RESTORATION OF DUNE HABITATS IN ØSTERILD KLITPLANTAGE – BASELINE MONITORING 2011

Scientific Report from DCE – Danish Centre for Environment and Energy No.13 2011

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Data sheet

Series title and no.: Scientific Report from DCE – Danish Centre for Environment and Energy No. 13

Title: Restoration of dune habitats in Østerild Klitplantage - baseline monitoring 2011

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Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dmu.au.dk/en

Year of publication: November 2011
Editing completed: November 2011
Editor: Tommy Asferg
Referees: Danish Nature Agency and Anthony Fox

Financial support: Ministry of Environment

Please cite as: Nygaard, B., Wind, P. & Ejrnæs, R. 2011. Restoration of dune habitats in Østerild Klitplantage - baseline monitoring 2011. Aarhus University, DCE – Danish Centre for Environment and Energy, 36 pp. - Scientific Report from DCE – Danish Centre for Environment and Energy No. 13
http://www.dmu.dk/Pub/SR13.pdf

Abstract: The establishment of a national test centre for wind turbines in Østerild Klitplantage will lead to clear-felling of up to 266 ha coniferous dune plantations. The agreement parties decided that the vegetation development from coniferous forest to open dune habitats should be monitored. The monitoring programme includes a recording of soil conditions and plant species composition prior to clear-cutting of the coniferous dune plantations (baseline monitoring) and a systematic recording of the changes during the first 10 years of the succession towards open dune habitats (post-construction monitoring). This report presents the sites and plots included in the monitoring programme as well as the main results of the baseline monitoring that was conducted in July 2011.

Keywords: Østerild, national test centre, monitoring, restoration, deforestation, dune habitats, vegetation development, wind turbines

Layout: Graphics Group, AU Silkeborg
Front page photo: Scots Pine plantation in the National Test Centre facility in Østerild Klitplantage.
Photo: Peter Wind

ISBN: 978-87-92825-25-4
ISSN (electronic): 2245-0203

Number of pages: 36

Internet version: The report is available in electronic format (pdf) at
http://www.dmu.dk/Pub/SR13.pdf

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Summary

The overall objective of the monitoring programme is to document the outcome of the restoration project which focuses upon creating open dune habitats following clear-cutting of dune plantations in the National Test Centre facility for wind turbines in Østerild Klitplantage. The monitoring programme includes a recording of soil conditions and plant species composition prior to clearing of dune plantations (baseline monitoring) and a systematic recording of the changes during the first 10 years of the succession towards open dune habitats (post-construction monitoring). This report presents the monitoring sites and plots as well as the main results of the baseline monitoring.

Monitoring sites and plots were laid out in a stratified random arrangement in order to accommodate the different starting points and restoration measures. Stratification was applied according to baseline condition (forest type), planned post-cutting treatments of litter layer and hydrology, expected management regimes, distance to appropriate seed sources and topography.

The dune plantations planned for clear-felling in the test area were predominantly coniferous forests, with introduced spruces, pines and firs (mainly *Picea sitchensis,* Sitka Spruce and *P. mugo,* Mountain Pine) as well as the native pine *Pinus sylvestris* (Scots Pine). The starting conditions are assumed to have a major impact on succession following deforestation and the monitoring sites thus include Mountain Pine, Sitka Spruce and Scots Pine stands.

In order to facilitate the restoration of grey dunes (habitat type 2130), dune heaths (habitat type 2140) and humid dune slacks (habitat type 2190) various post-cutting treatments of hydrology and accumulated soil organic matter will be implemented. The monitoring programme includes an assessment of the effect of these treatments on the rate and direction of vegetation development towards the target communities. Hopefully the results will lead to recommendations for improving the management of future conversions of plantations to dune habitats.

Prior to afforestation in late 1800, the dune areas in Østerild and Hjardemål Plantage were characterized by a high and presumably highly fluctuating water table and consequently moist and wet habitats were widespread in the area. A successful restoration of moist dune heaths (2140) and humid dune slacks (2190) will therefore require a restoration of the original hydrological regime. One of the planned actions in Østerild is thus to close drainage dykes and allow temporary pools and shallow lakes to develop or expand. The monitoring programme aims to follow the succession in dry and rewetted dune habitats, including areas that will be seasonally flooded.

Coniferous litter is acidic and the decomposition rate is very low, which leads to an accumulation of needles, cones and twigs on the forest floor. A thick litter layer in the coniferous forest may constitute a major constraint on the restoration of natural dune habitats. In cooperation with the Danish Nature Agency in Thy, we have included four different post-cutting experimental treatments of the accumulated organic matter: 1) removal of litter layer and exposure of bare soil in larger patches, 2) removal of litter layer

and exposure of bare soil in smaller patches, 3) burning of litter layer and 4) intact litter layer (control treatment).

Baseline monitoring was carried out in July 2011, prior to clear-cutting of the plantations and the methods are based on the variables in the NOVANA programme for terrestrial habitats (Fredshavn et al. 2011). We recorded the plant species composition and vegetation structure in a pin point frame (0.5 * 0.5 m) and a documentation circle with a radius of 5 m for each of the 100 monitoring plots. Furthermore, we collected soil samples from all plots for pH measurements (100 samples) and C/N ratio analyses (24 samples) and we measured the thickness of the accumulated organic matter in the forest floor (the litter layer).

We found that species richness was highest in Scots Pine stands and lowest in Sitka Spruce sites. The most widespread species were *Deschampsia flexuosa*, *Picea sitchensis*, *Pleurozium schreberi* and *Hypnum jutlandicum*, all occurring in more than 50% of the plots. Furthermore *Molinia caerulea*, *Dryopteris carthusiana, Vaccinium uliginosum*, *Carex arenaria* and *Dicranum scoparium* were found in more than one third of the plots.

We compared the vegetation composition in the afforested dune plots in Østerild with reference dune plots from the NOVANA monitoring and found that the vegetation in Mountain Pine stands have the largest floristic similarity with acidic grey dune and relatively dry dune heath, while plots in Scots Pine stands mainly share species with moist dune heath and relatively dry dune slack. The forest floor vegetation in the Sitka Spruce stands differs markedly from all open dune target vegetation types.

We found the highest average vegetation height in Scots Pine stands, while a distinct herb layer was absent or highly scattered in one of the Sitka Spruce stands. Furthermore, we found that two out of three Scots Pine stands had a relatively high cover of dwarf shrubs of which *Vaccinium uliginosum* was the most abundant species followed by *Empetrum nigrum*, *Calluna vulgaris*, *Erica tetralix* and *Myrica gale*. Dwarf shrubs were absent or highly scattered in the two Sitka Spruce stands.

We examined the cover and species composition of bryophytes and terricolous lichens (growing on soil surface). We found 18 bryophytes species and a relatively high cover of bryophytes in two of the three Scots Pine stands and the Mountain Pine stands. The most abundant bryophytes were *Pleurozium schreberi* and *Hypnum jutlandicum*, both very common species in coniferous forests.

Furthermore we found 7 terricolous lichen species, but a very low lichen cover in the forest floor. Lichen cover exceeded 5% in only 3 plots in the Mountain Pine stand.

We found a very high canopy cover in the Sitka Spruce stands with very few gaps for light penetration. Light penetration through the forest canopy was relatively high in one out of four plots in the Mountain Pine stand and plots from one of the Scots Pine stands.

We found highly acidic soils in the Sitka Spruce stands (pH around 2.75) and one of the Scots Pine stands. In the Mountain Pine stand and one of the Scots Pine stand soil pH was slightly higher, while in one Scots Pine stand 50% of the samples had a pH value above 3. Furthermore, we found that in grey dune (2130), dune heath (2140) and dune slack (2190) plots from the NOVANA programme, soil acidity was on average one pH unit higher than the afforested dunes in Østerild (3.8 on average versus 2.8). The low pH-values may impose significant constraints on the restoration of dune communities as acidification as it is known to lead to species loss in heathland and acidic grassland.

We found the thickest litter layer in one of the two Sitka Spruce plantations with a median litter depth of 12 cm. In the Mountain Pine stand the thickness of the litter layer was rather low, with a median value of 4 cm.

Generally the measured carbon-nitrogen ratios in the top-soil were rather low. The highest values were recorded in the 4 samples from the Mountain Pine stand (median = 29), while the C:N ratio was considerably lower in one of the 3 Scots Pine stands (median =19). We found a significant negative correlation between soil pH and the C:N ratio, which indicates that the decomposition of organic material in the forest soil is closely connected with pH.

Resume

Det overordnede formål med overvågningsprogrammet er at dokumentere successionen mod åbne klitnaturtyper efter rydningen af nåletræsbevoksninger i det nationale testcenter for vindmøller i Østerild Klitplantage. Overvågningsprogrammet omfatter en registrering af jordbundsforhold, vegetationens struktur og artssammensætning, før træerne fældes ("baseline overvågning"), og en systematisk registrering af ændringerne gennem de første 10 år af successionen mod lysåbne klit-naturtyper ("post-construction overvågning"). Denne rapport præsenterer udvælgelsen af overvågningsstationer og prøvefelter og de overordnede resultater fra baseline-overvågningen.

Overvågningsstationer og prøvefelter blev udlagt stratificeret tilfældigt med henblik på at dække variationen i udgangspunktet for vegetationsudviklingen og de behandlinger, der er skitseret i implementeringsplanen. Stratificeringen omfatter udgangspunktet (skovtype), de planlagte behandlinger af førne og hydrologi, forventet pleje og drift af den lysåbne klitnatur, afstand til egnede spredningskilder og topografi.

Skovrydningen foregår primært i nåleskove med introducerede arter af fyr og gran (særligt sitka-gran og bjerg-fyr) samt plantager med skov-fyr, der er en hjemmehørende art. Udgangspunktet antages at have en stor betydning for successionen efter skovrydningen, og overvågningsstationerne omfatter derfor bevoksninger med både sitka-gran (2), bjerg-fyr (1) og skov-fyr (3).

For at fremme udviklingen mod grå/grøn klit (habitattype 2130), klithede (habitattype 2140) og fugtig klitlavning (habitattype 2190) er en række efterbehandlinger af førnelaget og en genopretning af det hydrologiske regime inkluderet i implementeringsplanen for det nationale testcenter i Østerild. Overvågningsprogrammet omfatter en vurdering af effekten af de planlagte behandlinger på successionens hastighed og retning. Resultaterne vil så vidt muligt indgå i anbefalinger til fremtidige genopretningsprojekter, hvor formålet er at konvertere plantage til lysåbne naturtyper.

Før tilplantningen sidst i 1800-tallet var klitterne i Østerild og Hjardemål Plantage karakteriseret ved en høj og fluktuerende vandstand, og fugtige og våde plantesamfund var vidt udbredte i landskabet. En succesfuld restaurering af fugtige klitheder (2140) og fugtige klitlavninger (2190) vil derfor forudsætte genopretning af det hydrologiske regime. I Østerild indgår det derfor i implementeringsplanen, at en del af de eksisterende afvandingsgrøfter skal kastes til hvorved der udvikles en række temporære vandhuller og lavvandede søer. Overvågningsprogrammet vil følge udviklingen i tørre og fugtig naturtyper, herunder tidvis oversvømmede arealer.

I nåletræsplantager er førnen sur, og nedbrydningsraten er lav, hvilket fører til en ophobning af nåle, kogler og kviste på skovbunden. Et tykt førnelag kan begrænse mulighederne for at retablere de naturlige plantesamfund i klitterne. I samarbejde med Naturstyrelsen i Thy har vi valgt at følge udviklingen ved fire forskellige behandlinger af det ophobede organiske materiale: 1) fjernelse af førne og eksponering af bar jord i større områder, 2) pletvis fjernelse af førne og eksponering af bar jord, 3) afbrænding af førnelaget og 4) intakt førnelag (kontrol behandling).

Baseline-overvågningen blev udført i begyndelsen af juli 2011 og var afsluttet, inden skov blev ryddet. Overvågningen er udført efter de metoder, der indgår i den nationale overvågning af habitatdirektivets terrestriske naturtyper (NOVANA programmet) (Fredshavn et al. 2011). For hvert af de 100 prøvefelter har vi foretaget en registrering af artssammensætning og vegetationsstruktur i en pin point ramme (0,5 * 0,5 m) og en dokumentationscirkel med en radius på 5 m. Desuden har vi indsamlet jordprøver i prøvefelterne til analyse af pH (100 prøver) og C/N-ratio (24 prøver), og vi målte tykkelsen af det ophobede organiske materiale på skovbunden (førnelaget).

Vi fandt den største artsrigdom i skov-fyr bevoksningerne og den laveste i skovbunden under sitka-gran. De mest udbredte arter var *Deschampsia flexuosa* (bølget bunke), *Picea sitchensis* (sitka-gran), *Pleurozium schreberi* og *Hypnum jutlandicum*, der alle forekom i mere end 50% af prøvefelterne. Yderligere fandt vi *Molinia caerulea* (blåtop), *Dryopteris carthusiana* (smalbladet mangeløv), *Vaccinium uliginosum* (mose-bølle), *Carex arenaria* (sand-star) og *Dicranum scoparium* i mere end hvert tredje prøvefelt.

Vi sammenlignede artssammensætningen i klitplantagerne i Østerild med reference-prøvefelter fra NOVANA overvågningen og fandt, at vegetationen under bjerg-fyr havde den største floristiske lighed med sure grå klitter og relativt tørre klitheder, medens bundvegetationen i skov-fyr bevoksningerne primært delte arter med fugtige klitheder og relativt tørre klitlavninger. Artsammensætningen i sitka-plantagerne var tydeligt forskellig fra den lysåbne referencevegetation.

Vi fandt den højeste gennemsnitlige vegetationshøjde i skov-fyr bevoksningerne, medens et egentligt urtelag var fraværende eller meget spredt i den ene af de to sitka-gran-bevoksninger. Endvidere fandt vi en relativt høj dækning af dværgbuske i to af de tre skov-fyr-bevoksninger, hvoraf *Vaccinium uliginosum* (mosebølle) var hyppigst forekommende efterfulgt af *Empetrum nigrum* (revling), *Calluna vulgaris* (hedelyng), *Erica tetralix* (klokkelyng) og *Myrica gale* (mose-pors). Dværgbuske var fraværende eller yderst spredt forekommende i de to sitka-gran-plantager.

Vi undersøgte dækningsgraden og artssammensætningen af mosser og jordboende laver. Samlet fandt vi 18 arter af mosser, og der var en relativt høj dækning af mosser under skov-fyr (to ud af tre bevoksninger) og bjerg-fyr. De mest udbredte arter var *Pleurozium schreberi* og *Hypnum jutlandicum*, der begge er almindeligt forekommende i nåleskove i Danmark. Vi fandt endvidere 7 jordboende lavarter, men generelt en meget lav dækning af laver i skovbunden. Dækningen af laver var over 5% i blot 3 prøvefelter, der alle var i bjerg-fyr-bevoksningen.

Vi fandt en meget høj kronedækning i sitka-gran-plantagerne med meget få huller, hvor lyset kan trænge igennem. Derimod var der en relativt høj gennemtrængning af lys i kronelaget i hvert fjerde prøvefelt i bjerg-fyr-bevoksningen og i prøvefelter fra den ene af de 3 skov-fyr-bevoksninger.

Vi fandt meget lave pH-værdier i skovbunden under sitka-gran (pH omkring 2,75) og den ene af skov-fyr bevoksningerne. Under bjerg-fyr og i en af de 3 skov-fyr-bevoksninger var pH lidt højere, medens 50% af prøvefelterne i en anden skov-fyr-bevoksning var over 3. Vi sammenlignede jordbundens surhedsgrad med NOVANA-prøvefelter fra grå/grøn klit (2130), klithede (2140) og fugtig klitlavning (2190) og fandt, at pH i gennemsnit var en enhed højere i referenceområderne end i klitplantagerne ved Østerild (3,8 mod 2,8). De lave pH-værdier kan medføre en væsentlig begræsning i mulighederne for en vellykket restaurering af klit naturtyper, da forsuring er kendt for at føre til tab af arter på heder og overdrev.

Vi fandt de tykkeste førnelag i en af de to sitka-gran-plantager med en median-værdi på 12 cm. Under bjerg-fyr er førnelaget derimod ganske tyndt (median = 4 cm).

Generelt fandt vi ganske lave C/N-værdier i de indsamlede jordprøver. De højeste værdier blev målt i de 4 jordprøver, der var indsamlet i bjerg-fyr-plantagen (median = 29), medens C/N-værdierne var betydeligt lavere i jordbunden under den ene af de 3 skov-fyr-bevoksninger (median =19). Vi fandt en signifikant negativ korrelation mellem pH og C/N-ratio, hvilket indikerer, at nedbrydningen af organisk materiale i skovbunden er tæt forbundet med surhedsgraden.

1 Objectives

The overall objective of the monitoring programme is to monitor the vegetation succession from open and dense coniferous forest in the first 10 years after clear-cutting of dune plantations in the test area of the National Test Centre facility for wind turbines in Østerild Klitplantage. Based on monitoring results we will evaluate the success of restoration of open habitats with grey dune, dune heath and humid dune slacks.

The monitoring programme is designed to assess and quantify the importance of site conditions and the post-construction treatments for a successful development towards natural dune communities and to generate evidence-based knowledge about the processes involved.

The monitoring programme consists of baseline recording of soil conditions and species composition of the vegetation prior to clearing of dune plantations (baseline monitoring) and a systematic monitoring of the succession from open or dense coniferous forest to open dune habitats with grey dune, dune heath and humid dune slacks after deforestation, re-established hydrology and removal of litter (effect monitoring).

We define the baseline conditions for vegetation development as the conditions prior to deforestation. The baseline monitoring will thus take place in 2011 before the clearing of the plantations commences. This approach ensures that the insight gained into vegetation recovery after clear-cutting can be used to assess the future potential for restoration that could occur arising from further conversion of plantations to dune habitats along Danish coasts.

The effect monitoring will be conducted when the planned treatments (litter removal and hydrological changes) have been implemented (By- og Landskabsstyrelsen 2010). For sites without post-construction treatments the monitoring of vegetation recovery from clear-felling starts in 2013. For the remaining sites post-construction monitoring starts in 2017, where treatments of litter layer and hydrology are expected to be fully implemented.

1.1 Target communities

Depending on the local topography and hydrology the cleared areas are expected to develop towards various open dune communities, listed on the Annex 1 of the Habitats Directive (European Communities 1992) (se Figure 1):

1. Fixed coastal dunes with herbaceous vegetation ('grey dune') (habitat type 2130).
   This habitat consists of open and frequently disturbed vegetation on acidic, leached and nutrient poor sand with *Corynephorus canescens* as the most common vascular plant along with *Carex arenaria, Ammophila arenaria* and *Jasione montana*. Occasionally, the vegetation is very rich in cryptogams, particularly *Cladonia spp*.

2. Decalcified fixed dunes with *Empetrum nigrum* ('dune heath') (habitat type 2140).

On dry sand the vegetation have been colonised by a relatively closed dwarf scrub vegetation with *Empetrum nigrum* and *Calluna vulgaris*. Dry dune heaths may contain a rich cryptogam flora, particularly *Cladonia spp.* On moist and wet sand the vegetation have been colonised by a closed dwarf scrub vegetation with *Vaccinium uliginosum, Empetrum nigrum, Erica tetralix, Calluna vulgaris*, *Vaccinium oxycoccos* and *Myrica gale.*

3. Humid dune slacks (habitat type 2190)
   Wet and seasonally flooded depressions with pioneer swards, fens and pools on acidic or calcareous sand. The vegetation encompasses many different plant communities depending on moisture, seasonal fluctuations in water level, pH, natural disturbances and management (Ejrnæs et al. 2009).

The monitoring programme aims to follow vegetation development in areas assumed to develop towards the above-mentioned natural dune communities.

Figure 1. Target communities for natural vegetation recovery after clear-cutting of coniferous forest in dune landscapes. The left picture is a hilly dune landscape with grey dune and dry dune heath (in the northern part of the test area), in the middle a wet dune heath with Calluna vulgaris, Molinia caerolea and Myrica gale and to the right humid depressions with Sphagnum, Trichophorum caespitosum and Narthecium ossifragum (western part of Tømmerby Kær).

2 Site and plot selection

The monitoring programme investigates the effects of the most important site conditions on the rate and direction of vegetation development towards the target communities after clear-cutting of dune plantations. In Østerild the target is to restore grey dune (habitat type 2130), dune heath (habitat type 2140) and humid dune slack (habitat type 2190) vegetation in afforested areas with dense coniferous forests, mainly with *Picea sitchensis* (Sitka Spruce, sitka-gran), *Pinus sylvestris* (Scots Pine, skov-fyr) and *P. mugo* (Mountain Pine, bjerg-fyr) forests. In the implementation plan (By- og Landskabsstyrelsen 2010) various post-cutting treatments of the litter layer and changes in hydrology have been suggested in order to enhance the chances of a successful development towards the target communities.

The site selection and plot position in the monitoring programme is thus stratified random, and the stratification is applied according to baseline conditions, post-cutting treatments of litter layer and hydrology, future management regimes, distance to appropriate seed sources and topography.

2.1 Site selection

2.1.1 Baseline conditions

The rate and direction of vegetation development is dependent on the baseline conditions. In the test area of the National Test Centre facility in Østerild the deforested plantations can be divided into four major forest types:

- Approximately 40% (106 ha) of the forest planned for clear-cutting in Østerild consists of dense coniferous plantations with introduced spruces (*Picea sitchensis* and *P. omorica*), pines (*Pinus contorta*) and firs (*Abies alba*) on former dune heathland. Plantations with *Picea sitchensis*, a species that endures seasonally high groundwater levels, cover more than 30% of the area to be deforested. The forest floor is covered with a thick layer of organic matter (needles, cones and twigs) where atmospheric nitrogen from the past decades has been accumulated.

- Another 40% of the project area is covered with Scots Pine forests. In less dense stands, the understory consists of a well-developed dwarf shrub vegetation with *Calluna vulgaris*, *Erica tetralix*, *Empetrum nigrum* and *Vaccinium uliginosum*.

- Mountain Pine stands cover 13% of the deforested area and is restricted to the dry and hilly dune landscape in the northern part of the test area. The plantation includes patches with a relatively open canopy with a scattered occurrence of lichens, bryophytes and dwarf shrubs (Figure 3).

- Finally, deciduous forests with oak, beach and birch cover 6% of the area. Vegetation development in these sites will not be covered by the monitoring programme.

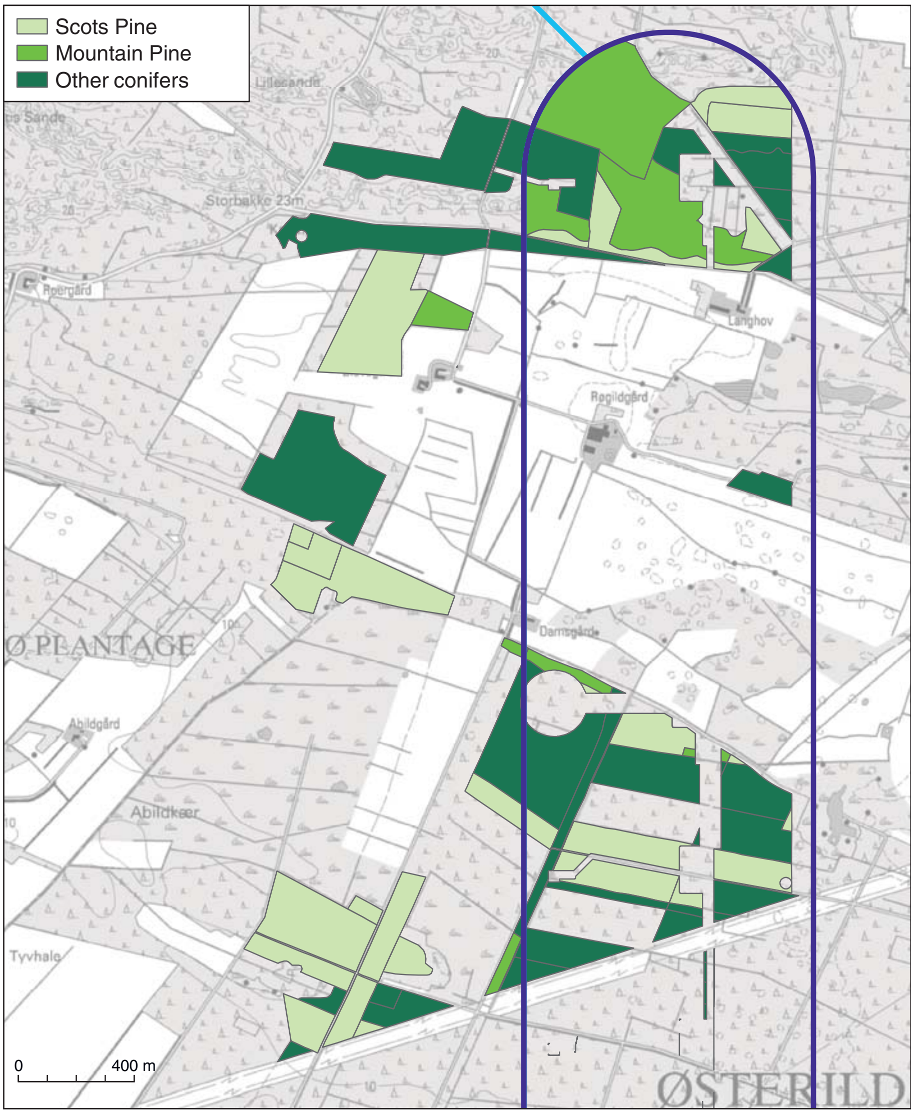


Figure 2. Pre-construction distribution of the three coniferous forest types in the test centre area. The map shows coniferous forests that are planned for clear-cutting. Future construction sites and roads have been excluded from the map. Based on GIS-maps from the Danish Nature Agency in Thy.

The starting conditions in the above mentioned forest types differ markedly with respect to flora, topography and soil conditions, and vegetation recovery is thus expected to follow different trajectories. The monitoring programme is designed to cover vegetation development in the three coniferous forest types (Figure 2 and 3). Accordingly, we have placed 20 plots in the Mountain Pine stand in the northern part of the test area, 30 plots in three different Scots Pine stands and 50 plots in two Sitka Spruce stands (Table 1).

Figure 3. Different baseline conditions for vegetation development in the Østerild area. 1) Dense coniferous forest with spruces, pines and firs, 2) open Scots Pine forests with a well-developed dwarf shrub layer at the forest floor and 3) open Mountain Pine forest.

2.1.2 Hydrology

The project area is former sea bed, shaped by land uplift and shifting sand. Prior to afforestation in late 1800, the dune areas in Østerild and Hjardemål Plantage were characterized by a high and presumably highly fluctuating water table and consequently moist and wet habitats were widespread in the area (Miljøministeriet 2009). Because of intensive drainage prior to afforestation, dune slacks with nutrient poor wet heathland (2140) and mire vegetation (2190) are now restricted to a few poorly drained open areas.

A successful development towards a natural flora associated with moist dune heaths (2140) and humid dune slacks (2190) requires an adequate restoration of the hydrological regime. One of the planned actions is thus to restore a more natural hydrology, mainly by closing drainage dykes and allowing temporary pools and shallow lakes to develop or expand (By- og Landskabsstyrelsen 2010). The monitoring programme aims to follow the development in dry, moist and wet dune habitats as well as seasonally flooded areas (Figure 4). We have placed 60 plots in unaltered dry areas and 40 plots within planned wetlands, where the hydrological conditions will be altered towards moist or wet conditions (Table 1).

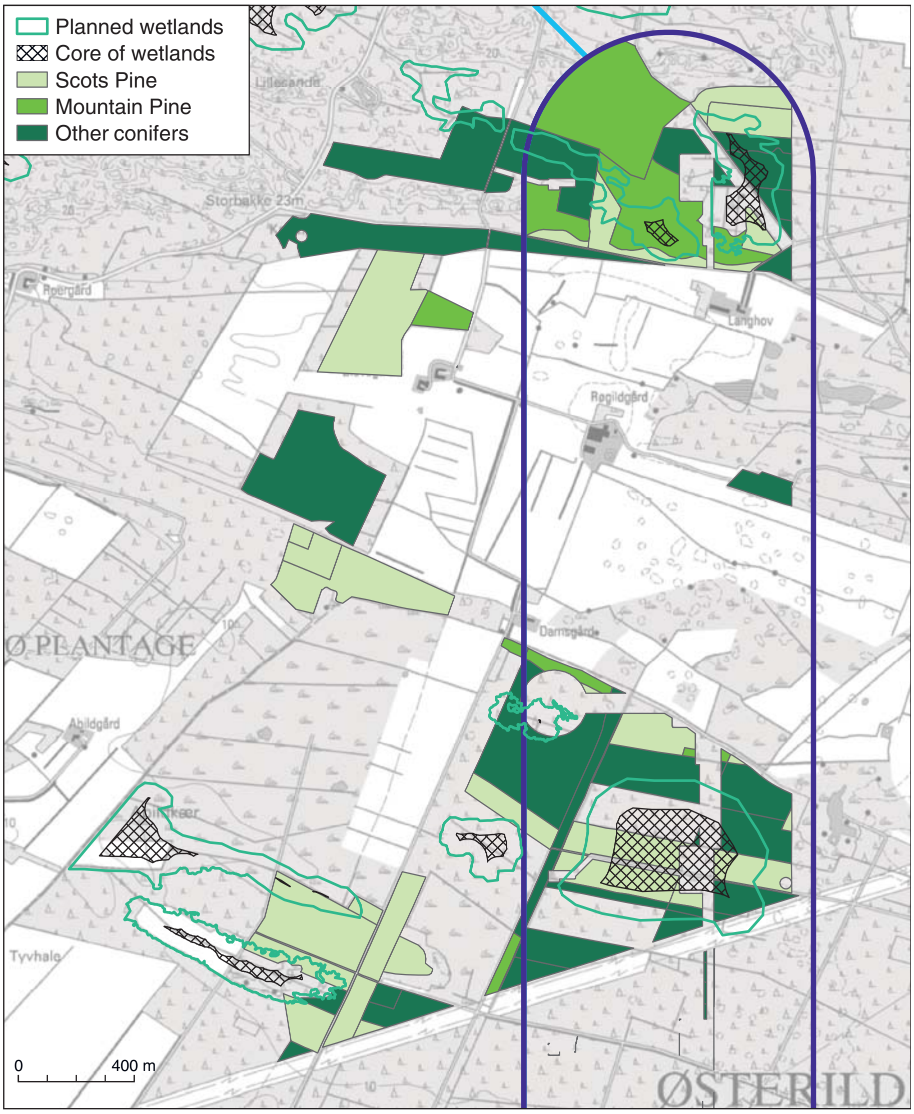


Figure 4. Planned wetlands in the test area as one of the post-construction treatments. In selected areas a natural hydrological condition will be restored by closure of drainage dykes, allowing temporary pools and shallow lakes to develop or expand. The central areas are marked with a 100 m buffer zone from the wetland border and here the post-construction conditions are assumed to be rather wet. Based on GIS-maps from the Danish Nature Agency in Thy.

2.1.3 Litter treatments

Coniferous litter is acidic and the decomposition rate is very low, which leads to an accumulation of needles, cones and twigs on the forest floor (Figure 5). A thick litter layer in the coniferous forest may constitute a major constraint to a successful restoration of natural dune habitats (Sturgess & Atkinson 1993). In the implementation plan (By- og Landskabsstyrelsen 2010) four different post-cutting treatments of the litter layer have been suggested in order to study cost-effective restoration of open habitats from cleared plantations: 1) Sod cutting and removal of litter, 2) sod cutting and burning on site, 3) burning, 4) small-scale soil disturbances and 5) control.

Figure 5. Sitka Spruce forest in the Østerild area with a 20-30 cm thick layer of accumulated organic matter. A range of post-cutting treatments of the accumulated organic matter have been suggested in the implementation plan and the monitoring programme will follow the vegetation development from four different treatments.

In cooperation with the Danish Nature Agency in Thy, we have included four different post-cutting treatments of the accumulated organic matter in the monitoring programme. Furthermore, we have delimited the litter treatments to two of the three forest types, one of the Sitka Spruce stands (site 7 and 8) and the Mountain Pine stand (site 1 and 2). This selection is motivated by the expectation that a thick litter layer in dense coniferous forests will constrain restoration of the target communities. Hence the chances of a successful succession towards dune habitats are smaller than in the open, hilly Mountain Pine stands and open Scots Pine forests with rich dwarf shrub vegetation in the understory.

We have planned to monitor the vegetation development in a deforested Sitka Spruce stand with the following treatments of the litter layer:

1. Removal of litter layer and exposure of bare soil in larger patches. Removal of the litter layer will enhance the development of open sand dune vegetation with improved opportunities for colonisation of species and lowering of the nutrient concentration in the soil. This treatment will be implemented in areas covering 10 plots in the Sitka Spruce stand at site 7 and 8 and 10 plots in the Mountain Pine forest at site 2.
2. Removal of litter layer and exposure of bare soil in smaller patches (by disc ploughing or tree root removal). Total removal of the litter layer is a time-consuming and expensive restoration method, and in the monitoring programme we included this treatment as a less costly alternative. This treatment merely rearranges the litter and exposes stripes or patches of mineral soil for colonisation of pioneer species. This treatment will be implemented in areas covering 10 plots in the Sitka Spruce stand at site 7 and 8.
3. Burning of litter layer, which is a common restoration method in dunes and heaths, targeting the removal of organic matter as well as accumulated nitrogen. Burning is expected to favour the initial successional stages

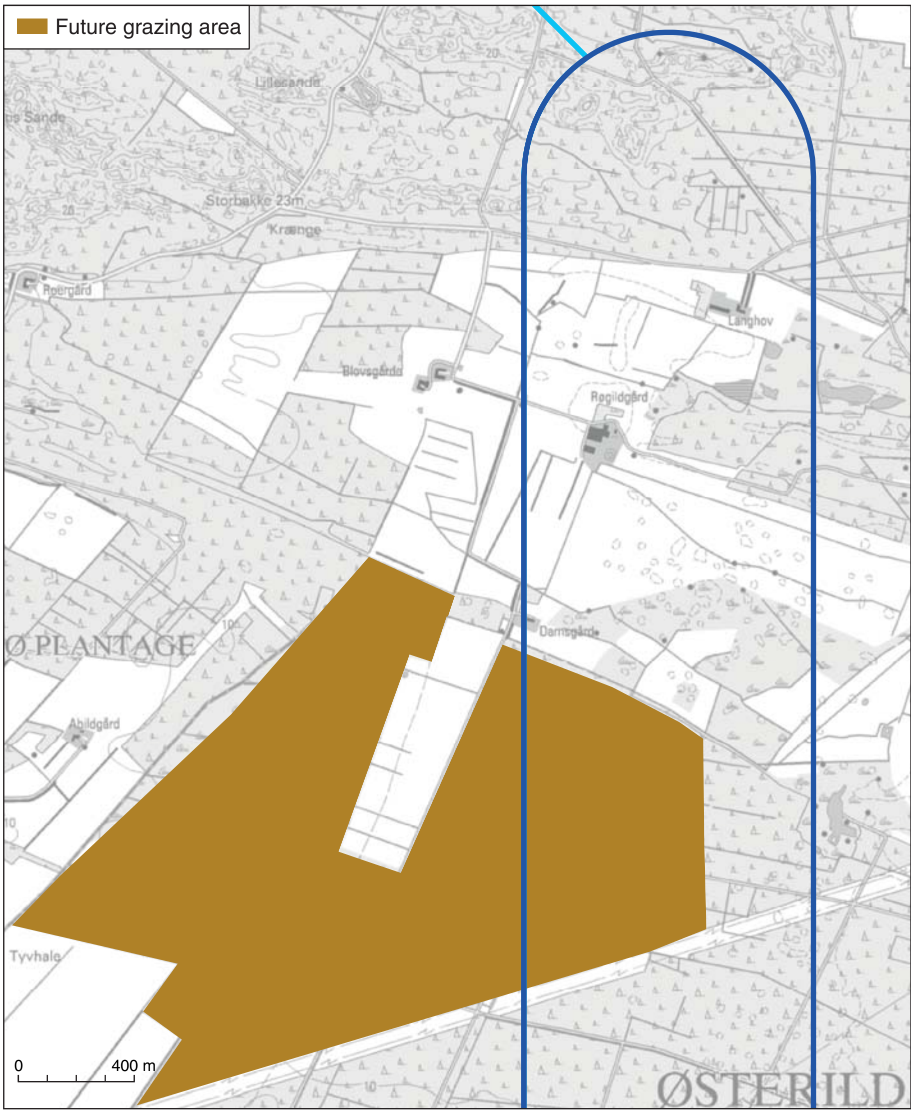
towards the target dune communities. Burning will be carried out in spots exceeding the size of the 5 m documentation plots. This treatment will be implemented in areas covering 10 plots in the Sitka Spruce stand at site 7 and 8.

4. Intact litter layer (control treatment). In the remaining 60 plots the accumulated organic material will be left undisturbed when the clear-felling is completed. Although we expected this control to be less effective in terms of reaching the target, it is included in order to study the full range of method costs.

2.1.4 Grazing

Erosion, deposition and sand drift are among the natural processes that create and maintain active dunes. Along with a low availability of nutrients a high and fluctuating groundwater table, wildfires and grazing herbivores these natural dynamic processes keep the vegetation open. In order to restore natural dynamic processes, it has been suggested in the implementation plan, that burning and live stock grazing should be established in selected areas. The monitoring programme is designed to follow and compare the development in both managed and unmanaged areas (Figure 6). Accordingly, we have placed 60 plots within areas planned for live stock grazing and 40 plots outside the fenced areas (Table 1).

Figure 6. Areas planned for livestock grazing. Based on GIS-maps from the Danish Nature Agency in Thy.



2.1.5 Topography

In the northern part of the test area the landscape is hilly and various dry dune habitats are expected to develop after clear-felling of the Mountain Pine forest, depending on slope and aspect. Therefore the monitoring programme will link vegetation recovery to the topographical variation of the monitoring plots. We have calculated aspect and slope in 10 m grid cells with the digital elevation model and placed the permanent plots in areas with a mean slope above 5 m in the 100 m² grid (yellow and red signature in Figure 7b).

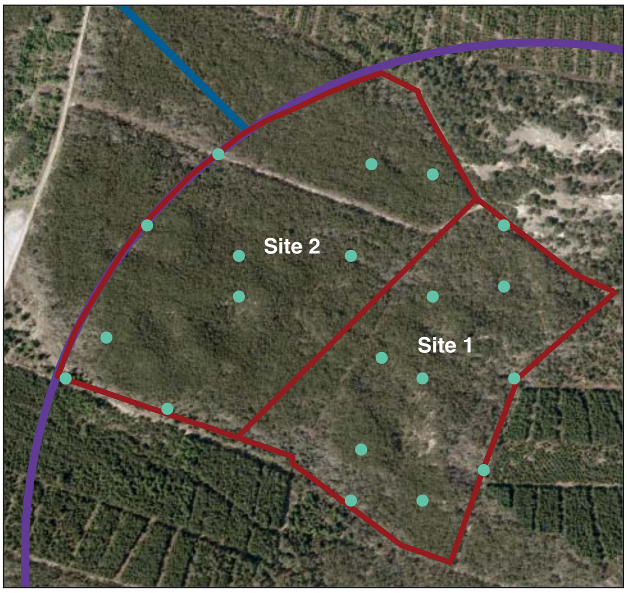


Figure 7a. Position of 20 plots in the Mountain Pine stand at site 1 and 2.

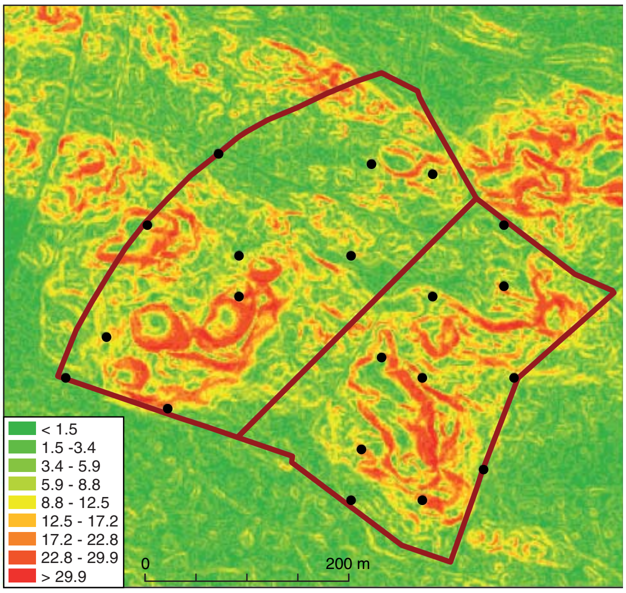


Figure 7b. Topographic variation in the Mountain Pine stand. Mean slope in site 1 and 2 was calculated with the digital elevation model and the monitoring plots were placed in areas with a mean slope above 5 m.

2.1.6 Site presentation

We have selected 12 monitoring sites stratified according to the above mentioned variation in baseline conditions (Sitka Spruce, Scots Pine and Mountain Pine forests), post-cutting changes in hydrology (dry versus moist-wet), treatment of litter layer (intact, burning, removal and ploughing), topography (mean slope) and planned areas for livestock grazing (grazing versus unmanaged) (Figure 8, Figure 9 and Table 1).

In each monitoring site the importance of dispersal limitation of target species is investigated by placing a subset (two out of five) of the monitoring plots in the margin of restored sites in close vicinity to neighbouring open target habitat (section 2.2.1).

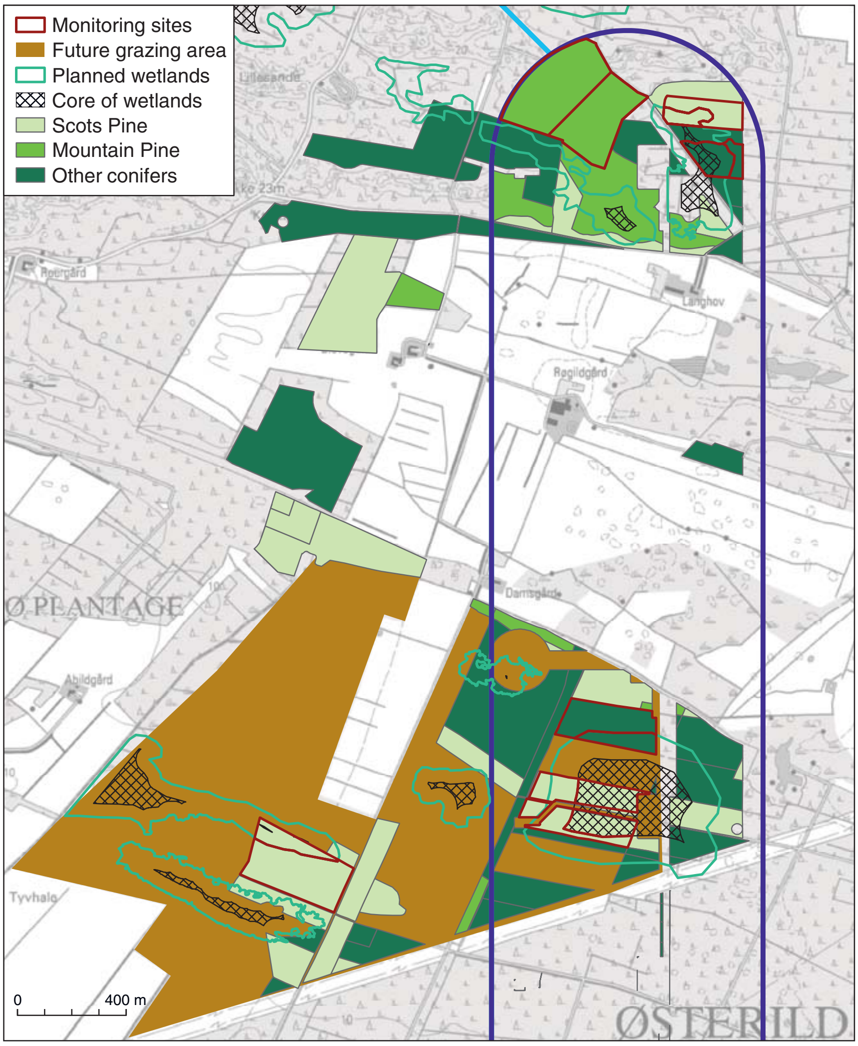
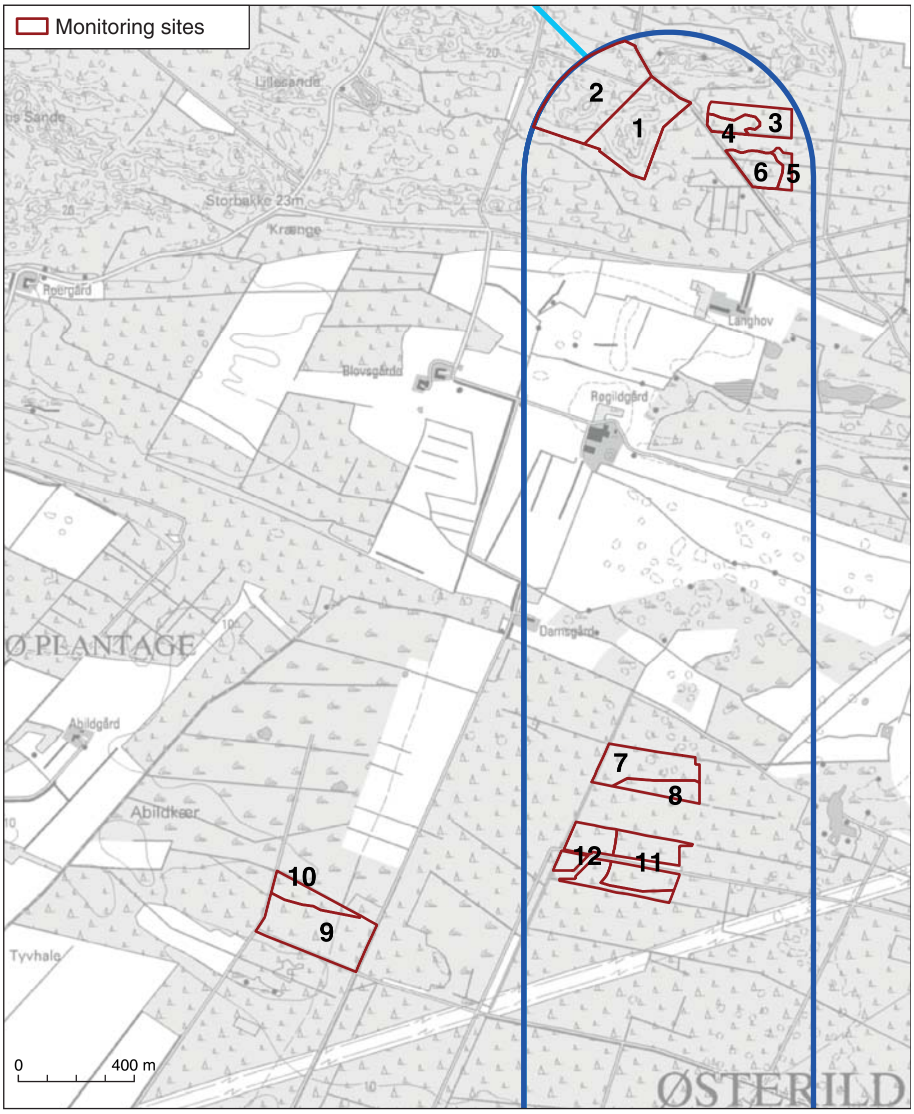


Figure 8. Selection of 12 monitoring sites stratified by baseline conditions, post-cutting changes in hydrology and litter layer, mean slope and planned livestock grazing. Based on GIS-maps from the Danish Nature Agency in Thy.

Table 1. The 100 monitoring plots are divided between 12 monitoring sites. For each site baseline conditions (forest type), age of forest stand, post-cutting treatments regarding moisture regime (planned wetlands), grazing and litter layer and number of plots are listed.

Site number	Baseline conditions (forest type)	Stand age	Post-cutting treatments			Number of plots
			Moisture	Grazing	Litter	
1	Mountain Pine forest	1937	Dry	No	Intact	10
2			Dry	No	Burning	10
3	Scots Pine forest	1927	Dry	No	Intact	5
4			Moist	No	Intact	5
9		1964	Dry	Yes	Intact	5
10			Moist	Yes	Intact	5
11		1963	Moist	Yes	Intact	5
12			Dry	Yes	Intact	5
5	Sitka Spruce forest	1983	Dry	No	Intact	5
6			Moist	No	Intact	5
7		1972	Dry	Yes	Intact	5
					Burning	5
					Sod cutting	5
					Ploughing	5
8			Moist	Yes	Intact	5
					Burning	5
					Sod cutting	5
					Ploughing	5

Figure 9. Monitoring sites in the test area of the National Test Centre facility in Østerild.

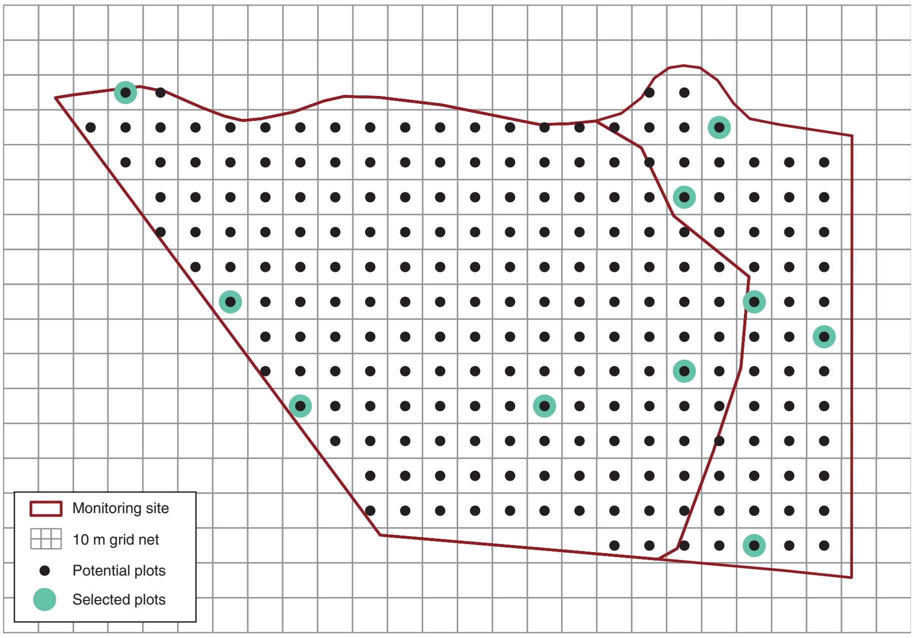


2.2 Monitoring plots

2.2.1 Plot selection

We selected 100 monitoring plots randomly among grid cells in the 10 m reference net (Fredshavn et al. 2011) (se Figure 10). In each of the 12 monitoring sites vegetation development is monitored in five randomly placed plots (Figure 10). In the two sites with Mountain Pine forest an additional 5 plots have been placed in order to cover the topographical variation. In site 7 and 8 where a litter treatment experiment is planned, we have placed 20 plots. The plots were marked as way points in a GPS prior to baseline monitoring.

Figure 10. Selection of monitoring plots within site 5 and 6.



The monitoring plots will be marked permanently in the field in connection with the first post-construction monitoring, in order to ensure that the repeated measures detect change in the exact same areas. The plots will be marked with a small metal rod that can be relocated with a metal detector. With this approach we accept a minor uncertainty (GPS) in the position of plots in the baseline situation, in order to avoid destruction of permanent markings during clear-cutting and treatments of the litter layer.

2.2.2 Distance to appropriate source habitats

In each site the importance of dispersal of target species have been investigated by placing a subset of the monitoring plots in the margin of restored sites, neighbouring open habitat (Figure 11).

The local species pools available for colonisation of restored sites and the order of arriving species has a major impact on the rate and direction of vegetation development (Ejrnæs et al. 2006). The probability of a successful restoration is generally considered to be greatest on sites where the native vegetation was only recently replaced, and where existing target vegetation types can act as a source of colonising species. Distance to nearest potential seed source is thus assumed to have an important effect on the number of native species that will colonise restored sites.

In each site two out of five plots have been placed randomly amongst the marginal plots, within 5 m from neighbouring open habitats such as dunes, heaths and open areas along forest roads and dykes in order to provide a documentation of the rate and direction of vegetation development in areas with a high probability of an early dispersal of target species. The remaining three plots are placed randomly in the matrix interior of each monitoring site (Figure 11b).

Figure 11a. In the plantations of Østerild and Hjardemål many target species for open dune habitat restoration grow in open zones along forest roads.

Figure 11b. In each monitoring site two out of five plots have been placed within 5 m from neighbouring open habitats such as dunes, heaths and open areas along forest roads and dykes (yellow triangles), while the remaining plots were placed randomly in the matrix interior.

3 Baseline monitoring

Baseline monitoring was carried out from the 4th to the 13th of July 2011, prior to clear-cutting of the plantations.

3.1 Methods

The monitoring methods are by default based on the variables in the new NOVANA programme for terrestrial habitats (Fredshavn et al. 2011). Minor adjustments have been conducted in order to ensure documentation of a wider part of the biodiversity in the dune ecosystem, e.g. recording lichen flora at the species level and documentation of light penetration through the tree canopy.

Each plot consists of a core square of 0.5 * 0.5 m (the pin point frame) and a circle with a radius of 5 m (78.5 m^2, the 5 m circle). The monitoring programme encompasses sampling of vegetation composition and structure, substrate and soil chemistry in either the frame or the 5 m circle (see Table 2). In the monitoring programme bryophytes and terricolous lichens (growing on soil surface) are recorded at species level, as the cryptogam flora represent a considerable part of the biodiversity in Danish dunes.

Table 2. Overview of variables included in the monitoring programme at the National Test Centre Østerild. * Soil content of organic matter and total nitrogen has been measured in two plots at each monitoring site.

Monitoring variables	Frame	Circle	Baseline	Post-construction	
	(0.25 m^2)	(78.9 m^2)		2013-2019	2021
Vegetation composition					
Species abundances	X				
Vascular plant species at species level			X	X	X
Bryophytes at species level			X	X	X
Lichens at species level			X	X	X
Species composition		X			
Vascular plant species at species level			X	X	X
Vegetation structure					
Vegetation height	X		X	X	X
Cover of dwarf shrubs		X	X	X	X
Cover of trees and bushes		X		X	X
Cover of open water				X	X
Canopy density		X	X		
Substrate					
Cover of open water	X		X	X	X
Cover of bare soil	X		X	X	X
Cover of litter	X		X	X	X
Litter depth		X	X	X	
Soil chemistry					
pH	X		X		X
Organic matter *	X		X		X
Total nitrogen *	X		X		X

3.2 Results - vegetation

3.2.1 Vegetation composition

Species richness

We recorded 87 taxa in the 100 plots, with species numbers ranging from 31 species in a 5 m circle in the Scots Pine stand at site 9 to 1 species (*P. sitchensis*) in the Sitka Spruce stand at site 8. On average the species numbers in the 5 m circles were highest in the Scots Pine stands in site 9-12 and lowest in the four Sitka Spruce sites (Figure 12). Species richness in the pin point frames was markedly lower with highest number of species (7) in site 9 and 12. In the Sitka Spruce stands we encountered on average 2.9 species in the 50 plots (of which one species was *P. sitchensis*). In comparison species richness in the 1521 reference dunes plots in Thy (Figure 13) was significantly higher. The species lists (5 m circles) contained on average 19.6, 14.4 and 20.4 species in plots from grey dune (2130), dunes heath (2140) and humid dune slacks (2190), respectively.

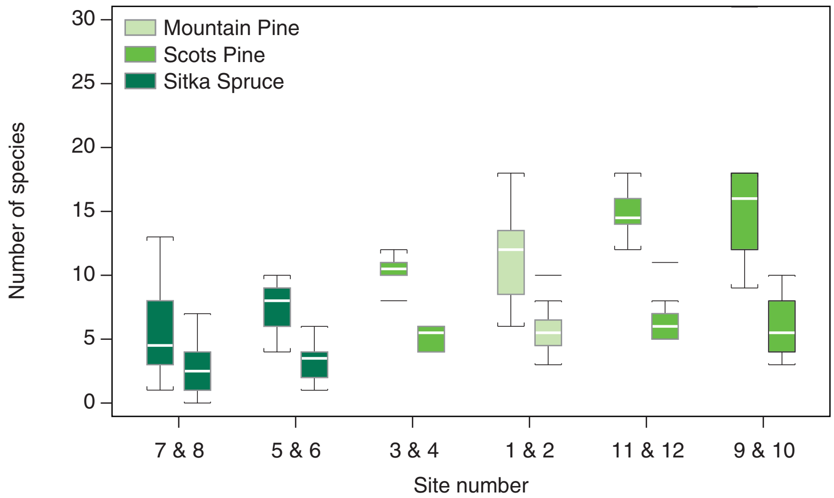


Figure 12. Species richness (number of species) in pin point frames (0.25 m2) and 5 m circles (78.9 m2) of plots from the 12 monitoring sites. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

In the Østerild plots we encountered 15 herbacous species, 10 grasses, 7 rushes and sedges, 5 dwarf shrub species, 13 deciduous bushes and trees, 7 coniferous trees, 5 ferns, 18 bryophytes and 7 lichens. The most widespread species were *Deschampsia flexuosa* (bølget bunke), *Picea sitchensis* (sitka-gran), *Pleurozium schreberi* and *Hypnum jutlandicum*, all occurring in more than 50% of the plots (Table 3). Furthermore *Molinia caerulea* (blåtop), *Dryopteris carthusiana* (smalbladet mangeløv), *Vaccinium uliginosum* (mose-bølle), *Carex arenaria* (sand-star) and *Dicranum scoparium* were found in more than one third of the plots.

Table 3. The most frequent species (in %) in the 100 plots arranged by sites and forest type.

	Mountain Pine		Sitka Spruce				Scots Pine						All
Species name	**1**	**2**	**5**	**6**	**7**	**8**	**3**	**4**	**9**	**10**	**11**	**12**	**sites**
Coniferous trees													
Picea sitchensis	40	60	100	80	95	100	60	40	20	0	80	100	73
Pinus sylvestris	30	10	0	0	0	0	100	100	100	100	80	100	33
Pinus mugo	90	100	60	60	0	0	0	0	0	0	0	0	25
Deciduous trees													
Quercus robur	40	50	60	80	20	5	0	20	60	40	20	20	29
Dwarf shrubs													
Vaccinium uliginosum	40	30	40	40	0	30	100	80	80	80	40	40	38
Empetrum nigrum	80	60	0	0	0	5	60	20	100	40	40	60	31
Calluna vulgaris	50	40	0	0	5	35	0	0	40	40	80	20	26
Erica tetralix	10	20	0	0	0	10	20	20	80	60	60	80	21
Myrica gale	0	0	0	0	0	5	20	0	20	60	80	100	15
Herbs													
Deschampsia flexuosa	100	100	80	80	40	55	100	100	100	100	80	100	76
Molinia caerulea	10	20	60	100	35	40	80	40	40	100	100	100	49
Carex arenaria	70	60	20	40	10	0	80	100	100	80	0	0	36
Trientalis europaeus	30	10	20	40	0	0	100	100	20	20	20	0	20
Carex nigra var. nigra	0	0	20	20	5	10	60	60	20	40	20	40	17
Luzula multiflora	0	0	0	0	5	0	0	40	40	40	20	40	10
Ferns													
Dryopteris carthusiana	50	30	60	40	30	15	80	100	100	100	40	80	47
Dryopteris dilatata	20	10	0	0	5	5	0	0	60	100	40	60	18
Bryophyte species													
Pleurozium schreberi	100	90	40	20	10	5	100	100	80	40	80	80	62
Hypnum jutlandicum	80	90	60	40	90	80	20	20	40	60	100	60	62
Dicranum scoparium	80	80	20	60	55	50	0	0	20	0	40	20	35
Chiloscyphus latifolius	30	40	0	20	25	5	0	0	20	40	0	40	18
Ptilidium ciliare	30	20	0	0	0	0	0	0	20	0	0	0	6
Eurhynchium striatum	0	0	0	0	5	5	0	0	20	0	0	40	5
Lichen species													
Cladonia chlorophaea agg.	0	30	0	0	15	0	0	0	0	0	0	0	6
Cladonia portentosa	10	20	0	0	0	0	0	0	0	0	0	0	3
Cladonia cfr. glauca	10	10	0	0	5	0	0	0	0	0	0	0	3

Comparison with NOVANA data

During the succession from forest to dune habitats the vegetation composition will change with regard to both species composition and individual species abundances. The speed and direction of succession depend on the baseline conditions. In open stands of Mountain Pine or Scots Pine the forest floor vegetation consists of species characteristic of the target communities while succession in dense plantations starts more or less from scratch.

Figure 13. Distribution of NOVANA monitoring stations in Thy with dune vegetation. In the 35 stations 1521 plots with grey dune (2130), dune heath (2140) or humid dune slack (2190) vegetation have been monitored in the period 2004-2010.

In order to quantify the distance from the baseline situation prior to cutting with the restoration target, we compared the vegetation composition in the 100 afforested dune plots in Østerild with 1521 reference dune plots selected from 35 NOVANA monitoring stations in the Thy area (Figure 13). We did the comparison by applying Detrended Correspondence Analysis (DCA) (Hill 1979) to the 100 forest plots from Østerild and the 1521 dune plots in the Thy area (Figure 13). In the NOVANA programme bryophytes are only registered at the species level in plots with grey dune vegetation (2130) and lichens are recorded as reindeer lichens, cup lichens and other lichens in all habitattypes. The ordination analysis was therefore based solely on the composition of vascular plant species.

The position of the 1621 plots along the first two ordination axes is shown in Figure 14. The first axis was interpreted as a moisture gradient ranging from very dry grey dunes with *Thymus serpyllum* (smalbladet timian), *Corynephorus canescens* (sandskæg), *Jasione montana* (blåmunke), *Cerastium semidecandrum* (femhannet hønsetarm) and *Plantago maritima* (strand-vejbred) to mire vegetation in rather wet humid dune slacks with *Menyanthes trifoliata* (bukkeblad), *Equisetum fluviatile* (dynd-padderok), *Carex rostrata* (næb-star) and *Phragmites australis* (tagrør). The dune plots along the second ordination axis ranges from dune grassland with *Achillea ptarmica* (nyse-røllike), *Lolium perenne* (alm. rajgræs), *Helictotrichon pratense* (alm. enghavre), *Elytrigia repens ssp. repens* (alm. kvik), *Trifolium pratense* (rød-kløver) and *Dactylis glomerata* (alm. hundegræs) to open grey dune vegetation with *Corynephorus canescens* (sandskæg) and *Jasione montana* (blåmunke) and dune heaths with dwarf shrubs species (*Vaccinium uliginosum*, mose-bølle, *V. oxycoccus*, tranebær, *Myrica gale*, pors, *Calluna vulgaris,* hedelyng, *Empetrum nigrum,* revling, *Erica tetralix,* klokkelyng) and *Deschampsia flexuosa* (bølget bunke). This floristic gradient corresponds to a combined gradient in pH and nutrient availability.

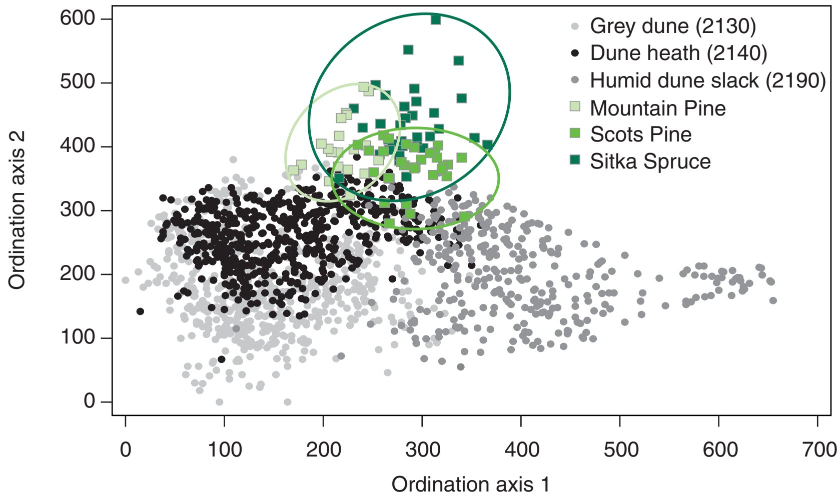


Figure 14. Position of the 100 afforested and 1521 reference dune plots along the first two ordination axes. The first axis represents a moisture gradient and the second axis a combined gradient in pH and nutrient availability.

The afforested dune plots in Østerild are situated in the middle of the moisture-gradient (the first ordination axis) and in the acidic and nutrient poor end of the second floristic gradient. Plots in Mountain Pine stands have the largest floristic similarity with acidic grey dune and relatively dry dune heath, while plots in Scots Pine stands mainly share species with moist dune heath and relatively dry dune slack. The forest floor vegetation in the Sitka Spruce stands differs markedly from all open dune target vegetation types.

3.2.2 Vegetation height

Height of the herb layer (including dwarf shrubs) has been measured along the four sides of the pin point frame (Fredshavn et al. 2011). Vegetation height ranged from 0 to 40 cm, with the highest average height in Scots Pine stands at site 9 and 10 (Figure 15). A distinct herb layer is absent or highly scattered in the Sitka Spruce stand at site 7 and 8.

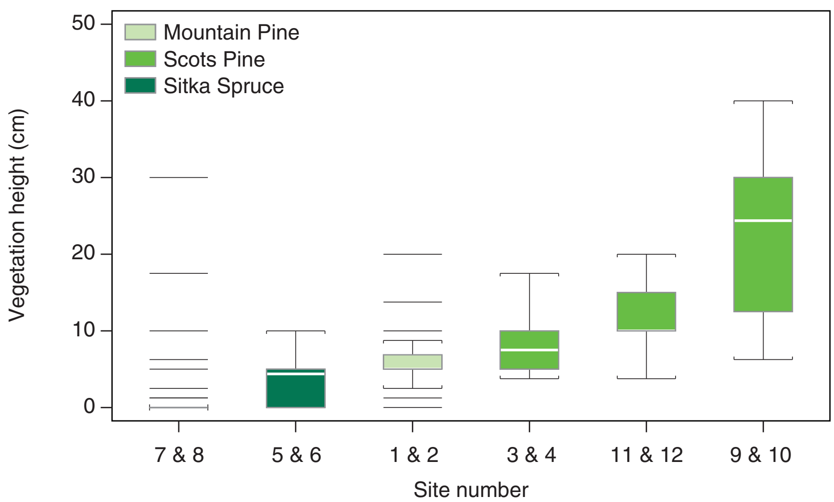


Figure 15. Vegetation height in the 12 monitoring sites grouped by the six forest stands. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

3.2.3 Cover of dwarf shrubs

Cover of dwarf shrubs was measured by visual inspection of the 5 m circles. Dwarf shrub cover ranged from 0 to 95%, with the highest average cover in Scots Pine stands at site 3, 4, 9 and 10 (Figure 16). Dwarf shrubs were absent or highly scattered in the Sitka Spruce stands. In the Østerild plots we recorded 5 dwarf shrub species of which *Vaccinium uliginosum* (mose-bølle) occurred most frequently (38% of the plots, se Table 3) followed by *Empetrum nigrum*, *Calluna vulgaris*, *Erica tetralix* and *Myrica gale* (15% and almost solely in Scots Pine plots).

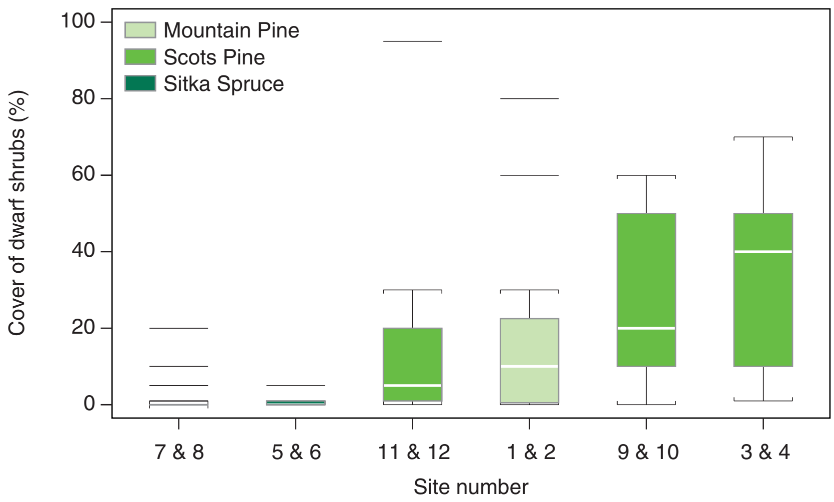


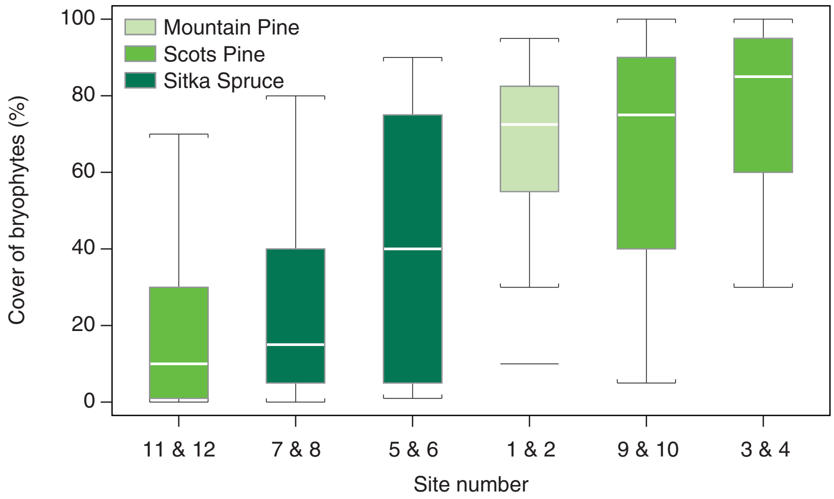
Figure 16. Cover of dwarf shrubs (%) in the 12 monitoring sites grouped by the six forest stands. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

3.2.4 Cover of cryptogam species

The cover of bryophytes and terricolous lichens (growing on soil surface) was measured by visual inspection of the 5 m circles. Bryophyte cover ranged from 0 to 100%, with the highest average cover in Scots Pine stands at site 3/4 and 9/10 (Figure 17) and the Mountain Pine stands (site 1 and 2). The lowest cover was recorded in the Scots Pine stand in site 11 and 12 as well as the Sitka Spruce stand in site 7 and 8, where bryophytes covered 10 and 15% of the forest floor in 50% of the plots (the median values). We encountered 18 bryophytes in the 100 plots, of which 14 species were recorded in less than 6% of the plots. The most abundant bryophytes were *Pleurozium schreberi* and *Hypnum jutlandicum* (found in all monitoring sites), both very common species in coniferous forests. A comparison with the bryophyte composition in the NOVANA grey dune (2130) plots in Thy (Figure 13) showed that only 9 out of 18 species from the Østerild plots have also been recorded in the reference dunes, and only four out of 23 species from the reference plots were encountered in the afforested dune plots.

The cover of terricolous (growing on soil surface) lichens ranged from 0 to 60%, with a cover above 5% in only 3 plots in the Mountain Pine stand. The highest average cover of lichens was recorded in site 1 (8.4%) where lichens were encountered in 6 out of 10 plots. In site 2 the average cover was 1.3% but with a more consistent occurrence (in 9 out of 10 plots). In the remaining sites lichens were either absent or highly scattered (cover < 1%) in the forest floor. We encountered 7 terricolous lichen species in the 100 plots, of which 4 species were recorded in a single plot. The most frequent species were *Cladonia chlorophaea agg.*, *Cladonia portentosa* and *Cladonia cf. glauca,* recorded in 6, 3 and 3 plots, respectively.

Figure 17. Cover of bryophytes (%) in the 12 monitoring sites grouped by the six forest stands. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

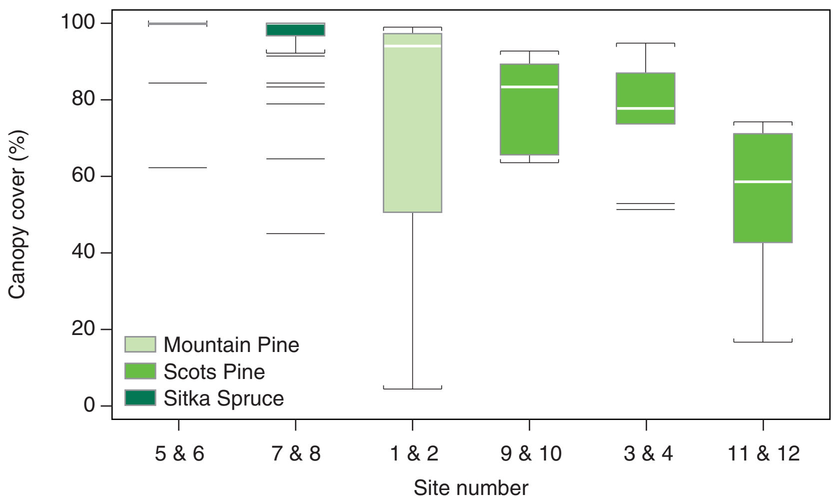


3.2.5 Canopy cover

Light penetration through the forest canopy was estimated in the baseline monitoring (prior to clear-cutting) with a convex spherical densiometre. The method is described in the technical instruction for monitoring of terrestrial habitats (Fredshavn et al. 2011).

We found a very high canopy cover in the Sitka Spruce stands with very few gaps for light penetration (Figure 18). In the Mountain Pine stand canopy cover varied considerably and in 10 out of 20 plots canopy cover exceeded 95%. In five plots canopy cover was less than 50%. The Scots Pine stand in site 11 and 12 had a rather low canopy cover and a higher penetration of light to the understory. At these two sites the cover of woody plants below 1 metre is significantly higher than at the other 10 sites.

Figure 18. Canopy cover (%) in the 12 monitoring sites grouped by the six forest stands. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.



3.3 Results - soil

During the field inventory we collected soil samples from all 100 plots for pH measurements and C/N ratio analyses. Soil samples were collected in the top 10 cm of the soil surface in each corner of the pinpoint frame with a core sampler (Fredshavn et al. 2011). The four subsamples were subsequently pooled in one bulk sample. The soil samples were oven-dried at 50º C, then sieved through a 2 mm sieve to separate fine earth from coarse particles.

3.3.1 Soil acidity

Soil pH is a decisive factor for plant growth, nutrient availability and microbial activity. In Østerild soil pH have been measured in connection with the baseline monitoring and the measurement will be repeated in the last post-construction recording. We measured pH in the supernatant of a 10 g dried soil and 25 ml 1 *M* CaCl suspension.

The pH values range from 2.48 to 3.77, with an average of all 100 samples at 2.83. We found the lowest pH values in Sitka Spruce stands (site 5 to 8) (Figure 19). In site 7 and 8 50% of the samples ranged between 2.6 and 2.75 and in only one sample soil pH exceeded 3. At site 5 and 6 pH was slightly higher, but still 9 out of 10 samples had a pH value under 3. Stützer (1998) found slightly higher pH values (CaCl) in an 80 year old Sitka Spruce plantation in Hvidbjerg Plantage in Thy and Nielsen et al. (1999) measured pH values (H_2O) around 3.4 in the top soil of an inland Sitka Spruce plantation on former heath at Hjelm Hede.

In the Mountain Pine stand 50% of the soil samples had a pH value between 2.8 and 3 and five samples had a pH slightly above 3. The Scots Pine stands showed a larger variation in soil pH. In site 3 and 4 the soil was highly acidic and comparable to the conditions in site 5 and 6 (all sample with pH below 3). In the Scots Pine stand in site 9 and 10 we measured a slightly higher soil pH (median = 2.95) and in site 11 and 12 50% of the samples had a pH value above 3.

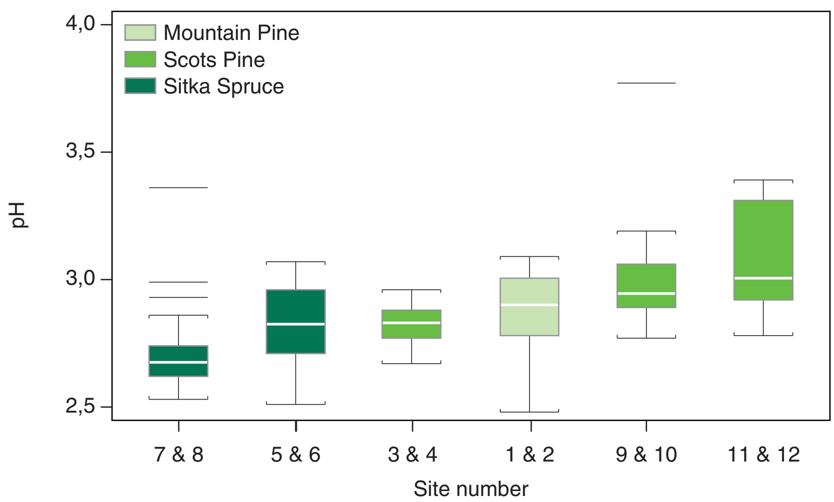


Figure 19. Soil acidity for each plot in the 12 monitoring sites grouped by the six forest stands. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

In the Østerild area the parent material is base-poor aeolian sediment. The low pH can be explained by the low buffer capacity in decalcified dune sand and the continuous deposition of acid litter from coniferous plantations will thus lead to a rapid acidification of the soil (Stützer 1998).

We compared the measured soil pH values in the 100 coniferous forest plots at Østerild with NOVANA plots sampled in grey dunes (2130), dune heaths (2140) and dune slacks (2190) from the entire country (3183 samples) and in monitoring stations near Østerild (Figure 13) (378 samples). Generally, dune soils in Thy are more acidic than the average soil pH in Danish dunes (Figure 20), possibly due to a low content of calcium carbonate. Furthermore, leaching of the soil surface is most pronounced in dune heaths, leading to a loss of calcium carbonate and increased soil acidity. The pH values of the reference dune plots in the area were nevertheless considerably higher than the afforested dunes in Østerild (3.8 on average versus 2.8). Less than 1% of the dune samples had a pH value below 3. Two grey dune monitoring stations (1144 and 1146) situated within or near the test area had an average soil pH of 3.5 and 3.7, which is markedly higher than the afforested dunes.

The results of our comparison between afforested and reference dunes in Thy are in accordance with a study of afforested dunes in Western Jutland, where Stützer (1998) found that pH (CaCl) values of the dune sediment decreased from 4 to 3 within 30 years after planting. The acidification proceeded to a depth of 20 - 30 cm within a period of 100 years and podzolisation was found to be the dominant soil forming process leading to a translocation of Al and Fe to the subsoil (Stützer 1998).

The low pH values may impose significant constraints on the restoration of dune communities as acidification as it is known to lead to loss of vulnerable species in heathland and acidic grassland (Strandberg et al. 2011).

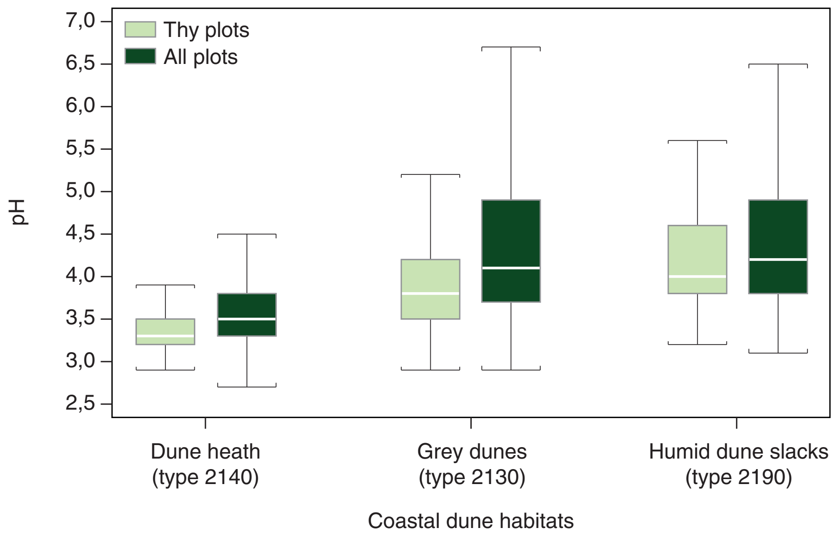


Figure 20. Soil pH in NOVANA plots from dune heath (2140), grey dune (2130) and humid dune slacks (2190) for the entire country and monitoring stations in Thy (Figure 13). Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show the middle 50% of the data (25 and 75 percentiles) and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

3.3.2 Litter depth

We measured the depth of the accumulated organic matter in the litter layer in each corner of the pinpoint frame (Fredshavn et al. 2011) during the baseline monitoring. This measurement will be repeated in the first post-construction recording. The litter depth varied from 1 to 20 cm, which is considerably lower than in some of the dense coniferous forest in Østerild, where we have measured litter layers of 20-30 cm depth. Litter depth was highest in the Sitka Spruce plantation at site 5 and 6, where the median thickness of the layer of organic material was 12 cm and varied from 0 to 20 cm (Figure 21). Stützer (1998) found similar litter depths in an 80 year old Sitka Spruce plantation in Hvidbjerg Plantage in Thy. The Scots Pine stand at site 3 and 4 dates back to 1927 and here the litter depth was considerably larger than at site 9 to12, where the stands are 50 years old. In the Mountain Pine stand the thickness of the layer of organic material was rather low, with a median value of 4 cm.

As a thick litter layer in the coniferous forest is known to constitute a major constraint to a successful restoration of natural dune habitats we have included four different post-cutting treatments of the accumulated organic matter in the monitoring programme (se section 2.1.3). All four treatments will be implemented in the Sitka Spruce stand at site 7 and 8, where the litter layer is 8 cm thick (median) and burning experiments will be conducted in the Mountain Pine stand (site 1 and 2).

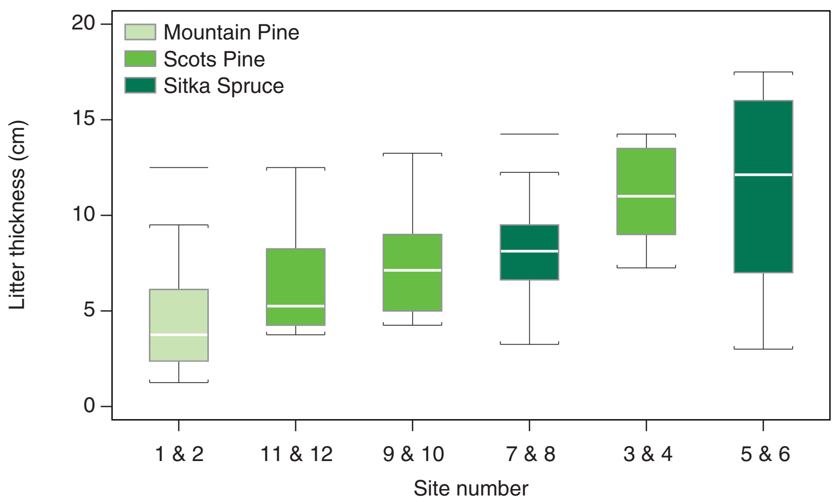


Figure 21. Average thickness (in cm) of the litter layer for each plot in the 12 monitoring sites grouped by the six forest stands. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show 25 and 75 percentiles and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.

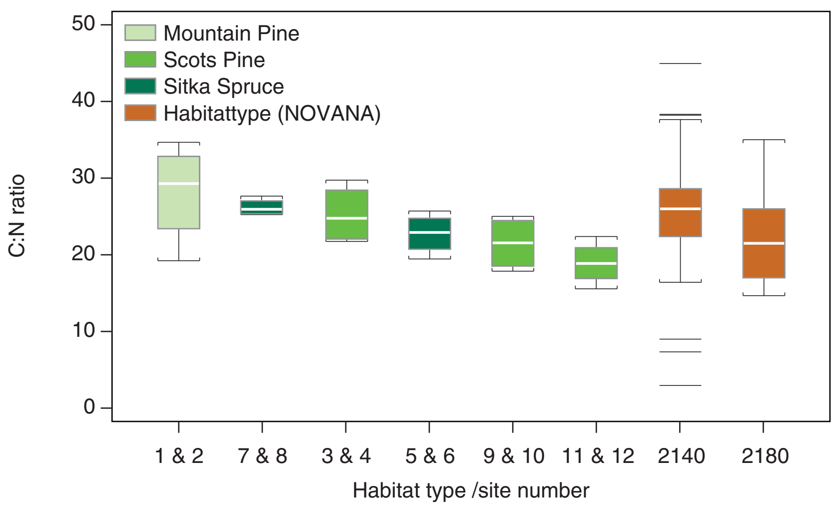
3.3.3 Carbon-nitrogen ratio

Carbon and nitrogen content was measured in two soil samples from each monitoring site. The measurements will be repeated in the final post-construction recording in 2021. Total nitrogen (ISO 13878) and total carbon (ISO 10694) content (in %) by dry combustion was determined by Eurofins Miljø A/S. With measurements of total carbon and nitrogen content in the soil it is possible to calculate the C:N ratio, which is an indicator of both decomposition rates of the accumulated organic matter and the nitrogen availability for plant growth. The ratio is not a simple measure of plant available nitrogen and a high C:N ratio may be found in sites with low soil pH, high production of hard degradable litter (e.g. phenolic compounds in conifer needles), low nitrogen supply and/or high leaching of nutrients. Correspondingly a low C:N ratio indicates that the organic matter is readily degradable, nitrogen supply is high and/or leaching of nutrients is low.

C:N ratios in the top-soil varied from 16 to 35 with highest values in the four samples from the Mountain Pine stand (median = 29) (Figure 22). The ratio was considerably lower in the Scots Pine stand in site 11 and 12, with a median value around 19. In comparison the median C:N ratio was 26 in dune heaths (93 plots from habitat type 2140) and 22 in wooded dunes (35 plots from habitat type 2180) covered by the national monitoring programme (NOVANA) (Fredshavn et al. 2011). In comparison Nielsen et al. (1999) found a markedly higher C:N ratio (~ 35) in the top soil of an inland Sitka Spruce plantation on former heath at Hjelm hede.

We found a significant negative correlation between soil pH and the C:N ratio, which indicates that the decomposition of organic material in the forest soil is closely connected with pH. The same correlation is known from Danish coastal dune habitats (Damgaard et al. 2008).

Figure 22. Carbon-nitrogen ratio in soil samples in the 12 monitoring sites grouped by the six forest stands and in NOVANA plots from dune heath (2140) and wooded dunes (2180) for the entire country. Data is presented in a box-plot where the median (the middle observation in a ranked series of data) is marked with a horizontal white line. The coloured boxes show 25 and 75 percentiles and the horizontal whiskers show the 10 and 90 percentiles. Outlying values are shown with isolated horizontal lines.



4 Quality assurance and data storage

4.1 Quality assurance

The applied methods correspond to the NOVANA monitoring programme for terrestrial habitats (Fredshavn et al. 2011). The NOVANA methods have been applied on more than 70,000 plots since 2004. Procedures for quality assurance of the sampled data in Østerild follow the technical guidelines for the new NOVANA programme (2011-2015).

4.2 Data storage

The registration forms and database entry facilities from the NOVANA programme has been modified to include the additional parameters recorded in the monitoring in Østerild. So far the data regarding vegetation composition, vegetations structure, substrate and soil chemistry is stored at Aarhus University. Data will as far as possible be made accessible through the internet.

5 Aknowledgements

We are grateful to Ako Mirza for pH measurements, Kirsten Coolidge for assistance with the GIS analysis and Roar S. Poulsen for identification of lichen species.

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RESTORATION OF DUNE HABITATS IN ØSTERILD KLITPLANTAGE - BASELINE MONITORING 2011

The establishment of a national test centre for wind turbines in Østerild Klitplantage will lead to clear-felling of up to 266 ha coniferous dune plantations. The agreement parties decided that the vegetation development from coniferous forest to open dune habitats should be monitored. The monitoring programme includes a recording of soil conditions and plant species composition prior to clear-cutting of the coniferous dune plantations (baseline monitoring) and a systematic recording of the changes during the first 10 years of the succession towards open dune habitats (post-construction monitoring). This report presents the sites and plots included in the monitoring programme as well as the main results of the baseline monitoring that was conducted in July 2011.

ISBN: 978-87-92825-25-4
ISSN: 2245-0203