EU-LIFE project "Restoration of Dune Habitats along the Danish West Coast": LIFE02NAT/DK/8584

Report concerning the intensive monitoring of dune heaths 2002 to 2005 (Action F2).

Ib Johnsen[1], Torben Riis-Nielsen, Steen N. Christensen & Mogens Ring Petersen

[1] Corresponding author: Ib Johnsen professor, PhD, Biological Institute, University of Copenhagen

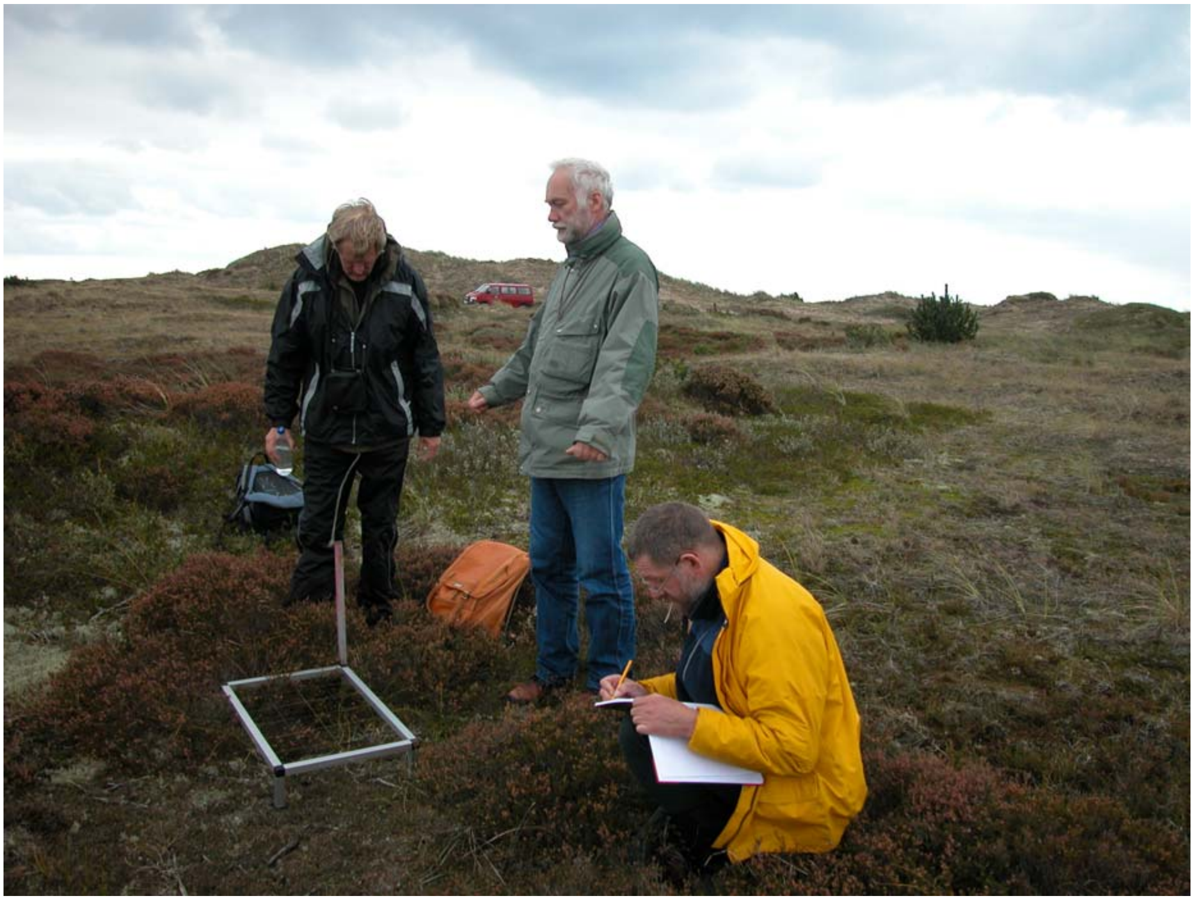


Figure 1. From Hulsig Heath, November 2005. PhD Torben Riis-Nielsen, MSc Steen N. Christensen and MSc Mogens Ring Petersen during field work.

With this picture I wish to acknowledge the hard work done by my co-workers in high spirit during the field analyses and the subsequent data treatment.

Table of contents.

Introduction.

This report is one of the outcomes of the EU-LIFE project "Restoration of Dune Habitats along the Danish West Coast": LIFE02NAT/DK/8584.
During this part of the joined project the aim was to produce results to identify and qualify the best possible way to restore and maintain the Atlantic coastal dune heath, based on experiences obtained from various parts of the large Danish share of this high priority ecosystem in Europe. The study has generated a large number of results, of which some have yet to be analysed.
The study includes analyses of the vegetation of dune ecosystems before and shortly (up to three years) after management, including different ways of removal of self-sown mountain pine (*Pinus mugo*) and lodgepole pine (*P. contorta*) as well as use of e.g. extensive grazing as a heath restoration and long-term maintenance method.
The vegetation analyses took partly place outside but adjacent to the managed dune heath areas to describe the original minimally disturbed ecosystem (close to the expected outcome of the management effort), partly within the managed areas before and after the restoration treatment by the regional County or State Forest District under the Danish Forest and Nature Agency.
The recorded starting point (reference) before treatment and the character of the early succession after treatment were used to predict the probable outcome of the management effort and to suggest measures to maintain the Atlantic coastal heath to fulfil the criteria for acceptable favourable conservation status according to the Habitat Directive.
The Atlantic coastal heath in Denmark is a very complex ecosystem, being a mosaic of patches with different dominants and characteristic species, subject to the variation mainly with respect to hydrology and soil properties. The pre-quaternary formations vary strongly within the country, thus causing high variation in mineral composition of the subsoil. Normally, however, the coastal heath subsoil is overlain by aeolic sand, depleted of most of its mineral content.

The monitoring field work.

The SCI sites visited during the F2 action is shown in Table 1.

NATURA 2002 designation	SCI no.	Geographic Name
DK00FX005	2	South of Råbjerg Mile
DK00FX118	10	Højsande, Læsø
DK00FX121	13	Svinkløv
DK00EY124	16	Bulbjerg
DK00AX172	72	Lyngbos Hede; Kærgård Plantage
DK00AX173	73	Kallesmærsk Hede; Grærup Hede
DK00AY176	78	Wadden Sea, Fanø
DK00AY176	78	Wadden Sea, Rømø
DK00EX265	184	Klitheder mellem Stenbjerg og Lodbjerg
DK00EX266	185	Lild Strand
DK00FX274	193	Ejstrup klit og Egvands Bakker

Table 1. The sites analysed during the intensive monitoring project part (F2).

SCI site no. 2, Råbjerg Mile and surroundings.

This site has a high representation of undisturbed dune heath on acid sandy soil, representing the reference condition on the Skaw Spit (Skagens Odde) coast.

Figure 2 show an example of the vegetation without adverse impact of invading conifers. The heterogeneity of the mosaic grey dune heath is evident, as the vegetation described in Figure 2 is composed of frequent species occurring mainly on the heath plains together with dune species characteristic of north facing slopes like *Peltigera hymenina*, *Polypodium vulgare* and *Pleurozium schreberi* and species characteristic of south facing slopes like *Corynephorus canescens*, *Cetraria aculeata* and *Cladonia foliacea*.

The small differences in climatic conditions influence the distribution pattern of the species, and the climate characteristic of north facing slopes with higher relative humidity and reduced light exposure is somewhat similar to the climate in an open stand of *Pinus mugo*. Indeed, the dominant species found in such open conifer stands typically e.g. include pleurocarpous bryophytes like *Pleurozium schreberi*.

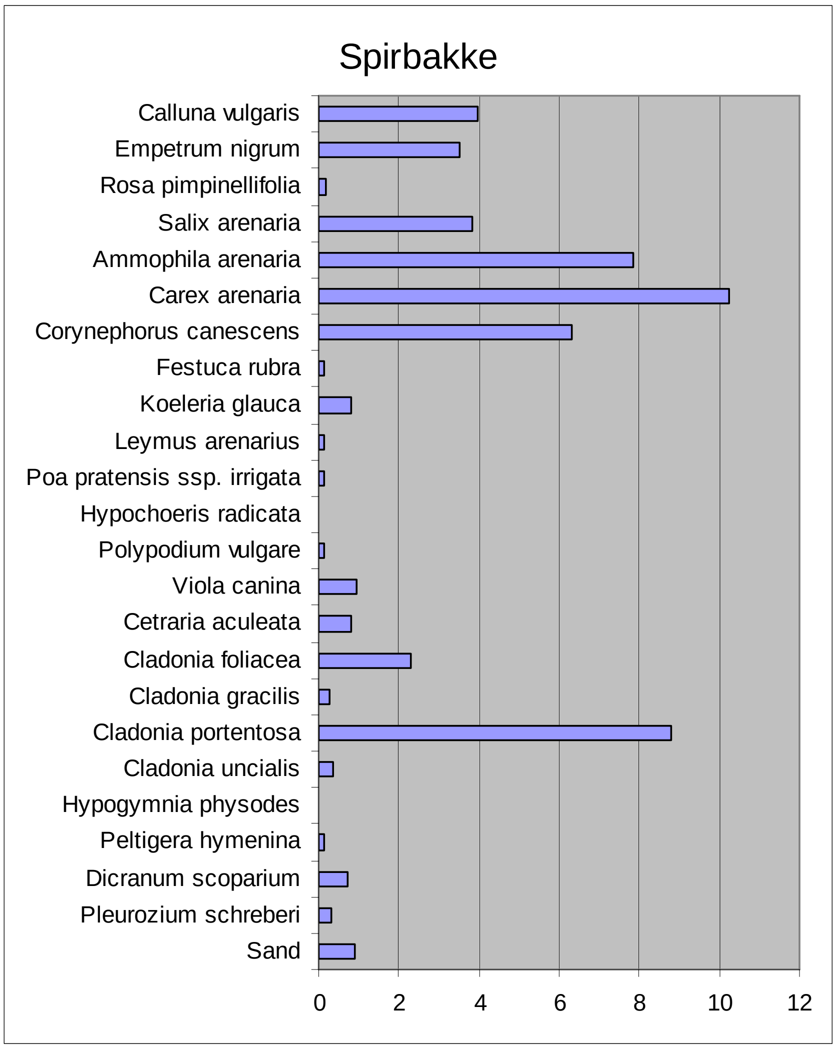


Figure 2. Typical species composition and relative cover (Pin Point frequency) of undisturbed grey dune vegetation acid sand. Only high frequency species are shown.

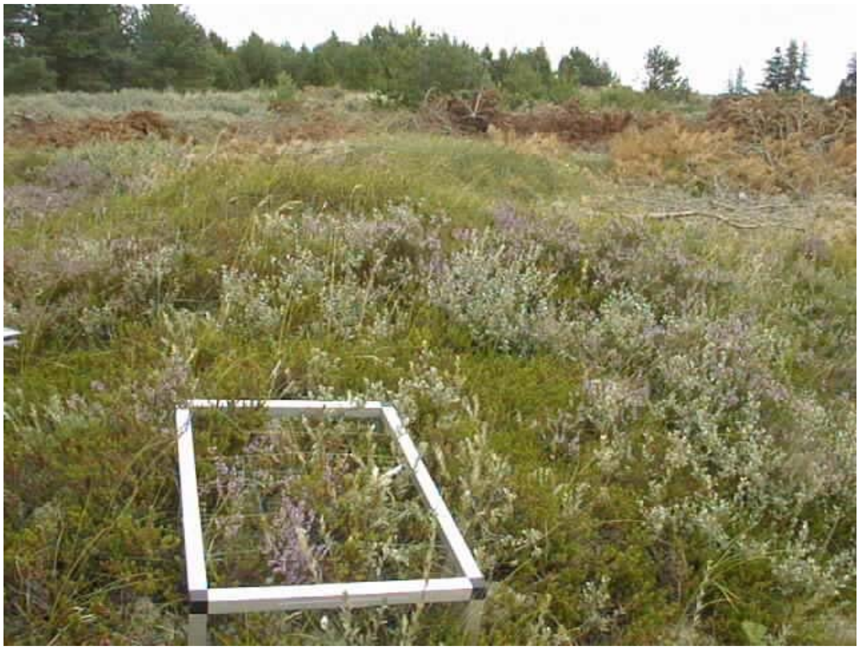
SCI 2 sites around Lodskovvad Mile.

GPS coordinates (WSG84)	Deg	Min	Sec	
Felt 1	57	37	44	North
	10	24	0	East
GPS coordinates (WSG84)	Deg	Min	Sec	
Felt 2	57	37	41	North
	10	23	59	East

Map showing the two plots: Felt 1 and Felt 2, Lodskovvad

Description of the area, where the plots were established:

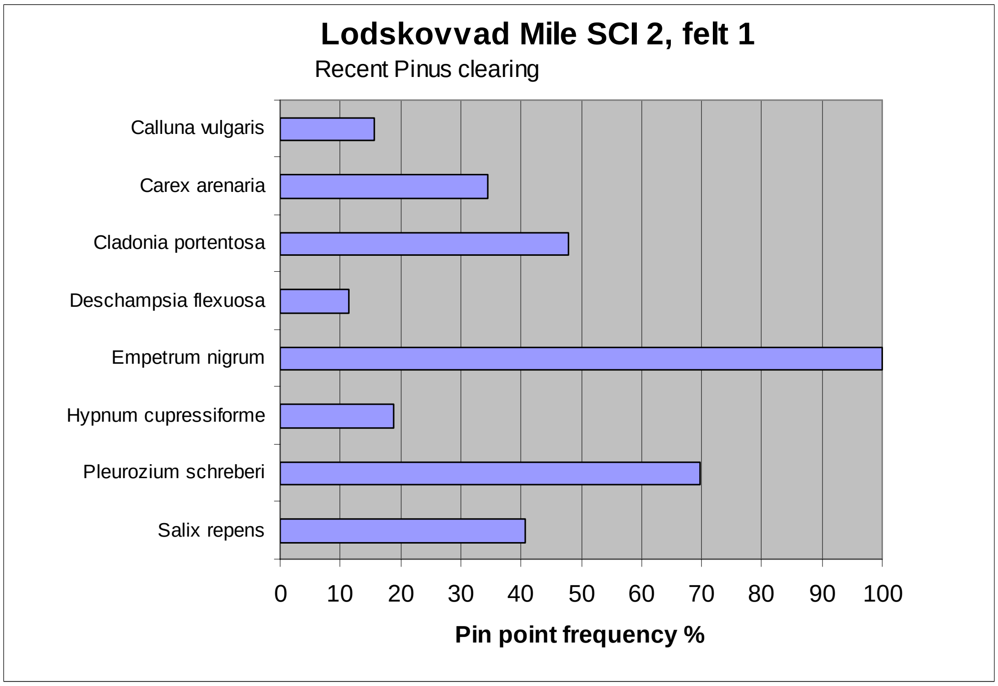
The heath area is under invasion of various conifer species, mainly Pinus mugo, Pinus contorta and Picea sitchensis. It is by 2003 still rather open, but in the most close tree vegetation, a marked change has taken place in vegetation structure and composition. The dwarf shrub most dominant in these areas is Empetrum nigrum, with Carex arenaria as subdominant. This reflect the fact, that Empetrum nigrum is the most sensitive dwarf shrub to physical impact, has a low compensation point and benefits most rapidly from nutrient supply (e.g. supplied from the tree canopies by leaching).



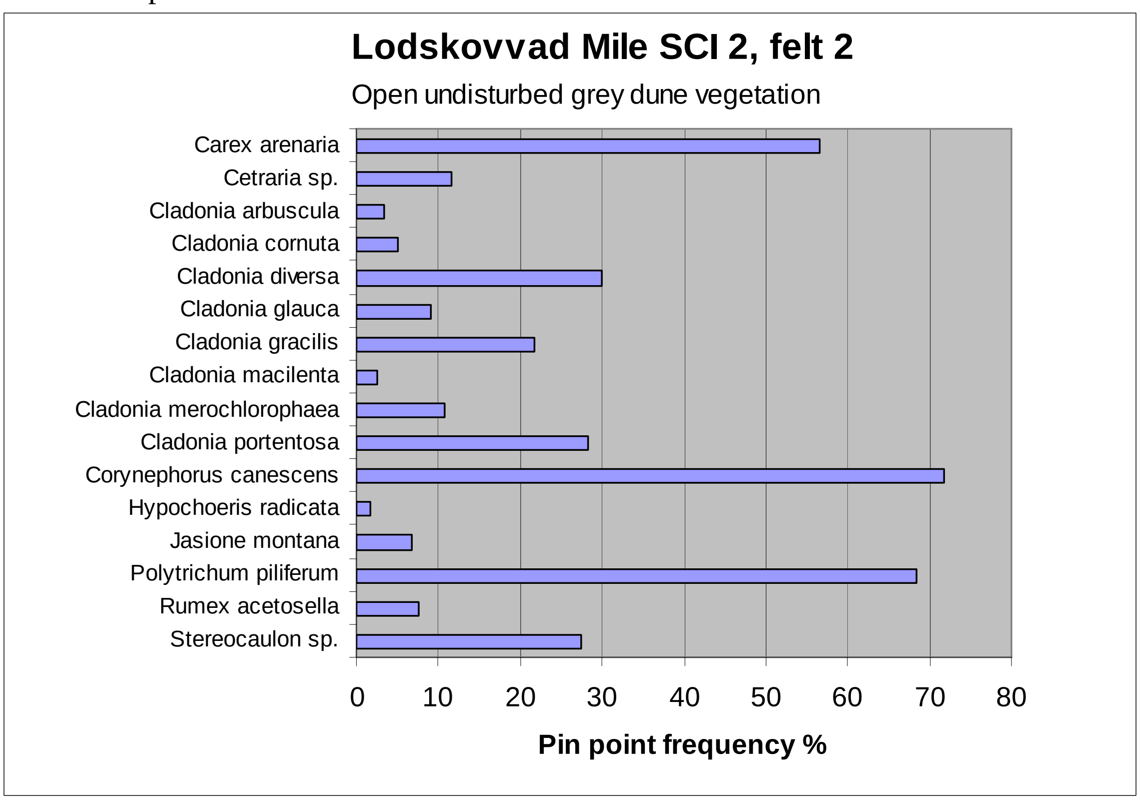
Permanent plot (felt 1) in recently cleared area, Lodskovvad.

Permanent plot (felt 2) in recently cleared area, Lodskovvad.

Vegetation analyses from 2003:



The figure shows a species poor community with only 5 phanerogams, 2 bryophytes and one lichen species.



In this plot are 6 phanerogams (including Ammophila arenaria), 10 lichen species and 1 bryophyte.

SCI 10. Højsande, Læsø

At the island of Læsø, recordings of the flora of the grey dunes adjacent to and within the managed areas were made.

The area Højsande includes large areas with high ground water table and covered with Betula spp. (B. verrucosa and B. pubescens) forest. The removal of Pinus spp. from Højsande do not prevent the re-growth of the deciduous forest in the low lying areas, but may delay or even prevent establishment of forests at the dunes themselves. It is particularly important to monitor the vegetation development in the cleared areas in the years ahead, to answer the two questions: 1) Is the open condition stable, or does the Betula spp. forest invade the dunes? 2) Do the red-listed and rare species from the neighbouring grey dune reenter the cleared dunes?

The vegetation of the dune heaths at Læsø is extremely valuable, and reestablishment of the open dune heath at Læsø is of particular high importance from a botanical point of view. The following table with comments qualify this statement.

Genus	**Species**	**Comment**
Acarospora	fuscata	Epilithic lichen
Aira	praecox	Phanerogam
Alectoria	**sarmentosa var. vexillifera**	**Red-listed, ice age relict. Epigeic lichen**
Ammophila	arenaria	Phanerogam
Calluna	vulgaris	Phanerogam
Campylopus	introflexus	Bryophyte
Cephaloziella	divaricata	Hepatic
Ceratodon	purpureus	Bryophyte
Cetraria	aculeata	Epigeic lichen
Cetraria	chlorophylla	Epigeic lichen
Cetraria	**ericetorum**	**Rare. Epigeic lichen**
Cetraria	islandica	Epigeic lichen
Cetraria	muricata	Epigeic lichen
Cladonia	ciliata	Epigeic lichen
Cladonia	diversa	Epigeic lichen
Cladonia	floerkeana	Epigeic lichen
Cladonia	glauca	Epigeic lichen
Cladonia	gracilis	Epigeic lichen
Cladonia	merochlorophaea	Epigeic lichen
Cladonia	phyllophora	Epigeic lichen
Cladonia	pleurota	Epigeic lichen
Cladonia	portentosa	Epigeic lichen
Cladonia	pyxidata	Epigeic lichen
Cladonia	rangiferina	Epigeic lichen
Cladonia	scabriuscula	Epigeic lichen
Cladonia	**stellaris**	**Red-listed, ice age relict. Epigeic lichen**

Cladonia	uncialis	Epigeic lichen
Cladonia	zopfii	Epigeic lichen
Cladonia	anomaea	Epigeic lichen
Cladonia	arbuscula	Epigeic lichen
Cladonia	foliacea	Epigeic lichen
Corynephorus	canescens	Phanerogam
Deschampsia	flexuosa	Phanerogam
Dicranum	scoparium	Bryophyte
Dicranum	polysetum	Bryophyte
Drepanocladus	uncinatus	Bryophyte
Empetrum	nigrum	Phanerogam
Erica	tetralix	Phanerogam
Erophila	verna	Phanerogam
Festuca	rubra var. arenaria	Phanerogam
Hieracium	umbellatum	Phanerogam
Hylocomium	splendens	Bryophyte
Hypnum	cupressiforme	Bryophyte
Hypochoeris	radicata	Phanerogam
Hypogymnia	physodes	Epigeic and epiphytic lichen
Jasione	montana	Phanerogam
Klebsormidium	sp.	Green alga
Placynthiella	uliginosa	Epigeic lichen
Lotus	corniculatus	Phanerogam
Luzula	campestris	Phanerogam
Ochrolechia	**frigida**	**Red-listed, ice age relict. Epigeic lichen**
Parmelia	mougeotii	Epilithic lichen
Parmelia	saxatilis	Epilithic lichen
Platismatia	glauca	Epigeic lichen
Pleurozium	schreberi	Bryophyte
Polypodium	vulgare	Fern
Polytrichum	juniperinum	Bryophyte
Polytrichum	piliferum	Bryophyte
Pseudevernia	furfuracea	Epigeic lichen
Ptilidium	ciliare	Hepatic
Racomitrium	ericoides	Bryophyte
Rhizocarpon	geographicum	Epilithic lichen
Rhizocarpon	obscuratum	Epilithic lichen
Rhizocarpon	richardii	Epilithic lichen
Rhizocarpon	lecanorinum	Epilithic lichen
Rhytidiadelphus	squarrosus	Bryophyte
Rhytidiadelphus	triquetrus	Bryophyte
Salix	repens	Phanerogam
Stereocaulon	condensatum	Epigeic lichen
Stereocaulon	saxatile	Epigeic lichen
Teesdalia	nudicaulis	Phanerogam

Trapeliopsis	granulosa	Epigeic lichen
Viola	canina	Phanerogam

SCI 13. Svinkløv and Kollerup Klit.

SCI 13 sites at Svinkløv.

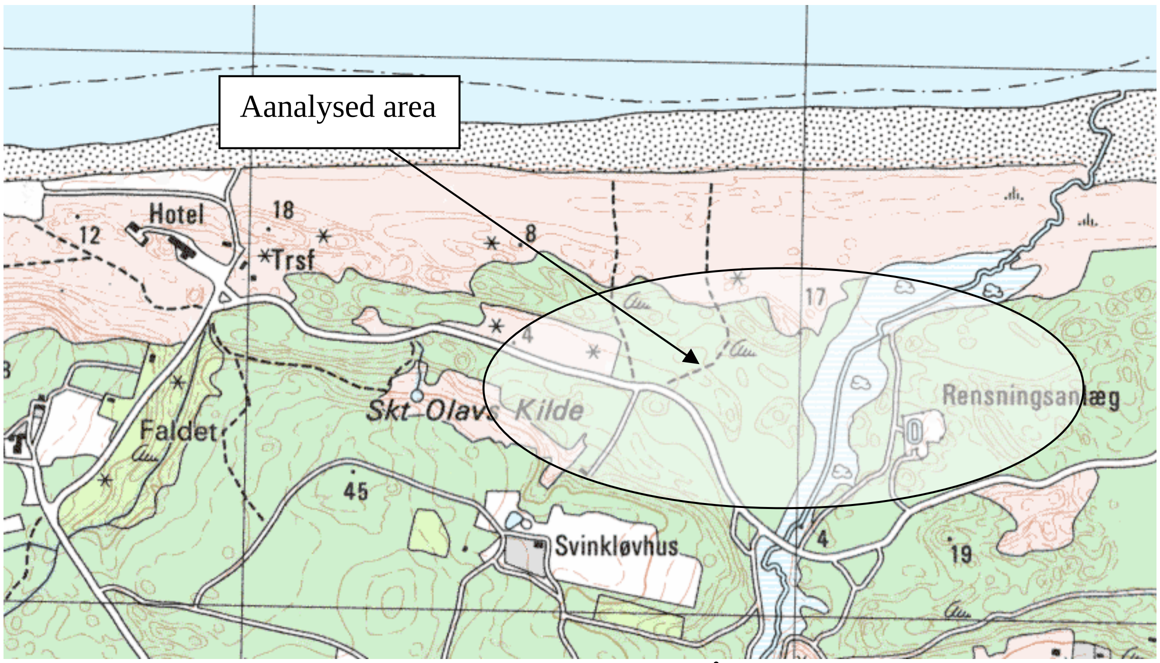


Figure 3. The analysed area at Svinkløv, near mouth of Slette Å.

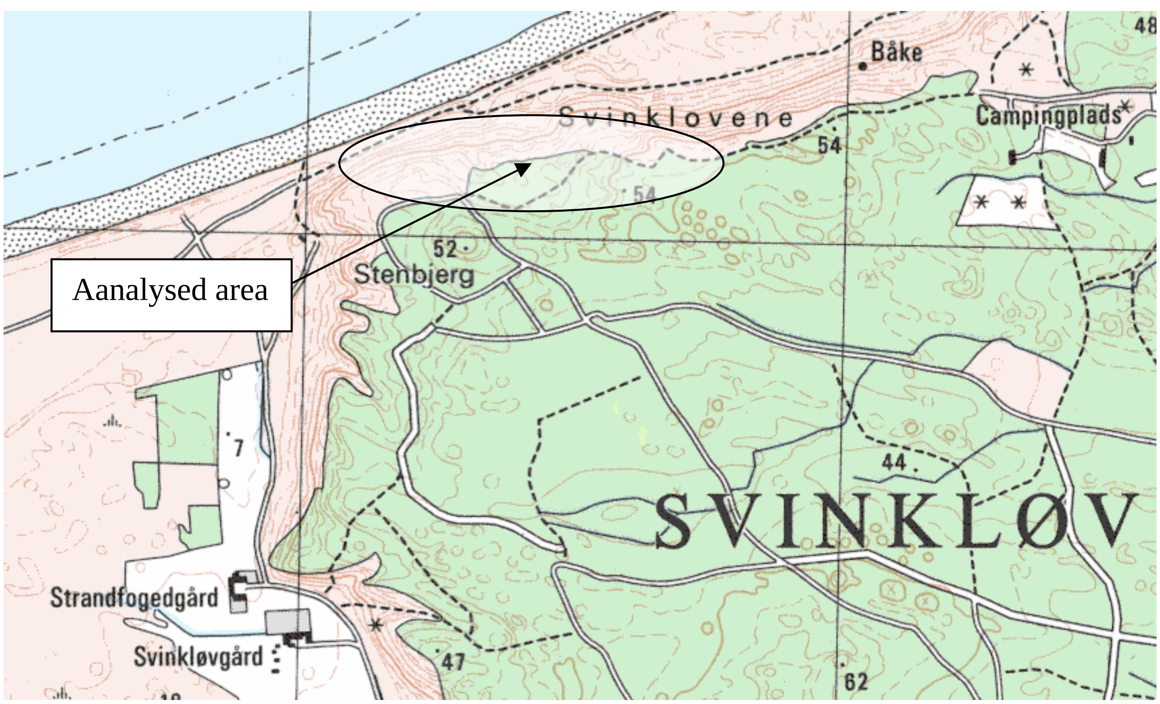


Figure 4. The analysed area close to Svinklovene and Grønnestrand

The area is dominated by dwarf shrub heath and dry grassland with juniper, reflecting former grazing land-use. The proximity of cretaceous deposits and the resulting mineral supply from below is reflected in the frequent occurrence of e.g. *Cladonia furcata* and *Cladonia rangiformis*.
The investigated area includes heath around the mouth of Slette Å, Svinklovene (western end of plantation) and just east of Grønne Strand (highest point: Stenbjerg)

Geographic position	Comments	Time of clearing of conifers	Permanent plot established	Dominant epigeic species
Position: 57^o 09'01 N; 9^o 20'54 E	Recently cleared; no records due to strong disturbance	Jan/Feb 03	No	
57^o 09'00 N; 9^o 20'53 E	Not yet cleared		Yes, 6th March 2003	Empetrum nigrum and Pleurozium schreberi
57^o 09'04 N; 9^o 20'57 E	Recently cleared; No records due to strong disturbance	Jan/Feb 03	No	
57^o 08'55 N; 9^o 18'03 E	No records due to strong disturbance	Jan/Feb 03	No	Litorina-slope cleared for *Picea sitchensis* and *Pinus mugo*. Plantation of *P. sitchensis* extends to top of slope. Exposed soil rich in chalk occur due to wind and water erosion
57^o 07'36 N; 9^o 18'04 E	Open area with dune heath and no invasion of conifers		No	High biodiversity due to complexity of topography and soil properties

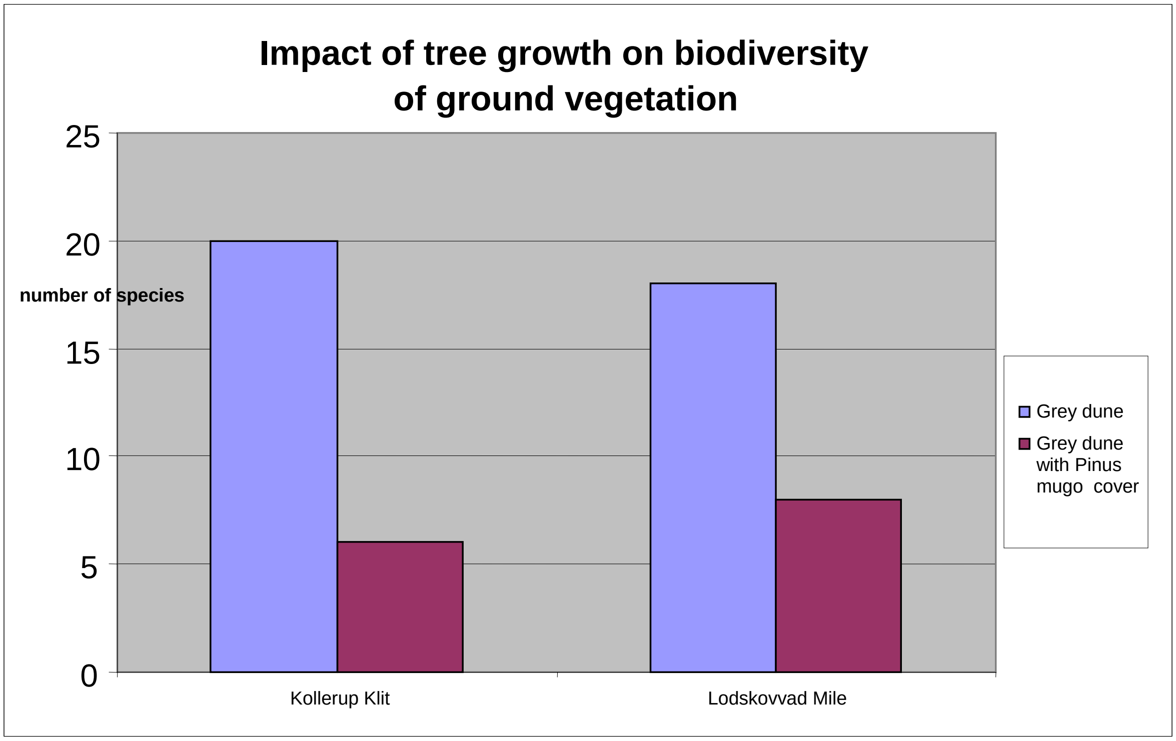


Figure 5. The reduction in the epigeic vegetation biodiversity of plants, lichens and bryophytes with invasion of Pinus mugo in grey dune heaths.

In figure 5 is shown the major impact on biodiversity due to invasion of *Pinus mugo* to dune heaths. Even if the greuy dune does not belong to the systems with highest biodiversity, the number of species of plants, bryophytes and lichens together is reduced by 60 to 75 %. Furthermore, the species lost by the invasion generally are species adapted to the conditions characteristic of grey dune heath, and therefore often uncommon and threatened.

SCI 13 sites at Kollerup.

GPS coordinates (WSG84)	Deg	Min	Sec	
Felt 1	57	7	55	North
	9	17	42	East
GPS coordinates (WSG84)	Deg	Min	Sec	
Felt 2	57	7	53	North
	9	17	40	East

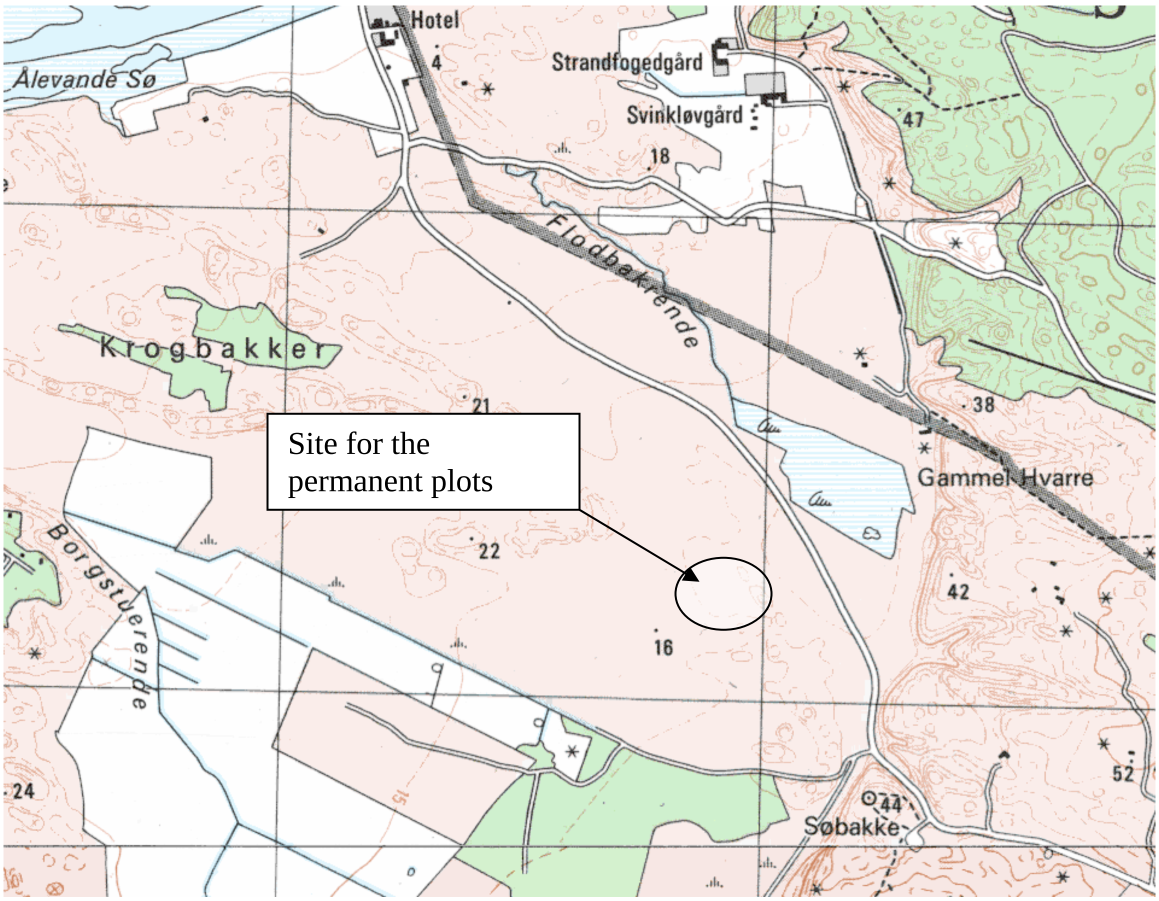


Figure 6. Map showing the two plots: Plot 1 and plot 2, Kollerup

Description of the area, where the plots were established:

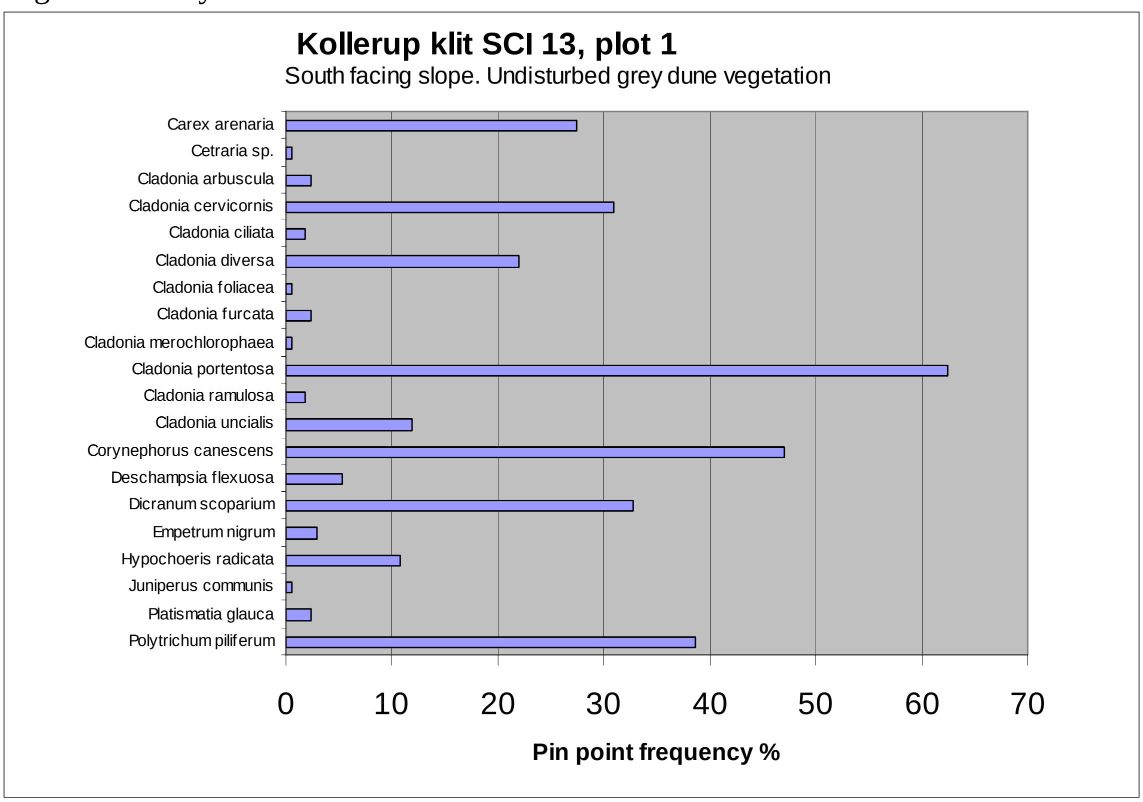
The heath area is very open, and management has taken place over at least two periods. At some places, the conifers have been left at the site with all their needles, causing addition of minerals to the heath. This is probably reflected in the strong spot wise dominance of *Deschampsia flexuosa* at some places throughout the area at Kollerup.


View of the area at Kollerup, seen from S to N.


Permanent plot (felt 1) in cleared area, Kollerup


Permanent plot (felt 2) in grey dune, Kollerup

Vegetation analyses from 2003:



In this plot are 7 phanerogams (including Calluna vulgaris), 12 lichen species and 2 bryophytes.

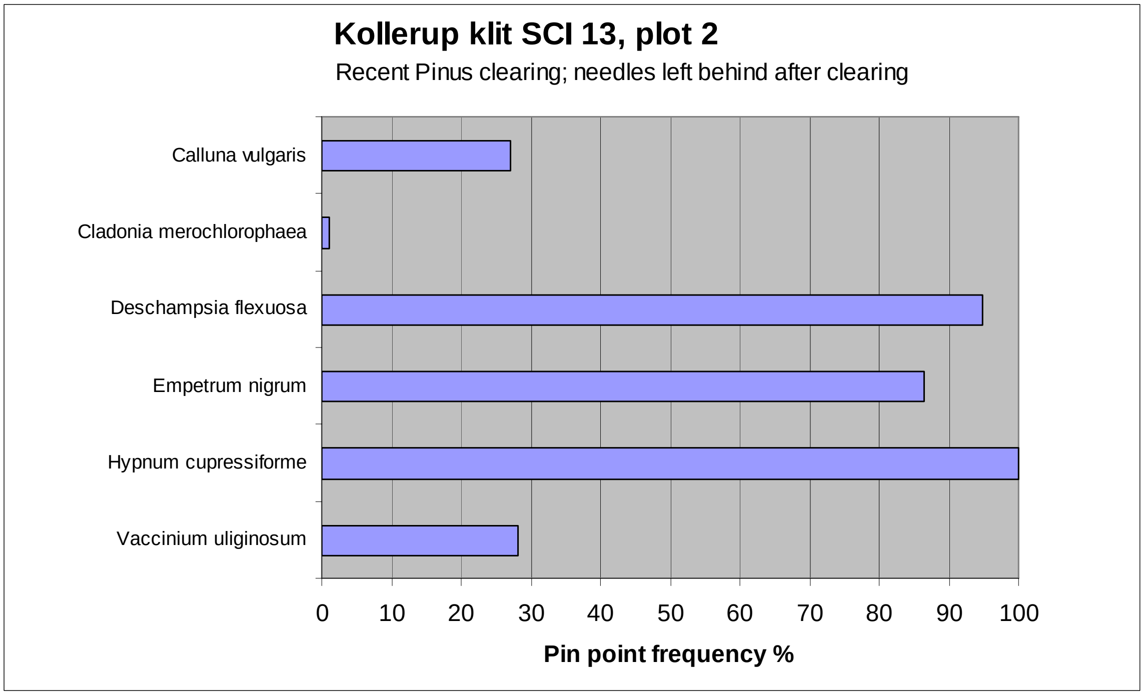


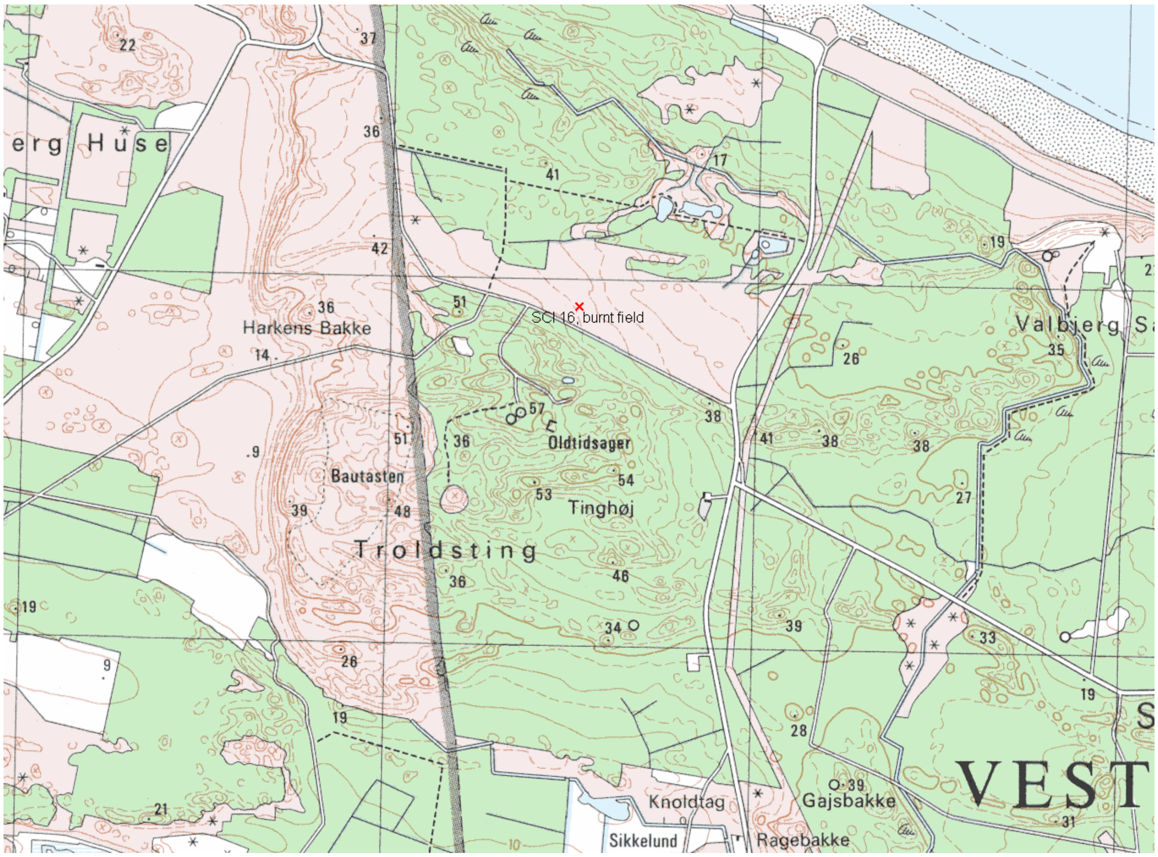
Figure 7. Vegetation following conifer cutting and leaving all biomass at site

Figure 7 shows a species poor community with only 4 phanerogams, 1 bryophyte and 1 lichen species.
The reason why only few species occur is firstly, that the clearing here was recent (two years back) and secondly that the needles were left behind. *Hypnum cupressiforme* is a dominant bryophyte, also present under *Pinus mugo* cover, while the strong dominance of *Deschampsia flexuosa* reflects the release of minerals and nutrients from needle decomposition.

SCI 16. Bulbjerg.

Locality at:

	degrees	minutes	seconds	
GPS coordinates (wgs84):	57	8	48	North
	9	2	24	East



List of Species (June 2003): 72 species of plants, lichens and bryophytes.

Agrostis canina
Ammophila arenaria
Briza media
Calamagrostis epigeios
Calluna vulgaris
Carex nigra
Carex panicea
Carex pilulifera
Cetraria sp. (Coelocaulon)
Cirsium helenioides
Cirsium paustre
Cladonia ciliata
Cladonia glauca
Cladonia portentosa
Cladonia uncialis
Crepis sp.
Juncus articulatus
Juncus balticus
Juncus bulbosus
Juncus conglomeratus
Knautia arvensis
Luzula congesta
Molinia coerulea
Nardus stricta
Oxycoccus palustris
Picea sitchensis
Phragmites communis
Picea sitchensis (seedlings)
Pinus contorta (seedlings)
Pinus mugo (seedlings)
Platismatia glauca
Pleurozium schreberi

Dactylorhiza incarnata	Polytrichum commune
Dactylorhiza maculata	Polytrichum piliferum
Dactylorhiza maculata	Populus tremula
Deschampsia caespitosa	Potentilla erecta
Deschampsia flexuosa	Pseudevernia furfuracea
Dicranum scoparium	Pyrola minor
Empetrum nigrum	Pyrola rotundifolia ssp. rotundifolia
Erica tetralix	Ranunculus flammula
Eriophorum angustifolium	Rhytidiadelphus triquetrus
Eriophorum vaginatum	Rosa pimpinellifolia
Genista anglica	Salix aurita
Geranium sanguineum	Salix cinerea
Hylocomium splendens	Salix repens
Hypnum cupressiforme	Scirpus caespitosus
Hypochoeris radicata	Scleropodium purum
Hypogymnia physodes	Succisa pratensis
	Vaccinium uliginosum

The analyzed area did not show any signs of burning, as the cleared material had been collected in piles and burnt on separate spots. There is, however, a substantial germination of conifers.

SCI 72. Lyngbos Hede and Kærgaard.

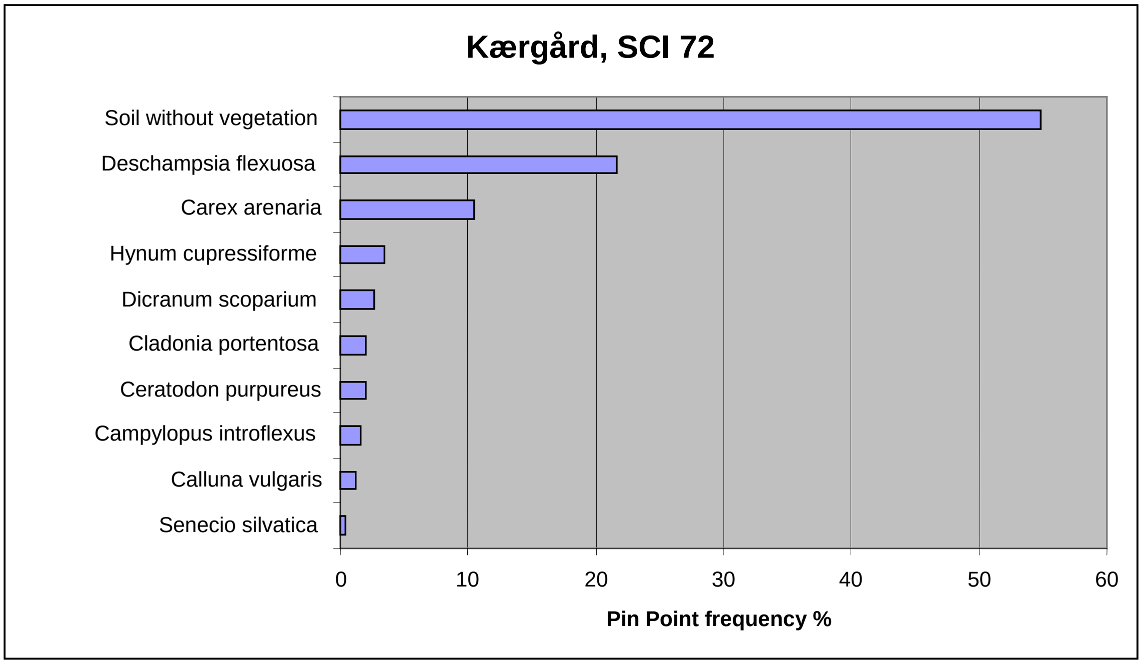


Figure 8. Species composition and cover app. 1 year after clear cutting of Pinus mugo

Figure 9. The clearing analysed by transect. Results shown in Figure 6

Figure 10. The clearing analysed by transect. Results shown in Figure 11.

In figure 11, the invasion of mainly epigeic lichens on the naked top soil is evident. The communities pioneering in the open gaps are species from the organophilic as well as minerophilic groups. The heterogeneity of the cleared area is thus reflected in the first succession stages. Both organic material and mineral soil are being exposed and become substrate for the cryptogam dominated pioneer community.

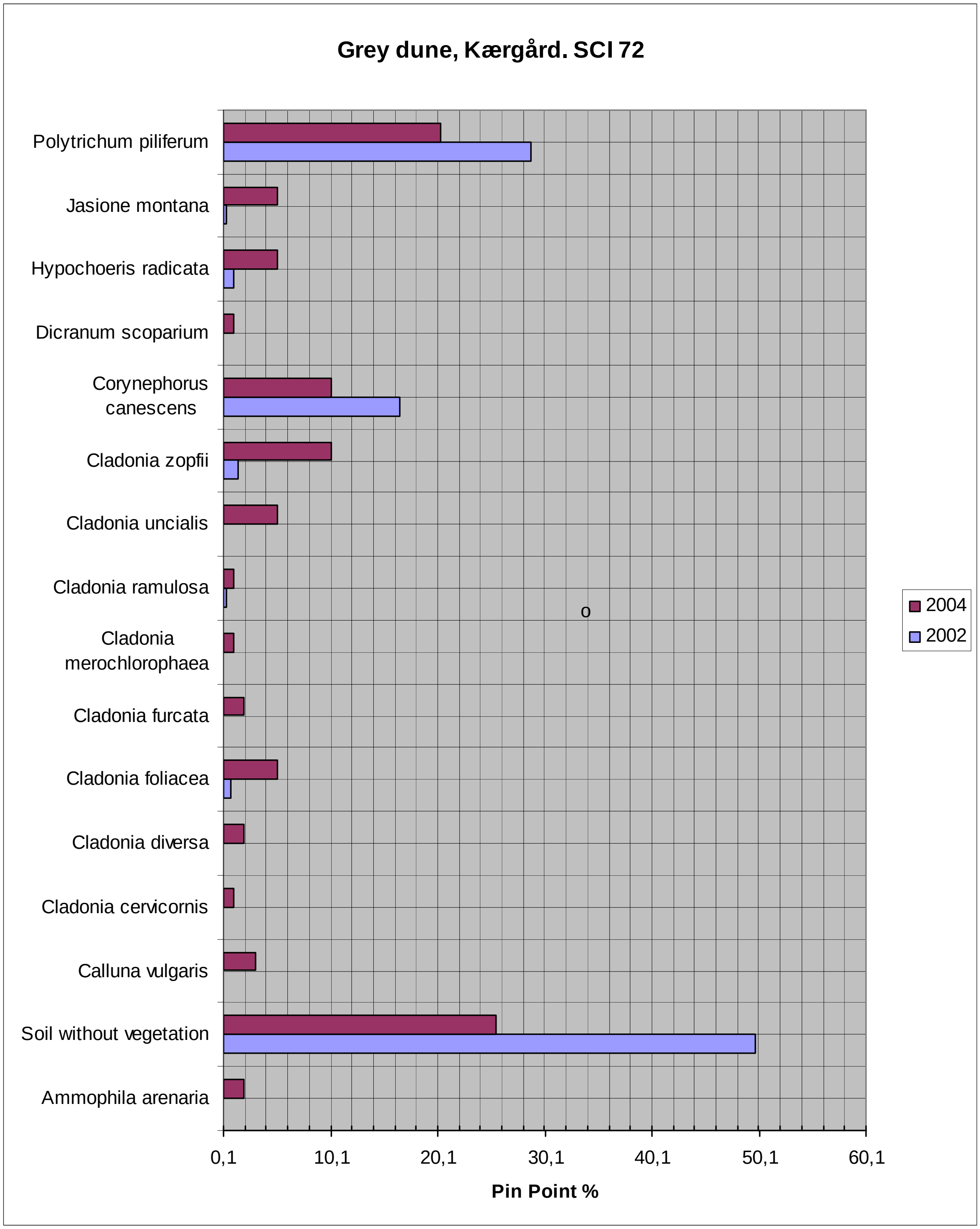


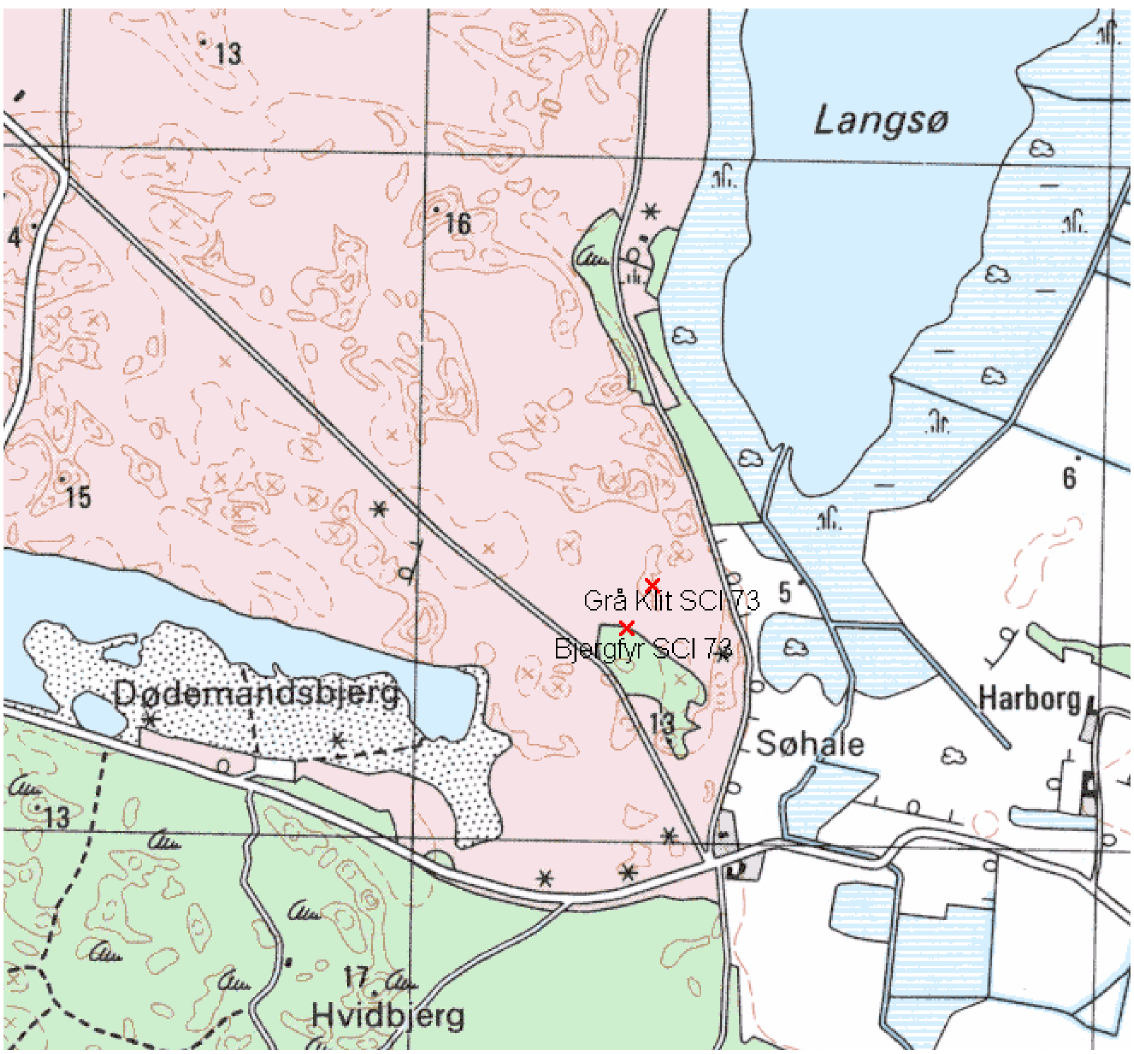
Figure 11. Comparison of 2002 and 2004 at the permanent plots in Kærgård.

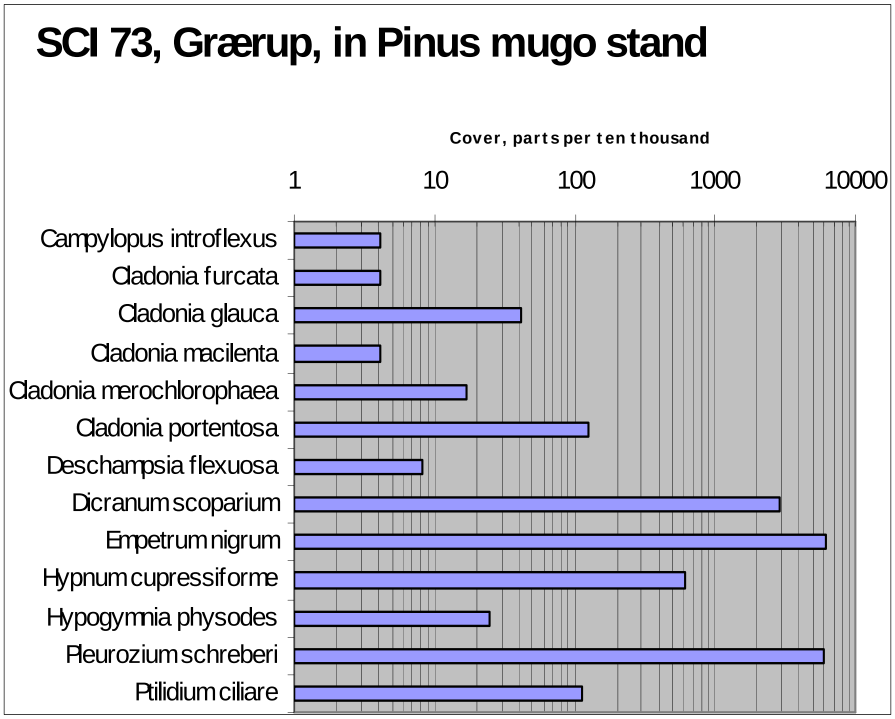
SCI 73 Grærup

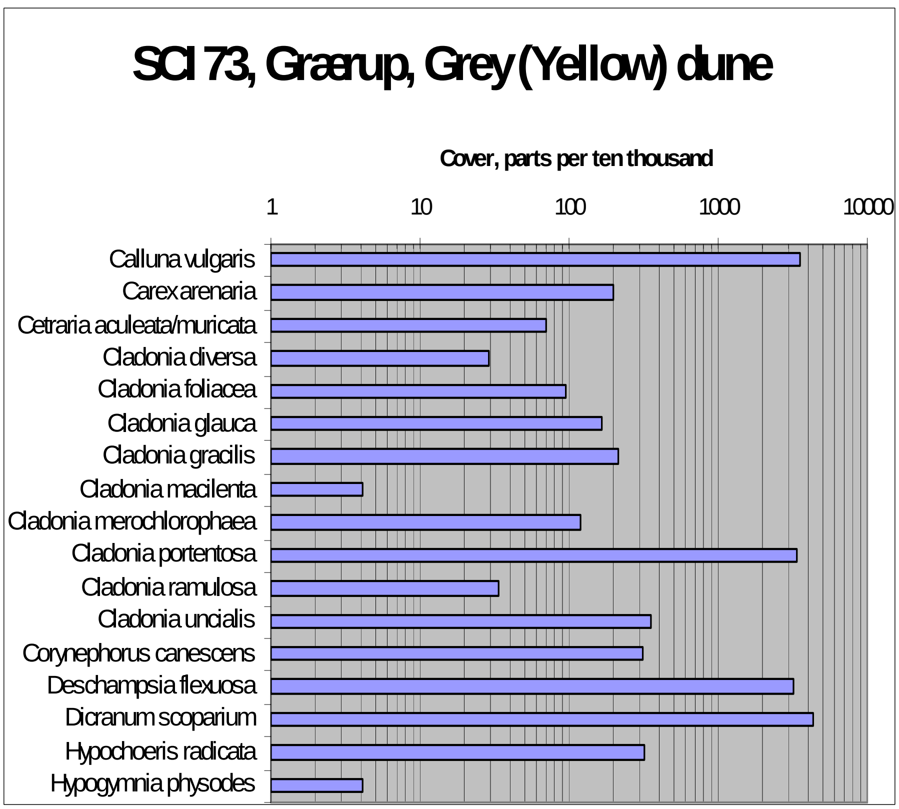
Pinus mugo stand

Grey (Yellow) dune

Figure 12. SCI 73 Grærup; permanent plots




SCI 73, Grærup, in Pinus mugo stand
Cover, parts per ten thousand
1
10
100
1000
10000
Campylopus introflexus
Cladonia furcata
Cladonia glauca
Cladonia macilenta
Cladonia merochlorophaea
Cladonia portentosa
Deschampsia flexuosa
Dicranum scoparium
Empetrum nigrum
Hypnum cupressiforme
Hypogymnia physodes
Pleurozium schreberi
Ptilidium ciliare


SCI 73, Grærup, Grey (Yellow) dune
Cover, parts per ten thousand
1
10
100
1000
10000
Calluna vulgaris
Carex arenaria
Cetraria aculeata/muricata
Cladonia diversa
Cladonia foliacea
Cladonia glauca
Cladonia gracilis
Cladonia macilenta
Cladonia merochlorophaea
Cladonia portentosa
Cladonia ramulosa
Cladonia uncialis
Corynephorus canescens
Deschampsia flexuosa
Dicranum scoparium
Hypochoeris radicata
Hypogymnia physodes

SCI 78. Fanø

The area between Pælebjerg and Silkebjerg was visited 2002 before clearing took place. Three permanent plots were established and analysed, one in grey dune with no Pinus mugo growth, one in a yet open vegetation of Pinus mugo and finally one in dry grassland on acid, sandy soil, formerly grazed heath.

	North			East		
Position (WGS84):	degrees	minutes	seconds	degrees	minutes	seconds
Dry grassland	55	22	51	8	25	16
Open Pinus mugo stand	55	22	47	8	25	7
Grey dune	55	23	5	8	24	51

Figure 13. Position of the permanent plots at Fanø.

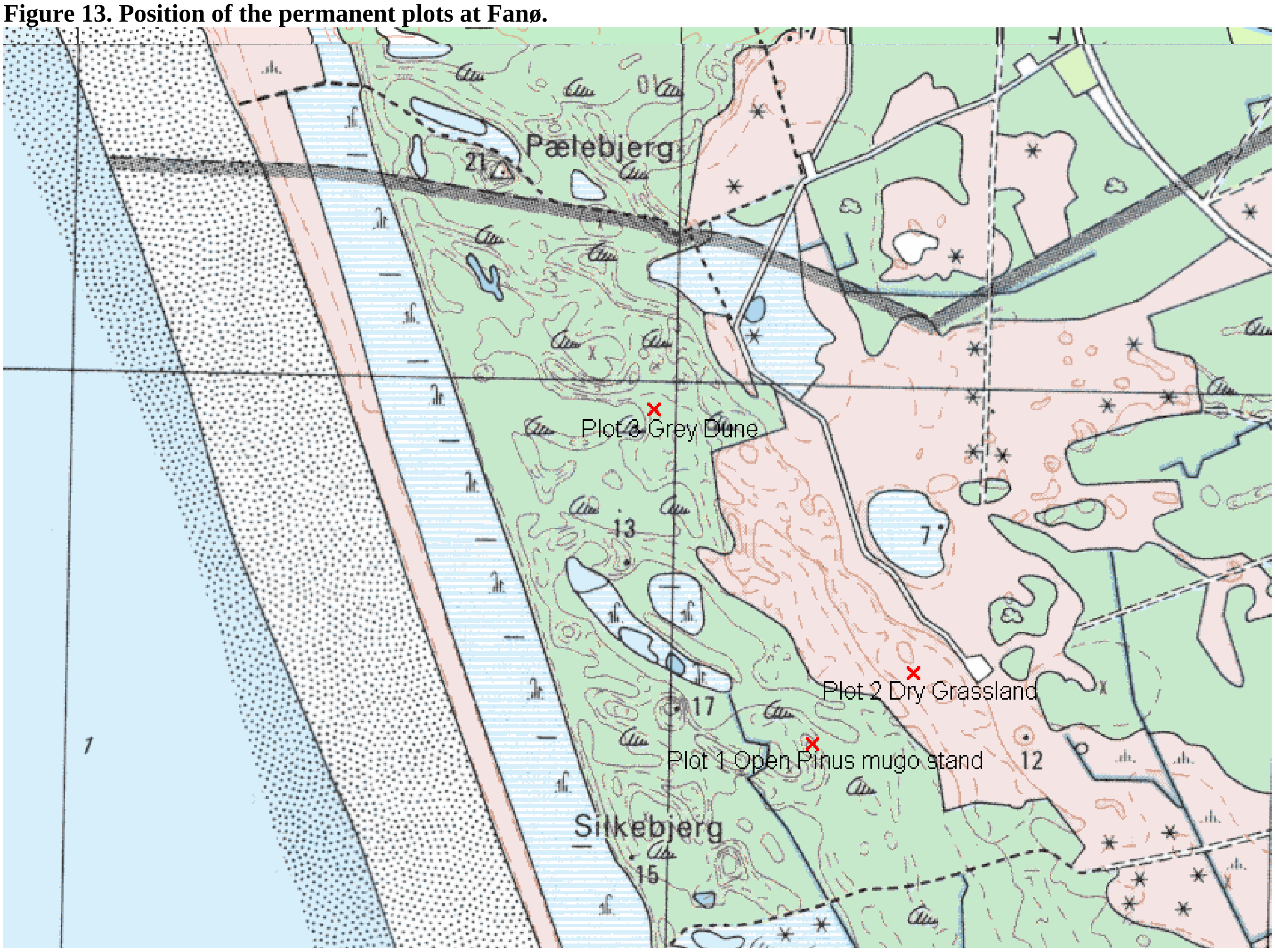


Figure 14. From the grey dune area between Pælebjerg and Silkebjerg, Fanø

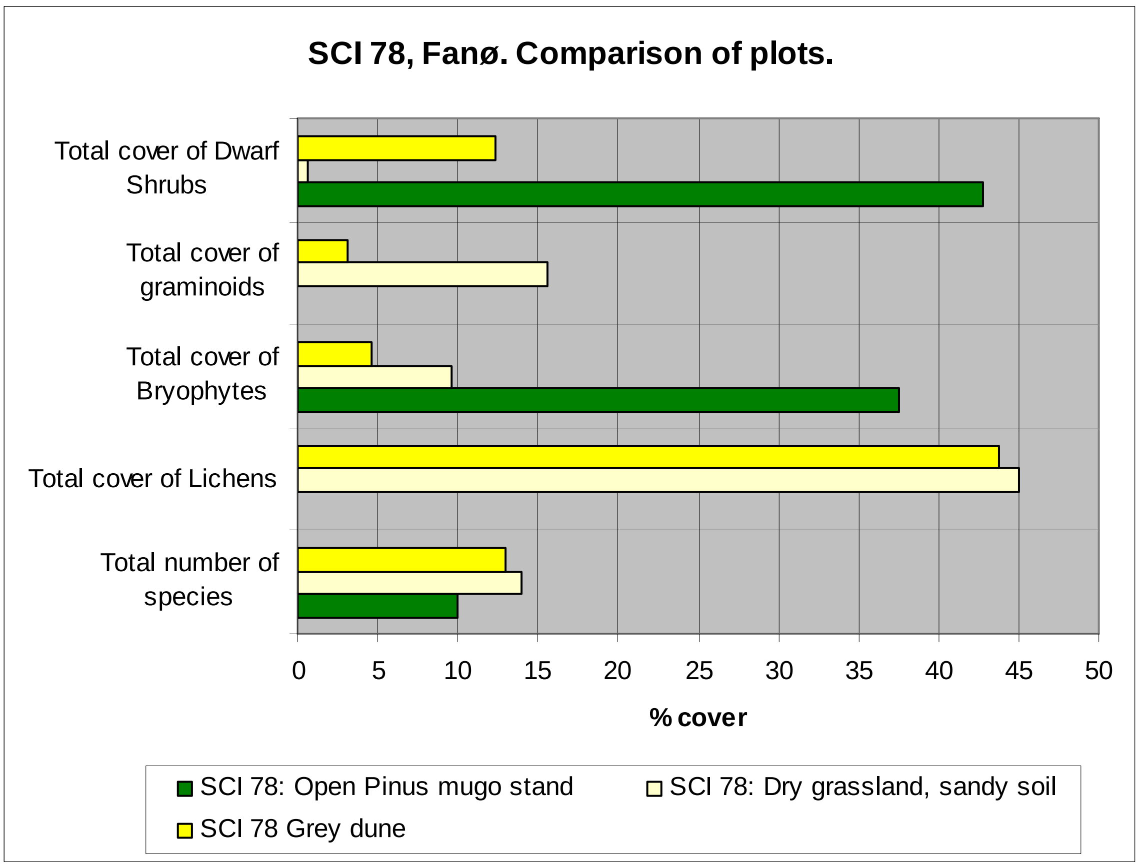
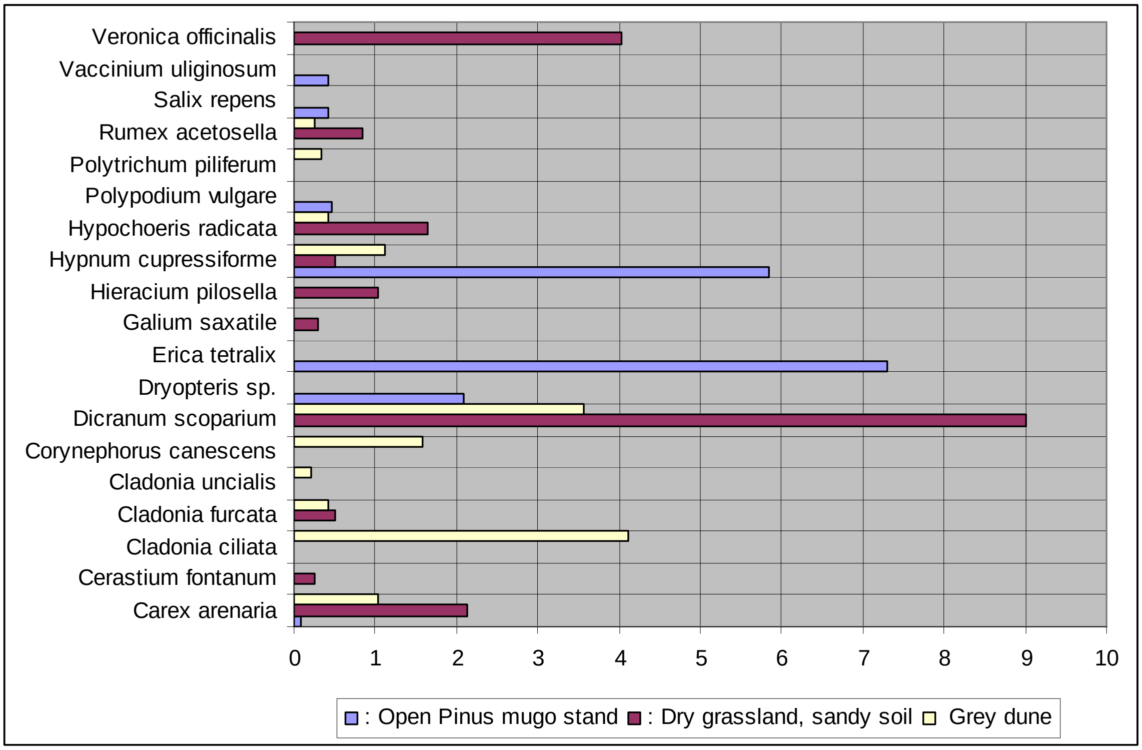
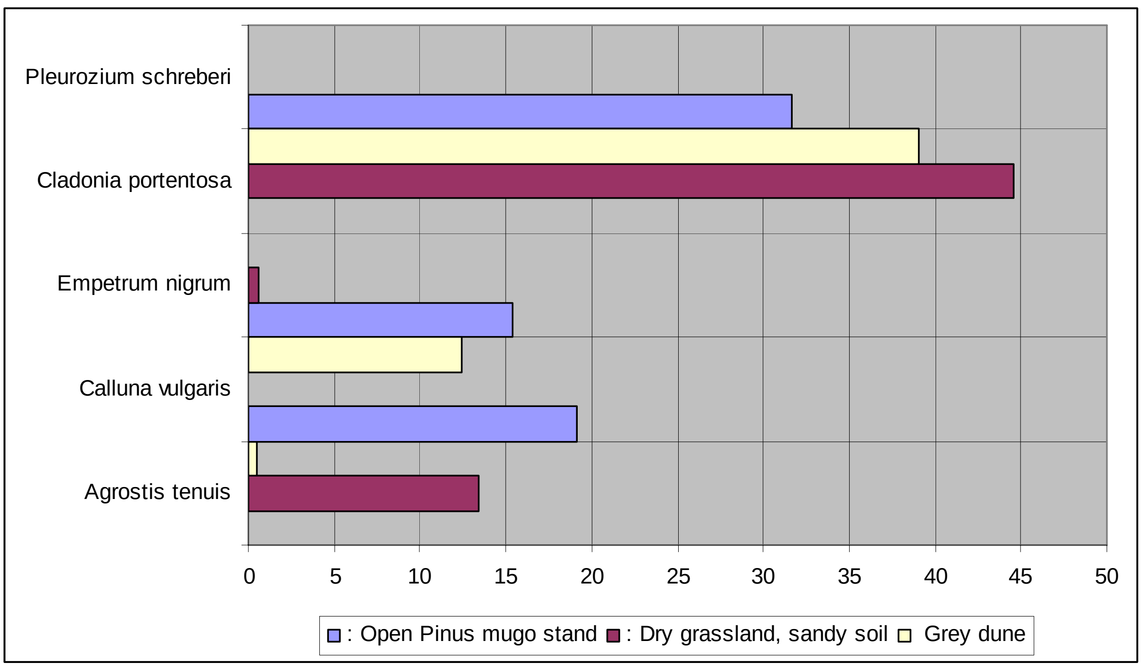


Figure 15. Comparison of the ground vegetation at the plots at Fanø

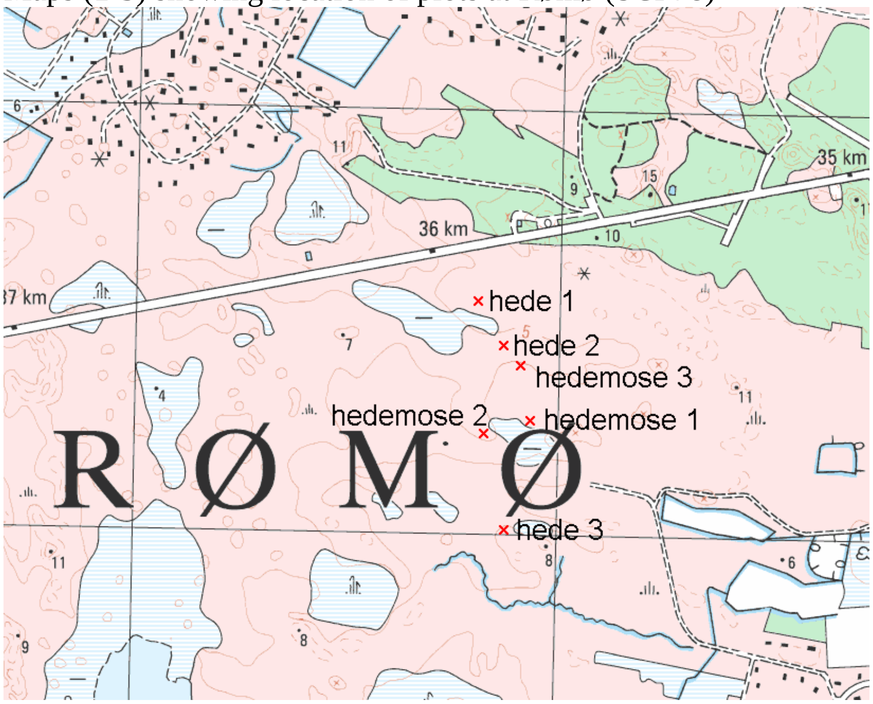
It is seen from Figure 15, that dwarf shrubs (Calluna vulgaris and Empetrum nigrum) and bryophytes (mainly Pleurozium schreberi) dominate the heath with some Pinus mugo cover; the species while epigeic lichens are nearly absent.
In the figures below, the species composition of the three communities is shown.


Veronica officinalis
Vaccinium uliginosum
Salix repens
Rumex acetosella
Polytrichum piliferum
Polypodium vulgare
Hypochoeris radicata
Hypnum cupressiforme
Hieracium pilosella
Galium saxatile
Erica tetralix
Dryopteris sp.
Dicranum scoparium
Corynephorus canescens
Cladonia uncialis
Cladonia furcata
Cladonia ciliata
Cerastium fontanum
Carex arenaria
0 1 2 3 4 5 6 7 8 9 10
: Open Pinus mugo stand
: Dry grassland, sandy soil
Grey dune


Pleurozium schreberi
Cladonia portentosa
Empetrum nigrum
Calluna vulgaris
Agrostis tenuis
0 5 10 15 20 25 30 35 40 45 50
: Open Pinus mugo stand
: Dry grassland, sandy soil
Grey dune

SCI 78. Rømø

Maps (1-3) showing location of plots at Rømø (SCI 78)



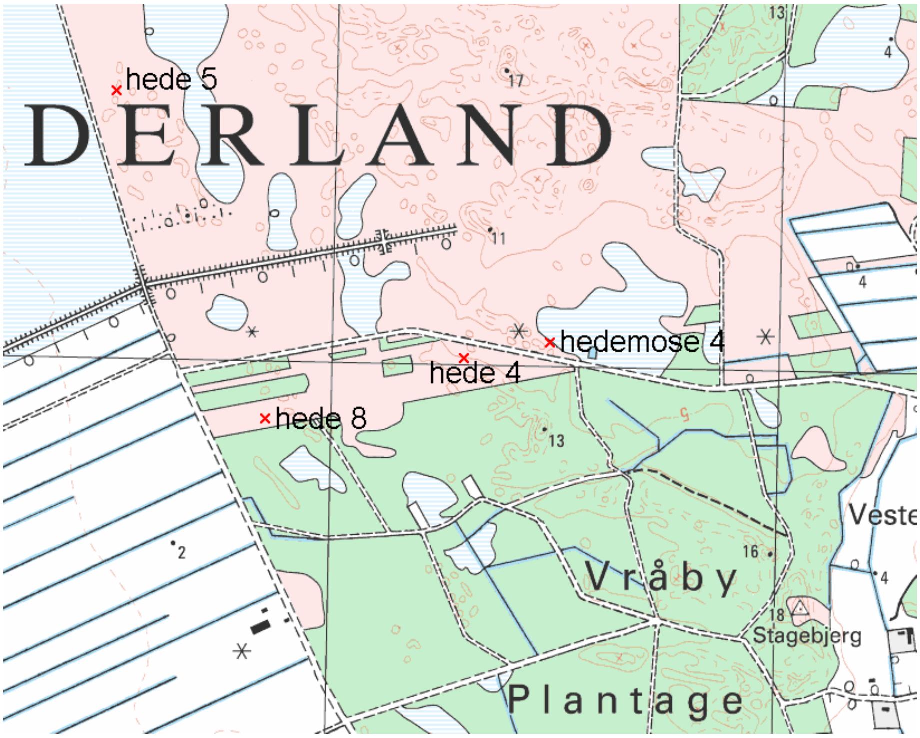


Table with gegraphic positions of investigated locations at Rømø (SCI 78)

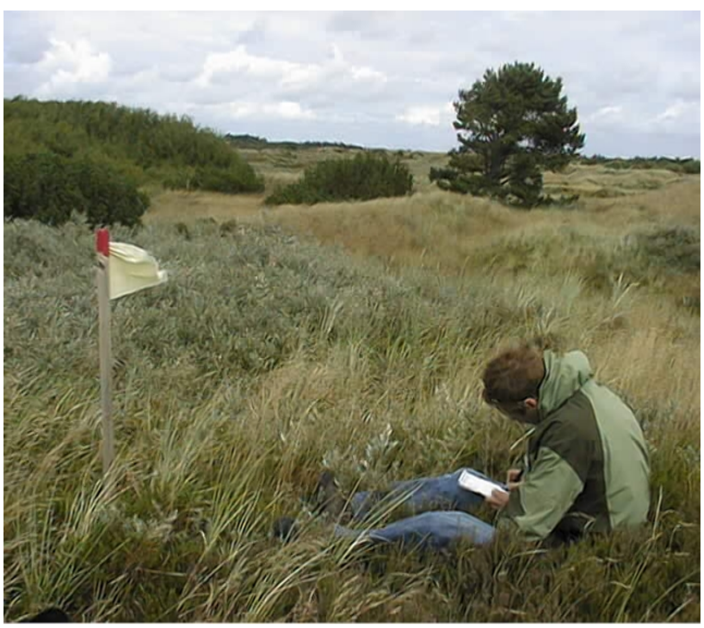
Designation	Latitude (N)	Length (E)	Remarks
Hede 1 Stabil hede	55 08' 55"	08 31' 34"	Stable heath, no sanddrift
Hede 1 Vindbrud	55 08' 55"	08 31' 34"	Blow-out and surroundings
Hede 2	55 08' 51"	08 31' 37"	
Hede 3	55 08' 37"	08 31' 39"	
Hede 4	55 06' 26"	08 31' 02"	
Hede 5	55 06' 44"	08 30' 18"	
Hede 6	55 07' 13"	08 30' 20"	
Hede 7	55 07' 10"	08 30' 29"	
Hede 8	55 06' 22"	08 30' 40"	
Hedemose 1	55 08' 47"	08 31' 38"	
Hedemose 2	55 08' 44"	08 31' 36"	
Hedemose 3	55 08' 50"	08 31' 39"	
Hedemose 4	55 06' 27"	08 31' 13"	
Hedemose 5 flyvesandsklit	55 07' 15"	08 30' 09"	Aeolic dune, stabilised
Hedemose 5 selve mosen	55 07' 15"	08 30' 09"	The main part of the dune slack
Hedemose 6 selve mosen	55 07' 06"	08 30' 35"	The main part of the dune slack

Pictures from each location at Rømø (SCI 78)

Hede 1 Stabil hede. Heath with strong dominance of Empetrum and Calluna; invasion of Pinus spp.

Hede 2. Heath with old dune slack. Dominants are Empetrum and Erica tetralix (right)

Hede 3. Deschampsia flexuosa dominant



Hede 4. Deschampsia flexuosa dominant

Hede 5. Top: Empetrum dominance with Deschampsia flexuosa invading. Little or no lichen cover. Bottom: Similar, but with stronger Empetrum dominance

Hede 6. Aeloic dunes, now stable with dense cover of Empetrum and Deschampsia flexuosa

Hede 7. Strong dominance of Deschampsia flexuosa. Very little Calluna, but high Cladonia spp. cover.

Hede 8. Top and bottom: Dune ridge with Empetrum, Calluna and Deschampsia flexuosa as dominants.

Hedemose 1. Dune slack with Molinia coerulea and occurrence of Gentiana pneumonanthe

Hedemose 2. Dune slack with Molinia coerulea and Eriophorum angustifolium. Salix repens in foreground.

Hedemose 3. Zonated vegetation around dune slack with (from left) Empetrum - Erica tetralix - Molinia.

Hedemose 4. Former grazed dune slack with high cover of Eleocharis multicaulis and Sphagnum spp.

The pictures of hedemose 3 and 4 expose the large variation of the dune slack communities. It shows, that land-use practice of the wetlands in the coastal heaths has a profound influence on the vegetation development. These two locations indicate, that given maintenance of open tree-less and nutrient poor conditions, a wide range of plant communities may develop, all being a part of the highly complex coastal heath ecosystem. The conifers in the background represent a major potential threat.

Hedemose 5. Slack with Molinia and Phragmites australis; little Calamagrostis canescens

Hedemose 6. Slack with strong dominance of Molinia coerulea

Estimated mean cover percentages for species groups, Rømø (SCI 78)

Dune heath (hede) no.:	Hede 1a	Hede 1b	Hede 2	Hede 3	Hede 4	Hede 5	Hede 6	Hede 7	Hede 8
Dwarf shrubs	77,5	2,5	82,5	7,5	12,5	70	65	2,5	55
Conifers	5	0	5	2,5	0	0	0	0	2,5
Graminoids, totally	55	2,5	15	5	80	5	17,5	60	72,5
Lichens, totally	2,5	7,5	5	2,5	17,5	3	7,5	70	10
Sum of species cover (%)	145	25	115	27,5	120	93	112,5	135	145

Estimated mean cover percentages species groups, Rømø (SCI 78)

Dune slack (hedemose) nr.:	1	2	3	4	5 (dune)	5	6
Dwarf shrubs	7,5	5	95	7,5	80	5	7,5
Conifers	0	0	5	0	0	0	0
Graminoids, totally	80	10	92,5	82,5	12,5	82,5	92,5
Lichens, totally	0	0	0	0	0	0	0
Sum of species cover (%)	120	35	195	110	97,5	99,5	102,5

Methods.

Botanical inventories.
The botanical inventories were performed as E-W or N-S transect analyses with description of plant communities and their relative abundance along the lines, which were separated by about 50 m. The topography was reported, and digital pictures were taken from points with positions determined by GPS.
Species occurrence in general, and occurrence of rare species as well as indicator species (i.e. species particularly characteristic for a certain plant community) was noted. The communities were also characterised in terms of relative cover between the groups: Dwarf shrubs, herbaceous plants, graminoids, epigeic lichens (mainly *Cladonia* spp.) and bryophytes. The area of gaps, mainly with biological crusts, in percentage of total for the plant community in question, was recorded.

Permanent Plots.
The permanent plots were always placed as pairs (with one exception: Fanø) in order to describe a before/after situation. The 'before situation' is linked to a specific management action, and the 'after situation' refers to the original, more or less ideal state of the ecosystem at the specific part of the project site.
The geographic position was measured for the marker placed in the middle of 4 rectangular shaped grids, each with 24 squares of 20*20 cm2. For each square, the cover for all species was estimated in %. The total number of squares per plot was thus 96. The analysis is quite time-consuming even with experienced personnel. The plots were photographed digitally.

Vegetation analysis method for the burnt spots:
A rectangular frame measuring 40 cm * 60 cm was divided into 24 small quadrates each measuring 10 cm * 10 cm using a nylon mesh (Figure 16). The data retrieved were in the following categories:
a) Number of quadrates with occurrence of the species in question relative to the theoretical total of 24
b) The cover of the species within each quadrate, estimated by eye in %
c) The number of hits of the species at each meshes crossing point relative to the theoretical total of 15 (pin point frequency).

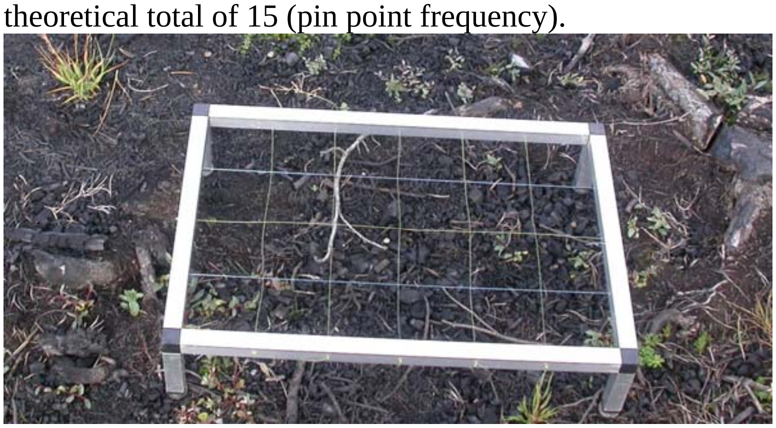


Figure 16. Frame used for vegetation analysis

Results and discussion.

In this chapter, selected results from the previous chapters are used to highlight the main findings, which are discussed in relation to the overall aim: To describe guidelines for best management practice in relation to the Atlantic coastal heath in Denmark.

How does the succession proceed after clearing of forest-like conifer growth (mainly Pinus mugo) in grey dune vegetation?

The figures below show the typical succession after removal of conifer growth. The example is from Stokmile, Skagen Plantation north of Hulsig Heath. The time period was from 1981 to 1999. The area was photographed 2005 (see below). The starting point was a closed stand of *Pinus mugo*, which was cut with subsequent immediate removal of the above ground biomass from the area. It is seen, that after approximately 10 years, the pattern of change no longer seems to be related to the clearing event. In stead, the natural cyclical succession of heaths with *Calluna vulgaris* as a dominant takes over.

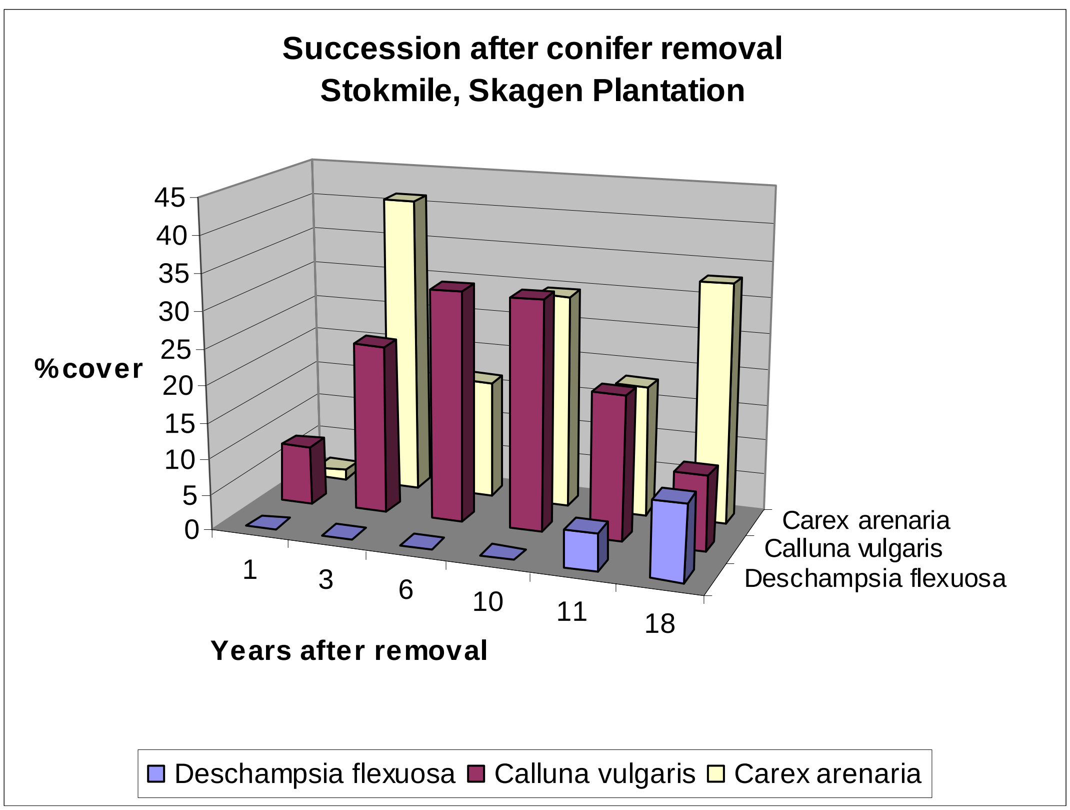


Figure 17. Succession after conifer removal, dominant phanerogams

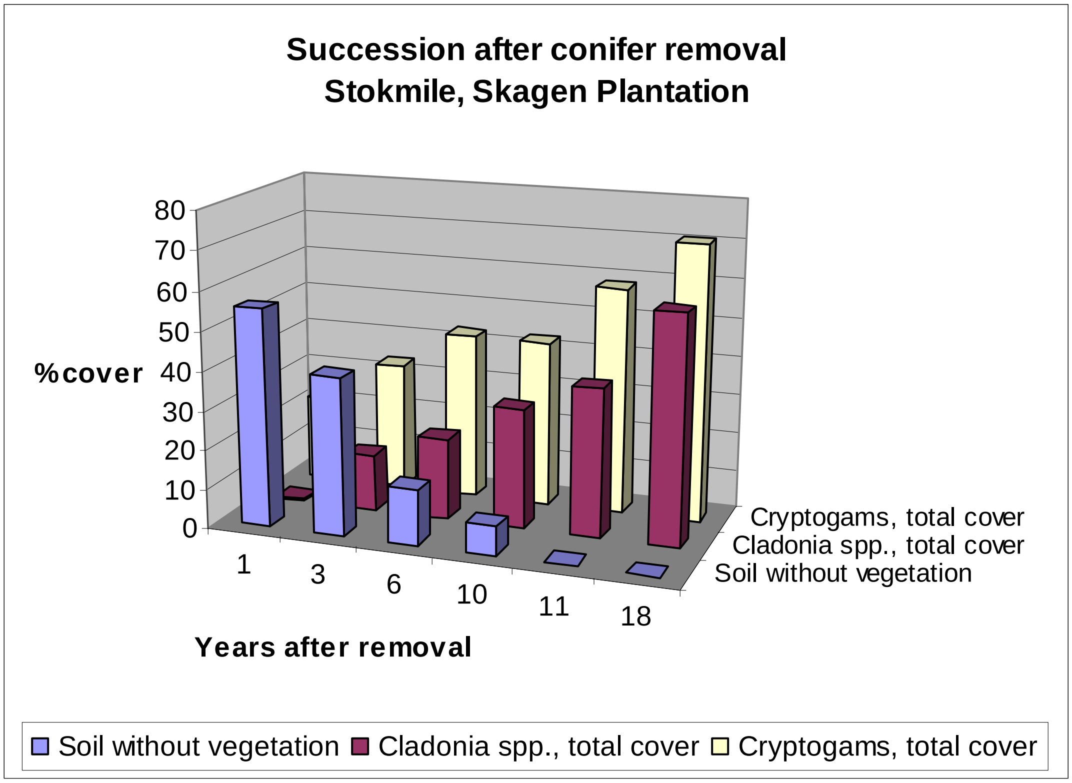


Figure 18. Succession after conifer removal. Ground cover, mainly cryptogams

Figure 19. Stokmile, area cleared 1981. Photograph from 2005.

The above figures from Stokmile suggest that the grey dune vegetation is fully recovered after approximately 10 years. The high dominance of Carex arenaria few years after clearing of the conifers seem to fade and the species finally cover about one third of the area. There may be a change in grass cover, especially two species are becoming more and more frequent in the Stokmile clearing: Deschampsia flexuosa and Calamagrostis epigeios. The reason for this may be higher deposition of nutrients from the atmosphere.

The mechanical clearing method is of importance for a positive outcome of the dune heath regeneration. It is necessary to remove all above ground tree biomass from the cleared area, before any significant needle loss has taken place. Most of the minerals accumulated in the tree biomass are concentrated in the needles. The removal of newly cut tree biomass must be done, when tree saws (motorized or hand-held power saws) of various kinds have been used.

The cut material may be left in piles for burning at selected spots (discussed below), or chopped into wood chips for energy production.

Using weed and brush cutters should preferably be avoided, as the above ground biomass is being left at the site. Instead of weed and brush cutters, removal of tree seedlings by hand pulling is preferable, even if the task is more tedious.

The grey dune vegetation is particularly sensitive to mechanical disturbance, and motorized transport should always be avoided in the dunes. In stead, motorized transportation of cut tree biomass should take place using vehicles with broad, non-profile tyres, and the route should be placed about 50 m from the foot of any dunes, i.e. close to the edge of the adjacent flat (often with dune slack vegetation). The tracks formed by these vehicles may be used later for a similar purpose. The vegetation recovery in such tracks is rather fast, but the micro topography change is changed nearly permanent.

Figure 20. Tracks left in dune slack terrain after clearing of Pinus mugo. Lodskovvad, November 25th 2003.

The follow up after first time removal of Pinus mugo is necessary to secure the restoration generation of the former dune heath vegetation and its maintenance.

The follow up should include the following:
1. Phase 1. Manual removal of seedlings every year for at least three years/
2. Phase 2. Continued manual removal eventually combined with mosaic burning (s.d.)

How does the succession proceed after fire? Analyses of fire spots from burning of organic material from cuttings and mosaic burning sites

The field work to evaluate the impact of fire as management tool was made in SCI no 2 (Lodskovvad and Hvide Klit) and Hulsig Heath (former LIFE project report: Nature Conservation on Hulsig Hede, LIFE-Nature Final Report. June 2002). It is based on detailed analyses of the vegetation development in the spots themselves as well as transects analyses of the impact on the surrounding vegetation from fire.

Succession at spots and their immediate surroundings, where tree cuttings have been burned

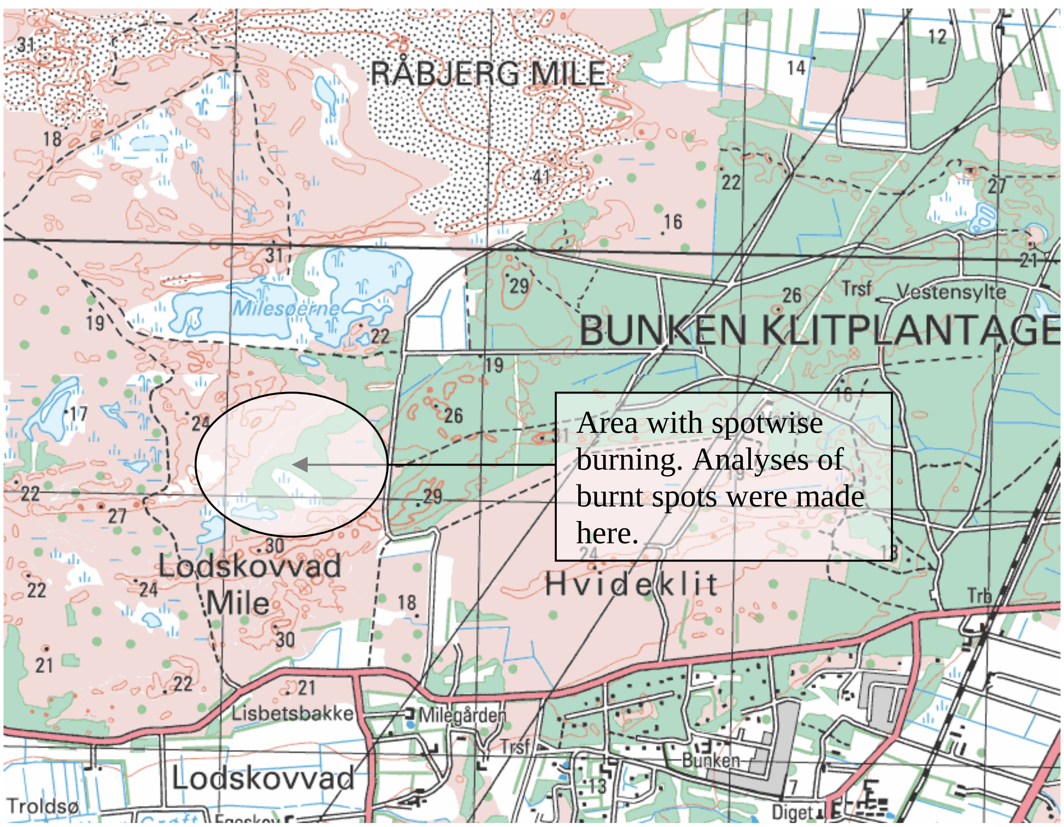


Figure 21. Map showing the analysed area of SCI 2 with burnt spots. Management by County of Nordjylland.

Figure 22. Pile burning at spots distributed over a large area, formerly covered with Pinus mugo. Lodskovvad Mile, November 25th 2003

The succession at the burnt spot sites was as follows:
Pioneer stage with few, rapidly invading plants, bryophytes and fungi. The plant species are often *Senecio silvaticus* and *Chamaenerion angustifolium*; the bryophyte species of main importance is *Funaria hygrometrica*. Several fungus species invade the spots at this early stage, e.g. *Peziza echinispora* This stage last for 1-2 years, depending of the substrate; in most dune heaths the substrate is sandy and easily depleted of its mineral content, thus reducing the time span of the pioneer stage.
The second intermediary stage is typically dominated by the phanerogams *Carex arenaria*, *Salix repens* and *Carex panicea*; some germination of *Calluna vulgaris* seeds take place. Bryophytes characteristic of this stage are *Polytrichum* spp. and *Ceratodon purpureus*. Lichens enter the scene here, typically crustose species like *Placynthiella* spp. and *Trapeliopsis granulosa* as well as primary foliose thalli of *Cladonia* spp. The second stage last for app. 2 years, from the 2nd to the 4th year after burning.
The final stage represents the phase, where the actual regeneration of the original dune heath takes place. Depending of the amount of organic matter in the top soil, the succession includes a stage with organophilic lichen species mainly of the genus *Cladonia*.
The end point is always the well known mosaic community of dwarf shrubs, graminoids and gaps with *Cladonia* sect. *Cladina* spp. and bryophytes like *Dicranum* spp., *Hypnum* spp. and *Pleurozium schreberi*. Figures 8 and 9 show examples of the pioneer stage based on analyses of burnt spots shortly after burning, from SCI 2 (Lodskovvad and Hvide Klit). The examples are from an area with short distance to the ground water table, with depressions often flooded during winter. The maximum distance to the ground water table during summer time is estimated to 1 m. The occurrence of species like *Erica tetralix*, *Agrostis canina*, *Phragmites australis, Carex nigra* and *Myrica gale* reflects the short vertical distance to the ground water table.

Figure 23. The bryophyte *Funaria hygrometrica* on burnt spot, SCI 2, Lodskovvad, October 6th 2004. The picture was taken only few months after burning.

Figure 24. The discomycete *Peziza echinispora* on burnt spot, SCI 2, Lodskovvad, October 6th 2004. The picture was taken only few months after burning.

Figure 25. Area recently cleared with burnt spots, separated by app. 25 m. The vegetation is still composed of the graminoid communities of the *Pinus mugo* thickets. The burnt spots are only few months old. SCI 2, Lodskovvad, October 6th 2004.

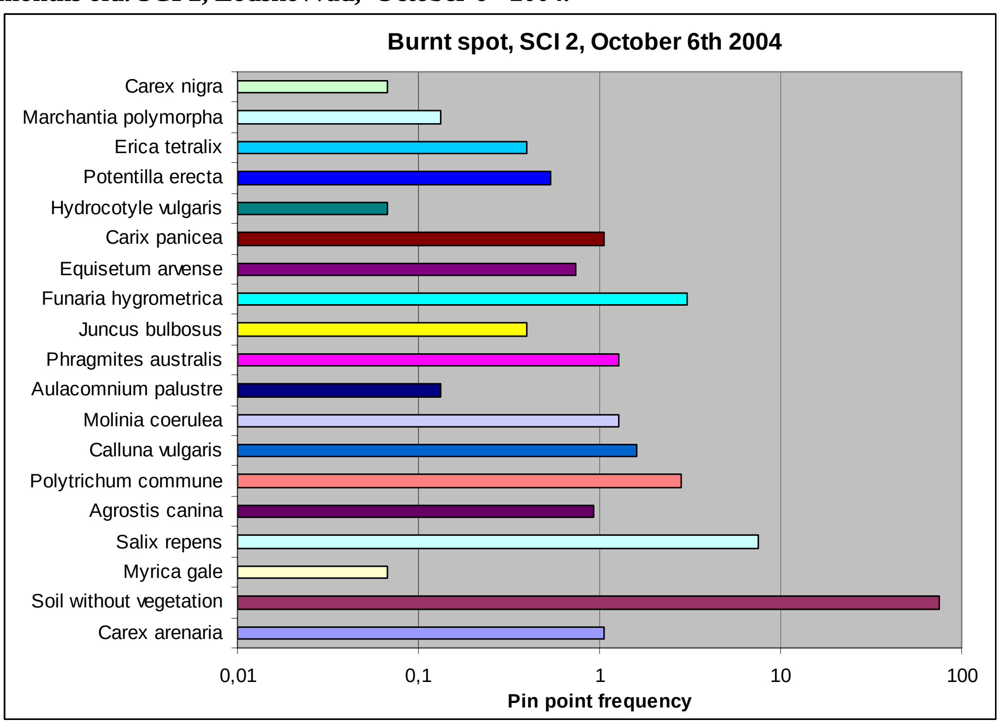


Figure 26. Vegetation on burnt spot in dune slack community

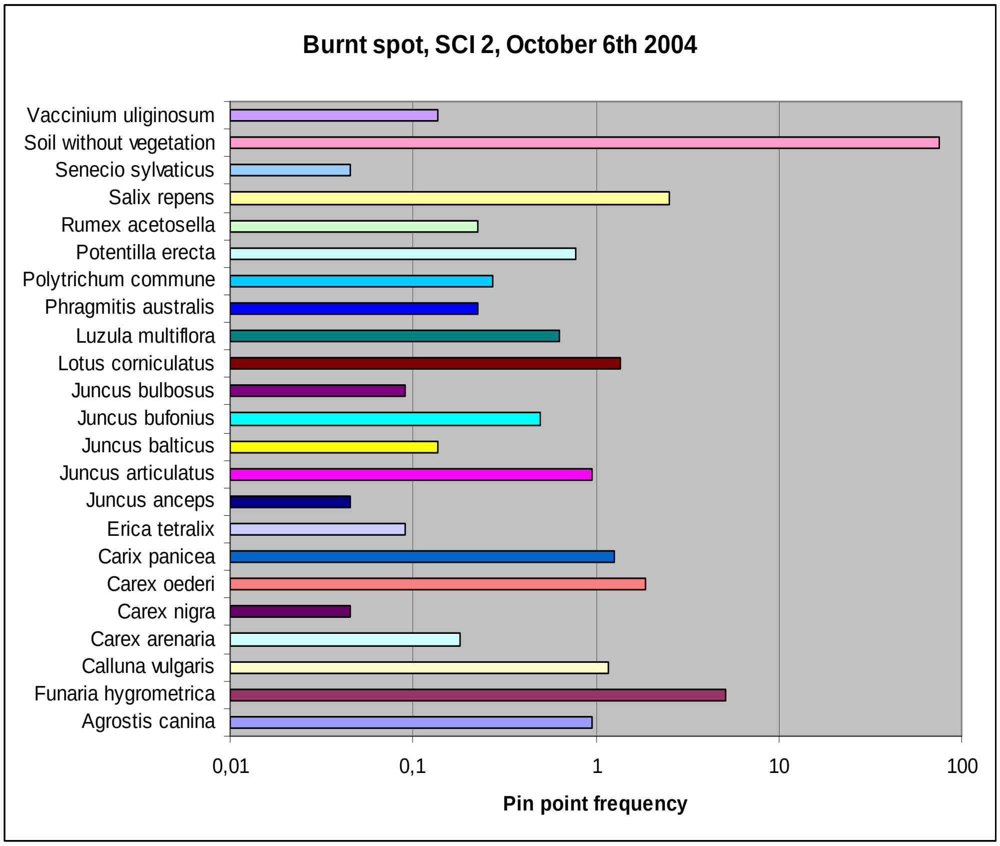


Figure 27. Vegetation on burnt spot in dune slack community

Mosaic burning

The mosaic burning is a feasible management method, as the method secures common occurrence of several succession stages of dune heath, including the initial phase. Due to challenge from serotiny in e.g. *Pinus contorta*, it is preferable to restrict the use of mosaic burning to areas, where proximity to nutrient and mineral resources (below and/or above ground) induce a rapid change in the heath vegetation towards grass dominance, which may cause nearly irreversible changes in the heath ecosystem, if left to proceed.

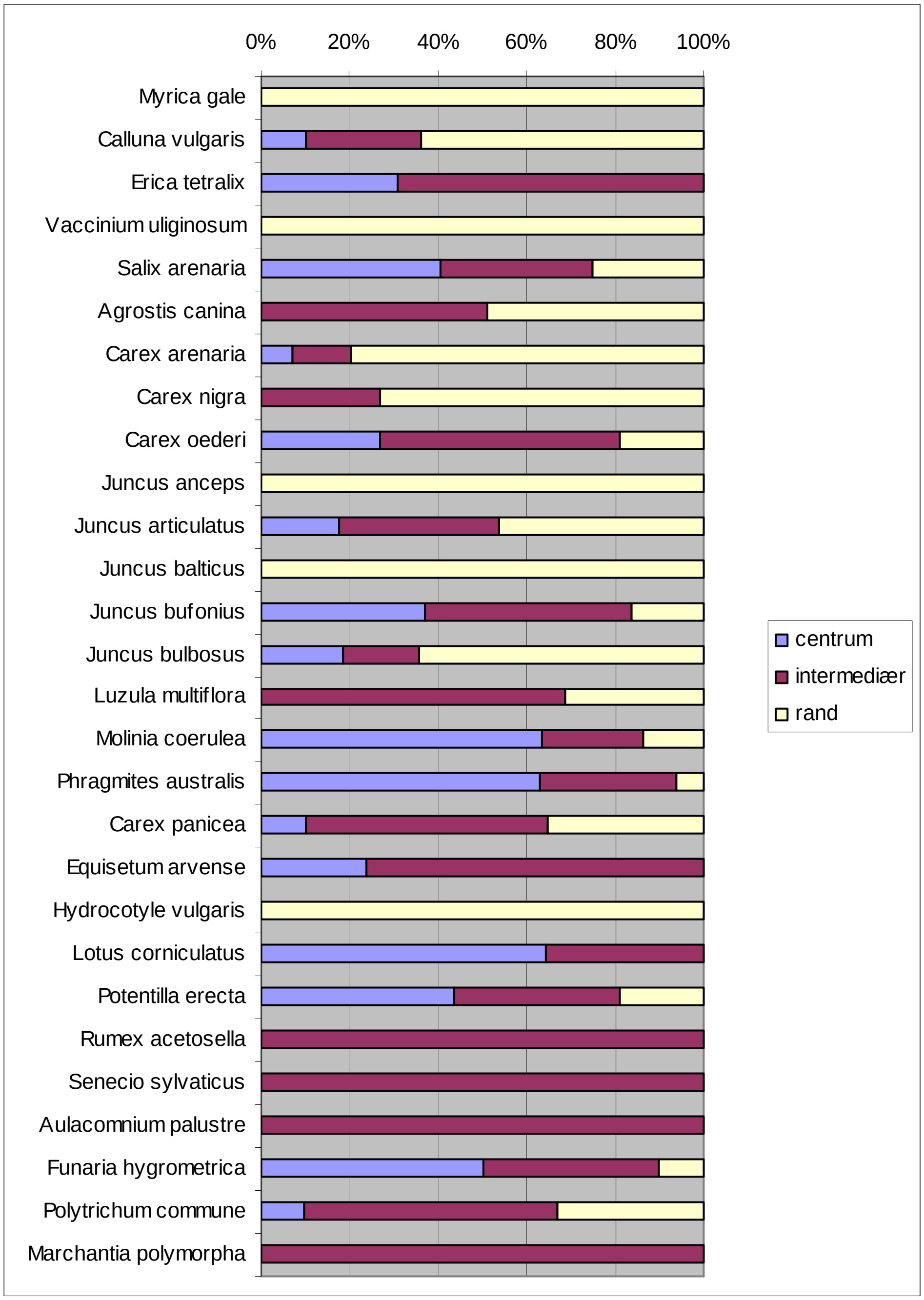


Figure 28. Distribution of species on a burnt spot shortly after pile burning

Post-fire succession in extended heath areas with invasion of especially *Pinus mugo* and *P. contorta*:

The data retrieved from Lodskovvad and Hvide Klit of SCI 2 here was compared to data from a fire 1996 at Hulsig Hede, where analyses were made across the front limit of the naturally extinguished fire into the intact, original heath vegetation. The succession with respect to dominants from 1997 to 2004 at Hulsig Hede is shown in Figure 29.

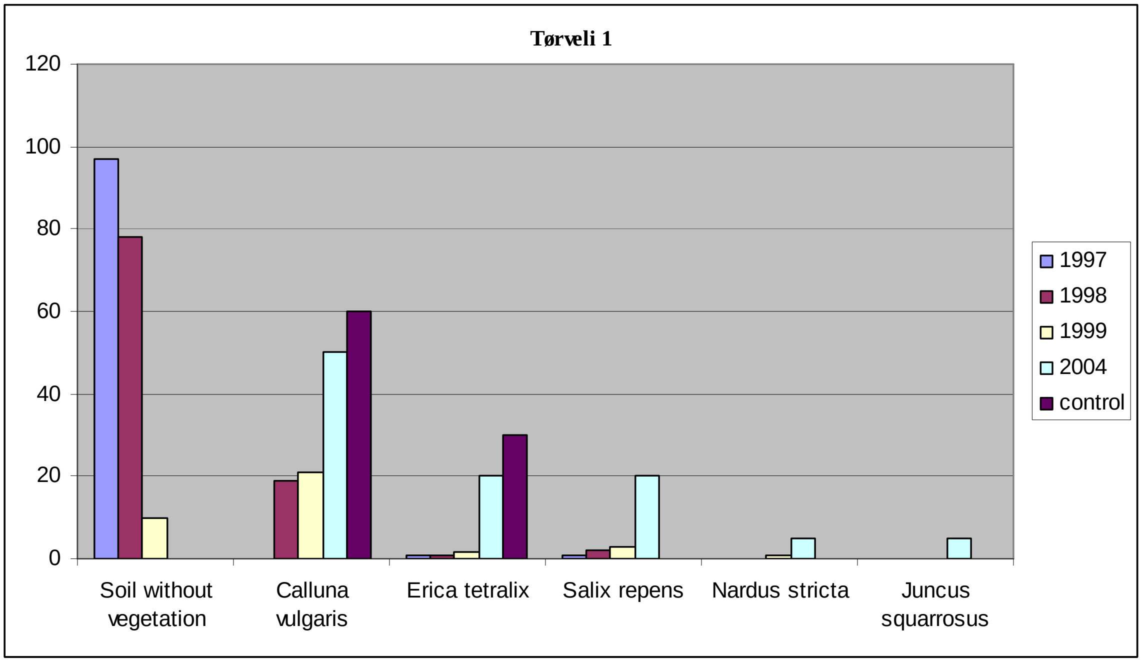


Figure 29. Succession after fire, Hulsig Heath. Heath flat burned naturally 1996.

Figure 30. The site for Tørveli 2 analyses. To the right is the control: Unburned dwarf shrub dominated heath. The limit of the fire 1996 is shown, and the time series based on analysis of the area to the left of the photo.

The development in biodiversity follows the scheme of the natural, circular succession characteristic of *Calluna vulgaris*-dominated heaths. The burnt flats may be compared to gaps replacing dying senescent *Calluna* dwarf shrubs according to their app. 30 years life cycle. The highest biodiversity in this analysis was observed between 3 and 8 years after burning, mainly pioneer species of plants, lichens and bryophytes. The control represents a senescent heath area, with a rather low biodiversity, dominated by *Calluna vulgaris* and *Erica tetralix*.

In Figure 31 the succession after the fire 1996 is shown for a large, flat dune slack area – an aeolic deflation plateau. The succession is different from the one showed in Figure 29 as the dune slack dwarf shrub *Erica tetralix* and the bog bryophyte *Polytrichum commune* dominates at the end. Again, the time span to recover from the disturbance, in this case a natural fire is about 10 years. In some areas, the succession may proceed to form shrub land with *Salix* spp. (mainly *Salix repens, S. aurita* and *S. canescens*) or open forests primarily of *Betula* spp. and *Populus tremula*. This latter stage is highly influenced by the climatic conditions, and retrogression is often observed. In modern time, however, the changing climate (higher temperature and perhaps increasing precipitation) as well as high atmospheric deposition of nutrients, may favour the development of the final forested succession stage.

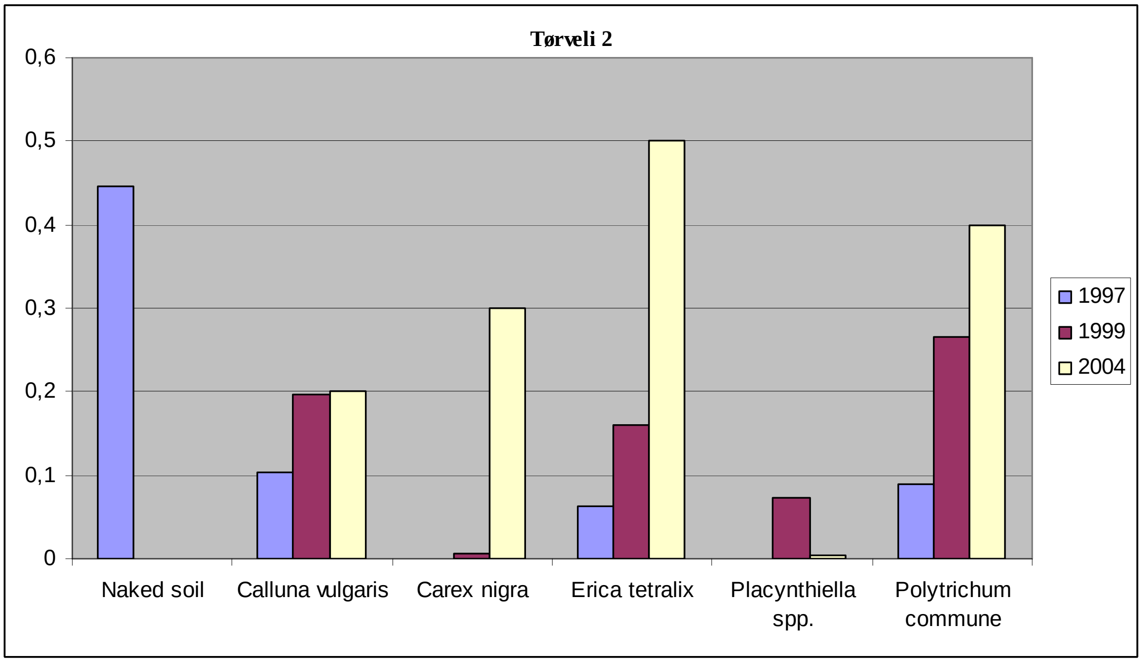


Figure 31. Succession after fire, Hulsig Heath. Area close to ground water table[2]

Furthermore, the findings were compared to the results by Vestergaard, P. & Alstrup, V. (2001) Recovery of Danish coastal dune vegetation after a wildfire)

What is the ideal time interval between burnings at selected fire spots?

The answer to this question depends on the success with manual removal of pine seedlings during the first three years after clear cutting of a certain heath area. Using always the same spots, a frequency of 5-10 years is recommended, if this approach is considered necessary due to reinvasion of *Pinus* spp.

[2] Placynthiella spp.: P. uliginosa, P. oligotropha and P. icmalea

What is the ideal geographic position and distance between the fire spots?

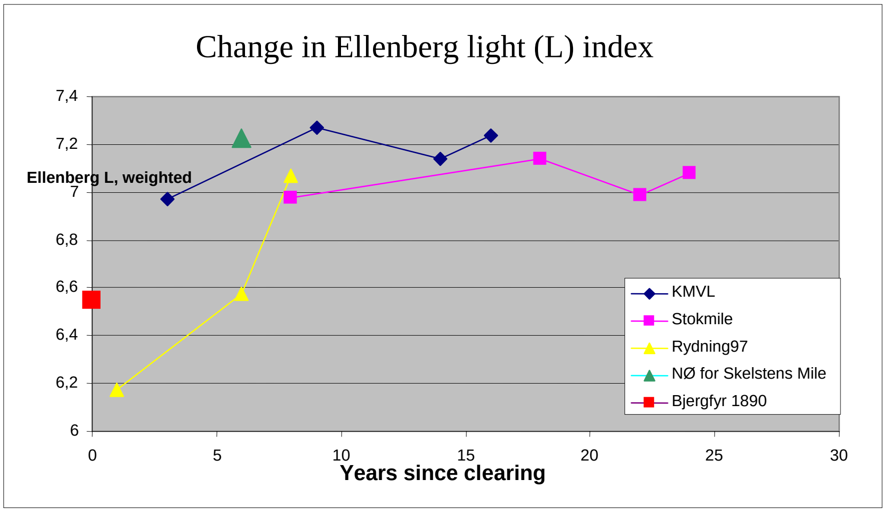
The fire spots should be placed with a mutual distance of app. 50 meters, preferably on flat terrain. The fire pots should never be placed on the grey dunes or in the transition zone between grey dunes and the neighbouring flat terrain, often with dune slack vegetation. Transportation of tree cuttings should be manually or by trucks with broad, non-profile tyres. The tracks left after truck transportation should be left unchanged.

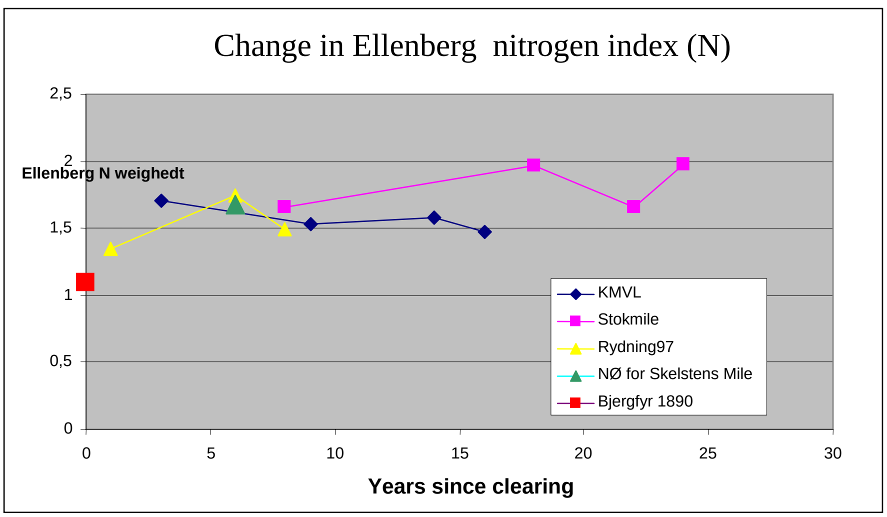
What are the main effects of fire on vegetation dynamics, e.g. due to serotiny, and nutrient circulation?

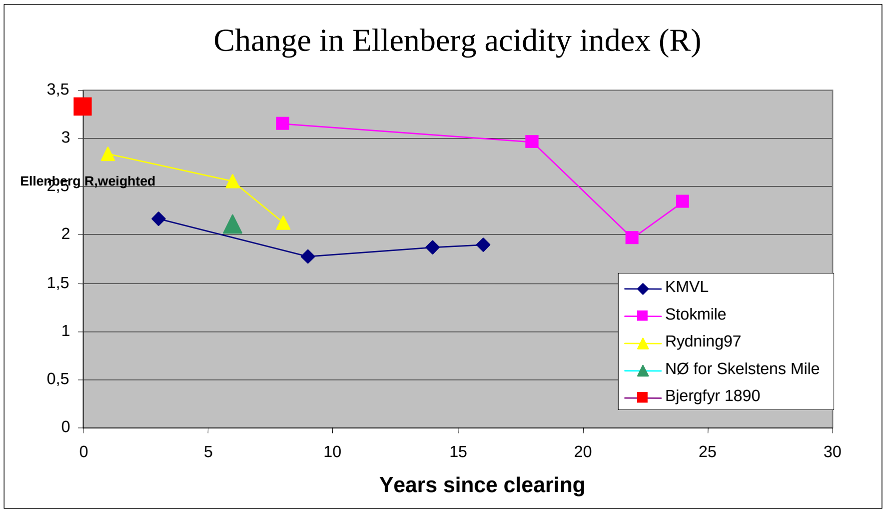
This question is very broad, and only aspects of its answer of direct relevance of coastal heath management shall be mentioned here. Naturally, coastal heath fires occurred almost only after lightning strikes, and should accordingly be considered an exception in management practice. The main problems due to burning in coastal heaths are: The increased germination of conifer seeds (mainly *Pinus contorta*) due to serotiny and the locally strong impact of minerals released during the fire. On the other hand, fire restarts the cyclical succession process characteristic for heaths, and may favour the initial succession stages, which today are suppressed due to the more favourable climatic and nutritional conditions. Furthermore, the fire releases e.g. nitrogen and phosphorous compounds to the atmosphere, which may be removed from the heath ecosystem.

The change in ecological conditions as reflected in the succession of the ground vegetation after conifer clearing.

The figures below based on weighted Ellenberg indices for all plant groups of the ground vegetation, show some general changes in the ecological conditions, as they change with time following clearing of *Pinus* spp. and *Picea* spp.







It is seen, that the light index increases with time, as species adapted to high light exposure become more abundant. These light species are mainly species of the grey dune community in this case. It is seen from the graph that the change ceases after ca. 10 years, in accordance with the above mentioned vegetation development.(Figure 17 & Figure 18).

Also the N index increases slightly, which probably is due to the atmospheric deposition of nitrogen compounds. The acidity index R drops over time, which reflects the leaching of minerals from the top soil, here mainly sand with only very little organic matter.

Discussion

It can be seen from the above that a succession towards the original dry sand heath begins very soon after the clearing of Mountain Pine. The speed of succession is slow if the starting point was a closed, forest-like Mountain Pine plantation which had existed as such for a long period of time, e.g. more than 50 years. In this case, long phases of dominance with Sand Sedge (*Carex arenaria*) and grass species are observed, which can be attributed to the more beneficial nutrient and mineral conditions as a result of the earlier Mountain Pine growth's accumulation of nutrient salts and minerals in litter and humus under the trees. However, it cannot be excluded that today's atmospheric deposition of nitrogen compounds (in Denmark of the order of 15-20 kg N ha^{-1} $year^{-1}$, which is believed to be 5-10 times larger than 60 years ago) means that this graminoid-dominated phase will be maintained over a longer period in relation to earlier.

In addition, it can be seen that the shift in composition of species which is to be expected after burning in this area is very slight. In both dry and wet areas of Hulsig Hede which suffered a natural fire in 1996, a rapid invasion of species which are associated with the early stages in the development of the dry sand heath has occurred. Only in one area has asporadic invasion of narrow-leaved fireweed (*Chamaenerion angustifolium*) and Heath Groundsel (*Senecio silvaticus*) been observed; both species are already declining after 3 years.

The clearing of Mountain Pine which has been carried out has been a success, and according to these studies the area will be well on the way to returning to the original dry dune heath only about 6 years after clearing has taken place. The large unbroken areas with closely-scattered self-propagating Mountain Pine which are suddenly opened will, however, be mainly populated by plant communities which are associated with the initial stages in the dune heath's natural cyclical dynamics. A period of at least 30 years will have to elapse before it is to be expected that all phases are represented as in the old thy sand heath. However, it should be noted that just 10 years after the clearing of Mountain Pine, a total of 16 species of *Cladonia* spp. and 30 species of cryptogams were found in some of the areas studied.

Vigorous new growth of Mountain Pine has been found in parts of the mechanically cleared and burnt areas, which underlines the need for a fast and consistent follow-up of the clearing work already carried out. If conservation work in the form of the removal of new growth of Mountain Pine (which can be carried out by hand) is not implemented within the next few years, the extensive clearing work will have been wasted.

It is deemed that annual inspection and clearing will be necessary for a 5-year period after the first major clearing. It will subsequently be possible to reduce the frequency of inspection and clearing to every three to five years.

It is recommended to continue monitoring of the habitat in the areas based on the previously laid out permanent sampling areas and transects. In this way it will be possible to assess whether the vegetation dynamics are developing as expected, and the need for any conservation measures in order to achieve the goals for the Atlantic coastal heath habitat can be continuously evaluated.

The Mountain Pine invasion in dune heaths has meant a rapid acceleration of succession towards closed woodland, particularly in the low-lying areas. Before clearing, this woodland consisted of Mountain Pine, Downy Birch (*Betula pubescens*)and Silver Birch (*Betula verrucosa*), European Aspen (*Populus tremula*), Grey Willow (*Salix canescens*), Eared Willow (*Salix aurita*), Common Rowan (*Sorbus aucuparia*) and scattered Common Oak (*Quercus robur*). Following a selective removal of Mountain Pine from these succession woodland areas, the deciduous trees remain; the climate has become harsher and the hydrological circle has changed radically after the clearing of Mountain Pine, so it may be assumed that the woodland succession will be arrested and that a minor retrogression will probably take place. There has always been and will continue to be thicket of willow and birch in the heath slacks which can act as a shelter and foraging site for the area's wildlife. It has also been seen that some of the remaining deciduous tree groups which previously stood in Mountain Pine-dominated plantations die as a result of the drastic change in conditions as a consequence of clearing. It is recommended that, in connection with the monitoring program, the heath slack's vegetation development is followed with particular focus on the slacks in which a massive invasion of Mountain Pine had occurred.

Grazing in the area plays a role for the development of the vegetation. A grazing intensity calculated as the number of sheep per ha should not exceed the figure 0.1. It is necessary for the authorities to ensure that this grazing intensity is not exceeded.

With the current numbers of visitors to most of the dune heath, tourist wear is not believed – with a few exceptions - to lead to an unacceptable impact on the vegetation. There is thus no reason to introduce restrictions with regard to tourism at present, but this aspect should also be closely followed by the authorities. A way of regulating the wear and tear on the vegetation from visitors is the construction of car parks and marked paths through less vulnerable areas; in fact, this already happens.

Experience from this project in combination with former LIFE projects at Hulsig and on Anholt has revealed the following succession process:

> Starting point: Old Mountain Pine with well-developed organic top soil layer, flat terrain: Wavy Hair Grass and Sand Sedge dominate for the first 10 years, after which heather and reindeer lichens migrate to the area; after 18 years the original type of vegetation is yet to be fully developed.
>
> Starting point: Old Mountain Pine on sandy base, thin organic top soil layer, flat terrain: Sand Sedge is almost completely dominant for the first 5-10 years, and acrocarpous mosses such as Dicranum scoparium and reindeer mosses begin to appear after about 2 years. After 18 years the grey dune/dry sand heath is more or less re-established.
>
> Starting point: Old Mountain Pine with well-developed organic top soil layer, south-facing slopes: Crowberry, Sand Sedge and pioneer lichen communities migrate into the area and establish open vegetation. In the course of 18 years the grey dune community is practically re-established.
>
> Starting point: Old Mountain Pine with well-developed organic top soil, north facing slopes: Moss dominance disappears after about 5 years and is replaced by organophilic lichen communities, and reindeer mosses belonging to the subgenus *Cladina* appear within 5 years.

Conclusions and guidelines for best management practice with respect to Atlantic coastal heaths.

Overall conclusions

1. The Mountain Pine invasion and development towards forest growth involves determination of the growth of the trees' biomass and an accumulating amount of humus consisting of macro nutrients (particularly N, P and K compounds) and a number of other minerals on the forest floor, such that the heath's bio-geo-chemical banks and ecological cycle are radically changed to a completely new cycle of matter. This new system forms the basis of a more productive ecosystem which has the alpine tree species Mountain Pine as a dominant feature and whose prerequisite is in part the Mountain Pine's unique adaptation to extreme growth conditions (pioneer species at the tree-line in the Alps) and in part the accumulation of matter in biomass and humus mentioned above. Today this accumulation is bolstered by human activities which result in air pollution — with nutrients, among other things. The overall effect on the original grey dunes and dry sand heath ecosystem is the suppression of, in particular, dwarf shrub dominated vegetation such that a rather uniform forest habitat occurs with a more or less dense crown and ground vegetation dominated by a few pleurocarpous mosses (almost exclusively *Hypnum cupressiforme*/*Hypnum jutlandicum*, *Pleurozium schreberi* and *Hylocomium splendens*) and/or reindeer mosses (almost exclusively *Cladonia portentosa* and *Cladonia ciliata*, both belonging to the subgenus *Cladina*). The biggest biological variation in this new forest habitat is found in the form of epiphytic lichens on Mountain Pine trunks and branches.
2. Re-establishment of the original grey dune or dune heath requires removal of the accumulation of matter described above and the prevention of its return in the future. This must take place through the removal of the Mountain Pine above the ground, whereas stumps and roots can be left. It is particularly important that needle-carrying branches are removed and chipped or burned at selected sites where the direct effect of this is as insignificant as possible. The succession towards the original vegetation begins immediately, but the length of the re-establishment period is particularly dependent on the age and exposure of the Mountain Pine (dependent on relief).
3. With the removal of old, dense, planted Mountain Pine a time scale of 15-18 years is not sufficient to recreate a dwarf shrub heath with *Cladina* spp., whereas 10 years appear to be sufficient if the removal is of an open self-propagating Mountain Pine thicket with several gaps.
4. The corresponding development in the event of a starting point with young Mountain Pine (self-propagating) is in all cases faster than above, and an important conclusion is therefore that clearing must take place at a very early stage and conservation work must be carried out on an ongoing basis in order to prevent the Mountain Pine from re-establishing itself.

5. Reestablishment of the original Atlantic coastal heath after clearing of *Pinus mugo* may last between 5 and 15 years, depending of the density and age of the *Pinus mugo* stands; furthermore, the recovery is inhibited in areas neighbouring intensive agricultural land.
6. The succession after *Pinus mugo* clearing usually follows a sequence of three steps: a) Open flats with pioneer species of plants, lichens, bryophytes and fungi; b) Flats dominated by *Carex arenaria* and *Salix repens*; c) Dominance of *Calluna vulgaris* and *Deschampsia flexuosa* with scattered cover of *Cladonia* spp. and acrocarpous bryophytes.
7. The terricolous lichen species *Flavocetraria nivalis*, *Ochrolechia frigida*, *Cladonia stellaris* and *Alectoria sarmentosa* var. *vexillifera* are considered ice age relicts (i.e. their occurrence in coastal heaths probably date back to the post-glacial period after the Weichsel ice age, which ended about 14000 years ago). Partly during this study, their distribution and vigour has been demonstrated to undergo a rapid decline. To some extent, this may be counteracted by the clearing of self sown *Pinus* and *Picea* species in the coastal heaths.
8. Grey dune and dune heath vegetation can be regenerated after clearing and other impacts. It has been shown that dune heath is an ecosystem which possesses a high degree of reversibility. Nature conservation therefore makes sense in such an area provided that major external impacts do not alter the basic conditions for the vegetation.
9. The conservation initiatives carried out have been successful, and throughout the project area a development is taking place which will result - either in the short-term or the long-term - in the regeneration of the original dune heath ecosystems.
10. The effect of the atmospheric deposition of nutrient salts cannot be ascertained precisely, in addition to which climatic changes may play a hitherto unknown role for the succession currently in progress.
11. It is crucially important that a follow-up to the conservation initiatives in the form of the clearing of Mountain Pine growth takes place, and ongoing monitoring of the development of the vegetation is recommended.
12. The use of mosaic burning to areas, where proximity to nutrient and mineral resources, i.e. dune heaths affected strongly by the sea, moraine deposits and/or agricultural land.

Guidelines for best management practice with respect to Atlantic coastal heaths

1. Clearing of invasive exotic conifers should take place at the earliest possible occasion. The reason is that trees are highly competitive with respect to light and change the microclimate strongly, especially with respect to temperature and humidity variation. Furthermore, trees accumulate organic matter and minerals in the topsoil, which prolongs the recovery time for the original conditions for the nutrient poor dune heath.

2. Clearing of *Pinus mugo* should always imply a total removal of the above ground biomass, including needles and cones. The total above ground biomass should be collected and burnt on selected spots in the field or chopped outside the cleared heath area, e.g. for use in power plants. The choice of burning in piles at selected spots is only recommended, when very large, rather inaccessible heath areas are to be managed.

3. Manual removal of self sown young plants of *Pinus* sp. is necessary every year at least the first three years immediately after clearing of stands of *Pinus* sp. Thereafter the manual removal should be done every third year, until no seed germination of *Pinus* sp. occur.

4. In some parts of the coastal heaths, extensive grazing (mainly by sheep, but in some cases cattle) is recommended to maintain open vegetation dominated by herbs, after clearing of self sown *Pinus* sp. and/or *Picea* sp. This is particularly recommended, with close proximity to moraine deposits below the Aeolian sandy top soil. This is e.g. the case in large parts of SCI 78 in the present project.

5. It is beneficial (in practical and economic terms) to carry out the clearing of Mountain Pine in dry sand heaths and bogs with heavy equipment on wide, preferably slick, tyres such that driving takes place as much as possible in the same tracks and preferably in the slacks, avoiding the transition zone between the dry heath vegetation and the dune slack. The most valuable plant communities occur in the broad zone and the transition zone between the bog and dune areas.

6. Fire spots for pile burning should be placed with a mutual distance of app. 50 meters, preferably on flat terrain. The fire pots should never be placed on the grey dunes or in the transition zone between grey dunes and the neighbouring flat terrain, often with dune slack vegetation. Transportation of tree cuttings should be manually or by trucks with broad, non-profile tyres. The tracks left after truck transportation should be left unchanged.

7. A time interval of 5-10 years is recommended between burnings at selected fire spots, using always the same spots, if this approach is considered necessary due to reinvasion of conifers.

The above guidelines summarize the experience from this and previous LIFE projects. It must be emphasized, that only through continuous management and monitoring of the vegetation and its ecological conditions may we be able to maintain the extremely valuable dune heath ecosystem in Denmark.

Acknowledgements

The financial support from the EU-LIFE programme is highly appreciated, and thanks are also due to the Danish Forest and Nature Agency, Thy National Forest District in particular, for managing and coordinating the present project in Denmark.

Ib Johnsen, December 2005

Background literature

Alonso, I. & Hartley, S. E. 1998. Effects of nutrient supply, light availability and herbivory on the growth of heather and three competing grass species. Plant Ecology 137: 203-2 12.

Alonso, I, Hartley, S. E., Thurlow, M. 2001. Competition between heather and grasses on Scottish moorlands: Interacting effects of nutrient enrichment and grazing regime. Journal of Vegetation Science 12: 249-260.

Ampe, C. & Langohr, R. 2001. Morphological characterization of humus forms in coastal dune systems: experience from the Flemish coast northwest France. pp. 422-428 in: Houston, J. A., Edmondson, S. E. & Rooney, P. J. (red.), Coastal Dune Management. Shared Experience of European Conservation Practice. Liverpool University Press, Liverpool. *458* p.

Andersen, A. G., Boesen, D. F. , Holmen, K., Jacobsen, N., Lewinsky, J., Mogensen, G., Rasmussen, K. and Rasmussen, L. 1976. Den danske mosfiora. I. Bladmosser. Gyldendal, Copenhagen. 356 p.

Atkinson, D. 1988. Effects of afforestation on a sand-dune grassland. British Ecological Society Bulletin 19: 99-101

Avis, A. M. & Lubke, R.A. 1996. Dynamics and succession of coastal dune vegetation in the Eastern Cape, South Africa. Landscape and Urban Planning 34: 23 7-254

Barclay-Estrup, P. & Gimingham, C. H. 1969. The description and interpretation of cyclical processes in a heath community: I. Vegetational change in relation to the *Calluna* cycle. Journal of Ecology *57(3):* 737-758.

Barkman, J. J. 1990. Ecological differences between *Calluna*- and Empetrum-dominated dry heath communities in Drenthe, the Netherlands. Acta Bota.nica Neerlandica 39(1): 75-92.

Bell, *3.* N. B. & Talus, 3. H. 1973. Biological Flora of the British Isles. Empetrum nigrum L. Journal of Ecology 61: 289-305.

Berendse, F. 1990. Organic matter accumulation and nitrogen mineralisation during secondary succession in heath. Journal of Ecology 78: 413-427.

Berg, B. & Staaf, H. 1981. Leaching, accumulation and release of nitrogen in decomposing forest litter. Ecological Bulletin 33: 163-178

Berg, B. 1986. Nutrient release from litter and humus in coniferous forest soils – a mini review. Scand. J. For. Res. 1: 3 *59-369.*

Brandt, E. & Christensen, S. N. 1994. Danske klitter – en oversigtlig kortl~gning. Bind 1-2.Danish Ministry of the Environment, Danish Forest and Nature Agency.

Bridges, E. M. 1997. World Soils. Chap. 1-4, 9. Third edition. Cambridge University Press, Cambridge. 170 p.

Brown, A.C. & McLachlan, A. 1990. Ecology of Sandy Shores. Chap. 12. Elsevier, Amsterdam, Oxford, New York, Tokyo. 320 p.

Brâkenhielm, S. & Liu, Q**.** 1998. Long-term effects of clear-felling on vegetation dynamics and species diversity in a boreal pine forest. Biodiversity and Conservation 7: 207-220.

Böcher, T. W. 1980. Klitvegetation. pp. 252-293 in: Nerrevang, A. & Lundø, J. (red.), Danmarks natur, bind 4. Kyst, klit og marsk. Politikens Forlag A/S, Copenhagen. *524* p.

Chapman, S.B. 1970. The nutrient content of the soil and root system of a dry heath ecosystem. Journal of Ecology *58:* 445-452.

Christensen, S. N. 1989. Floristic and vegetational changes in a permanent plot in a Danish coastal dune heath. Ann. Bot. Fennici 26: 389-397.

Christensen, Steen N. & Ib Johnsen (2001): The lichen-rich coastal heath vegetation on the isle of Anholt, Denmark - description, history and development. - *Journal of Coastal Conservation* 7: 1-12.

Christensen, Steen N. & Ib Johnsen (2001): The lichen-rich coastal heath vegetation on the isle of Anholt, Denmark - conservation and management. - *Journal of Coastal Conservation* 7: 13-22.

Diaz Barradas, M. C. , During, H. J. & Terlou, M. 1992. The structure of Bryophyte communities in the dunes of Meijendel, Netherlands. pp. 313-323 in: Carter, R. W. G., Curtis, 1. 0. F. & Sheehy-Skeffinton, M. 3. (red.), Coastal Dunes. Geomorphology, Ecology and Management for Conservation. Balkema, Rotterdam. 533 p.

Donelan, M. & Thompson, K. 1980. Distribution of buried viable seeds along a successional series. Biological Conservation 17: 297-311.

During, H. J. 1992. Ecological classifications of bryophytes and lichens. pp. 1-31 in: Bates, J. W. & Farmer, A. M. (red.), Bryophytes and Lichens in a changing Environment. Clarendon Press, Oxford. 404 p.

Egler, F. E. 1954. Vegetation Concepts I. Initial floristic composition, a factor in old-field vegetation development. Vegetatio 4: 412-417

Feilberg, A. 1981. Klitter og sandflugt. pp. 211-233 in: Nerrevang, A. & Lundø, J. (red.), Danniarks Natur, bind 10. Mennesket og naturen. Politikens Forlag A/S, Copenhagen. 448 p.

Feilberg, A. & Jensen, F. 1992. Management and conservation of sand dunes in Denmark. pp. 429-437 in: Carter, R. W. G., Curtis, 1. G. F. & Sheehy-Skeffinton, M. J. (red.), Coastal Dunes. Geomorphology, Ecology and Management for Conservation. Balkema, Rotterdam. 533 p.

Giesler, R., Högberg, M. and Hogberg, P. 1998. Soil chemistry and plants in Fennoscandian boreal forest as exemplified by a local gradient. Ecology 79(1): 119-137

Gimingham, C. H. 1978. Calluna and its associated species: Some aspects of co-existence in communities. Vegetatio 36(3): 179-186.

Gimingham, C. H. 1987. Harnessing the wind of change: Heathland ecology in retrospect and Prospect. Journal of Ecology *75:* 895-914.

Gimingham, C. H. 1988. A reappraisal of cyclical processes in *Calluna* heath. Vegetatio 77: 61-64.

Gimingham, C. H. 1989. Heather and heathlands. Botanical Journal of the Linnean Society 101: 263-268.

Grandin, U. 2001. Short-term and long-term variation in seed bank/vegetation relations along an environmental and successional gradient. Ecography 24: 731-741.

Granström, A. 1987. Seed viability of fourteen species during five years of storage in a forest soil. Journal of Ecology *75:* 321-331.

Granström, A. 1988. Seed banks at six open and afforested heathiand sites in southern Sweden. Journal of Applied Ecology *25:* 297-306.

Grime, J. P. 1974. Vegetation classification by references to strategies. Nature 250: 26-31.

Grime, J. P., Hodgson, J. G. & Hunt, R. 1989. Comparative plant ecology: a functional approach to common British species. pp. *1-52,* 647-653. Unwin Hyman, London. 742 p.

Grime, J. P. 2001. Plant strategies, vegetation processes and ecosystem properties. Chap. 1-9. John Wiley & Sons Ltd., Chichester. [417]p.

Hackett, C. 1967. Ecological aspects of the nutrition of *Deschampsiafiexuosa* (L.) Trim. III. Investigation of phosphorus requirement and response to aluminium in water culture, and a study of growth in soil. Journal of Ecology *55:* 83 1-840.

Hansen, B. & Nielsen, K. E. 1998. Comparison of acidic deposition to semi-natural eco-systems in Denmark – coastal heath, inland heath and oak wood. Atmospheric Environment 32(6): 1075-1086

Hansen, K. (red.) 1981. Dansk feitfiora. Gyldendal, Copenhagen. 757 p.

Hallingback, T. & Holmásen, I. 1981. Mossor. En fälthandbok. Interpublishing. Stockholm. 287 p. Hawkes, J. C. Pyatt, D. 0. & White, I. M. S. 1997. Using Ellenberg indicator values to assess soil quality in British forests from ground vegetation: a pilot study. Journal of Applied Ecology 34: 375-387.

Heil, 0. W. & Bruggink, M. 1983. Raised nutrient levels change heathland into grassland. Vegetatio 53: 113-120.

Helsper, H. P. G. & Klerken, G. A. M. 1984. Germination of *Calluna vulgaris* (L.) Hull in vitro under different pH-conditions. Acta Botanica Neerlandica 33(3): 347-353.

Henriksen, H. A. 1988. Skoven og dens dyrkning. pp. 429-438, 598. The Danish Forest Association, Nyt Nordisk Forlag Arnold Busck, Copenhagen. 664 s.

Hill, M. 0. & Gauch, H. G. Jr. 1980. Detrended correspondence analysis: An improved ordination technique. Vegetatio 42: 47-58.

Hill, M. 0. & Wallace, H. L. 1981. The density of viable seed in soils of forest plantations in upland Britain. Journal of Ecology 69: 693-709.

Hobbs, R. 3. 1984. Possible chemical interactions among heathplants. Oikos 43: 23-29.

Holmen, K. (revideret afMogensen, 0. S.) 1980. Skovens mosser. pp. 301-307 in: Nørrevang, A. & Lundø, 3. (red.), Danmarks natur, bind 6. Skovene. Politikens Forlag AJS, Copenhagen. 604 p.

Hullu, E. de & Gimingham, C. H. 1984. Germination and establishment of seedlings in different phases of the *Calluna* life cycle in a Scottish heathiand. Vegetatio 58: 115-121.

Humphrey, J. W., Newton, A. C., Peace, a. J. & Holden, E. 2000. The importance of conifer plantations in northern Britain as a habitat for native fungi. Biological Conservation 96: 241-252.

Isermann, M. & Cordes, H. 1992. Changes in dune vegetation on Spiekeroog (East Friesian islands) over a 30 year period. pp. 20 1-209 in: Carter, R. W. 0., Curtis, T. G. F.

& SheehySkeffinton, M. J. (red.), Coastal Dunes. Geomorphology, Ecology and Management for Conservation. Balkema, Rotterdam. 533 p.

Johansson, M. 1995. THE HEATH PROJECT: VI. The role of atmospheric nitrogen deposition on the mycorrhizal colonization of *Calluna vulgaris* (L.) Hull. in a Danish heathiand. Aarhus Geoscience 4: 125-130.

Jongman, R. H. G., ter Braak, C. J. F. and van Tongeren, 0. F. R. 1995. Data analysis in community and landscape ecology. Chap. *5,6,8.* Cambridge University Press, Cambridge. 299 pp.

Kelly, D. L. & Conolly, A. 2000. A review of the plant communities associated with Scots Pine *(Pinus sylvestris* L.) in Europe, and an evaluation of putative indicator/specialist species. Invest. Agr.: Sist. Recur. For.: Fuera de Serie 1: 16-39

Kent, M. & Coker, P. 1992. Vegetation Description and Analysis. A Practical Approach. Chap. *5,6,7,8.* Belhaven Press, London.

Ketner-Oostra, R. 2001. Expected positive effects of shoreface nourishment on the vegetation of calcium-poor dunes at Terschelling (The Netherlands). pp. 59-62 in: Houston, *3.* A., Edmondson, S. E. & Rooney, P. J. (red.), Coastal Dune Management. Shared Experience of European Conservation Practice. Liverpool University Press, Liverpool. 458 p.

Koerselman, W. & Meuleman, F. M. 1996. The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation. Journal of Applied Ecology 33: 1441-1450.

Kuhlman, H. 1980. Kystklitteme. S. 160-186 i: Nørrevang, A. & Lundø, J. (red.), Darimarks Natur, bind 4. Kyst, klit og marsk. Politikens Forlag A/S. Copenhagen. 524 p.

Lemauviel, S. & Roze, F. 2000. Ecological study of pine forest clearings along the French Atlantic sand dunes: Perspectives of restoration. Acta Oecologica 2 1(3): 179-192.

Longton, R. E. 1992. The role of bryophytes and lichens in terrestrial ecosystems. pp. 32-76 in: Bates, J. W. & Farmer, A. M. (red.), Bryophytes and Lichens in a changing Environment. Clarendon Press, Oxford. 404 p.

Lægaard, S. 1981. Heder, overdrev og enge. pp. 280-301 in: Nørrevang, A. & Lundø, J. (red.), Danmarks natur, bind 10. Mennesket og naturen. Politikens Forlag AJS, Copenhagen. 448 p.

Magnusson, M. 1981. Composition and successions of bryophytes and lichens in a coastal dune area in southern Sweden. University of Lund, Sweden. 52 p.

Magnusson, M. 1982. Composition and succession of lichen communities in an inner coastal dune area in southern Sweden. Lichenologist 14(2): 153-163.

Michelsen, A., Schmidt, I. K., Jonasson, S., Quarmby, C. & Sleep, D. 1996. Leaf ‘5N abundance of subarctic plants provides field evidence that ericoid, ectomycorrhizal and non-and arbuscular mycorrhizal species access different sources of soil nitrogen. Oecologia 105: 53-63.

Miles, J. 1981. Problems in heathland and grassland dynamics. Vegetatio 46: 6 1-74.

Moberg, R. & Holmâsen, I. 1982. Lavar. En fãlthandbok. Interpublishing, Stockholm. 240 p.

Møller, C. M. 1977. Vore skovtræarter og deres dyrkning. pp. 197-203, 2 10-215. The Danish Forest Association, Copenhagen. 552 p. Nielsen, K. E., Hansen, B., Ladekarl, U. L. and Nørnberg, P. 2000. Effects of N-deposition on ion trapping by B-horizons of Danish heathiands. Plant and Soil 223: *265-276.*

Noble, J. C., Bell, A. D. and Harper, J. L. 1979. The population biology of plants with clonal growth. I. The morphology and structural demography of *Carex arenaria.* Journal of Ecology 67: 983-1008.

Noble, J. C. 1982. Biological flora of the British Isles. Carex arenaria L. Journal of Ecology 70: 867-886.

Noble, J. C. & Marshall, C. 1983. The population biology of plants with clonal growth. II. The nutrient strategy and modular physiology of *Carex arenaria.* Journal of Ecology 71: 865-877.

Ovesen, C. H. & Vestergaard, P. 1994. Danske klitter – overvâgning, forvaitning og forskning. Danish Ministry of the Environment, Forest and Nature Agency. 142 p.

Ovesen, C. H. 2001. Management of Danish dunes today: theory and practice. pp. 302-305 in: Houston, J. A., Edinondson, S. E. & Rooney, P.3. (red.), Coastal Dune Management. Shared Experience of European Conservation Practice. Liverpool University Press, Liverpool. 458 p.

Persson, S. 1981. Ecological indicator values as an aid in the interpretation of ordination diagrams. Journal of Ecology 69, 71-84.

Pons, T. L. 1989. Dormancy, germination and mortality of seeds in heathland and inland sand dunes. Acta Botanica Neerlandica 38: 327-335.

Prentice, I. C., van Tongeren, 0. & Dc Smidt, J. T. 1987. Simulation of heathiand vegetation dynamics. Journal of Ecology 75: 203-219.

Prins, A. H., Berdowski, J. J. M. & Latuhihin, M. J. 1991. Effect of NH_4-fertilization on the maintenance of a *Ca/luna vulgaris* vegetation. Acta Botanica Neerlandica 40(4): 269-279.

Putwain, P. D. & Giliham, D. A. 1990. The significance of the dormant viable seed bank in the restoration of heathlands. Biological Conservation 52: 1-16.

Ranwell, D. S. 1972. Ecology of Salt Marshes and Sand Dunes. Chap. 1-3, 8-11, 13. Chapman and Hall, London. 258 p.

Ranwell, D. S. & Boar, R. 1986. Coast dune management guide. Institute of Terrestrial Ecology. Natural Environment Research Council. Huntingdon. 105 p.

Read, D. J. 1991. Mycorrhizas in ecosystems. Experientia 47: 376-39 1.

Read, D. J. 1996. The structure and function of the ericoid myconhizal root. Annals of Botany 77: 365-374.

Rhind, P. M., Blackstock, T. H. Hardy, H. S. Jones, R. E. & Sandison, W. 2001. The evolution of Newborough Warren dune system with particular reference to the past four decades. pp. 345-379 in: Houston, J. A., Edmondson, S. E. & Rooney, P. J. (red.), Coastal Dune Management. Shared Experience of European Conservation Practice. Liverpool University Press, Liverpool. 458 p.

Riis-Nielsen, I. 1995. THE HEATH PROJECT: V. Response of the heathland vegetation to nitrogen deposition. Aarhus Geoscience 4: 117-124.

Risager, M. 1991. Nitrogen depositionens indflydelse pA vegetationen I ekstremoligotrophic fen, med s~r1igt henblik pa Sphagnum. 124 pages. M.Sc. thesis, Botanical Institute, University of Copenhagen.

Ritchie, W. 2001. Coastal dunes: resultant dynamic position as a conservational managerial objective. pp. 1-14 in: Houston, J. A., Edmondson, S. E. & Rooney, P. J. (red.), Coastal Dune Management. Shared Experience of European Conservation Practice. Liverpool University Press, Liverpool. 458 p.

Santesson, R. 1984. The lichens of Sweden and Norway. pp. 57-58, 62-69, 93, 170, 182. Swedish Museum of Natural History, Stockholm and Uppsala. 333 p.

Schierup, H. H. & Jensen, A. 1981. Vejiedning i kemisk og fSsisk analyse afjordprøver og plantemateriale. pp. 69-73, 167-169. Botanical Institute, University of Aarhus.

Schippers, P., van Groenendael, J. M., Vleeshouwers, L. M. & Hunt, R. 2001. Herbaceous plant strategies in disturbed habitats. Oikos 95: 198-2 10.

Simpson, D. E. & Gee, M. 2001. Towards best practice in the sustainable management of sand dune habitats: 1. The restoration of open dune communities at Ainsdale Sand Dunes National Nature Reserve. pp. *255-261* in: Houston, J. A., Edmondson, S. E. & Rooney, P. (red.), Coastal Dune Management. Shared Experience of European Conservation Practice. Liverpool University Press, Liverpool. 458 p.

Danish Forest and Nature Agency. Driftsplan for Thy Statsskovdistrikt 1988 – 2003. pp. 41-*57*, 68-70.

Staaf, H. & Berg, B. 1982. Accumulation and release of plant nutrients in decomposing Scots pine needle litter. Long-term decomposition in a Scots pine forest II. Canadian Journal of Botany 60: 156 1-1568.

Sturgess, P. 1992. Clear-felling dune plantations: Studies in vegetation recovery. pp. 33 9-349 in: Carter, R. W. G., Curtis, T. G. F. & Sheehy-Skeffinton, M. J. (red.), Coastal Dunes. Geomorphology, Ecology and Management for Conservation. Balkema, Rotterdam. 533 p.

Sturgess, P. & Atkinson, D. 1993. The clearfelling of sand-dune plantations: Soil and vegetational processes in habitat restoration. Biological Conservation 66: 17 1-183.

Sveinbjörnsson, B. & Oechel, W. C. 1992. Controls on growth and productivity of bryophytes: environmental limitations under current and anticipated conditions. pp. 77-102 in: Bates, 3. W. & Farmer, A. M. (red.), Bryophytes and Lichens in a changing Environment. Clarendon Press, Oxford. 404 p.

Søchting, U. & Johnsen, 1. 1990. Overvågning af de danske lichenheder. Urt 1: 4-9

Söderström, L. 1992. Invasion and range expansions and contractions of bryophytes. pp. 131-158 in: Bates, J. W. & Farmer, A. M. (red.), Bryophytes and Lichens in a changing Environment. Clarendon Press, Oxford. 404 p.

Ter Braak, C. J. F. & Gremmen, N. 3. M. 1987. Ecological amplitudes of plant species and the internal consisitency of Ellenberg’s indicator values for moisture. Vegetatio 69: 79-87.

Ten Harkel, M. J. & van der Meulen, F. 1995. Impact of grazing and atmospheric nitrogen deposition on the vegetation of dry coastal dune grasslands. Journal of Vegetation Science 6: 445-452.

Troelstra, S. R., Wagenaar, R. & de Boer, W. 1990. Nitrification in Dutch heathiand soils. I. General soil characteristics and nitrification in undisturbed soil cores. Plant and Soil 127: 179-192.

Tybirk, K. & Nan Hansen, D. 1999. Revling i klitheden. Urt 23(4): 115-120

Van Aide1, 3. & Nelissen, H. *3.* M. 1979. Nutritional status of soil and plant species in several clearings in coniferous woods compared to that in two related habitats. Vegetatio 39(2): 115-121

Van der Maarel, E. et al 1985. Vegetation succession on the dunes near Oostvorne, The Netherlands; a comparison of the vegetation in 1959 and 1980. Vegetatio 58: 137-187

Van Zoest, 3. 1992. Gambling with nature? A new paradigm of nature and its consequences for nature management strategy. pp. *503-5* 15 in: Carter, R. W. G., Curtis, T. G. F. & Sheehy Skeffinton, M. (red.), Coastal Dunes. Geomorphology, Ecology and Management for Conservation. Balkema, Rotterdam. 533 p.

Vedel, H. 1980. Kulturskov. pp. 200-240 in: Nørrevang, A. & Lundø, J. (red.), Danmarks natur, bind 6. Skovene. Politikens Forlag A/S. Copenhagen. 604 p.

Veer, M. A. C. & Kooijman, A. M. 1997. Effects of grass-encroachment on vegetation and soil in Dutch dry dune grasslands. Plant and Soil 192: 119-128.

Vinther-Larsen, K. M. 1993. Plantage eller klit? – en undersøgelse af vegetationens udvikling klitomrAder efter f~ldning afbjergfyrplantager. University of Copenhagen. M.Sc. thesis (unpublished)

Vitousek, P. M. 1981. Clear-cutting and the nitrogen cycle. Ecological Bulletin 33: 631-642.

Wallén, B. 1980. Structure and dynamics of Calluna vulgaris on sand dunes in south Sweden. Oikos 35: 20-30.

Warming, E. 1909. Dansk P1antev~ekst 2. Klitterne. Kap. *5-11.* Nordisk Forlag. Copenhagen. 376 p.

Webb, N. R. & Vermatt, A. H. 1990. Changes in vegetational diversity on remnant heathiand fragments. Biological Conservation *53:* 253-264.

Wilhjelmudvalget 2001. Natur i Danmark - status, mål og midler - rapport fra Wilhjelmudvalgets arbejdsgruppe for naturkvalitet og naturovervågning. Danish Forest and Nature Agency, Copenhagen. 256 p.

Wilson, P. 1992. Trends and timescales in soil development on coastal dunes in the north of Ireland. pp. 153-162 in: Carter, R. W. G., Curtis, T. G. F. & Sheehy-Skeffinton, M. *3.* (red.), Coastal Dunes. Geomorphology, Ecology and Management for Conservation. Balkema, Rotterdam. 533 p.

Zinke, P. J. 1962. The pattern of influence of individual forest trees on soil properties. Ecology 43: 130-133.

Økland, R. H. 1990. Vegetation ecology: theory, methods and applications with reference to Fennoscandia. Sommerfeltia supplement. 233 p.