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Results from the monitoring programme 2011-2021

Scientific Report from DCE – Danish Centre for Environment and Energy No. 496 2022

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

Series title and no.:	Scientific Report from DCE – Danish Centre for Environment and Energy No. 496
Category:	Scientific advisory report
Title:	Restoration of dune habitats in Østerild
Subtitle:	Results from the monitoring programme 2011-2021
Authors:	Ane Kirstine Brunbjerg, Rasmus Ejrnæs and, Bettina Nygaard
Institution:	Aarhus University, Department of Ecoscience
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL:	http://dce.au.dk/en
Year of publication:	May 2022
Editing completed:	April 2022
Referee:	Jesper Erenskjold Moeslund
Quality assurance, DCE:	Jesper R. Fredshavn
Linguistic QA:	Charlotte Kler
External comments:	The comments can be found here: http://dce2.au.dk/pub/komm/SR496_komm.pdf
Financial support:	Funded by the Danish Nature Agency
Please cite as:	Brunbjerg, A.K., Ejrnæs, R. & Nygaard, B. 2022. Restoration of dune habitats in Østerild. Results from the monitoring programme 2011-2021. Aarhus University, DCE – Danish Centre for Environment and Energy, 42 pp. Scientific Report No. 496 http://dce2.au.dk/pub/SR496.pdf
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Abstract: The establishment of a national test centre for wind turbines in Østerild Klitplantage led to clear-cutting of 250 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 included 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-cutting monitoring). This report presents the effects of restoration on target communities and an evaluation of the effectiveness of the applied methods 10 years after the clear-cutting.
Vascular plant species richness increased during the 10-year period, but the number of indicator species adapted to nutrient poor and near-natural conditions was still lower than expected from a reference data set. Grazing had a positive effect on species richness. The change in species composition after clear-cutting was dependent on former forest stand type, and the majority of plots monitored in 2021 resembled habitat directive habitat types. However, our results indicate that the restoration was not fully successful regarding hydrology and nutrient content and we recommend careful and focused restoration of natural hydrology and natural grazing regimes when deforesting dune plantations in the future.

Keywords:	Østerild, national test centre, monitoring, restoration, deforestation, dune habitats, vegetation development, wind turbines
Layout:	Karin B. Madsen
Front page photo:	Bettina Nygaard
ISBN:	978-87-7156-684-0
ISSN (electronic):	2244-9981
Number of pages:	42
Internet version:	The report is available in electronic format (pdf) at http://dce2.au.dk/pub/SR496.pdf

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Preface

In June 2010, the Danish Parliament passed a Public Works Act to establish a national test centre for wind turbines near Østerild in Thy, Denmark. Initially, 250 ha coniferous plantation in Østerild and Hjardemål klitplantage was deforested. Additionally, this legislation required implementation of a 10-year bird, bat and vegetation monitoring programme. The Department of Bioscience (now Ecoscience) at Aarhus University was commissioned by the Danish Nature Agency to undertake such a monitoring programme in the test area. For birds and bats, the programme comprised one baseline (2011/12) and two post-cutting inventory periods (2013/14 and 2015/16). The vegetation programme comprised one baseline (2011) and five post-cutting inventories (2013-2021).

Here, we present the results of the vegetation part of the abovementioned 10-year monitoring of the vegetation recovery after deforestation.

Summary

The overall objective of the monitoring programme was to document the long-term effect of the restoration initiatives taken in Østerild Klitplantage to create open dune habitats following clear-cutting of the dune plantations in the National Test Centre facility for wind turbines.

In order to facilitate the restoration of grey dunes (Annex I habitat type code 2130), dune heaths (2140) and humid dune slacks (2190), we implemented various treatments of hydrology and accumulated soil organic matter. The monitoring programme included an assessment of the effect of these treatments on the rate and direction of vegetation development towards the target communities. The monitoring programme included a recording of soil conditions and plant species composition prior to clearing of dune plantations (baseline monitoring in 2011), a systematic recording of the changes during the first 10 years of the succession towards open dune habitats (post-cutting monitoring) as well as a final monitoring in 2021. This report presents the final analyses and results from the final monitoring.

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 *Pinus mugo* (Mountain Pine)) as well as the native pine *Pinus sylvestris* (Scots Pine). The starting conditions were assumed to have a major impact on succession following deforestation, and the monitoring sites thus included Mountain Pine, Sitka Spruce and Scots Pine stands.

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 1) baseline condition (forest type), 2) planned post-cutting treatments of litter layer, 3) hydrology and 4) expected management regimes (grazing).

The monitoring programme was designed to identify the most important site conditions as well as the best post-construction treatments for a successful development towards target communities. We considered treatment of the litter layer as a key part of the restoration process, as a thick litter layer in the coniferous forest may constitute a major constraint on the restoration of natural dune habitats. Coniferous litter is acidic, and the decomposition rate is very low. This leads to an accumulation of needles, cones and twigs on the forest floor. In the implementation plan, four different post-cutting experimental treatments of the accumulated organic matter were suggested: 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). The monitoring plots were thus distributed in the clear-cut areas in order to detect effects of the different treatments of the litter layer. However, the implemented post-cutting treatments turned out to be more uniform than expected when the monitoring programme was designed. The tree stumps and litter layer were thus treated by the same methods with stump crushing (158 ha) as the most widespread treatment followed by stump removal (56 ha) and depth milling (12 ha). Only minor areas were left untreated (control) and no areas were treated with burning. This has reduced the possibilities of using the monitoring data to evaluate restoration potentials of different methods.

Successful restoration of moist dune heaths (2140) and humid dune slacks (2190) also required focus on restoring the original hydrological regime. Prior to afforestation in late 18th century, the dune areas in Østerild and Hjardemål Plantage were characterised by a high, and presumably highly fluctuating, water table and, consequently, moist and wet habitats were widespread in the area. One of the planned actions in Østerild was thus to close drainage dykes and allow temporary pools and shallow lakes to develop or expand. The monitoring programme aimed to follow the succession in dry and rewetted dune habitats, including areas that were seasonally flooded. The restoration initiatives were expected to create suitable habitats for light-preferring and low growing vascular plants, bryophyte and lichen species, species demanding nutrient-poor conditions and species depending on a fluctuating water table and changing moistness. The implemented actions lead to vegetation resembling wet dunes in the national monitoring programme, but our results did not indicate full restoration of the natural hydrological conditions with high and fluctuating water table.

Baseline monitoring was carried out in July 2011 prior to clear-cutting of the plantations, and the methods were based on the variables in the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA) (Fredshavn et al. 2011). We recorded the plant species composition and vegetation structure in a pinpoint frame (½ x ½ 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).

Post-cutting monitoring of the vegetation was conducted in 2013 (20 plots in the dune area formerly dominated by *Pinus mugo*), 2015 (20 plots in the dune area formerly dominated by *Pinus mugo*), 2017 (all plots, n=100) and 2019 (n=76). The final monitoring was carried out in August 2021 (n=91) using the same methods as for baseline monitoring. Due to various construction work and deviations from the planned treatments, only 59 plots were monitored in 2011, 2017 and 2021. These were used for analyses comparing conditions in 2011 and 2021.

During the 10-year period after clear-cutting, we found that:

- Soil pH increased from very acidic conditions prior to clear-cutting to levels almost comparable to the target habitat types.

- Although the altered water regime did create new moist habitats in the project area holding species depending on fluctuating water coverage, a pronounced overall effect of changes in hydrology on species richness and composition was lacking.

- The number of vascular plant species increased significantly from 2011 to 2021, and grazing seemed to have a positive effect on species numbers. Forest stand age had a negative impact on plant species richness, indicating a need for detailed planning of restoration initiatives accounting for differences in forest stand age.

- Vegetation composition obviously changed after clear-cutting, with relatively quick colonization and establishment of species.

- The cover of sedges increased significantly overall, but the degree of dwarf shrub cover was dependent on forest type. The dominance of grasses compared to dwarf shrubs indicated high nutrient contents.

- The vegetation composition in previous *Pinus sylvestris* stands resembled the vegetation composition in previous *Picea sitchensis* stands more than *Pinus montanus* stands.

- The invasive bryophyte *Campylopus introflexus* showed a considerable increase in occurrence, but a decrease in coverage.

- The nutrient content (Ellenberg N) was higher in wet dunes and dwarf shrub heaths in Østerild as compared to a NOVANA reference data set.

- A number of plant species adapted to relatively nutrient poor conditions had colonized the former plantations, and c. 57 % of the plots (n=48) were predicted to belong to dry dunes and heaths. However, more than 11 % of the plots were predicted to belong to non-habitat nature, indicating that restoration initiatives were not fully successful.

We recommend introduction of grazers in natural densities to cause and maintain disturbance after clear-cutting and to investigate the effect of burning of litter (not tested in this study) as means to increase pH levels. The implemented actions did not allow for concluding on the effects of stumps and litter treatments, nor for recommendations on the overall optimal restoration procedure.

Restoration of natural hydrology was not complete, most likely because closing of part of the ditches was not sufficient to rewet the full Østerild area. Full restoration of hydrology was restricted due to consideration of the technical facilities and privately owned agricultural areas.

Resume

Det overordnede formål med overvågningsprogrammet var at dokumentere langtidseffekten af genopretningstiltagene i Østerild Klitplantage. Tiltagene var designede til at skabe åbne klithabitater efter rydning af nåletræsbevoksninger ved Testcenter Østerild.

For at fremme udviklingen mod grå / grøn klit (Annex I habitattype 2130), klithede (2140) og fugtig klitlavning (2190) var en række efterbehandlinger af førnelaget og en genopretning af det hydrologiske regime inkluderet i implementeringsplanen. Overvågningsprogrammet omfattede en vurdering af effekten af de planlagte behandlinger på successionens hastighed og retning og bestod af en registrering af jordbundsforhold, vegetationens struktur og artssammensætning forud for rydningen (baseline monitering i 2011) og en systematisk opgørelse af ændringer i løbet af de første 10 år af successionsprocessen (post-cutting monitering) samt den endelige effektmonitering i 2021. Denne rapport præsenterer de endelige analyser og resultater fra effektmoniteringen.

Skovrydningen foregik 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 omfattede derfor bevoksninger med både sitka-gran, bjerg-fyr og skov-fyr.

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

Vi opfattede behandling af førnelaget som en essentiel del af genetableringsprocessen, fordi et tykt førnelag kan begrænse mulighederne for at retablere de naturlige plantesamfund i klitterne. I nåletræsplantager er førnen sur, og nedbrydningsraten er lav, hvilket fører til en ophobning af nåle, kogler og kviste på skovbunden. I implementeringsplanen blev fire forskellige behandlinger af det ophobede organiske materiale foreslået: 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). De gennemførte efterbehandlinger af førnen var dog mere ensformige end antaget, med overfladeknusning af stød som den mest udbredte efterbehandlingsmetode (på 158 ha), efterfulgt af stødrydning på 56 ha og dybdefræsning på 12 ha. Kun mindre områder var uberørte (som kontrol arealer) og ingen arealer blev afbrændt. Dette har reduceret mulighederne for at bruge overvågningsdata til at evaluere potentialet af forskellige genopretningsmetoder.

Forstyrrelser i forbindelse med fældning af træer og fjernelse af stammer og stubbe kan medføre frigivelse af næringsstoffer, der kan fremme problematiske plantearter – fx plantearter, der foretrækker høje koncentrationer af næring i jorden eller invasive arter.

En succesfuld restaurering af fugtige klitheder (2140) og fugtige klitlavninger (2190) forudsatte genopretning af det hydrologiske regime. 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. I Østerild indgik det derfor i implementeringsplanen, at en del af de eksisterende afvandingsgrøfter skulle kastes til, hvorved en række temporære vandhuller og lavvandede søer ville udvikle sig. Overvågningsprogrammet fulgte udviklingen i tørre og fugtige naturtyper, herunder tidvis oversvømmede arealer.

Vi forventede, at genopretningstiltagene skabte egnede habitater for lyskrævende arter og lavt-voksende karplanter, mosser og laver; nøjsomme arter og arter, hvis tilstedeværelse var afhængig af fluktuerende vandstand og fugtighed. De gennemførte behandlinger førte til vegetation meget lig den, man finder i våde klitter overvåget i det nationale overvågningsprogram, men vores resultater indikerede samtidig, at det ikke var lykkedes at lave en fuldstændig genopretning af naturlig hydrologi med høj og fluktuerende vandstand.

Baseline-overvågningen blev udført i juli 2011 og var afsluttet, inden skoven blev ryddet. Overvågningen blev udført efter de metoder, der indgår i den nationale overvågning af habitatdirektivets terrestriske natur-typer (NOVANA programmet) (Fredshavn et al. 2011). For hvert af de 100 prøvefelter foretog vi en registrering af artssammensætning og vegetationsstruktur i en pin point ramme (½ * ½ m) og en dokumentationscirkel med en radius på 5 m. Desuden indsamlede vi 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).

Post-cutting overvågning blev foretaget i 2013 (20 prøvefelter i det klitareal, der oprindeligt var domineret af *Pinus mugo*), 2015 (20 prøveflader i det klitareal, der oprindeligt var domineret af *Pinus mugo*), 2017 (alle prøveflader, n=100) og 2019 (n=76). Den endelige overvågning blev foretaget i august 2021 (n=91) efter samme metode som baseline-overvågningen. På grund af anlægsarbejde og afvigelse fra de planlagte behandlinger var det kun 59 prøveflader, som gik igen i både 2011, 2017 og 2021. Sammenlignende analyser for 2011 og 2021 blev derfor kun lavet på denne delmængde af data.

I løbet af den 10-årige periode efter rydningen fandt vi at:

- Jordens pH steg signifikant og til niveauer, der næsten svarede til mål-habitattyperne.

- Selvom den ændrede hydrologi skabte nye fugtige og våde habitater inden for projektområdet, og selvom arter tilpasset fluktuerende vandstand og fugtighed indfandt sig, kunne en overordnet effekt af ændret hydrologi på artsrigdom og artssammensætning ikke påvises.

- Antallet af karplanter steg signifikant fra 2011 til 2021, og græsning var én af forklaringerne til den positive tendens. Tilplantningstidspunktet havde en negativ effekt på planteartsrigdommen, hvilket kunne indikere et behov for en gennemtænkt genopretningsplan, der tager højde for forskelle i skov-alder.

- Vegetationens sammensætning ændrede sig naturligvis efter rydningen med en relativt hurtig kolonisering og etablering af arter, men dominansforholdene mellem græsser og dværgbuske bar præg af høje næringsforhold.

- Dækningsgraden af halvgræsser steg signifikant, mens ændringen af dækningsgraden af dværgbuske afhang af skovtypen.

- Vegetationssammensætningen i områder, hvor der tidligere var *Pinus sylvestris,* lignede vegetationssammensætningen i områder, hvor der tidligere var *Picea sitchensis* mere end områder, hvor der før var *Pinus montanus.*

- Udbredelsen af den invasive mos *Campylopus introflexus* steg betragteligt i løbet af de 10 år, men dækningsgraden faldt.

- Mængden af tilgængelige næringsstoffer (Ellenberg N) var højere i våde klitter og dværgbuskheder i Østerild sammenlignet med et NOVANA reference datasæt.

- Plantearter tilpasset relativt næringsfattige kår havde etableret sig i de tidligere plantager, og cirka 57 % af prøvefelterne blev forudsagt at tilhøre tør klit og hede i vores analyser. Samtidig forudsagde analyserne, at mere end 11 % af prøvefladerne lignede ikke-habitatnatur. Dette indikerede, at restaureringen ikke er lykkedes fuldstændigt.

Vi anbefaler græsning ved naturlige tætheder efter rydning af klitplantager for at opretholde tilbagevendende forstyrrelser og nedsætte næringsbelastningen. Desuden bør effekten af afbrænding af førne undersøges som en måde at genskabe højere pH efter rydning. De gennemførte behandlinger gør det ikke muligt at komme med anbefalinger til den optimale behandling af stød og førne.

Genopretning af den naturlige hydrologi er ikke lykkedes fuldstændigt, sandsynligvis fordi tilkastningen af en mindre andel af grøfterne ikke har været tilstrækkelig til at opnå våde forhold på hele arealet. I praksis er den hydrologiske genopretning ved Testcenter Østerild begrænset af hensyn til de tekniske faciliteter og forholdene på privatejede marker i området.

1 Objectives

The overall objective of the vegetation monitoring programme launched in 2011 was to describe the direction of the vegetation succession and to gain evidence of the rate of vegetation recovery in the project area of the National Test Centre facility at Østerild in the Thy region in Northern Jutland. The National Test Centre was established in parts of the state-owned plantations Østerild Plantage and Hjardemål Plantage with various species of conifer trees. The aim of the monitoring programme was to monitor the vegetation succession from open and dense coniferous forest in the first 10 years after clear-cutting of the dune plantations. Based on monitoring results, we evaluate the success of restoration of open habitats with grey dune, dune heath and humid dune slacks (see description in section 1.1).

The planting of conifers in the Østerild area begun almost 130 years ago with the primary purpose of preventing sand drift and, secondarily, producing timber and firewood. In 2011, conifers still dominated the Østerild area, including the Østerild Plantage itself and the neighboring Hjardemål Plantage in the north. The introduced coniferous species *Picea sitchensis* (Sitka Spruce), *Pinus contorta* (Lodgepole Pine) and *Pinus mugo* (Mountain Pine) together with the native *Pinus sylvestris* (Scots Pine) were the main conifers present in the plantation areas where the National Test Centre facility for wind turbines was established and inaugurated in 2012.

After the clear-cutting of part of the dune plantation, the Danish Nature Agency in Thy introduced different types of management of the deforested areas, e.g. grazing and closing of ditches to raise the ground water level and establish waterbodies. The aim was to restore open habitat types such as grey dune, dry dune heath and humid dune slacks by permitting the natural vegetation cover to regenerate from the remaining seed bank and by dispersal of diaspores from neighboring open habitats.

In 2011, Aarhus University, Danish Centre for Environment and Energy (DCE), designed a vegetation monitoring programme to assess and quantify the importance of site conditions and the post-cutting treatments for a successful development towards natural communities and to generate evidence-based knowledge on the processes involved.

The monitoring programme consisted of a baseline recording of soil conditions and species composition of the vegetation prior to clearing of dune plantations (baseline monitoring) and 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). Baseline monitoring took place prior to the clear-cutting of the dune plantation in 2011 (Nygaard et al. 2011). The progress and conditions were evaluated regularly on a subset of plots in 2013, 2015, 2017 and 2019. Final monitoring was conducted in 2021.

The design of the monitoring programme aimed at gaining insight into vegetation recovery after clear-cutting with various treatments of the tree stumps and litter and making recommendations for future conversions of plantations to dune habitats. But the recommended (by DCE) and originally planned treatments, including burning and untreated sites, were substituted by the

Danish Nature Agency to include two cost-effective methods instead; stump crushing and stump removal in almost all the monitoring plots, preventing transfer of the results to management recommendations.

1.1 Target communities

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

1. Fixed coastal dunes with herbaceous vegetation ('grey dune') (Annex I habitat type code 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 rich in cryptogams, particularly *Cladonia spp*.

2. Decalcified fixed dunes with *Empetrum nigrum* ('dune heath') (Annex I habitat type code 2140). In this habitat type, dry sand has been colonized by 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 areas have been colonized by closed dwarf scrub vegetation with *Vaccinium uliginosum, Empetrum nigrum, Erica tetralix, Calluna vulgaris, Vaccinium oxycoccos* and *Myrica gale.*

3. Humid dune slacks (Annex I habitat type code 2190). This habitat type covers wet and seasonally flooded depressions with pioneer swards, fens and pools on acidic or calcareous sand. Hence, this habitat type is mainly defined by variation in moisture, seasonal fluctuations in water level, pH, natural disturbances and management, and therefore the vegetation encompasses many different plant communities (Ejrnæs et al. 2009).

2 Site and plot selection

The monitoring programme originally included 100 plots covering the expected variation in the development of the vegetation composition (see Nygaard et al. 2011). Prior to the initiation of baseline monitoring in 2011, the plots were positioned according to a stratified random approach relative to forest type (*Picea sitchensis*, *Pinus sylvestris* and *P. mugo*), expected post-cutting treatment of stumps and litter layer (By- og Landskabsstyrelsen 2010), hydrological changes, future management regimes (grazing), distance to areas with open habitat types (i.e. with appropriate seed sources) and topography.

As the implemented post-cutting treatments differed markedly from those planned in the design of the monitoring programme, 35 of the 100 plots were repositioned prior to the 2017 investigation.

The monitoring programme was designed to follow and compare the vegetation development in both managed and unmanaged areas. Originally, 60 of the 100 monitoring plots were placed in areas planned for livestock grazing, but in 2021 only 20 plots were grazed.

The National Test Centre area was located at a rather low altitude and on almost level ground. Topographical variation was only found in the northern part of the project area where a hilly dune landscape formerly covered with *Pinus mugo* forest occured (see Nygaard et al. 2011).

2.1 Baseline conditions

The rate and direction of vegetation development are 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:

- Prior to the clearcutting, 40 % of the area was covered with dense coniferous plantations dominated by the introduced spruce species *Picea sitchensis* and *P. omorica*, the pine *Pinus contorta* and the fir *Abies alba*. During the past decades, a thick layer of organic matter (needles, cones, twigs and branches) covering the forest floor had led to soil accumulation of atmospheric nitrogen, as more nitrogen is deposited on rough surfaces, e.g. forests (Erisman & Draaijers 2003). The vegetation cover consisted mostly of bryophytes, for instance *Hypnum cupressiforme* and *H. jutlandicum*.

- *Pinus sylvestris* forest covered another 40 % of the afforested area. In less dense stands, the understory consisted of well-developed dwarf shrub vegetation with *Calluna vulgaris*, *Erica tetralix*, *Empetrum nigrum* and *Vaccinium uliginosum*.

- *Pinus mugo* stands covered 10 % of the afforested area and were restricted to the dry and hilly dune landscape in the northern part of the Østerild National Test Centre facility area. The plantation was less uniform an included *Picea sitchensis* stands as well as patches with a relatively open forest canopy with scattered occurrence of lichens, bryophytes and dwarf shrubs.

- Deciduous forests with *Quercus* sp., *Fagus sylvatica* and *Betula* sp. covered 6 % of the afforested area, but were not included in the monitoring programme.

The monitoring programme was designed to cover vegetation development in the three coniferous forest types (Figure 2.1). Of the 100 monitoring plots, 20 were laid down in the *P. mugo*, 30 in the *P. sylvestris* and 50 in the *P. sitchensis* stands (Table 3.1 and Figure 9). As explained above, the starting conditions in the three forest types differed markedly with respect to flora, topography and soil conditions, and vegetation recovery was thus expected to follow different trajectories.

2.2 Post-cutting treatments

Coniferous litter is acidic, and the decomposition rate is very slow, which leads to accumulation of semi-decomposed needles, cones and twigs on the forest floor. A thick litter layer in the coniferous forest may constitute a major constraint to the successful restoration of natural dune habitats because of the resulting elevated nutrient contents (Sturgess & Atkinson 1993).

In traditional forest management, the tree trunks, representing the economic value, are removed, while tree stumps and the litter are left behind. If the aim is afforestation, new trees are planted between the stumps in the accumulated litter layer. If the aim is restoration of natural habitat types, the tree stumps and the litter layer should thus be removed to expose the underlying mineral soil.

In the original implementation plan (By- og Landskabsstyrelsen 2010), four different post-cutting treatments of the tree stumps and the litter layer were suggested to allow a study of cost-effective restoration of open habitat types developing in the clear-cut plantation areas. When the monitoring programme was designed in 2011, the post-cutting treatments of tree stumps and litter layer were expected to include 1) sod cutting and removal of litter, 2) sod cutting and burning on site, 3) burning in parts of the *Pinus mugo* stand in the hilly landscape in the north, 4) small-scale soil disturbance and 5) areas with untreated stumps and litter. The 100 monitoring plots were positioned under the assumption that these expected treatments of litter and tree stumps would be conducted.

However, the post-cutting treatment differed markedly from the original plan and included 1) stump crushing (158 ha; comminution of the topsoil after stump removal. This method accelerated decomposition, but did not remove nutrients from the area), 2) stump removal (56 ha; stumps were pulled and removed from the area including the topsoil) and 3) depth milling (12 ha; milling of topsoil) (Figure 2.1). Only the *Pinus mugo* stands, a very small part of a *Picea sitchensis* stand and the *Pinus sylvestris* stands in the western part of the project area were left without post-cutting treatments, and there were no burned sites or sites with removal of the entire litter layer (except for constructed lakes). Consequently, we had to reposition 35 of the 100 monitoring plots to account for this new situation. This was done prior to the 2017 monitoring to reflect the implemented treatments.

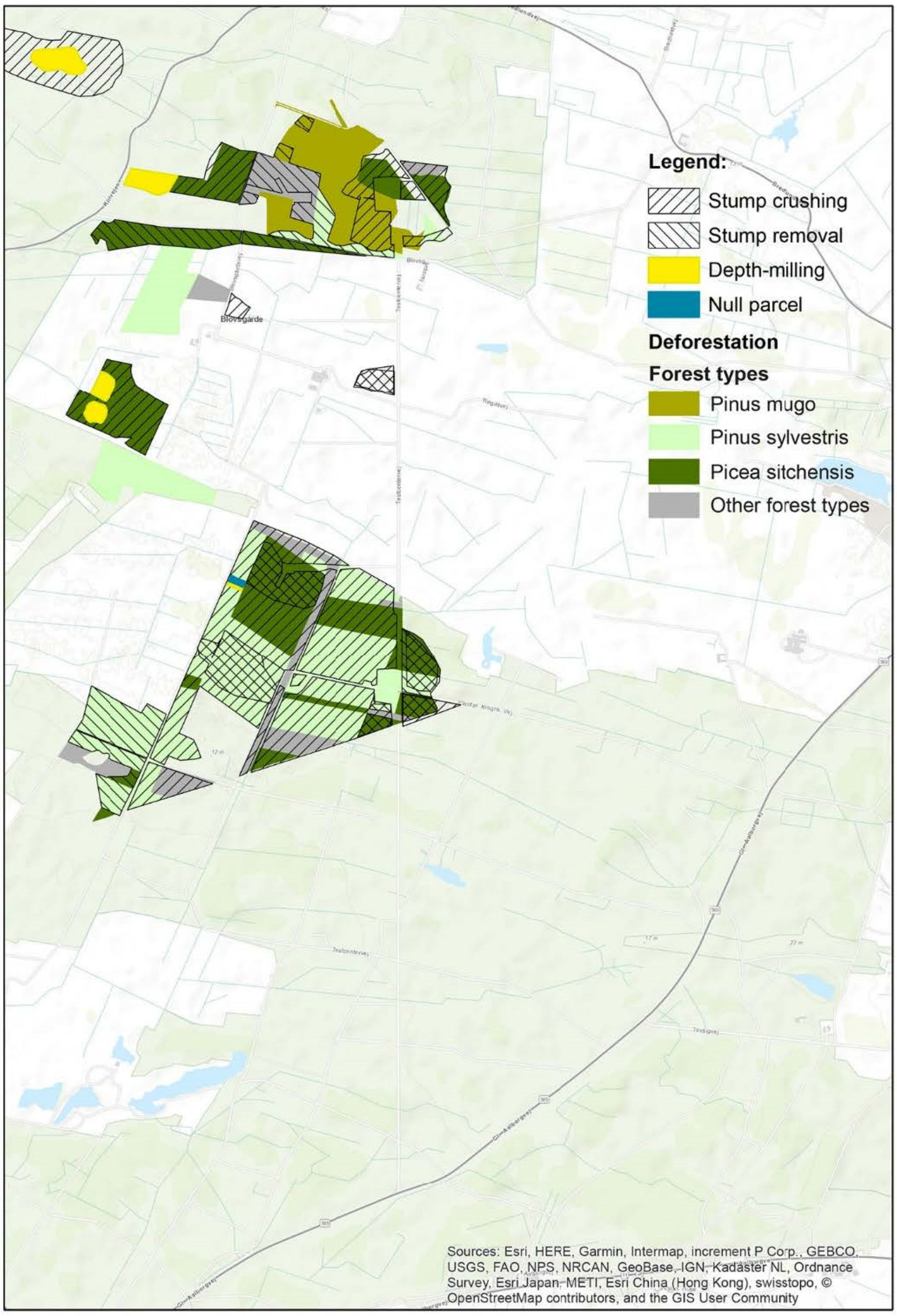


Figure 2.1. Distribution of coniferous forest types that were clear-cut from July 2011 to November 2012 in the Østerild National Test Centre facility area as well as the implemented post-cutting treatments of stumps and litter in 2014-2015. Based on GIS-maps from the Danish Nature Agency in Thy.

2.3 Hydrology

Formerly, the Østerild area was sea bottom, shaped by land uplift and shifting sand. Prior to afforestation in the late 1800s, the dune areas in the Østerild Plantage and the Hjardemål Plantage were characterised by a high and presumably fluctuating water table. Consequently, moist and wet habitats were widespread in the area (Miljøministeriet 2009). Because of intensive drainage prior to afforestation, nutrient-poor wet heathland (habitat type 2140) and dune slacks (habitat type 2190) were restricted to a few poorly drained open areas.

Successful development towards natural flora associated with moist dune heaths and humid dune slacks required adequate restoration of the hydrological regime. Thus, restoration of a more natural hydrology, mainly by closing drainage ditches and excavations (Figure 2.2), allowed temporary pools and shallow lakes to develop or expand (By- og Landskabsstyrelsen 2010).

The monitoring programme aimed to follow the development in dry, moist and wet dune habitats as well as seasonally flooded areas. Accordingly, originally 60 monitoring plots were established in unaltered dry areas and 40 plots in areas expected to encompass a hydrological gradient from dry to moist or wet conditions (Table 3.1). In 2017, the rearrangement of monitoring sites lead to a slightly larger proportion of dry sites.

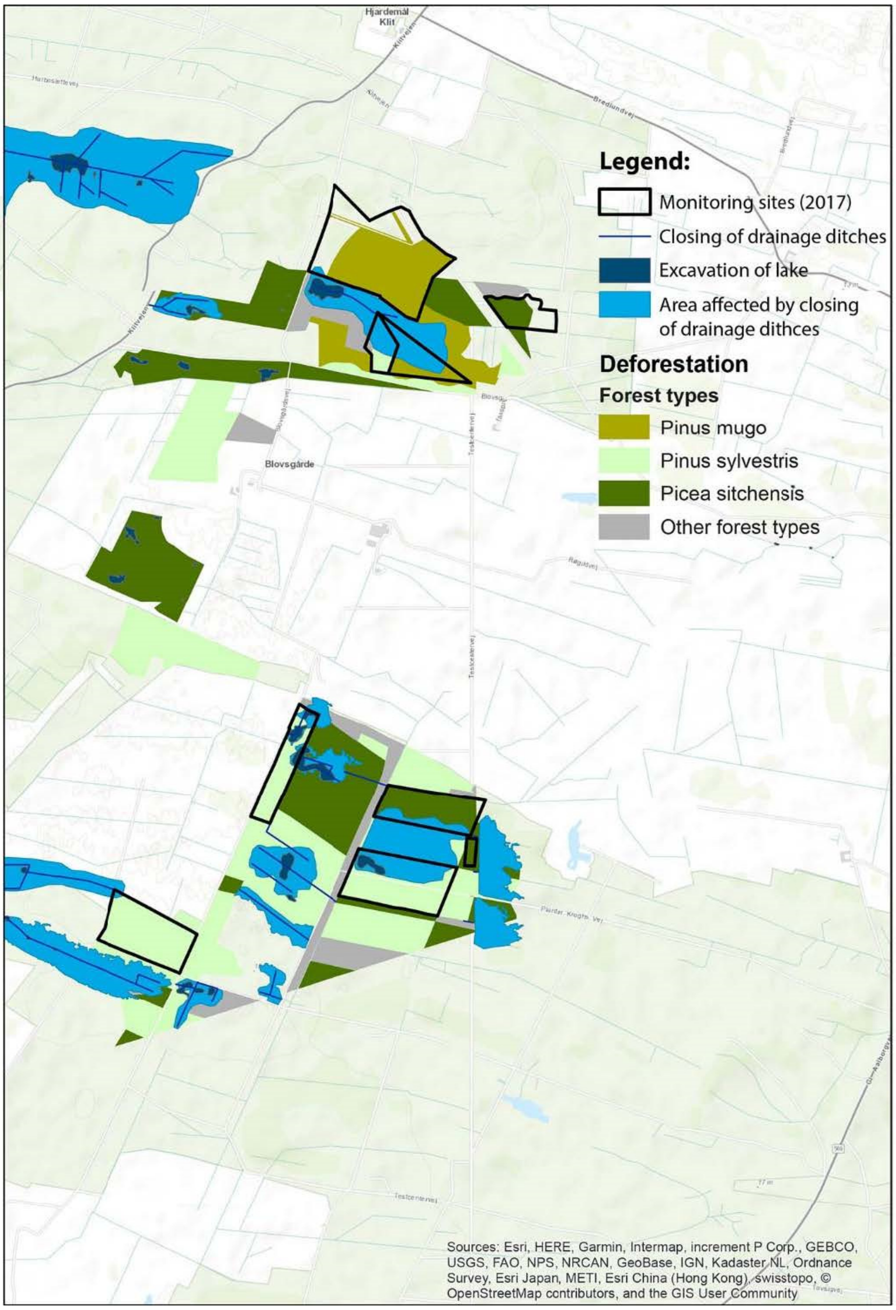


Figure 2.2. Implemented excavations of lakes and closure of drainage ditches in the test area and areas expected to be influenced by a higher groundwater level. Based on GIS-maps from the Danish Nature Agency in Thy.

2.4 Grazing

Erosion, sand 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 was suggested in the implementation plan that burning and livestock grazing should be established in selected areas. The monitoring programme was designed to follow and compare the development in both managed and unmanaged areas. Prior to baseline monitoring, we planned to place 60 plots within areas planned for livestock grazing and 40 plots outside grazed areas. However, only 20 plots were actually grazed from 2018 (Table 3.1).

As part of the daily management by The Danish Nature Agency, coniferous trees as well as *Cytisus scoparius* were continuously removed from the deforested areas by cutting, pulling by hand or brush cutter. This unquantified effort to prevent encroachment of course also affected the succession and, therefore, the monitoring.

3 Monitoring

3.1 Monitoring plots

Prior to clear-cutting, 100 monitoring plots were appointed and included in the baseline monitoring in 2011 (Table 3.1). In 2013 and 2015, 20 monitoring plots were investigated in the northernmost dune area in Hjardemål Plantage, which was formerly afforested with *Pinus mugo* (Wind 2013, 2016).

A total of 15 plots were excluded from deforestation after the baseline monitoring (sites 3-5 in Figure 9 in Nygaard et al. 2011) and were therefore excluded from the post-cutting monitoring and replaced by new plots in 2017. Also, as the implemented post-cutting treatments differed markedly from those planned in the design of the monitoring programme, another 20 of the 100 plots were repositioned prior to the 2017 investigation. To ensure a good representation of the implemented post-cutting treatments, we designated four new monitoring sites – no. 3, 4, 5 and 7 (Table 3.1). One of the new sites, no. 7, was established on the western side of the main unpaved field road of the National Test Centre facility in order to document the effect of the increasing pH caused by road dust. In 2017, the monitoring thus consisted of 65 original plots and 35 new plots.

In 2019, 76 plots were monitored. According to the monitoring plan, the 20 northernmost plots formerly afforested with *Pinus mugo* were skipped and another four plots were permanently excluded due to construction work. The final monitoring in 2021 was conducted in 91 plots, where four more plots were omitted due to construction work.

Table 3.1. Implemented excavations of lakes and closure of drainage ditches in the test area and areas expected to be influenced by a higher groundwater level. Based on GIS-maps from the Danish Nature Agency in Thy. The monitoring sites and their baseline condition (forest type), year of stand planting, post-cutting treatments regarding moisture regime (planned wetlands), grazing, litter layer and number of plots investigated in the particular year. 0 = no investigation of the plots in the particular year. The site numbers from the previous monitoring reports are shown in brackets in the first column. * Hilly dune area with great topographically variation. ** Monitoring site appointed and plots laid out in 2017. [1] Year in brackets for hydrological restoration by closing drainage ditches and excavation of shallow lakes,[2] Year in brackets for treatments of tree stumps and litter.

Site number	**Baseline condition (forest type)**	**Forest stand age**	**Post-cutting treatments**			**Number of plots**					
			Moisture [1]	**Grazing**	**Litter [2]**	**2011**	**2013**	**2015**	**2017**	**2019**	**2021**
1	*Pinus mugo* forest	84	Dry *	No	No treatment	20	20	20	20	0	19
4 **		85	Dry-moist (2014)	No	No treatment				5	5	5
					Stump crushing (2015)				5	5	5
2	*Picea sitchensis* forest	38	Dry	No	Stump crushing (2015)	5			5	5	5
					No clearcutting	5					
3 **		85	Dry-moist (2014)	No	Stump removal (2013)				5	5	5
(3-4)		94	Dry-moist (2014)	No	No clearcutting	10					
5 **		12	Dry	No	No treatment				5	5	5
					Stump crushing (2015)				5	5	5
					Depth milling (2015)				5	5	5
6		49	Dry-moist (2014)	No	Stump crushing (2015)	40			20	17	17
7 **		58	Dry	No	Stump crushing (2015)				5	5	2
8	*Pinus sylvestris* forest	58	Dry	No	Stump crushing (2015)	5			5	5	4
			Moist-wet (2014)	No		5			5	4	4
9		57	Dry	Yes	Stump removal (2014)	10			10	10	10
Total						100	20	20	100	76	91

Figure 3.1A and 3.1B: The location of the plots monitored in the Østerild area. A: northernmost plots. B: south-western plots. Dark green: plots monitored in both 2011, 2017 and 2021 (n=59). Light green: plots established in 2017 and remonitored in 2021 (n=32). Red: plots only included in baseline monitoring because clear-cutting was never conducted (n=16). Orange: plots omitted due to construction work (n=8). Blue: plots omitted in 2017 due to lack of differentiation in treatments (n=20).

3.2 Monitoring methods

Monitoring of the vegetation was conducted according to the methods described in the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA) (Fredshavn et al. 2011). Each monitoring plot consisted of a core square of ½ m × ½ m (the pinpoint frame) and a circle with a radius of 5 m (78.5 m^2, the 5 m circle).

GPS waypoints were used to locate the monitoring plots and digital pictures were taken in the direction south of the individual plots. The pictures proved to be a very useful tool supporting the GPS waypoints when finding the monitoring plots, reducing uncertainty in the rediscovery of the plot position.

Vascular plants were identified to species, while bryophytes and terricolous lichens (growing on the soil surface) were lumped into groups (Bryopsida, Liverworths, Sphagnum, Cladonia species, Cladina species and Other lichens).

Data on plant occurrence were supplemented by cover measurements of bryophytes, lichens, dwarf shrubs, trees and shrubs, bare substrate, open water and dead wood. We also measured depth of the litter layer, light penetration and vegetation height (Table 3.2).

In the baseline (2011) and final monitoring (2021), we collected soil samples from all 100 plots for pH measurements and C:N ratio analyses (Table 3.2). Soil samples were collected in the top 10 cm of the soil surface in each corner of the pinpoint frame with an earth auger (Fredshavn et al. 2011). The four subsamples were subsequently pooled in one bulk sample. The soil samples were oven-dried at 50ºC, ground to a fine powder and sieved through a 2 mm sieve to separate fine earth from coarse particles. Soil pH was measured in a slurry of 25 ml deionized water added to approximately 10g soil. The slurry was shaken vigorously, allowed to settle and then measured using a pH meter in the upper part of the suspension. Soil C and N content were analyzed on a subset of 24 samples in 2011 using an Elementar CHNS analyzer. C:N measurements were repeated in 2021, but only 13 of the 24 plots were part of the monitoring in 2021.

Table 3.1. The ecological parameters included in the monitoring programme. * Soil content of organic matter and total nitrogen were measured in 2011 in two plots at each monitoring site (24 measurements of which 13 were re-measured in 2021).

	Measured in		**Measure time**		
	Frame	**Circle**	**Baseline**	**Post-cutting**	
Monitoring variables	**(0.25 m^2)**	**(78.5 m^2)**	**2011**	**2013-19**	**2021**
Vegetation composition					
Species abundances	X	X	X	X	X
Vascular plant species			X	X	X
Bryophyte group			X	X	X
Lichen group			X	X	X
Vegetation structure					
Mean vegetation height	X		X	X	X
Cover of dwarf shrubs		X	X	X	X
Cover of trees and bushes		X	X	X	X
Cover of bryophytes		X	X	X	X
Cover of lichens		X	X	X	X
Canopy density		X	X	X	
Substrate					
Cover of open water	X	X	X	X	X
Cover of bare soil/sand	X	X	X	X	X
Cover of litter	X	X	X	X	X
Cover of dead wood	X	X		X	X
Litter depth		X	X	X	X
Soil chemistry					
pH	X		X		X
Organic matter *	X		X		X
Total nitrogen *	X		X		X

3.3 Final monitoring

The final monitoring was carried out in August 2021, ten years after the clear-cutting of the plantations in 2011.

Monitoring methods resembled the methods used for baseline monitoring, except for cover of dead wood and canopy density measures (Table 3.2).

4 Analyses and results

We conducted two sets of analyses. One analysis was conducted with the subset of monitoring plots that was sampled in 2011, 2017 and 2021 (n=59) in order to measure the changes in environmental conditions, species richness and plant species composition. The second analysis allowed us to evaluate restoration success and consisted of a comparison with a reference data set from the national monitoring programme (NOVANA) for monitoring Annex I habitat types in Denmark.

4.1 Changes in Østerild plots (2011-2021)

Due to changes in the position of the clear-cut areas and post-cutting treatments as well as unforeseen disturbances (e.g. road constructions) of the monitoring plots, 59 of the original 100 plots had a full 10-year monitoring history.

We used Student's t-test to detect significant changes in soil pH, litter depth soil C:N, Ellenberg Indicator Values (EIV, see section 4.1.3), and vegetation height during the 10-year period. The variance of all these parameters were normally distributed.

4.1.1 Soil pH and litter depth

Soil pH is an important factor for plant growth, nutrient availability and microbial activity. In the Østerild area, the geological parent material is base-poor aeolian sediment. Mean soil pH across the 59 plots was 3.3 in 2021, and soil pH significantly increased from 2.9 to 3.3 ($p < 0.001$) during the 10-year period after deforestation (Table 4.1). The low pH in 2011 can be explained by the low buffer capacity in decalcified dune sand and the continuous deposition of acid litter from coniferous plantations causing a rapid acidification of the soil (Stützer 1998). The increase in soil pH was also significant when testing the three original forest types. We found the greatest increase in former *Pinus mugo* stands (0.5, $p < 0.001$, n=19), almost as great a difference in former *Picea sitchensis* stands (0.4, $p < 0.001$, n= 22) and the smallest increase in former *Pinus sylvestris* stands (0.2, $p < 0.001$, n=18). Mean soil pH values in the NOVANA reference data set (described in section 4.3) were slightly higher than the Østerild pH measurements from 2021 (dune grassland: mean soil pH = 4.2, dwarf shrub heath: 3.4, wet dune: 3.6; Table 4.5), possibly due to a higher content of calcium carbonate in the coastal dunes in the reference data set.

Table 4.1. Mean soil pH measured in 2011 and 2021 for all plots and the three forest stand types. P-values from Student's t-test of the difference in means and number of plots in each stand type are given.

Stand	pH 2011	pH 2021	Difference	p-value	n
All	2.9	3.3	0.4	<0.001	59
Pinus mugo	2.9	3.4	0.5	<0.001	19
Picea sitchensis	2.7	3.2	0.5	<0.001	22
Pinus sylvestris	3.1	3.3	0.2	<0.001	18

We found a significant drop in litter depth from 6.8 cm in 2011 to 0.5 cm in 2021 ($p<0.001$, n=59), indicating that part of the litter was removed during stump removal and that the rest had decomposed almost completely after 6-7 years.

4.1.2 Soil C:N

Soil C:N ratio 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 plots with low soil pH, high production of hard degradable litter (e.g. phenolic compounds in conifer needles), low nitrogen supply or high leaching of nutrients. On the other hand, a low C:N ratio indicates that the organic matter is readily degradable, nitrogen supply is high or leaching of nutrients is low.

Soil C:N ratios did not differ significantly in 2011 and 2021 (Student's t-test, n=13, p=0.801). Generally, the measured C:N ratios in the top soil were rather low. The highest values were recorded in the four samples from the *Pinus mugo* stand (median 2011 = 29 (n=4), median 2021=31 (n=4)), while the C:N ratio was considerably lower in the *Pinus sylvestris* stands (median 2011 =19 (n=3), median 2021=20 (n=7)).

We found a significant negative correlation between soil pH and the C:N ratio (Spearman's Rho = -0.78, p = 0.002), in accordance with the well-established pH-dependence of decomposition of soil organic material. We see similar correlation in data from Danish coastal dune habitats (Damgaard et al. 2008).

4.1.3 Ellenberg indicator values

Apart from the measured environmental variables, plant lists can also reflect the environmental conditions in a given area. Based on the plot plant lists, we calculated plot mean Ellenberg Indicator Values (EIV's, Ellenberg et al. 1991, updated by Hill et al. 1999) indicating plant preferences for nutrient availability (EIV_N), soil acidity (EIV_R), soil moisture (EIV_F) and light (EIV_L). Ten of the plots did not hold vascular plants or held vascular plants that did not have assigned EIVs and therefore, plot mean values were only calculated for 49 of the 59 plots.

We found no significant change in EIV_F nor EIV_N values from 2011 to 2021 (Student's t-test, $p(EIV_F) = 0.725$, $p(EIV_N) = 0.811$, n=49 plots), but the plots spanned a larger part of the moisture gradient (EIV_F) in 2021 as compared to 2011 and a smaller part of the nutrient gradient (EIV_N) (Fig. 4.1).

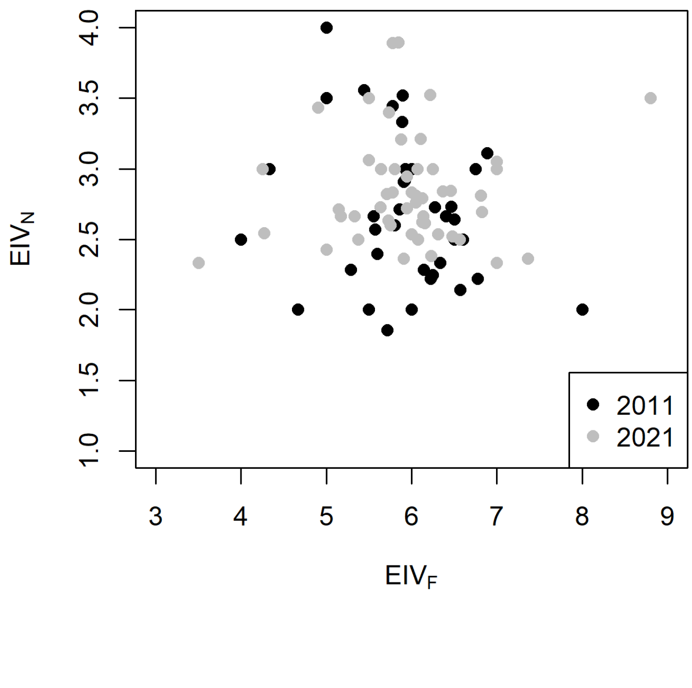


Figure 4.1. Mean site Ellenberg values for moisture (EIV_F) and nutrients (EIV_N) in 49 plots in 2011 (black) and 2021 (grey).

4.1.1 Vegetation height

We found a significant increase in herb layer vegetation height from 7.9 cm to 15.6 cm during the ten year period after clear-cutting (p-value < 0.001, n=59 plots), indicating that species composition and, hence, vegetation height has changed in response to the change in light conditions after, among other things, clear-cutting.

4.2 Species abundance, species richness and vegetation composition

We used pinpoint data (½ × ½ m frame) to identify the most common species as well as for calculating cover of dwarf shrubs, grasses, lichens and bryophytes.

We recorded 142 taxa in the 91 plots monitored in 2021 (recall that bryophytes and lichens were aggregated to six groups; each group counted as one taxon). The most widespread species/species group were *Bryopsida* (occurring in 98 % of the 91 plots), *Deschampsia flexuosa* (92 %), *Calluna vulgaris* and *Molinia caerulea* (86 %), *Cladonia sp.* (82 %), *Carex arenaria* and *Hypochoeris radicata* (70 %), *Erica tetralix* (66 %), *Holcus lanatus* and *Galium saxatile* (54 %), *Juncus effusus* (49 %) and *Juncus squarrosus* (47 %) (Appendix, Table 9.1). The change in abundance of the most common species from 2011 and 2021 was pronounced at least for some species, e.g. the occurrence of *Cladonia sp.* increased from 9 % of the plots in 2011 to 82 % in 2021; *Hypochoeris radicata* from 4 % in 2011 to 70 % in 2021; *Galium saxatile* and *Holcus lanatus* from 9 % in 2011 to 54 % in 2021; *Juncus effusus* from 6 % in 2011 to 49 % in 2021 and *Juncus squarrosus* from 1 % in 2011 to 47 % in 2021 (Table 9.1).

We investigated the changes (2011 to 2021) in occurrence of species most common in Danish dunes. The grasses *Deschampsia flexuosa* and *Molinia caerulea* were both common on sandy, nutrient poor grounds, with *M. caerulea* often dominating in moist areas. *Calluna vulgaris* and *Erica tetralix* were both dwarf shrubs common in nutrient poor soils in open habitats. *C. vulgaris* was characteristic of dry dune heaths, whereas *E. tetralix* was adapted to moist conditions, e.g. in wet dune heaths. We found a general increase in species occurrence of both grasses (*Deschampsia flexuosa*, *Molinia caerulea*) and dwarf shrubs (*Calluna vulgaris*, *Erica tetralix)* (Figure 4.2). Occurrence of *Calluna vulgaris* leveled off from 2017 to 2021. When investigating coverage instead of occurrence, grasses dominated (*Deschampsia flexuosa*, *Molinia caerulea*) and dwarf shrub coverage (*Calluna vulgaris*, *Erica tetralix)* was almost constant (Figure 4.3). By comparison, coverage of *Calluna vulgaris* in dune heaths (habitat type code 2140) monitored in the NOVANA programme was about twice the coverage in Østerild (31 %, https://novana.au.dk/naturtyper/kystklitter/klithede-2140/kontrolovervaagning-2004-2015/resultater/artssammensaetning).
Coverage of *Molinia caerulea* increased, particularly from 2017 to 2021, while coverage of *Deschampsia flexuosa* decreased slightly from 2017 to 2021 (Figure 4.3). Nevertheless, coverage of *Deschampsia flexuosa* was still high as compared to the coverage in NOVANA (20 %, https://novana.au.dk/naturtyper/kystklitter/klithede-2140/kontrolovervaagning-2004-2015/resultater/artssammensaetning). The difference in coverage as compared to the NOVANA plots indicates that the relationship among species regarding dominance has not yet settled, and the coverage of dwarf shrubs seems to be impeded by the more competitive grasses.

Figure 4.2. Occurrence (% of plots) of common species (*Deschampsia flexuosa* (Desch_flex), *Molinia caerula* (Mol_caer), *Calluna vulgaris* (Cal_vul) and *Erica tetralix* (Eri_tetr) and the invasive bryophyte *Campylopus introflexus* (Camp_int) in year 2011, 2017 and 2021 (n=59)

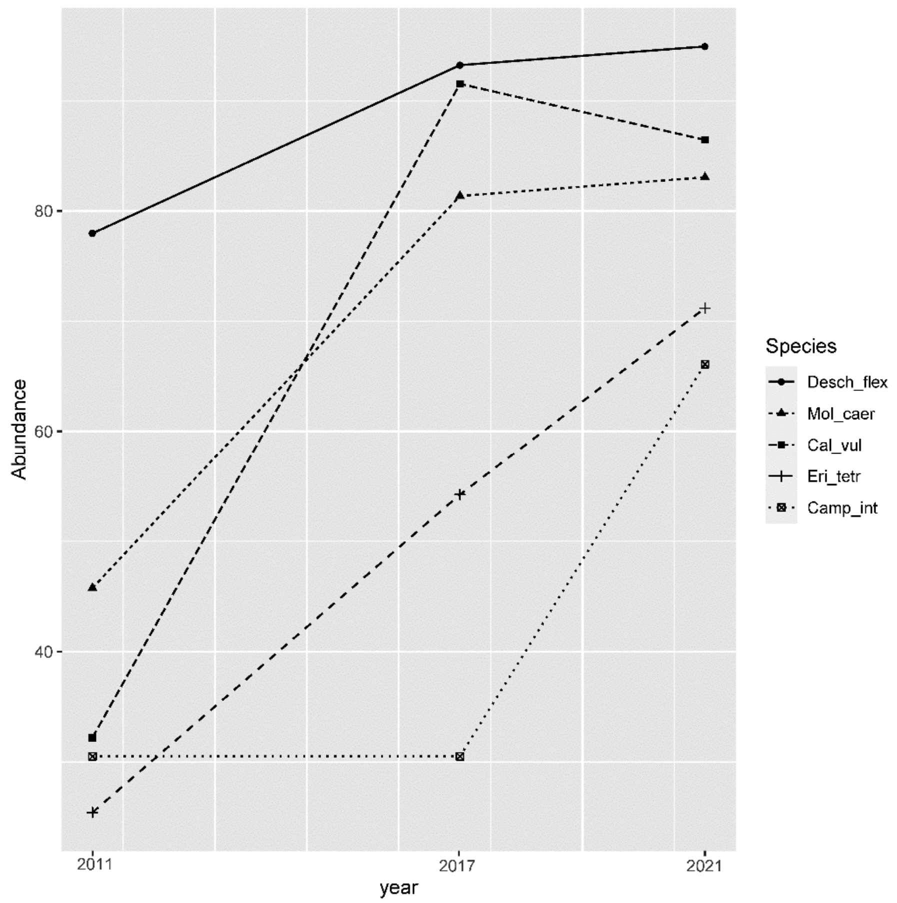
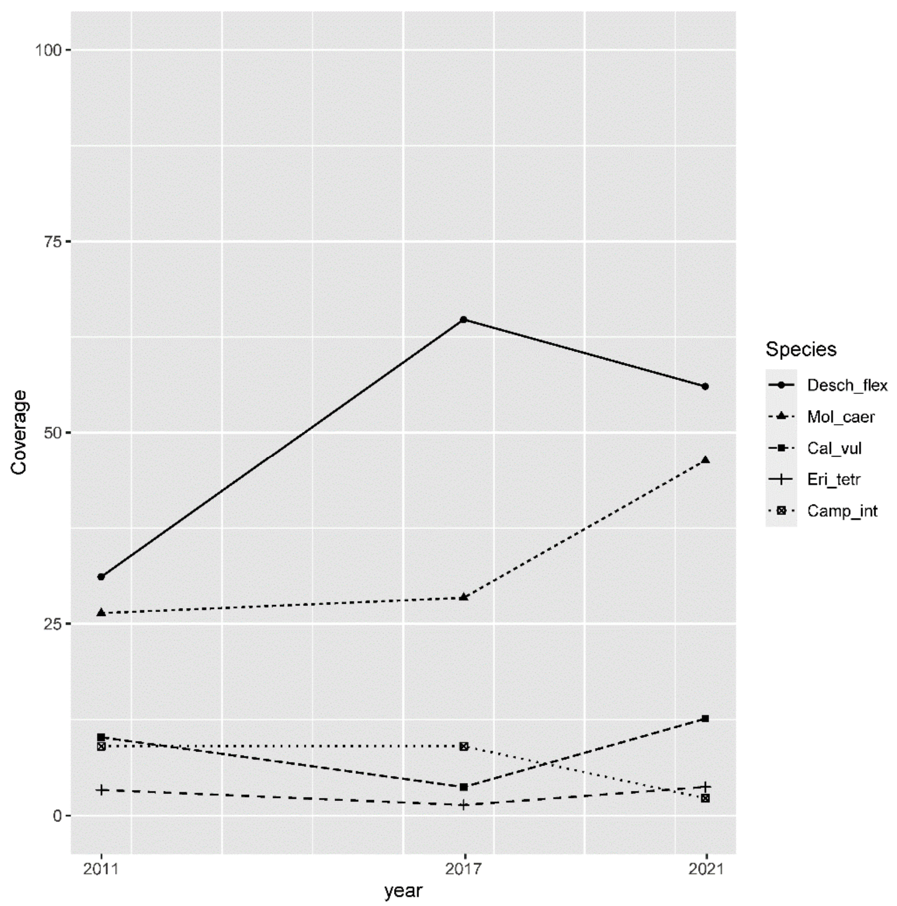


Figure 4.3. Coverage (%) of common species (*Deschampsia flexuosa* (Desch_flex), *Molinia caerula* (Mol_caer), *Calluna vulgaris* (Cal_vul) and *Erica tetralix* (Eri_tetr) and the invasive bryophyte *Campylopus introflexus* (Camp_int) in year 2011, 2017 and 2021 (n=59)



4.2.1 Coverage (sedges, dwarf shrubs, cryptogams)

We found a significant increase in coverage of sedges from 2011 to 2021 (35 % of pins in 2011 to 91 % in 2021, $p<0.0001$, n=59 plots), while no significant change in cryptogam or dwarf shrub coverage was detectable overall (n=59 plots). Dwarf shrub coverage did, however, increase significantly in *Picea sitchensis* stands (from 0 % in 2011 to 22 % in 2021, $p<0.01$) and decrease significantly in *Pinus sylvestris* stands (from 31 % in 2011 to 16 % in 2021, $p<0.05$). Dwarf shrubs made up an almost continuous ground cover prior to clear-cutting of the *Pinus sylvestris* stands.

4.2.2 Species richness

We calculated vascular plant species richness for each 5 m circle excluding all observations at genus level. We ran a Generalized Linear Model (GLM) with Poisson errors to investigate what affected vascular plant species richness in 2021, using soil pH, forest stand age, forest type (*Pinus mugo*, *Pinus sylvestris*, *Picea sitchensis*), post-cutting treatment (none, stump crushing, stump removal) and grazing (yes / no) as explanatory variables.

Vascular plant species richness varied widely between the monitoring plots in 2021 (range 4-43), but, in general, we found a significantly higher vascular plant species richness in 2021 (15 species on average) than in 2011 (7 species on average, Student's t-test: $p<0.001$, n=59 plots).

We found the largest increase in number of vascular plant species in the former *Picea sitchensis* stands (2011: 3 species, 2021: 16 species, Student's t-test: $p<0.001$, n=59 plots), where the species richness was very low in the closed canopy prior to clear-cutting. On average, the vascular plant species richness increased with five species in both *Pinus mugo* (7 to 12 species, Student's t-test: $p<0.01$, n=59 plots) and *Pinus sylvestris* (13 to 18 species, Student's t-test: $p<0.01$, n=59 plots) stands from 2011 to 2021.

We found more vascular plant species in grazed (22 species) compared to ungrazed plots (14 species, Student's t-test: $p<0.001$, n=59 plots) in 2021. However, we also found significantly more species in ungrazed plots in 2021 (14 species) as compared to ungrazed plots in 2011 (6 species, Student's t-test: $p<0.001$, n=59 plots), pointing to the general increase in species richness in response to the conversion of plantations to open dunes.

In the GLM, we found grazing to have a positive impact on species richness and forest stand age to have a negative impact on species richness (Table 4.2). The model explained 33.4 % of the variation in vascular plant species richness. Soil pH, post-cutting treatment and forest type did not have significant effects on change in species richness.

Table 4.2. Modelling output for the model using number of vascular plants (poisson) as response variables and soil pH, forest stand age (see Table 3.1), forest type, post-cutting treatment and grazing as explanatory variables. Estimates, standard errors (Std. error) and p-values are given. Deviance explained calculated as (null. deviance-deviance)/null. deviance was 33.4 %

Explanatory variable	Estimate	Std. error	p-value
Intercept	2.67	0.04	<0.001
Forest stand age	-0.12	0.04	0.001
Grazing	0.40	0.08	<0.001

4.2.3 Species composition

To get a measure of vegetation change during the 10-year period, we conducted an ordination (Nonmetric Multidimensional Scaling analysis, NMDS). Ordinations are used to reduce the information in difference in species composition among plots to the two-three most important floristic gradients explaining the distribution of species in plots. Using the ordination, the 59 Østerild plots were placed within the ordination space according to the species each plot held. Plots located close to each other in the ordination plot held similar species, while plots far apart were not similar regarding species composition and ecological conditions.

NMDS was run on a site × species matrix using plants at species level and the three groups of bryophytes and lichens.

An illustration of the NMDS ordination can be seen in figure 4.4. The first ordination axis (NMDS1) mostly represents a light gradient (indicated by the EIV_L vector pointing mainly to the right), i.e. a change from plantations with conifers (*Pinus mugo, Abies alba, Picea stichensis, Picea abies*) to open habitats dominated by forbs and grasses, whereas the second ordination axis (NMDS2) represents a nutrient availability and moisture gradient (indicated by the EIV_N and EIV_F vectors pointing downwards along NMDS2). The 3-dimensional NMDS explained 79.9 % of the variation in species composition, of which 43.4 % could be attributed to ordination axis 1.

From the ordination plot (Figure 4.4), we see an overall change in species composition (the 2011 ellipse (explanation in figure legend Figure 4.4) does not overlap with the 2017 and 2021 ellipse) during the 10-year period, reflecting succession after clear-cutting (Figure 4.4). Not surprisingly, the change from 2011 to 2017 was bigger than the change from 2017 to 2021, reflected by the change of location of the ellipses from 2011 to 2021. The size of the ellipses also changed in the 10-year period, with the 2011-ellipse covering the largest area, indicating more heterogeneity in species composition across plots in 2011 as compared to 2017 and 2021.

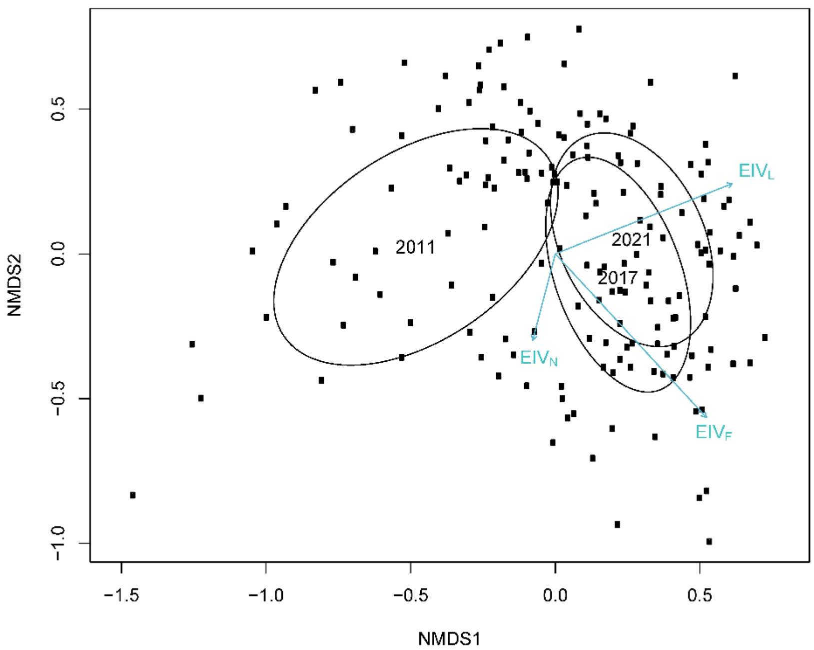


Figure 4.4. Nonmetric multidimensional scaling (NMDS) ordination of species registered in the 59 complete plots in 2011, 2017 and 2021. NMDS axis 1 and 2 are shown. Ellipses extends to the 0.4 confidence interval for years . Arrows indicate significant (p<0.001) correlation between ordination axes and environmental variables (EIV_N,EIV_F, and EIV_L). The size of the ellipses indicate the amount of variation in species composition for each year.

We analyzed which variables could explain the change in species composition from 2011 to 2021 (represented by the difference in ordination coordinates along NMDS axis 1 for 2021 and 2011 plots) using a Generalized Linear Model (GLM). We used vegetation change (NMDS-1 difference) as a response variable and soil pH in 2021, original forest type, age of forest prior to deforestation, treatment and grazing (presence / absence) as explanatory variables. We found the change in species composition during the 10-year period to be significantly related to forest type and forest stand age (Table 4.3). The model explained approximately 34 % of the variation in species composition from 2011 to 2021 (Adjusted r^2, Table 4.3). Soil pH, post-cutting treatment and grazing did not have significant effects on change in species composition.

Table 4.3. Modelling output for the model using change in species composition from 2011 to 2021 along NMDS axis 1 as response variables and soil pH, forest stand age, forest type, post-cutting treatment and grazing as explanatory variables. Estimates, standard errors and p-values are given. Adjusted r^2 =33.8 %

Explantory variable	Estimate	Std. error	p-value
Intercept	-0.37	0.40	0.352
Forest type *Picea sitchensis*	2.04	0.67	0.003
Forest type *Pinus sylvestris*	1.17	0.48	0.018
Forest stand age	0.62	0.28	0.032

In order to illustrate the importance of forest type to species composition, we plotted ellipses indicating the position of the majority of plots belonging to each forest type for year 2011, 2017 and 2021 (Figure 4.5). Species composition in *Picea sitchensis* plots differed the most from the rest of the plots in 2011. In 2017, species composition in *Pinus sylvestris* and *Picea sitchensis* were more similar (overlapping ellipses), while *Pinus mugo* plots were different (Figure 4.5). *Pinus sylvestris* stands varied the most in species composition in 2011 (the ellipse covers the largest area) and, indeed, some of the *P. sylvestris* stands were open with ground cover of dwarf shrubs prior to clear-cutting. Others were more closed and darker.

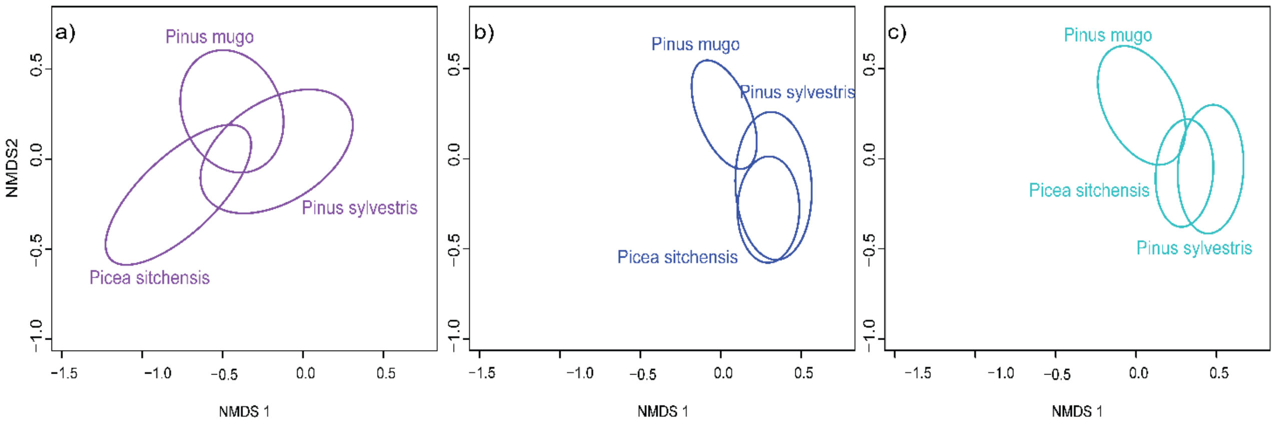


Figure 4.5. Nonmetric multidimensional scaling (NMDS) ordination of species registered in the 59 complete plots in 2011, 2017 and 2021. NMDS axis 1 and 2 are shown. Ellipses extends to the 0.4 confidence interval for years and forest types (purple = 2011, blue= 2017, cyan = 2021). The size of the ellipses indicate the amount of variation in species composition for each combination of forest type and year.

4.2.4 Specific species

We assessed the occurrence of indicator species across years as part of the evaluation of the restoration process. The list of indicator species consisted of species indicating near-natural conditions and low-nutrient contents as well as species considered very sensitive towards habitat changes as defined by Fredshavn et al. 2010. In 2021, we found a number of species indicating near-natural conditions and low nutrient contents (Table 4.4). There was no clear trend in the number of occurrences of indicator species during the 10-year period.

A small number of species (*Amelanchier spicata, Prunus serotina, Rosa rugosa* and *Campylopus introflexus)* found in the Østerild area are on the national list of invasive species (https://mst.dk/media/225663/invasive-arter-i-dk-lister.pdf) and therefore call for attention. However, *Amelanchier spicata* was only found in one plot in 2019, *Prunus serotina* was found in two plots in 2011, but the species occurrence seemed stable (found in three plots in 2019 and two plots in 2021). *Rosa rugosa* was only found in one plot in 2011. *Campylopus introflexus* showed a major increase in occurrence from 18 plots in 2017, 20 plots in 2019 to 39 plots in 2021 (Figure 4.2), however, coverage of *Campylopus introflexus* decreased slightly from 2011 to 2021 (Figure 4.3).

Table 4.4. Occurrence (number of plots) of species indicating near-natural conditions and low nutrient contents in the monitoring period. Indicator species considered very sensitive (**) towards habitat changes as defined by Fredshavn et al. 2010 are marked. The list of indicator species ('two-star species') was developed to indicate favorable conservation status cf. the Habitats Directive (European Commission 1992). +: the species was found just outside the plot.

Species	2011	2013	2015	2017	2019	2021
Achillea ptarmica				5	4	4
Carex panicea			1	7	3	8
Carex viridula var. pulchella				2	1	
Corynephorus canescens		1	3	4		4
*Drosera rotundifolia***				1		+
*Eleocharis multicaulis***				1	1	1
Euphrasia stricta				2	1	1
Hieracium umbellatum					1	
Jasione montana			1	2		4
Juncus anceps var. atricapillus				3	3	
Juncus filiformis				6	7	8
Lycopodium clavatum				2		
*Lycopodiella inundata***				1		
Luzula campestris					1	8
Pilosella officinarum			1			2
*Polygala serpylifolia***	2			1	2	1
Veronica officinalis					1	2

4.3 Comparison with a reference data set

To compare the Østerild vegetation plots to natural areas of high conservation value, we assembled a reference data set holding plant species lists from 5-m circular vegetation plots monitored in the national monitoring programme (NOVANA) for Annex 1 habitat types in Denmark (https://novana.au.dk/). We extracted data from coastal dune habitat types (Annex I habitat codes 2110, 2120, 2130, 2140, 2160, 2170, 2190, 2250), inland dunes (2310, 2320, 2330), heaths (4010, 4030), acidic grasslands (6230), meadows (6410) and acidic peat-forming mires and bogs (7140) within the Atlantic biogeographical region (https://novana.au.dk/naturprogrammet/biogeografiske-regioner), where the test centre is situated (Table 4.5). These habitat types represented the plant communities that we would expect our plots to resemble, given a successful restoration of the former dune plantations. We also extracted vegetation data from less natural areas with dunes, heaths, grasslands, meadows and bogs (2100, 4000, 6200, 6400, 7100), where the species composition did not meet the definitions of a habitat type in the Annex I of the Habitat Directive (European Commission, 1992). To ensure a proper sample size and because of similarities in vegetation across habitat types, we aggregated infrequent habitat types into the following groups: wet dunes (Annex I habitat codes 2190, 4010, 6410, 7140), dwarf shrub heaths (2140, 4030, 2310, 2320), fore dune (2110, 2120), dune shrubs (2160, 2170, 2250) and dune grasslands (2130, 2330). The following habitat types were not aggregated with other habitats: 2100, 4000, 6200, 6230, 6400, 7100 (Table 4.5).

Table 4.5. Overview of the groups and EU habitat types included together with number of plots and the Annex I habitat code. The estimated land cover (ha.) of each habitat group is given with priors used for quadratic discriminant analysis in parentheses (see main text).

Group name / EU Habitat type	Annex I code	No. of plots	Est. land cover (prior)	Mean soil pH
Dune grassland	2130, 2330	1069	10,896 ha (0.051 %)	4.23
Acidic grassland	6230	718	5,314 (0.025 %)	4.10
Fore dune	2110, 2120	155	1,750 (0.008 %)	6.62
Dwarf shrub heath	2140, 4030, 2310, 2320	3338	30,583 (0.144 %)	3.36
Dune shrub	2160, 2170, 2250	248	1,588 (0.008 %)	4.32
Wet dune	2190, 4010, 6410, 7140	2324	12,804 (0.182 %)	3.56
Non HD dune	2100, 4000	102	9,700 (0.046 %)	3.39
Non HD grassland	6200, 6400	174	104,400 (0.493 %)	4.37
Non HD mire	7100	76	9,000 (0.043 %)	3.89
SUM		8204		

Subspecies and variants were aggregated to species level, and mean plot Ellenberg values were calculated using the same method as described in 4.1.3.

To evaluate whether the Østerild plots resembled natural habitat types regarding plant composition and environmental conditions (represented by Ellenberg values), we ran a Quadratic Discriminant Analysis (QDA) on the reference data set to discriminate between habitat groups using EIV_N, EIV_R, EIV_F and EIV_L plot values. The QDA was used to predict the probability of our Østerild plots belonging to one of the habitat groups. Prior weights for each habitat group were used to avoid overfitting of habitat groups overrepresented in the data set as compared to the national coverage of the habitat types (https://novana.au.dk/naturtyper/kortlaegning/sammenfatning-2016-2019/de-kortlagte-arealer, Table 4.5).

Figure 4.6 illustrates the variation in moisture (y-axis, EIV_F) and acidity (x-axis, EIV_R) of the reference plots, and colors indicate the predicted habitat groups. The figure indicates that the habitat groups were separated nicely by the moisture and acidity gradients pointing to the importance of these gradients for species composition in the dune, heath and grassland habitats. Wet dunes dominated the upper half of the moisture axis and covered the full acidity gradient. Dwarf shrub heaths were drier and with high acidity (EIV_R values < 4.5), whereas acidic grasslands, dune grasslands, non-habitat directive grasslands and fore dunes were dry and with lower acidity (EIV_R values mostly > 4). When only considering the moisture and nutrient gradients, the Østerild plots seemed to distribute among all the reference habitats types and habitat groups, except the very dynamic fore dunes, but with the vast majority placed in dwarf shrub-dominated heath and dune and wet dunes (Figure 4.6). Also, the range of non-habitat types overlapped with the Østerild plots.

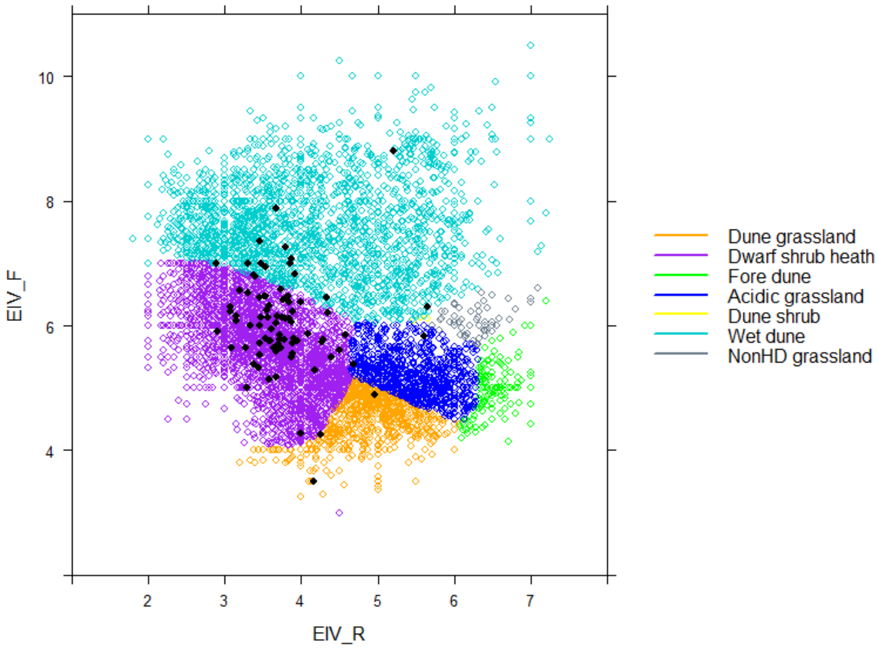


Figure 4.6. The predicted distribution of NOVANA reference plots (colored points) and the Østerild plots (black points) along the moisture (EIV_F) and reaction (EIV_R) gradients. See table 4.5 for an overview of the habitat groups. No nonHD mires and nonHD dunes were predicted in the QDA.

The pattern in Figure 4.6 was confirmed when predicting the most likely habitat types for the Østerild plots based on the reference data set and the plant preferences for nutrients (EIV_N), acidity (EIV_R), moisture (EIV_F) and light conditions (EIV_L) using the QDA. Most of the Østerild plots were predicted to belong to dwarf shrub heaths (48 out of 84 plots, Table 4.6), i.e. dry habitats having relatively high acidity (low EIV_R values) (Figure 4.6). More than 27 % of the plots were predicted to belong to wet dunes, pointing to the effect and importance of moisture condition for species composition. However, 10 (11.5 %) of the plots resembled grassland, where the species composition did not meet the definitions of a habitat type in the Annex I of the Habitat Directive. Furthermore, the classification was conducted on presence / absence data and not abundance, and the balance in dominance of species in the Østerild plot may therefore not resemble the one in the reference data set (see section 4.2). Seven of the 91 plots monitored in 2021 did not have Ellenberg values (as only few vascular plants with no assigned Ellenberg values were found in the plots) and were therefore omitted from the analyses.

During the 10-year period, the former *Pinus mugo* stands in the hilly areas in the northern part of Østerild (site 1, Table 3.1) developed into dwarf shrub heaths (left panel, Figure 4.7). The *Pinus mugo* and *Pinus sylvestris* stands (site 3 and 4, Table 3.1) in the less hilly areas developed into wet dunes near the constructed lakes (right panel, Figure 4.7), while the more dry areas developed into dwarf shrub heaths. Former *Pinus sylvestris* stands (site 5 and 8, Table 3.1) near the constructed lakes developed into wet dunes, while the dryer areas developed into non-habitat directive grassland and dwarf shrub heath (right panel, Figure 4.7). In the southwestern part of Østerild (site 9, Table 3.1), former *Pinus sylvestris* stands developed into dwarf shrub heaths (right panel,

Figure 4.7). Former *Picea sitchensis* stands (site 2, Table 3.1) in the northern part developed into dwarf shrub heath (panel 1, Figure 4.7), while the area close to the main construction road (site 6 and 7) developed into non-habitat directive grassland (panel 2, Figure 4.7).

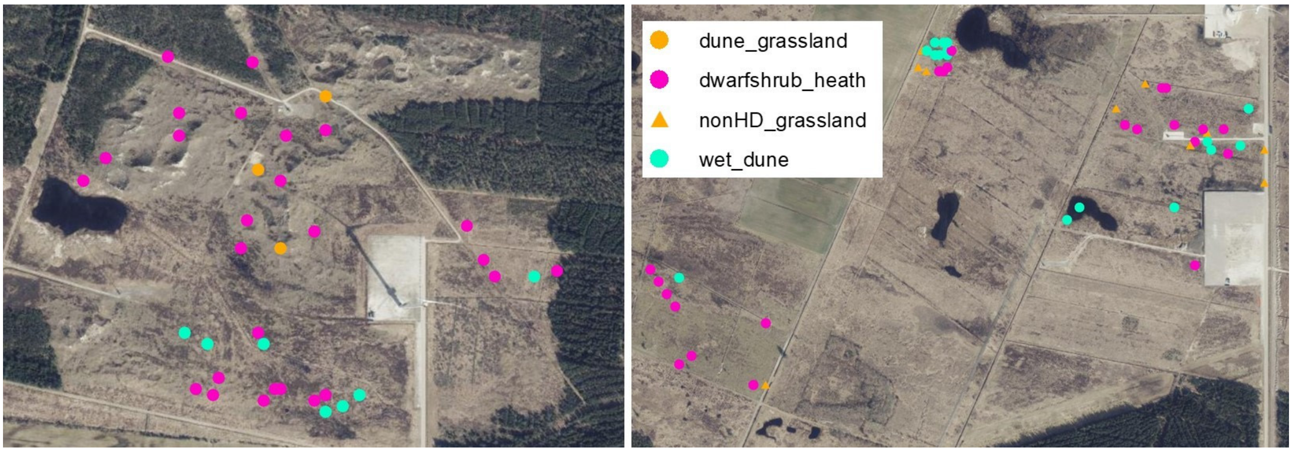


Figure 4.7. Predicted habitat types for the 84 plots monitored in 2021. Predictions are based on the QDA that discerns among habitat types/groups based on plant preferences for nutrients (EIV_N), acidity (EIV_R), moisture (EIV_F) and light conditions (EIV_L). Right panel: Northern part, left pane: southern part of Østerild. Dune grasslands are only found on the left-hand panel; non HD grasslands only on the right hand panel.

Table 4.6. Number of plots predicted to resemble habitat types/groups and non-habitat nature based on the QDA that discerns among habitat types/groups based on plant preferences for nutrients (EIV_N), acidity (EIV_R), moisture (EIV_F) and light conditions (EIV_L) (n=84).

Habitat type/group	No. plots
Dune grassland	3
Dwarf shrub heath	48
Fore dune	0
Acidic grassland	0
Dune shrub	0
Wet dune	23
Non-habitat nature	
Non HD dune	0
Non HD grassland	10
Non HD mire	0

We compared the mean EIV_F and EIV_N values for the reference dataset with the ones in the predicted habitat groups for the Østerild plots using Student's t-test.

Dwarf shrub heaths (including wet variants of habitattype 2140) in Østerild were significantly wetter and more nutrient rich than the reference data set, whereas wet dunes were significantly drier and more nutrient rich than the reference data set (Table 4.7).

Table 4.7. Mean Ellenberg F (EIV_F) and mean Ellenberg N (EIV_N) values for the main predicted habitat groups in Østerild and the reference data set. P-values for Student's t-test are given.

	Mean EIV_F			Mean EIV_N		
Habitat group	**Østerild**	**Reference**	**P-value**	**Østerild**	**Reference**	**P-value**
Dwarf shrub heath	5.86	5.67	0.005	2.76	2.53	<0.001
Wet dune	6.79	7.36	<0.001	2.94	2.78	0.027

To further compare the reference data set to the conditions in the Østerild plots, we summarized the number of indicator species considered very sensitive towards habitat changes (the so-called 'two-star' species, as defined by Fredshavn et al. 2010) for each habitat group in the reference data set and for the Østerild plots, respectively.

The mean number of indicator species considered sensitive towards habitat changes in the reference dataset ranged between 1.1 species in fore dunes to 1.6 species in acidic grasslands (Table 4.8). In the 91 Østerild plots monitored in 2021, the mean number of indicator species in the predicted habitat types were significantly lower than in the reference data set (Table 4.8).

We carried out all analyses in R (R core team, 2019).

Table 4.8. The mean number of indicator species considered very sensitive towards habitat changes (two-star species as defined by Fredshavn et al. 2021) per habitat group in the reference dataset and the Østerild data set (only for habitat types predicted in the Quadratic Discriminant analyses). P-values indicate significant difference between the number of indicator species in the two data sets.

Group name / EU Habitat type	Annex I code	Mean number of indicator species (Reference)	Mean number of indicator species (Østerild)
Dune grassland	2130, 2330	1.4	0 (p<0.001)
Acidic grassland	6230	1.6	
Fore dune	2110, 2120	1.1	
Dwarf shrub heath	2140, 4030, 2310, 2320	1.2	1.1 (p=0.048)
Dune shrub	2160, 2170, 2250	1.2	
Wet dune	2190, 4010, 6410, 7140	1.4	1.1 (p<0.001)
Non-habitat nature			
Non HD dune	2100, 4000	1.1	
Non HD grassland	6200, 6400	1.2	1.0 (p=0.031)
Non HD mire	7100	1.2	

5 Discussion

Due to changes in the position of the clear-cut areas and post-cutting treatments as well as unforeseen disturbances of the monitoring plots, we were left with 59 out of the original 100 plots having a full 10-year post-cutting history. This, of course, lowers the statistical strength of the analyses and reduces the applicability of the results.

The fact that 57 % of the plots were classified as dwarf dune shrubs, 27 % as wet dune and 4 % as dune grassland plots points to the great potential for restoring valuable open habitat types after deforestation of plantations along the western coast of Jutland. Restoration success in these dune landscapes was relatively high compared to the low success rates for wetland restoration (Baumane et al. 2021, Moeslund et al. in prep.). We believe this to be a result of the naturally infertile soils and the extensive management of plantations compared to that of arable fields. On the other hand, 12 % of the Østerild plots monitored in 2021 were classified to resemble non-habitat directive habitat types, indicating that restoring habitats does not cause an instant change in environmental conditions and species composition and that this kind of restoration will not always lead to target habitats of conservation interest in a considerable time after restoration.

Reestablishing near-natural hydrological conditions was one of the focal points in the original restoration plan for the Østerild area. More than 25 % of the plots monitored in 2021 were classified as wet dune, indicating that the plant composition in these plots resembled wet dune and heath vegetation. Furthermore, the aggregated habitat group dwarf shrub heath that most of the Østerild plots belonged to also includes wet dune heaths. At least some indicator species adapted to moist conditions were found in the Østerild plots monitored in 2021. However, EIV_F values did not change significantly- in the surveyed plots during the 10-year period (and the 7 years of changed hydrology) despite the effort to close ditches. This lack of change in EIV_F values suggests a status quo in hydrological conditions of the area. In general, it is difficult to evaluate whether the hydrological conditions have been successfully restored. Detailed information on the historical hydrological conditions in the Østerild area is lacking. According to historical maps (høje (1866-1899)/lave (1901-1971) målebordsblade, https://dataforsyningen.dk/), the Østerild area was mainly heathland 100-150 years ago. When assessing the hydrology map in the Danish Nature Indicator (Ejrnæs et al. 2021), the Østerild area consists mainly of low-lying areas. The above information indicates that the main habitat type in the Østerild area used to be wet dune heath (but this is uncertain, as the legends on the historical maps do not distinguish between dry and wet heath). In that case, the historical reference for the majority of Østerild plots is wet dune heath, leaving an unresolved potential regarding restoration of hydrological conditions in the surveyed area. Rewetting was achieved by lake construction and filling up ditches, but it is evident that these methods only affected part of the Østerild area (Figure 2.2). We suspect that former extensive drainage (ditching) still affects major parts of the Østerild area today. There is a great unfulfilled potential in Østerild regarding closing of main ditches, most likely because of consideration of the conditions in the test area and private interests (e.g. landowners). More specifically, full restoration of hydrology is restricted by the fact that privately owned agricultural areas within the Østerild area cannot be affected by hydrological initiatives and that the technical facilities in the area requires a specific (low) groundwater table. However, natural hydrology is one of the key factors for successful restoration of natural conditions, especially in naturally nutrient poor habitats, and if this is not fully restored communities are less likely to develop into high quality moist and wet habitats (Ejrnæs et al. 2021).

Although more than 50 % of the Østerild plots were classified as dwarf shrub heath, we did not find an overall increase in cover of dwarf shrubs during the 10-year period. However, behind this status quo is an increase in dwarf shrub cover in former *Picea sitchensis* stands and a drop in dwarf shrub cover in some of the former *Pinus sylvestris* stands, where dwarf shrubs were part of the vegetation prior to clear-cutting. The balance in coverage of dwarf shrubs and grasses seemed to be off as compared to the reference data set. This imbalance is most likely caused by relatively high nutrient contents in wet dunes and dwarf shrub heaths in Østerild as compared to the reference dataset affecting the interspecific competition. The post-cutting treatments of tree stumps and litter (stump removal, stump crushing and depth milling) were performed in 2014-2015, and the final registration of the species composition was thus conducted only 6-7 years after the last disturbance of vegetation and soil. Soil temperature and water availability increases after clear-cutting of forest stands, which leads to an increase in the decomposition of organic matter. Immediately after clear-cutting, the mineralization of nitrogen will exceed plant uptake and immobilization (Vitousek 1981). We expect that the untouched layers of needles, cones and twigs on the forest floor as well as the crushed stumps have led to a release of nutrients in Østerild favoring grasses at the expense of the stress-tolerant dwarf shrub species.

Grazing counteracts high nutrient levels, and we recommend an implementation of extensive grazing with a prolonged grazing period in the Østerild area. The existing grazing regime with relatively intensive summer grazing is not beneficial for a number of pollen and nectar feeding insects.

During the 10-year monitoring programme, we have documented a substantial and quick succession and change in species composition of the vegetation after clear-cutting and 6-7 years after treatments in Østerild. The changes were most pronounced in the sitka plantations and less evident in former *Pinus mugo* stands. The latter were relatively open plantations with fallen trees prior to clear-cutting. The number of vascular plant species increased significantly after clear-cutting as a response to lighter conditions compared to the relatively dark plantations. This indicated succession towards more species rich herb and grass dominated vegetation. The vegetation resembled dwarf shrub heath more than species rich grasslands (QDA classification), supposedly because of the infertile and acidic soils. Although species richness increased, the number of indicator species was still significantly lower than expected from the reference data set, indicating that the environmental conditions are not yet suitable for the missing indicator species or that the indicator species are dispersal limited. However, the distance to source populations is relatively short in the Østerild area. Nevertheless, successful establishment of indicator species requires an early arrival before the vegetation closes (Ejrnæs et al. 2006) and, in some cases, that e.g. the right mycorrhizae are present (Moeslund et al. 2017). In general, the restoration of dune habitats in Østerild has succeeded in becoming habitats for at least some species adapted to nutrient poor and near-natural conditions and species sensitive towards habitat changes.

In the Østerild area, a free-living stock of *Cervus elaphus* (red deer) and other species of grazing deer browse the vegetation un-limited. When the animals use the project area, they create gaps in the vegetation cover by treading and scraping the soil surface. Thus, the presence of deer is an important parameter in the management of vegetation cover. However, as the purpose of the management programme was to assess the change in the vegetation composition, it did not include the impact of free-living, grazing animals. Livestock grazing was not fully implemented as planned in the Østerild project (By- og Landskabsstyrelsen 2010). Hence, grazing occurred in 20 plots in 2021 in the form of summer grazing and at relatively high grazing densities with minimum 0.3-1.2 livestock units / ha, corresponding to 180-720 kg / ha (Ejrnæs et al. 2021). Grazing had a significantly positive effect on vascular plant species richness, but we expect high density grazing in summer to affect invertebrate diversity negatively due to carbon competition, leading to a decrease in natural host plant and floral resources (Sartorello et al. 2020). If converting to more natural grazing regimes (i.e. year-round grazing at natural grazing densities), we expect positive responses from especially phytophagous and pollinating invertebrates.

Vascular plant species richness as well as species composition were also affected by stand age of former plantations. The significantly negative effect on plant species richness indicates that restoring natural habitats may require detailed planning and more effort in older stands, possibly due to thicker litter layers and more acid soil conditions in old plantations. Dispersal limitation of target plant species into restored former plantations may also cause a delay in vegetation recovery. With respect to species composition, former *Pinus sylvestris* and *Picea sitchensis* communities were more similar than former *Pinus mugo* plots, which were primarily located in dry and hilly areas, and the forest stand prior to clear-cutting was old and relatively open with a relatively rich forest floor vegetation. Environmental conditions related to soil types and topography therefore most likely influence the outcome, but the sequence of colonization is also known to play a role in community assembly (Ejrnæs et al. 2006). The increase in pH during the 10-year period after deforestation indicates that the expected constraints on the restoration of dune communities due to low pH, acidification and consequential loss of vulnerable species (Strandberg et al. 2011) may not be pronounced.

We observed a substantial increase in abundance of the invasive bryophyte *Campylopus introflexus* during the 10-year period. The bryophyte was primarily found on wood chips and stumps after clear-cutting, and the occurrence may even have been promoted by clear-cutting. *C. introflexus* is known to colonize and spread readily and has become very common in Denmark (Klinck 2010). The bryophyte has the largest impact in lichen rich grey dunes and inland dunes in Northern Europe, but the impact may be local and temporal, and succession to original conditions can be expected after 15-20 years (Klinck 2010 and references herein). Further actions to combat this species are therefore not needed.

One of the main objectives of the project, and therefore a major part of the post-cutting treatment design, was to collect data and conduct analyses that enabled us to draw conclusions on the best way to restore former dune plantations after clear-cutting. However, the implemented treatments differed from the implementation plan regarding tree stump and litter layer treatments. We recommend monitoring the changes in species composition in future projects to gain further knowledge on the effect of restoration treatments – including burning and other relevant treatments not assessed in the present study.

Dune plantations are abundant along the western coast of Denmark. In light of the current trends focusing on restoring natural processes in ecological restoration of protected areas, we expect more deforestation and restoration of plantations in the near future. Based on the present results, we recommend restoration of natural hydrology when restoring dune vegetation in former plantations or other places, where hydrology has been altered. Re-introducing natural grazing regimes after deforestation may also benefit biodiversity, especially were nutrient levels are high.

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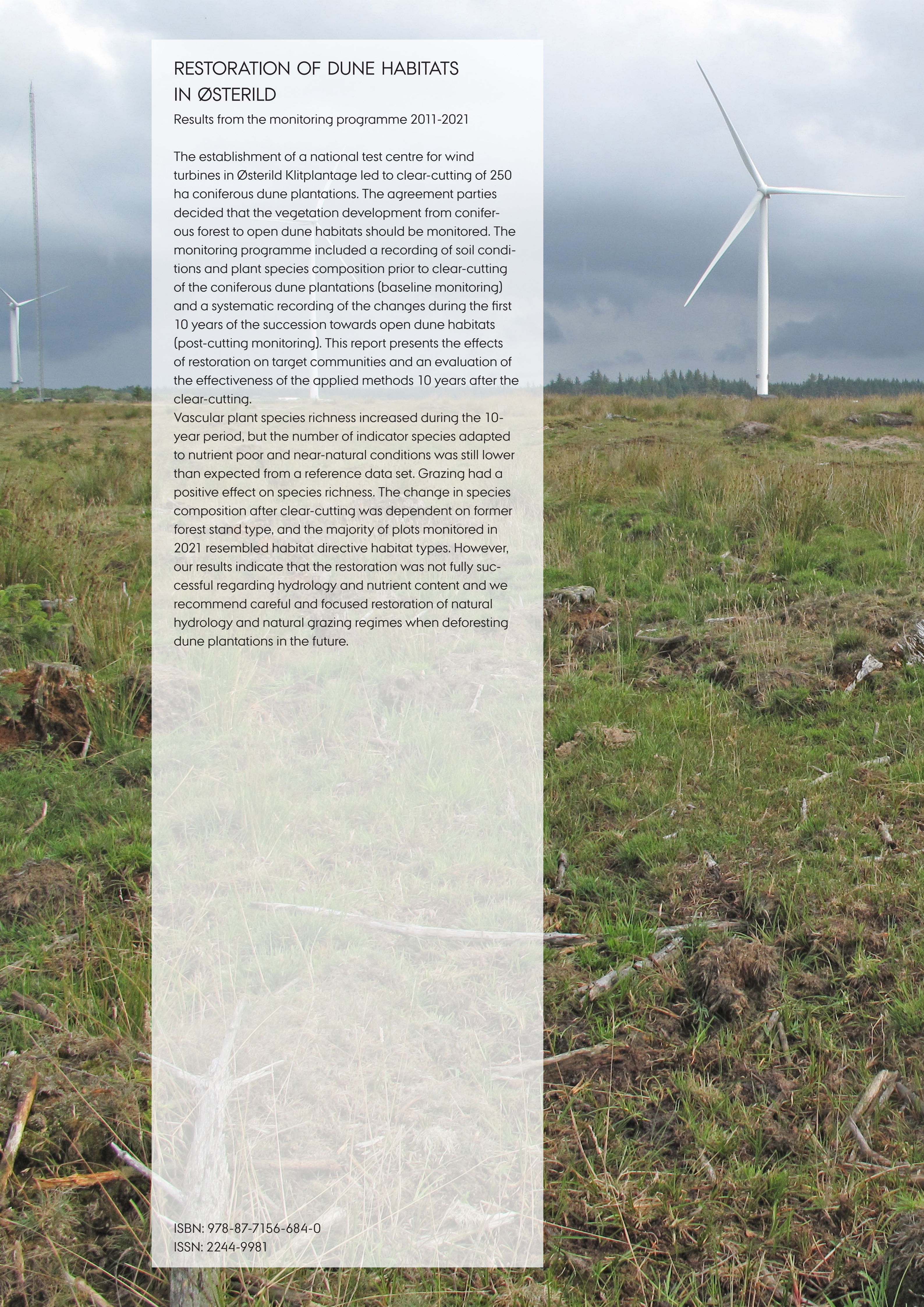
7 Appendix

Table 7.1. The most common species/species groups in 2011 (number of plots out of 100 plots and %) and 2021 (number of plots out of 91 plots and %)

Species/group	Occurrence 2011	Occurrence 2021
Bryopsida	95 (95 %)	89 (98 %)
Deschampsia flexuosa	76 (76 %)	84 (92 %)
Calluna vulgaris	26 (26 %)	78 (86 %)
Molinia caerulea	49 (49 %)	78 (86 %)
Cladonia sp.	9 (9 %)	75 (82 %)
Carex arenaria	36 (36 %)	64 (70 %)
Hypochoeris radicata	4 (4 %)	64 (70 %)
Erica tetralix	21 (21 %)	60 (66 %)
Holcus lanatus	6 (6 %)	49 (54 %)
Galium saxatile	9 (9 %)	49 (54 %)
Vaccinium uliginosum	38 (38 %)	47 (52 %)
Juncus effusus	6 (6 %)	45 (49 %)
Juncus squarrosus	1 (1 %)	43 (47 %)



RESTORATION OF DUNE HABITATS IN ØSTERILD

Results from the monitoring programme 2011-2021

The establishment of a national test centre for wind turbines in Østerild Klitplantage led to clear-cutting of 250 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 included 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-cutting monitoring). This report presents the effects of restoration on target communities and an evaluation of the effectiveness of the applied methods 10 years after the clear-cutting.

Vascular plant species richness increased during the 10-year period, but the number of indicator species adapted to nutrient poor and near-natural conditions was still lower than expected from a reference data set. Grazing had a positive effect on species richness. The change in species composition after clear-cutting was dependent on former forest stand type, and the majority of plots monitored in 2021 resembled habitat directive habitat types. However, our results indicate that the restoration was not fully successful regarding hydrology and nutrient content and we recommend careful and focused restoration of natural hydrology and natural grazing regimes when deforesting dune plantations in the future.

ISBN: 978-87-7156-684-0
ISSN: 2244-9981