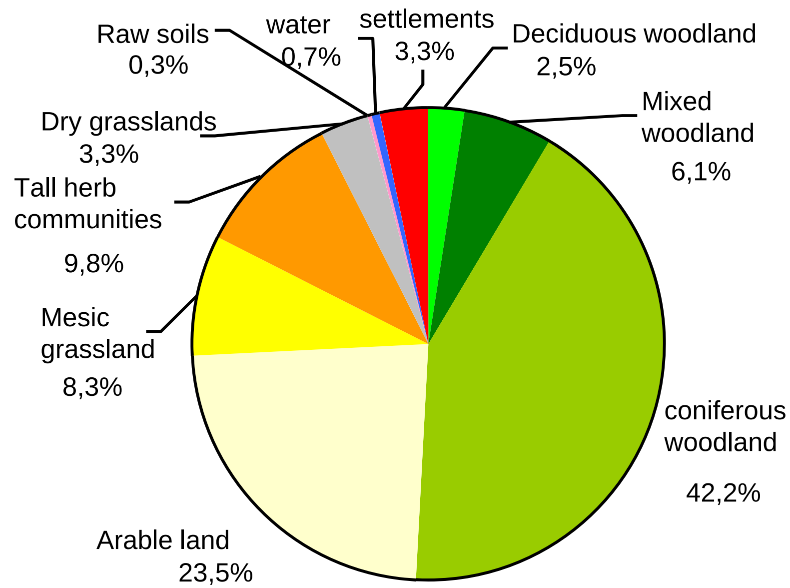
based on Landsat 7 ETM+ (14/08/2000); Digital segment based analysis

(University of Halle, Institute for Geography, Prof. Dr. Gläßer)

Southern region



Northern region



Differences between the northern and southern region

Land cover based on a classification of satellite images *
(Landsat7 ETM+, 14.08.2000)

	structures, relevant for colonisation processes	arable land	average number of species from the regional species pool in the 0-3km surrounding area
South	26.6 %	67.9 %	259 (+/- 46)
North	72.2 %	23.5 %	455 (+/- 60)

southern region: structure- and species-poor

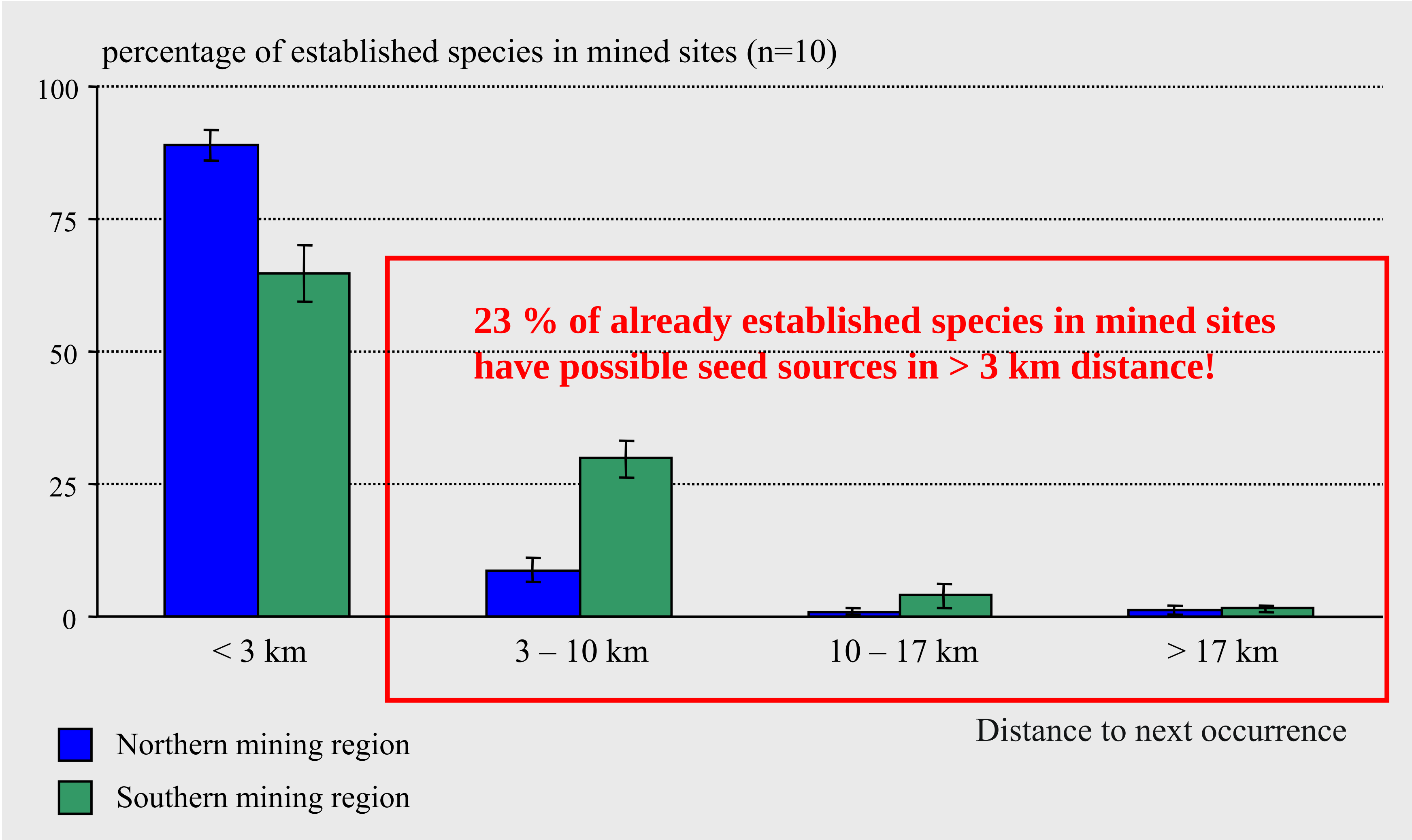
northern region: structure- and species-rich

* Nocker, U. & Gläßer, C. „The contribution of remote sensing and GIS for registration at vegetation structures in the surrounding of former open-cast mining areas“ (Univ. Halle, Institute for Geography, unpubl. data)

Question 2:

How far away are the next occurrences of plant species already growing in the mined sites?

Distance of species in mined sites to possible seed sources

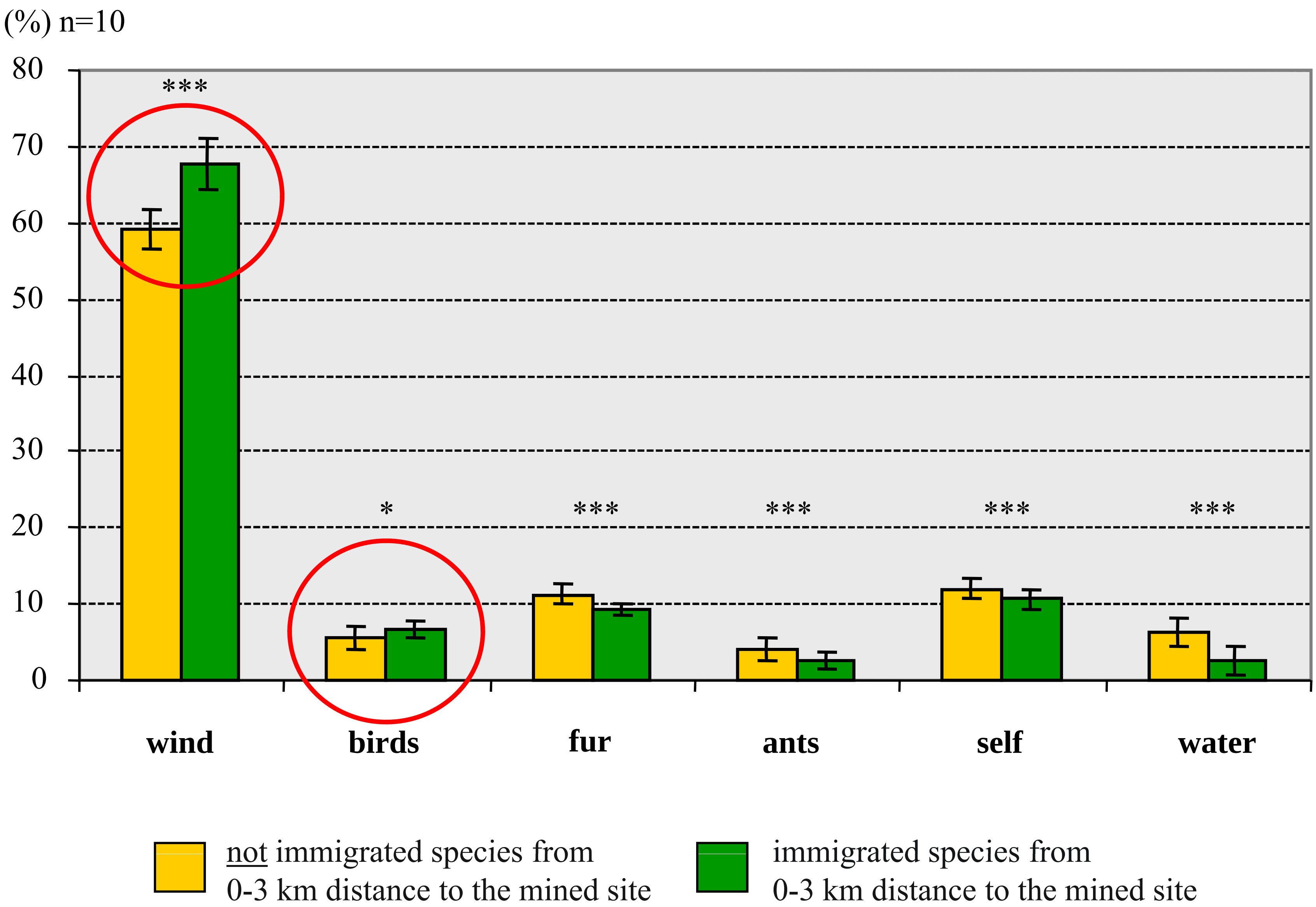


Kirmer, A., Tischew, S., Ozinga, W.A., von Lampe, M., Baasch, A., van Groenendael, J.M. (2008) Importance of regional species pools and functional traits in colonisation processes: predicting re-colonisation after large-scale destruction of ecosystems. Journal of Applied Ecology 45: 1523-1530.

Question 3:

Which dispersal strategies are most successful for immigration of plant species into the mined sites?

Successful dispersal strategy types for immigration into mined sites



Differences in species traits important for LDD

	All species		Only non-Red List		Only Red List	
	Immigrant	Non-immigrant	Immigrant	Non-immigrant	Immigrant	Non-immigrant
seed weight [mg]	**2.09**	2.76	**2.12**	2.88	**0.82**	1.11
n	1828	1411	1787	1315	41	96
± SE	*0.11*	*0.17*	*0.11*	*0.18*	*0.16*	*0.12*
P (U-test)	***		***			
terminal velocity [m/s]	**1.99**	2.39	**2.01**	2.42	**1.36**	1.94
n	1656	1078	1610	1007	46	71
± SE	*0.03*	*0.04*	*0.03*	*0.04*	*0.22*	*0.16*
P (T-test)	***		***		*	

SE = standard error; P = level of significance between immigrant vs. non-immigrant species.

Differences in seed weight and terminal velocity between immigrated and non-immigrated species (without phanerophytes and nanophanerophytes) of the regional species pools in the surroundings of 0-3 km of the mined sites were tested using either T-test (Levene test >0.05) or U-test (Levene test ≤ 0.05) depending on the normal distribution of the data. Significance levels were indicated in the following way: [*] 0.05≥P>0.01; [**] 0.01≥P>0.001; [***] P≤0.001. The number of cases in the analysis depended on the availability of data for seed weight and terminal velocity as well as the occurrence of species in the respective regional species pools.

Question 4:

Which traits/parameters proved to be significant for the occurrence of plant species in the actual species pools of the mined sites?

Method: Binary logistic regression with forward selection. Criterion for inclusion of variables in the forward selection was a probability of 0.05.

Variables for Binary Logistic Regression Analysis




ASP	actual species pool (dependent variable)
HSP	habitat species pool
RSP 0_17	regional species pool
distance	nearest distance to the respective mined site, ranging from class 1 (c. 0-3 km) to class 10 (c. 59-66 km)
north_south	affiliation to the northern or southern mining region
light availability	Ellenberg indicator for light availability
moisture	Ellenberg indicator for moisture
nitrogen availability	Ellenberg indicator for nitrogen availability
seed weight class	ranging from 1 (light) to 8 (heavy), dependent on the seed weight
seed longevity	persistence in the soil seed bank (classified with the seed longevity index ranging from 0 = low to 1 = high)
terminal velocity	terminal velocity of seeds [m/s]
dispersal potential wind	capacity for long distance dispersal by wind (0=low, 1=high)
dispersal potential water	capacity for long distance dispersal by water (0=low, 1=high)
dispersal potential fur	capacity for long distance dispersal by fur of animals (0=low, 1=high)
dispersal potential dung	capacity for long distance dispersal by dung of mammals (0=low, 1=high)
dispersal potential birds	capacity for long distance dispersal by bird droppings (0=low, 1=high)

Binary Logistic Regression Analysis

Variable	Regression coefficient	Wald	d.f.	P	Nagelkerke R^2
regional species pool 0-17 km	0.090	62.486	1	≤0.0005	0.235
terminal velocity	-0.224	29.268	1	≤0.0005	0.276
light availability	0.166	28.106	1	≤0.0005	0.284
habitat species pool	0.014	31.660	1	≤0.0005	0.289
dispersal potential wind	-0.614	20.667	1	≤0.0005	0.295
nitrogen availability	-0.082	16.342	1	≤0.0005	0.299
distance	-0.267	8.426	1	0.0037	0.302
dispersal potential birds	-0.514	4.323	1	0.0376	**0.303**
constant	-1.667	16.752	1	≤0.0005	

The regression coefficient indicates a positive or negative effect of the independent variable.

Wald statistic = measure of the relative effect size of the variable in the full model.

Nagelkerke R^2 = cumulative proportion of explained variance after entrance of the variable in the model.

Question 5:

How successful are Red List plant species in colonising the mined sites?

Saxony-Anhalt:	717 Red List Plant Species
Mined areas:	100 (= 14 %)




Successful establishing events of Red List Plant Species in mined sites

	Number of mined sites with successfully established Red List Species									
	1	2	3	4	5	6	7	8	9	10
Next occurrence										
<3 km	18	5	9	6	10		3			8
3-10 km	20	8	5	11	4		8			**2**
10-17 km	9	2	1	**3**	**1**		**3**			
>17 km	**1**	**3**	**3**							
Total number of Red List Species	48	9	6	5	3	0	2	0	0	1

1: e.g.
Achillea nobilis
Anagallis foemina
Botrychium matricariifolium
Campanula glomerata
Carex viridula
Carum carvi
Centaurium pulchellum
Chimaphila umbellata
Dactylorhiza maculata
Digitaria ischaemum
Diplotaxis muralis
Eleocharis acicularis
Epipactis palustris
Torilis arvensis

2:
Dactylorhiza fuchsii
Gymnadenia conopsea
Hieracium zizianum
Potamogeton berchtoldii
Pulicaria dysenterica
Rhinanthus minor
Salix repens
Trifolium aureum
Utricularia vulgaris agg.

3:
Cornus mas
Erucastrum nasturtiifolium
Dactylorhiza maculata
Platanthera chlorantha
Scleranthus polycarpos
Verbena officinalis

4:
Centaurea diffusa
Centaurium pulchellum
Hieracium bauhini
Ophrys apifera
Sanguisorba officinalis

5:
Dactylorhiza incarnata agg.
Epipactis palustris
Ophioglossum vulgatum

7:
Botrychium lunaria
Filago arvensis

10:
Hieracium piloselloides

Traveller over far distances ...

Erucastrum nasturtiifolium
next occurrence >17km
Red List Saxony-Anhalt 0

Ophrys apifera
next occurrence 3-10 km
Red List Saxony-Anhalt 3

Achillea nobilis
next occurrence 10-17 km
Red List Saxony-Anhalt 3

Botrychium matricariifolium
next occurrence >17 km
Red List Saxony-Anhalt 0

Pulicaria dysenterica
next occurrence 3-10 km
Red List Saxony-Anhalt 3

Dactylorhiza maculata
next occurrence 3-10 km
Red List Saxony-Anhalt 3

Thymelaea passerina
next occurrence (before 1949) 10-17 km
Red List Saxony-Anhalt 0

Chimaphila umbellata
next occurrence 3-10 km
Red List Saxony-Anhalt 1

Question 6:

Is it possible to detect long-distance dispersal events via seed traps?

Results from seed trap experiments

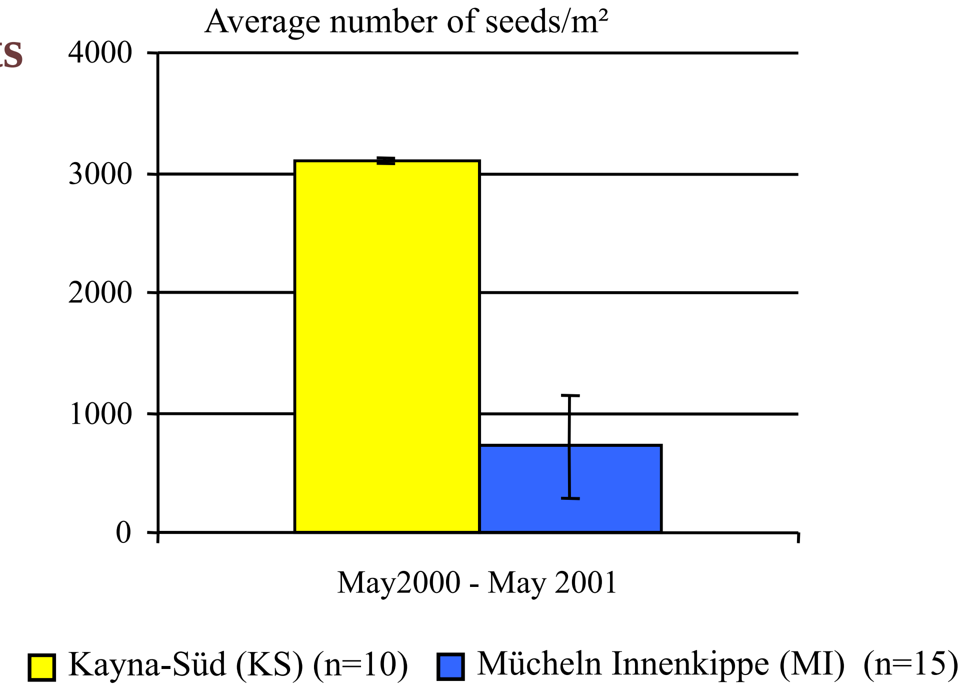
- 2 mined sites (Kayna-Süd, Mücheln Innenkippe)
- each with three 5m x 5m plots on lignite-rich raw soil with very low vegetation cover
- each plot with five seed traps (plastic funnels; Fischer 1987) with 24.1 cm diameter
- each funnel with a catching area of 456 cm^2
- samples were taken between May 2000 and May 2001 in regular intervals
- in Kayna-Süd, one plot had been destroyed

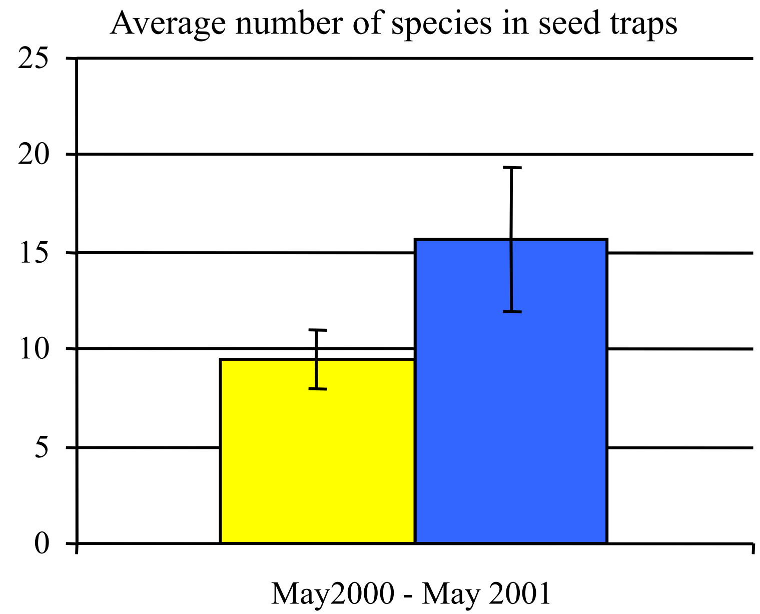
Seed traps in Kayna-Süd, photo: Sandra Mann 2000

Results from seed trap experiments

- all species found in the seed traps occur very frequently in the mined sites and in the vicinity of the traps
- total number of species: Kayna-Süd 13, Mücheln 30
- only 2 species were found in 100-300 m distance to the seed traps; all other species are present within 100 m distance to the seed traps (consistent with other seed trap experiments in mined sites: Tischew, unpubl. data, Kirmer 2004)

⇨ seed traps seem to be not suitable to detect long-distance dispersal events





Long-distance dispersal in cultural landscapes – evidence from lignite mines (1)

Large-distance dispersal events are assumed to be very rare to observe

Mining areas act as ”large seed traps” in the landscape and accumulate species during several decades

It is difficult to proof successful colonisation resulting from long-distance dispersal

Seed traps are not suitable because of the small catching area. Colonisation of areas starting with primary succession can be used as an indirect proof for LDD if data of the surrounding area are available (e.g. *del Moral et al. 2005, Kirmer et al. 2008*).

Colonisation in small-scale restoration trials is often limited (e.g. Verhagen et al. 2001, Bischoff 2002)

Mining areas have a very large extension with many niches for establishment. The high amount of species immigrating only once or twice into the study sites indicates that LDD events are not regular and both small-scale restoration sites and short time frames will impede successful colonisation.

Wind is an efficient vector for LDD especially in weather conditions characterised by thermal turbulence and updrafts (e.g. *Tackenberg et al. 2003, Nathan et al. 2005*)

Mining areas are often located in structure-poor industrial landscapes with a high wind permeability. But also non-standard means of dispersal (e.g. *Higgins et al. 2003*) are often responsible for LDD events: wind-dispersed seeds may sometimes be dispersed by birds.

- Abundance in the regional species pool is more important than the actual distance of the next seed source

  It seems that a higher seed pressure is more effective than occurrence in the vicinity of the mined site

Long-distance dispersal in cultural landscapes – evidence from lignite mines (2)

Effective dispersal strategy types (e.g. wind, birds) with functional traits related to LDD (e.g. low terminal velocity) improve the chance for immigration
Rare species with a generally low abundance in the surrounding areas can nevertheless accumulate in the mined sites because they have small seeds and a low terminal velocity and can therefore bridge relatively large distances (e.g. *Ash et al. 1994*: up to 40 km).

- Site conditions typical for pioneer sites (high light availability, low nutrient content) enhance the chance of establishment
In times of increasing nutrient availability (*Pearson & Dawson 2005*), plant nutrient requirements can outrank LDD (*Soons & Ozinga 2005*). Especially species, adapted to open, nutrient-deficient habitats will profit from mining site conditions. In the mined sites, the amount of nutrient-demanding species is very low. .

- After large-scale open-cast mining, colonisation via spontaneous succession is leading to valuable biotope mosaics with habitats for many rare and endangered plant species
In the federal state Saxony-Anhalt, 36 % of all higher plants are growing in former and active mining sites (Saxony-Anhalt: 20443 km², mining areas: 150 km² = 0.7 %)

Implications for restoration practice

Creation of favourable conditions for spontaneous succession in active mining sites

- Selection of large-scale areas (at least 400 ha, optimal 2000 ha) (→ low disturbance, low nutrient input from the surroundings)
- Influence on the final dumping of substrate and on relief shaping in the final phase of mining activities (high heterogeneity of substrate)
- Intentional preservation or creation of varied structures, such as e.g. hollows, tips, areas with shallow water, variously shaped shores and slopes (high heterogeneity of geomorphological structures)
- Permission for dynamic processes under consideration of slope stability (high dynamic)

⇨ **high niche availability**

Implications for restoration practice

- In German mining plans usually 10-15 % of the area should be designated as priority areas for “Nature and Landscape”

- Traditional restoration strategies should be limited for the benefit of spontaneous succession

- The colonisation of mining sites by plants is influenced by the species pool of a relatively wide margin (up to 20 km)

- **Especially in structure-poor, intensively used landscapes, mining sites should consist of large, nutrient-poor areas that were decisive for the gradually accumulation of suitable plant species**

BUT:

Our results should not facilitate decisions to open new mining sites in areas with valuable habitats difficult to restore

only in industrial landscapes mining of mineral resources (e.g. lime, sand, lignite) in combination with appropriate ecological restoration (preservation of large, nutrient-poor sites with heterogeneous site conditions without recultivation measures) will lead in the end to the spontaneous development of biotope mosaics that offer habitats for many threatened plant and animal species.

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Thank You for Your attention!