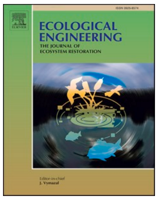
Ecological Engineering 184 (2022) 106789

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Assessing the effect of mitigation efforts to improve vegetation recovery in powerline construction sites across Norway

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ARTICLE INFO

Keywords:
Construction sites
Evaluation
Land-use
Mitigation
Revegetation
Vegetation cover

ABSTRACT

Land-use related to technical infrastructure puts great pressure on nature and landscapes globally. We used a screening approach to evaluate vegetation development in 295 construction sites related to upkeeping of the national power grid in Norway and assessed if and how active measures for vegetation recovery can contribute to mitigate negative impacts on biodiversity and natural carbon storage. Bayesian networks were developed to assess the effect of interventions on the vegetation cover, and an ensemble learning algorithm (Boruta) was used to assess variable importance. Multivariate analysis was run to investigate plant functional group composition. The screening approach uncovered some broad results; A large diversity of installation types are associated with gridline-systems, and the large variation of mitigation measures are hard to classify and evaluate. Years since restoration, region and site ID were important to explain the total vegetation cover, while restoration treatment, soil and installation type were not important. Graminoids dominate the total vegetation cover, in both seeded and non-seeded sites. More detailed studies will contribute to more accurate evaluation of different measures and vegetation recovery. Lack of documentation and well-designed monitoring hamper the development of reliable procedures of mitigation in construction projects, as the ecological outcome of the efforts can be questioned.

1. Introduction

Today 75% of global land areas are under heavy human pressure, leading to biodiversity loss, reduction of ecosystem services and social challenges (IPBES, 2019). Land-use change, including road and powerlines construction and renewable energy installations, drives 23% of anthropogenic greenhouse gas emissions globally, contributing to climate change (IPCC, 2019). The protection and enhancement of natural carbon storage and sequestration in intact ecosystems is currently an effective way to combat climate change (IPCC 2019) and will be a significant contributor to reducing greenhouse gas emissions (Griscom et al., 2017). In addition, protecting land and restoring degraded land will give co-benefits such as conserving biodiversity and providing ecosystem services (Jung et al., 2021; Strassburg et al., 2020).

The United Nations Assembly has appointed 2021–2030 to be the UN Decade on Ecosystem Restoration, aiming to “massively scale up the restoration of degraded and destroyed ecosystems” (UNEP, FAO, 2020). As part of the EU Biodiversity Strategy, the Commission has launched an action to ensure no net loss of biodiversity to hamper further degradation of areas with biological attributes (European Commission, 2021). By this action, the EU put clear obligations on industry and society to minimise land use in future economic development.

Land-use related to technical infrastructure, such as powerlines, roads, renewable energy plants, and urbanisation places major pressure on nature and landscapes globally (IPBES, 2018). The mitigation hierarchy is a tool that guides users towards limiting the negative impacts on biodiversity (Stevenson and Weber, 2020). The hierarchy describes four steps, (1) Avoiding impact by setting aside areas or changing location for new construction, (2) Implementing measures that reduce the impacts that cannot be avoided, (3) Implementing restoration measures, such as removal of temporal infrastructure or restoration of previously degraded land within the development site, and finally (4) Restoration of land outside the development area, to compensate for the damage that cannot be reduced or restored within the site (Ekstrom et al., 2015; McKenney and Kiesecker, 2010). When planning new power lines, the mitigation hierarchy comes into practise through Environmetal Impact Analysis,

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https://doi.org/10.1016/j.ecoleng.2022.106789
Received 4 January 2022; Received in revised form 6 August 2022; Accepted 2 September 2022

Fig. 1. Sample plots ($n = 295$) from field survey of construction sites related to power transmission gridline projects throughout Norway.

where requirements are set for avoiding, limiting, repairing and, if possible, compensating for significant effects on the environment and society (Anon, 2017). Power lines can be located both close to and far away from other infrastructure, and come into greater conflict with wilderness areas, because there is considerable pressure on the authorities to locate power lines far away from residential areas and other areas with clear societal interests. By reducing the net loss of natural capital in construction projects through mitigation and restoration of impact, owners of such projects can reduce carbon emissions and biodiversity loss from degraded land and contribute to upscaling of restoration.

There is a long tradition of conducting mitigating measures in degraded vegetation and landscapes following development projects (Aradottir and Hagen, 2013). The motivation has varied with the paradigms of landscape management, from the 1960's main idea of greening and the aesthetical value of vegetation that could be recreated within a short time (Aradottir and Hagen, 2013; Perrow and Davy, 2002), to the last decades' focus on ecosystem restoration, targeting the function and appearance of natural ecosystems (McDonald et al., 2016). The possible trade-offs between restoring for single ecosystem services, such as carbon sequestration, at the cost of biodiversity (Lindenmayer et al., 2012), keep the discussion about implementing the measures best suited for the purpose of the restoration alive. However, the lack of documentation and evaluation of restoration in general (Nilsson et al., 2016), and mitigation measures in particular (Evju et al., 2020), is striking and hampers the improvement of ecologically successful and cost-effective solutions.

In Norway, the land-cover of wilderness (here; interference-free areas with >5 km distance to heavy infrastructure, INON-index) has diminished from 50% in the year 1900 to 11.5% in, 2018 (Norwegian Environmental Agency, 2021). Development of renewable energy, such as wind-power plants, hydropower plants and transmission grids, caused a significant part of this loss and still does (Norwegian Environmental

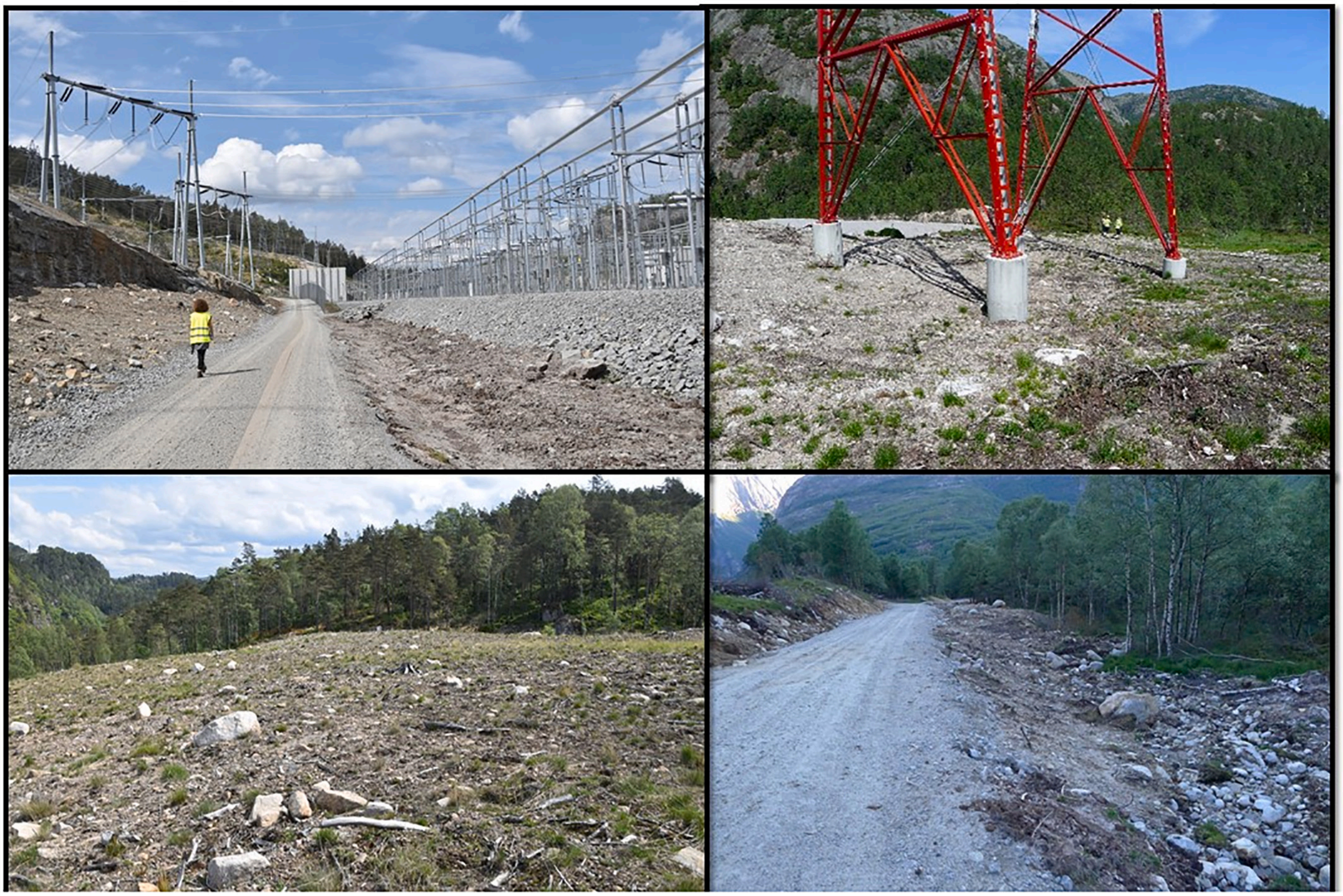

Fig. 2. Constructions to upgrade the power grid modify the landscape dramatically, destroy the vegetation cover, and limit the conditions for recovery. Examples of different installation types; transformer station (upper left), power mast (upper right), landfill (bottom left), and access roads (bottom right).

Agency, 2021). Statnett is a state company that owns and operates the Norwegian power grid system (https://www.statnett.no/en/). Statnett currently runs a large-scale upgrading of the national grid, investing approximately 6–10 billion Euro before 2030. Construction and upgrading of powerlines, transmission grids and substations will cause severe impact on ecosystems across the country (Statnett, 2021).

In some of the present and previous Statnett grid projects, different revegetation treatments have been applied to mitigate and restore degraded land. The implemented vegetation treatments have, so far, not been assessed or evaluated, and consequently there is limited input available for planning of present and future projects. In addition, a “level of success” against which the efforts can be evaluated is lacking (Ruiz-Jaen and Aide, 2005). Assessments are needed for ecological and commercial reasons; to ensure that the mitigation efforts have the desired impact on biodiversity and climate change, and to reduce the risk of wasting time and energy on failed efforts. The experiences from construction of power grids have obvious common features to other development projects (such as road construction, and new and upgraded wind- and hydropower plants), and an assessment would have a high value of transfer across industries. The need for exchange of scientific knowledge and technical skills for successful restoration has been highlighted and documented repeatedly (e.g. Hagen et al., 2021; Mitsch, 2014). Our approach is to use a simple screening of vegetation in construction sites as a response to the need for systematic evaluation of the most common vegetation treatments for mitigation, and also the need to find a procedure that is easy to perform and achievable in logistic and economic terms within mitigation projects.

In this study we evaluate 295 construction sites across Norway by a screening approach to assess if and how active measures for vegetation recovery can contribute to limiting negative impact on biodiversity and natural carbon storages from large construction projects. In this study, our focus will be on measures to reduce and restore impacts within the development site. All sites have been constructed individually, depending on the specific constraints in each powerline project, (i.e. this is an observational study without an experimental design). The construction sites differ in age, type of construction, native vegetation, climate and environmental conditions, and type of revegetation treatment. The aims for this study are; 1. to record and describe the diverse vegetation treatments used under different conditions and to relate to historical, ecological, geographical, and technical explanations for these practices, 2. to test which environmental and technical variables are important to explain the variation in vegetation recovery between the construction sites, using revegetation technique, geographical position, age since treatment, and soil conditions as explanatory factors, and 3. to evaluate if data collected by this screening approach is sufficient to suggest procedures for future vegetation treatment under different conditions to mitigate environmental impact.

2. Materials and methods

2.1. Study sites

We assessed 295 construction sites within 280 construction areas related to the power transmission grid across Norway in 2019 (Fig. 1). Statnett operates >11,000 km grid of powerlines comprising all main Norwegian geographic regions and climatic zones, ranging from the northernmost site in Troms & Finnmark county (70°N) to the southernmost site in Agder county (58°N) (Fig. 1), are included in the study.

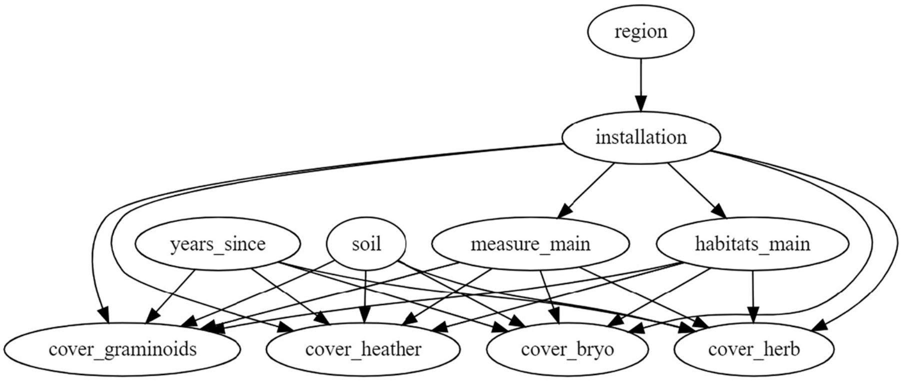

Fig. 3. The Bayesian Network model for total vegetation cover in 294 construction sites.

This gradient covers nemoral, boreal and southern Arctic biogeographic zones (Moen, 1999). Length of growing season (calculated as number of days when average temperature exceeds 5 °C) ranged between 200 days in the southernmost site to 130 days in the northernmost site, and the average annual temperature accordingly from 8 °C to −2 °C (Moen, 1999). Most sites were situated along the coast or inner fjords, corresponding with transfer need of electricity from Norwegian hydropower and wind-power plants into cities and industrial areas along the coastline (Statnett, 2021).

Different types of installations were assessed. Background data for construction sites were made available from internal documents and project descriptions by Statnett, including data on type and characteristics of the installations, timing and technical preparations, contractors, and suggested methods for mitigation in very general terms (Statnett, 2020). This type of heavy construction work normally causes severely degraded vegetation and soil cover, hence leaving the sites with poor conditions for vegetation recovery (Fig. 2). Mitigation, in terms of vegetation and soil recovery and visual improvement of landscapes, is often described in general terms in the Construction and Environmental Management Plan (CEMP) for the construction projects, such as "*Topsoil must be retained and backfilled after digging*" and "*The Contractor must restore construction areas to their original or natural condition to the extent possible before leaving the area*" (Statnett, 2020).

Different revegetation treatments were applied by project owner during and after the construction to improve the establishment of a new vegetation cover. Information on revegetation treatment, such as if the sites has been seeded, type of seeds (commercial/native, species, mixtures), added fertilizer or any other soil improvements, was collected from the internal documents. The goals for the treatments varied, and were formulated in general terms, such as; establishment of any new vegetation, establishment of native vegetation cover, or preparation for vegetation that resembles the intact surrounding vegetation. Several projects have no formulated goals for revegetation at all.

2.2. Study design

Sites were grouped by geographic region; South, East, West, Central and North. To be included, a site had to fill the assumptions that construction work related to powerlines had been conducted, and that some relevant documentation about the revegetation treatment was available. Further, the site should be easily accessible from open roads, and not fenced. Due to the ambitions of including sites across the country, the sites had to fit into travel logistics. Each site was assigned to the surrounding habitat type and subtype and type of installation. The size of the installations varied, and as the area affected by construction differed, the size of restoration sites varied. We have considered the installation type as a proxy for size of restoration site in the analyses.

A number of environmental attributes were recorded in the field at the restoration site level. Slope (*steep, medium, flat*) and landscape heterogeneity (*even/homogenous landscape shape across the site* or *varying/different landscape features across the site*) were recorded as mean visual impression in each site. We recorded soil type and used categories based on surface observations, including *peat, gravel*, and mixed soil categories (combinations with organic soil present as *mixed organic*, combinations with only mineral soil types as *mixed mineral*, mixes with no dominant soil type as *mix*).The condition (*vigorous, medium, poor*) and distribution (*even, patchy, compressed*) of vegetation cover were recorded, based on visual inspection on site. In all sites we recorded total vegetation cover, cover of seven functional plant groups (trees, shrubs, herbs, heather, graminoids, bryophytes, lichens) and leaf litter in the following five classes: 1 ≤ 1%, 2 ≤ 10%, 3 = 10–25%, 4 = 25–50%, 5 = 50–75%, 6≥ 75%. Occurrence of invasive vascular plant species (Norwegian Biodiversity Information Centre, 2018) was recorded in all sites.

We used project descriptions, and notes and dialogue with contractors to record year of treatment and which revegetation and landscaping treatments were used at the individual sites, and how they were applied, allowing us to categorise mitigation treatments into main classes and subclasses.

2.3. Statistical analysis

The majority of sites (279) were <10 years old, and the remaining 15 sites were between 20 and 50 years old. Sites older than 10 years were excluded from the analysis, since they made up a small and diverging proportion of the total dataset. Only one site was treated with organic fibre mats, and this site was excluded from the analysis. As explanatory variables in the models, we included installation type (categorical), time since restoration (continuous), restoration treatment (categorical), soil type (categorical), habitat type (categorical) and region (categorical). To reduce the complexity of the models we did not use habitat subtypes or treatment subtypes. The variables landscape heterogeneity, slope, and condition, were excluded from the analysis as very little variation was observed for these variables.

To assess the effect of revegetation treatments on the vegetation cover we developed a series of Bayesian Networks in the HydeNet R package (Dalton and Nutter, 2020). Bayesian Networks (BNs) are graphical representations of a network of variables (nodes) whereby related variables are joined by an arc (or edge) which represents a set of conditional probabilities (Fig. 3). Conditional probabilities encode the probability that a node is in a particular state, given the state of its parent nodes. BNs can incorporate categorical and continuous data (and where they do are often referred to as hybrid networks). Full Bayesian hierarchical models allow more complete propagation of uncertainty than BNs, but BNs are less computationally complex and are, thus, much more transparent to stakeholders (Bedding and Lilly, 2004; Bujkiewicz et al., 2011). HydeNet utilises the JAGs (Plummer, 2003) program to compile BNs. We used 50,000 iterations for each network.

We utilised the "Boruta" algorithm (R package "Boruta", Kursa and

Table 1
Distribution of all assessed sites assigned to geographic region and years since restoration.

Region	Number of sites	Years since restoration (mean +/− SD)
South	32	3.5 ± 1.3
East	15	6.0 ± 0.0
West	82	8.5 ± 12.0
Central	69	5.9 ± 9.2
North	97	4.1 ± 5.7
Total	**295**	

Table 2
Distribution of all sites assigned to habitat type and subtype.

Habitat type	Habitat subtype	Number of sites
Forest	Conifer forest	26
	Deciduous forest	30
	Mixed forest	109
	Low-alpine birch forest	18
Wetland	Peatland/mire	23
Seminatural landscape	Traditional cultural landscape	4
	New cultural landscape	12
Plantation or clearcut area	Plantation or clearcut area	13
Heathland	Alpine heathland	4
	Coastal heathland	4
Peatland – forest mosaic	Peatland – forest mosaic	52
Total		**295**

Table 3
Power grid installation types assessed in the study.

Installation type	Number of sites	Characteristics and size
Ditch/cable ditch	12	Long and narrow sections (typically 10 m × >1000 m)
Vehicle track	19	Long and narrow sections (typically 10 m × >100 m)
Landfill / heap	45	Large areas, often homogenous, with added surplus of soil or peat (often >1 ha)
Powermast understructure	143	Limited sites around the base of power masts (typically 50 m × 50 m)
Construction area	32	Large areas strongly modified (up to 1 ha)
Restored road	10	Long and narrow sections (typically 20 m × >100 m)
Road verges / hillside	34	Narrow sections along both sides of existing roads (typically 10 m × >1000 m on each side)
Total	**295**	

Rudnicki, 2010) to assess variable importance. Boruta adds randomness to the variable set by creating shuffled copies of all variables (known as "shadow features"). Then it runs a random forest classifier on the extended dataset (Breiman, 2001), and assesses the mean decrease in accuracy to evaluate the importance of each variable (higher are more "important"). At each iteration, Boruta assesses if each variable has a higher *Z*-score than the maximum Z-score of its shadow features. Variables with scores lower than shadow features are deemed highly unimportant and removed from the set. The algorithm runs until all variables are confirmed or rejected (or it reaches a specified limit of runs—here, we used 500 trees maximum).

We investigated the plant functional group composition with multivariate methods. We used global non-metric multidimensional scaling (GNMDS) ordination on the site-by-functional plant group cover (Kruskal, 1964a, 1964b; Minchin, 1987). The GNMDS was run with Bray-Curtis dissimilarity measure, 100 initial configurations, maximum 200 iterations and stress tolerance 10–7, and four dimensions (following recommendations by: Liu and Økland, 2008; Økland, 1996). We replaced unreliable Bray–Curtis distances (>0.8) by geodesic distances, using the "step-across" method (Williamson, 1978).

Table 4
Recorded vegetation treatments and sub-treatment and distribution of sites receiving each treatment.

Vegetation treatment	Sub-treatment	Number of sites	Explanation
Unknown	Unknown	11	Lack of documentation or missing. Information about treatment not recovered.
Natural recovery	No treatment and natural recovery	78	No active mitigation measures performed, and the site left for natural recovery. Large variation in conditions for recovery, depending on natural conditions in each site.
Seeded	Seeded only	22	Commercial grass seed mixture in combination with fertilizer (synthetic granule) added.
	Seeded and fibre-mats	1	Site dressed by fibre mat (coconut or straw), seeded with commercial grass seed mixture and fertilized.
	Seeded and topsoil	12	Some topsoil left in the site, seeded with commercial grass seed mixture and fertilized.
Topsoil	*Re*-used topsoil	120	Local topsoil removed during initial construction phase, stored, and put back on the site after construction was completed. Soil applied loosely.
	Stirred local topsoil	12	Local topsoil stirred and arranged in the site during construction.
	Local topsoil packed	23	Local topsoil removed during initial construction phase, stored, and put back on the site after construction was completed. Topsoil packed when applied.
	Introduced topsoil	3	Topsoil brought in from outside (5–10 km distance) and put on the site after construction phase. Soil applied loosely.
	Landfill	5	The establishment of new installations often implies surplus of gravel and rock, and in some projects these volumes are placed in permanent landfills in the construction site.
	Peat landfill	2	When new installations are placed in peatland or mires, the surplus of peat soil is placed in permanent peat landfills in the construction site.
Gravel added	Gravel added	6	Gravel added as topping on the site after construction phase.
Total		**295**	

To assess the importance of the restoration measures and environmental variables on the vegetation composition we used linear models with GNMDS axis scores for the sites as response variable and restoration treatment and environmental variables as predictors. Axis scores were analysed as a function of restoration treatment, years since restoration, region, installation type, habitat type and soil. We tested for correlation between the variables with corrected contingency coefficient using chi-squared statistic, and can conclude that the variables are independent. In the model selection models were reduced using the selection criterion AIC (Burnham et al., 2011). R package AICcmodavg (Mazerolle, 2020) was used for the AIC selection (Burnham et al., 2011). Descriptive figures were made with ggplot2 (Wickham, 2016). The GNMDS was run with vegan (Oksanen et al., 2020) and MASS (Venables and Ripley, 2002). All processing and analysis were done in R version 4.0.3 (R Core Team, 2020) and RStudio (RStudio Team, 2020).

Fig. 4. The most frequent treatments used to promote new vegetation in the construction sites were (from left to right); 'no treatment', 'seeding', and 'topsoil' (further details on the measures in Table 4).

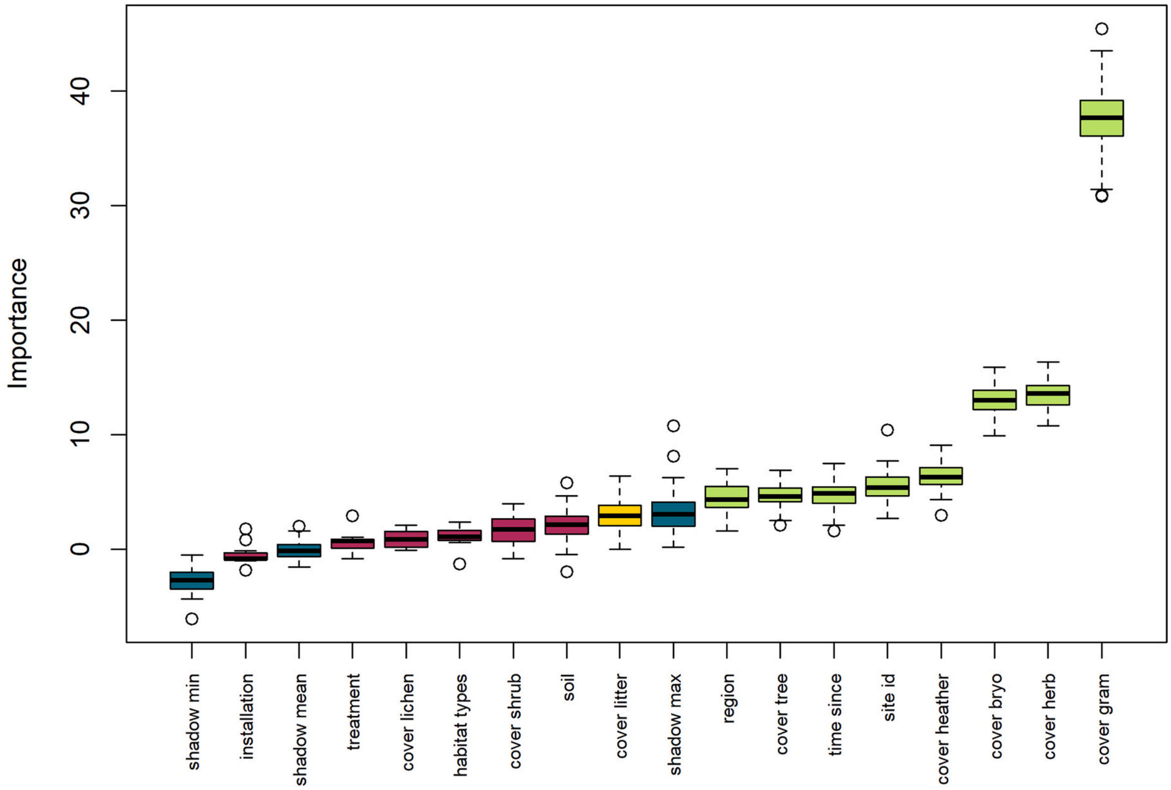

Fig. 5. Variable importance (the loss of accuracy of classification) of single variables to explain the total vegetation cover in the sites. Variables with high or medium importance for the total vegetation cover are highlighted in green and yellow, and variables with low importance are highlighted in red. Shadow feature minimum, mean and maximum are highlighted in blue. Shadow min, mean and max refer to the shadow features calculated in the Boruta algorithm (see methods); cover bryo = cover bryophytes, cover gram = cover graminoids. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results

3.1. *Diversity of sites; installation types, habitat and vegetation treatments*

The 295 sites were distributed across the main geographic regions (Table 1) and habitats (Table 2) of Norway. The sites included a diversity of installation types typical for power grid development and upkeeping, and these were grouped in seven types (Table 3) which were used in the statistical analyses.

Six main vegetation treatment types were recorded (Table 4), but measures varied somewhat between treatment types, thus, we identified 13 "sub-treatment" types. For some of the sites the information about treatment was limited or absent. In some cases, treatment type could still be identified in the field, otherwise sites were classified as 'unknown' (Table 4). The most frequent main treatments were 'no treatment' (78 sites), 'seeding' (34 sites), and 'topsoil' (158 sites) (Fig. 4).

3.2. *Vegetation pattern and explanatory environmental variables*

The boruta algorithm revealed that cover of graminoids was the most important factor to describe total plant cover in the sites, followed by cover of herbs, bryophytes, and heather, and site ID, years since restoration, tree cover and region (Fig. 5). Next, plant litter cover was of some importance to explain the total vegetation cover, while soil, shrub cover, habitat types, lichen cover, restoration treatment and installation type were not important (Fig. 5).

Total cover of vegetation at the sites varied from 10 to 100%. Graminoids were most frequent, with mean cover above 25% for all

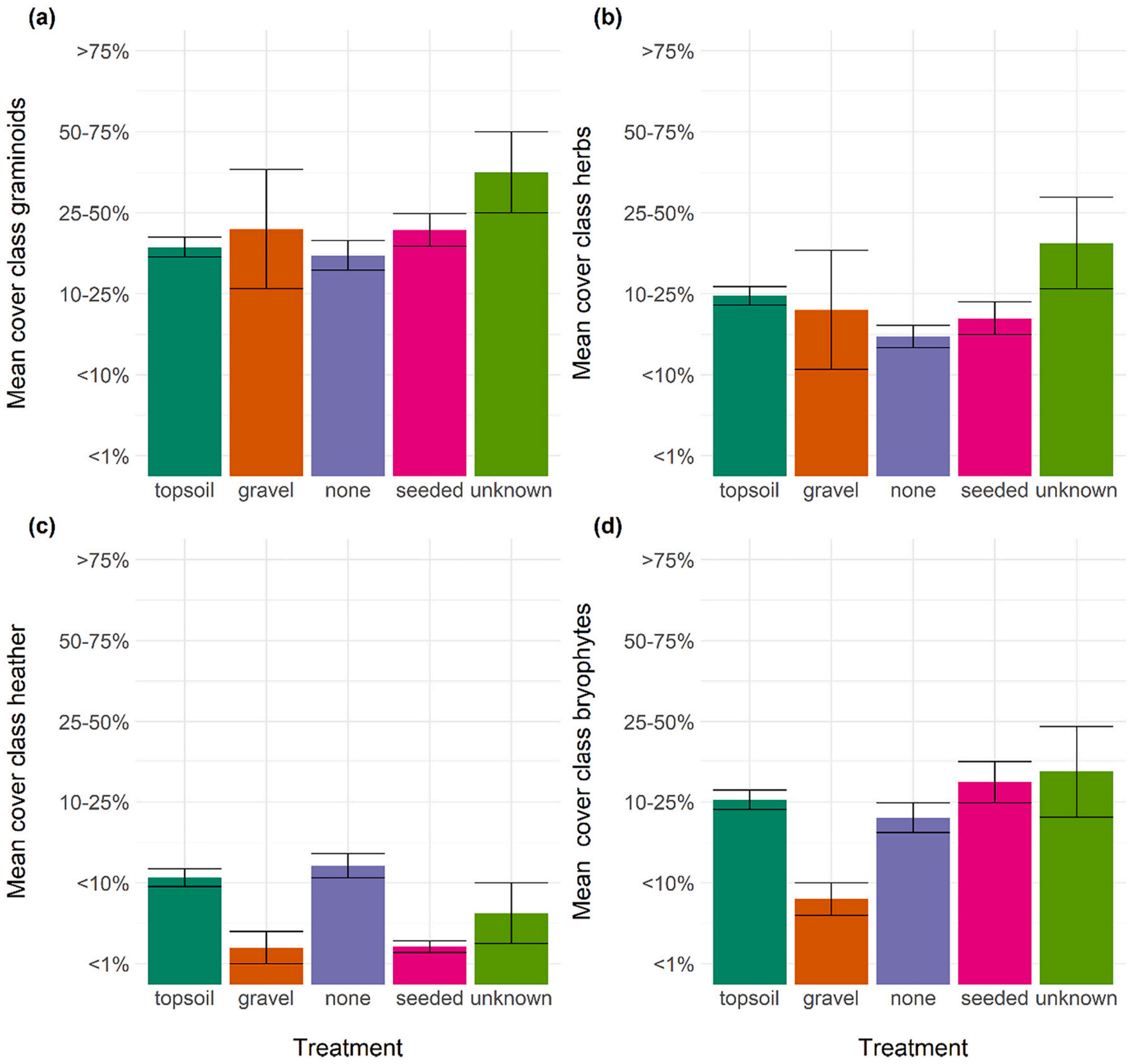

Fig. 6. Mean vegetation cover class for functional plant groups graminoids (a), herbs (b), heather (c), and bryophytes (d) under different revegetation measures.

revegetation treatments (Fig. 6a), exceeding the mean cover of herbs (Fig. 6b), heather (Fig. 6c) and bryophyte species (Fig. 6d). Mean cover varied most in gravel treatment, both within and between functional plant groups, while the cover in topsoil treatment was more stable and higher for most plant groups (Fig. 6). Cover increased with time since restoration for graminoids (Fig. 7a), herbs (Fig. 7b), and bryophytes (Fig. 7d), but did not change over time for heather (Fig. 7c).

In total 26 plants of seven non-native species were recorded in the 295 sites. Most plants were recorded in the southern (12) and eastern (8) regions (central: 4, western: 2, northern: 0). The most common species were *Barbarea vulgaris* ($n = 7$) and *Lupinus polyphyllus* ($n = 5$).

The Bayesian Networks simulated the distribution of the functional plant group cover for the most important plant groups for different vegetation treatments (Fig. 8) and different installation types (Fig. 9). We assumed, that where treatments were effective, we would see the distribution shift towards the higher values of functional plant group cover. However, the overall pattern showed small differences in probability of distribution outcome for all variables, with some minor irregularities. For heather cover (Fig. 8c), the 'none' and 'topsoil' treatments seemed to be slightly more effective for developing cover, compared to the other treatments. For bryophyte cover (Fig. 8d), 'gravel' was the only treatment that was slightly less effective for developing cover. The different installation types affected functional plant group cover slightly more than vegetation treatment (Fig. 9). For graminoid cover, 'powermast' and 'ditch' had more positive effects on cover development, compared to the other installation types (Fig. 9a). For herb cover, construction area had a more negative effect on cover development Fig. 9b). Heather cover was positively affected by installation type 'powermast' (Fig. 9c).

The ordination of plant functional group composition revealed variation in both the first (range − 0.50 to 0.57 half change units), second (range − 0.40 to 0.37 half change units), third (range − 0.32 to 0.40 half change units) and forth axis (range − 0.36 to 0.30 half change units) (Fig. 10, Appendix A Fig. A1).

Installation type, time since restoration and soil type combined explained 20% of variation (R^2 adjusted) in plant functional group composition along the first axis (Table 5). The installation types vehicle track, landfills, construction areas and road verges were located more to the positive end of the axis, whereas ditches and powermasts were on the negative end. Sites with mixed mineral soils were also located more on the positive end than sites with other soil types.

On axis 2, region and restoration treatment contributed to explaining 13% of variation in composition (Table 5), particularly separating eastern and western sites (Fig. 10a), and sites with seeded and gravel treatment from sites with no treatment. Installation type, region and restoration treatment combined explained 16% of variation in plant functional group composition on axis 3 (Table 5), with some differences in axis placement of ditches, landfills and construction areas compared

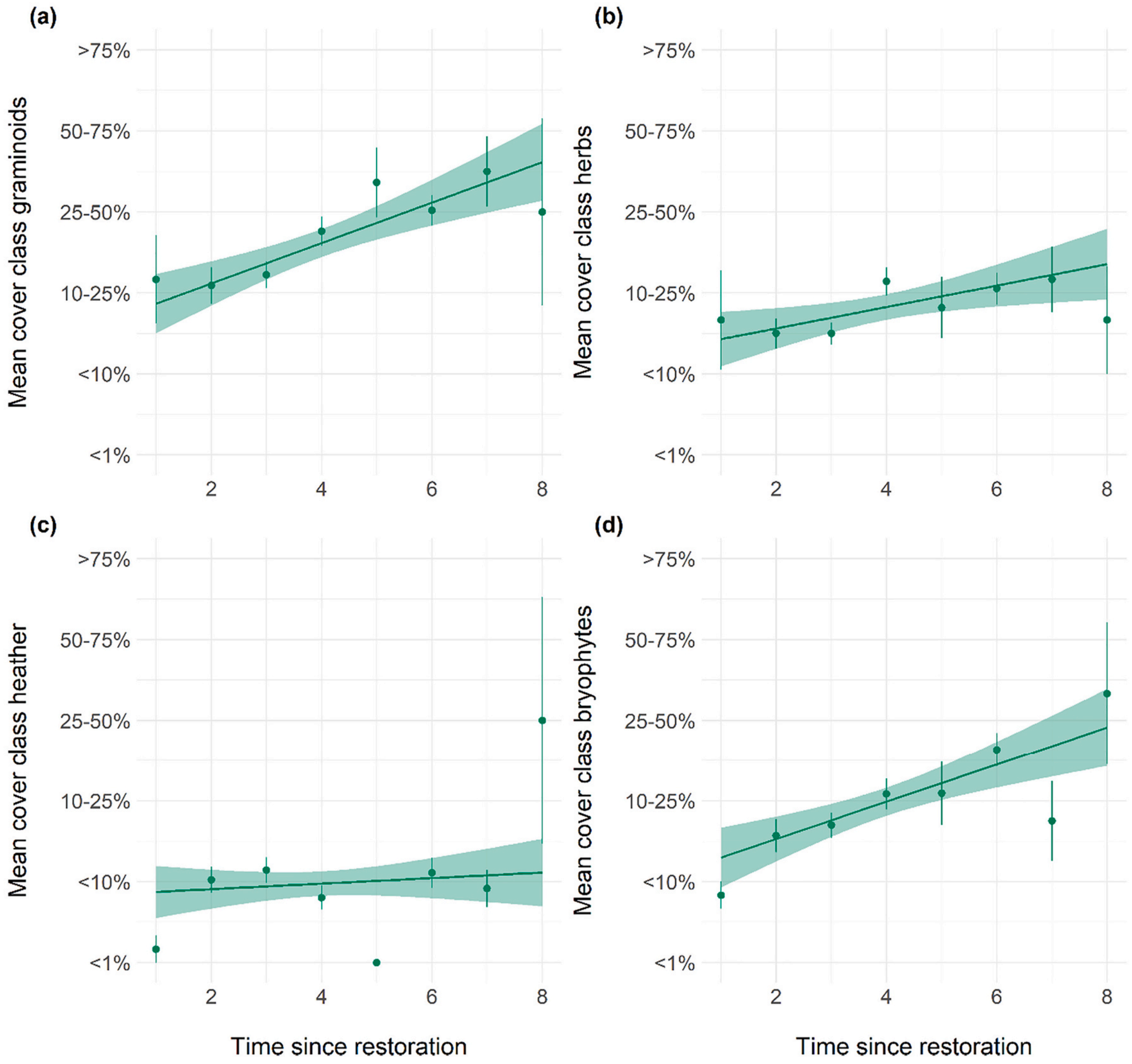

Fig. 7. Mean vegetation cover class along a time gradient of time since restoration for functional plant groups graminoids (a), herbs (b), heather (c), and bryophytes (d).

to other installation types, and with southern and northern sites clearly separated. Only 7% of variation on axis 4 was explained (Table 5), with seeded sites being located slightly more to the positive end of the axis than sites with other treatments. Surrounding habitat types did not contribute to explain variation in plant functional group composition.

The plant functional groups of herbs, graminoids, shrubs, bryophytes and heather were located on the negative end of the first axis, while lichen and trees were located on the center and positive end of axis 1 (Appendix A Figs. A2-A4).

4. Discussion

This study demonstrates the large number and types of installations associated with development of power gridline systems. Further, it illustrates the variety of revegetation treatments, and sub treatments, being carried out in such development projects, and how difficult it is to evaluate the outcome/success of these treatments.

4.1. Power gridline installations contribute to heavy pressure on ecosystems

We assessed a large number of sites along the Norwegian power grid. Power masts (typically appx. 50 × 50 m at base) are the most numerous installation type in this study (49%). However, the larger installation types, such as construction areas, landfills (up to several ha) and restored temporary roads, represent even stronger impacts as they have entirely reshaped landscape features without remaining original vegetation. Road verges along permanent access roads might be several kilometres long, and the roads are typically also used by local stakeholders and landowners after the constructions are completed. In addition, a number of moderate disturbances, such as ditches and vehicle tracks, with some original terrain and vegetation left, are associated with all installation types. None of the study sites are within the perimeter of transformer stations, as these are heavy industrial sites and new vegetation is not wanted (Fig. 2; upper left).

The sites cover all main terrestrial ecosystem types, confirming the distribution of national power gridlines and associated installations across Norway (Gillund and Pereira, 2015). Not surprisingly, most sites were located in previous forest ecosystems, as it is the ecosystem with the largest cover in Norway (Bryn et al., 2018). There are installations in all main forest types as gridlines cross the elevational gradient of forests, from alpine birch and conifer forest to deciduous forests (Moen, 1999). Power gridline installations contribute to fragmentation of forest ecosystems, and mitigating further negative impact from power gridline development on forest ecosystems is highly relevant, as this ecosystem is simultaneously under high pressure from forestry (Jakobsson and

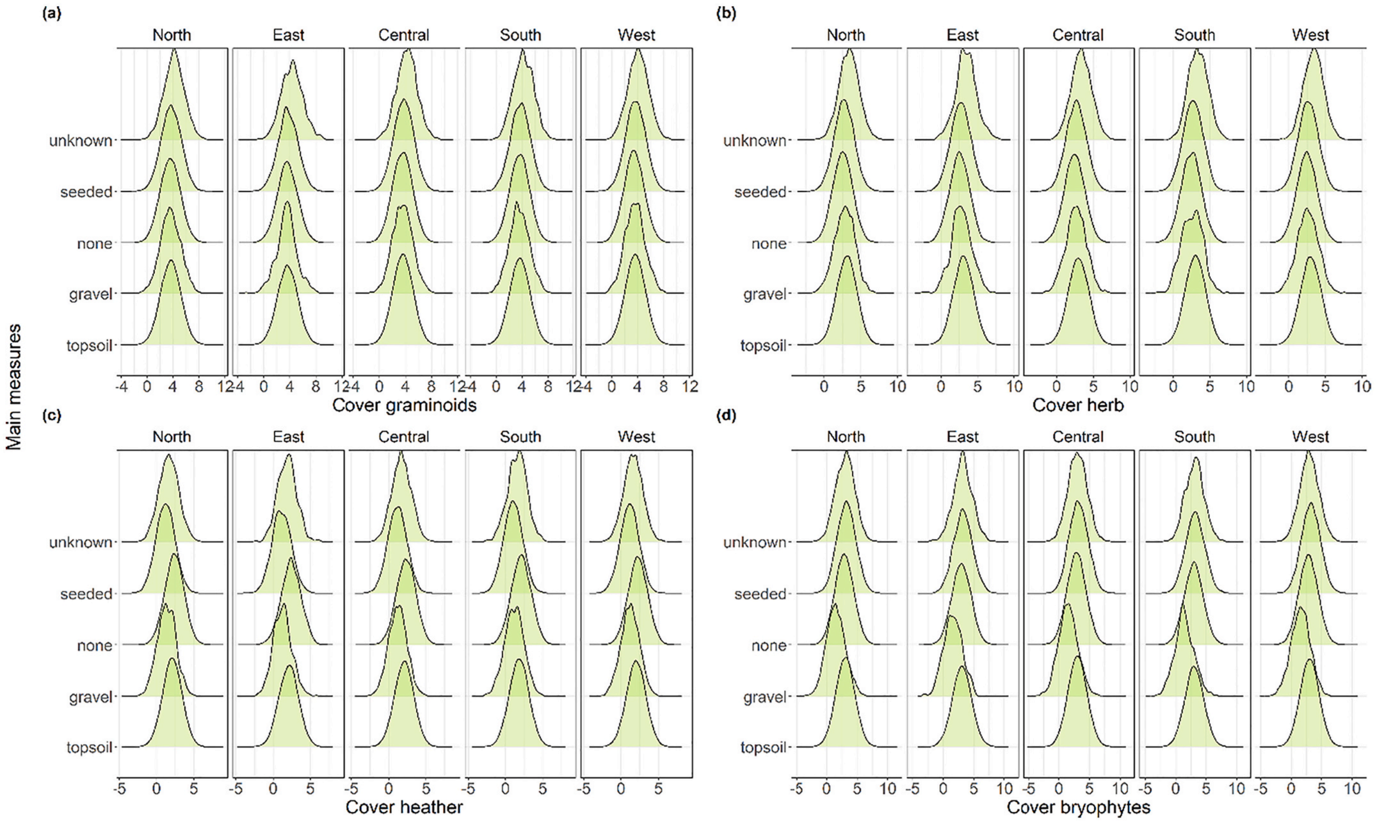

Fig. 8. Probability of vegetation cover for the most important functional plant groups (a-d), for each main vegetation treatment (unknown, seeded, no treatment, gravel added, topsoil added).

Pedersen, 2020). Peatland is the second most influenced ecosystem in our study, but is likely underreported as they are mostly degraded within areas that now are inside transformer perimeter, and thus not restored or part of our study. Peatlands are extremely carbon rich ecosystems and should be avoided in construction work to mitigate climate change (Nayak et al., 2010). The very low occurrence of invasive species in our study is positive, and support studies from Norway that invasive species are most common near populated areas and are still at low numbers in remote nature areas (Hendrichsen et al., 2020), such as most of the sites in this study. Global warming will most likely contribute to increase the potential for invasive species also in northern ecosystems (Haeuser et al., 2018).

4.2. *A diverse collection of vegetation treatments*

The recorded vegetation treatments in this study represent familiar revegetation methods used to mitigate degradation in construction work over the last decades; seeding with commercial seed mixtures, reuse of original topsoil, adding gravel and relying on natural recovery (see for example Aradottir and Hagen, 2013; Kimball et al., 2015; Perrow and Davy, 2002). However, we also observe a number of modifications, adjustments, combinations and simplifications of treatments, such as how to apply the topsoil (e.g., loose on top vs compressed; local vs introduced soil), what species are used in seed mixtures, degree and type of fertilizer added to the seeding, use of fibre-mats in combination with other treatments, thickness of soil, and density of applied seeds. Guidelines available for vegetation treatment in mitigation are very general (Evjen et al., 2021; Statnett, 2020), and the number of possible customisations that might occur during the implementation stage, leads to an almost infinite variation of treatments. This complicates the comparison and testing of effects and investigation of differences between treatments. I.e., with merging of subclasses in Table 4, there is a risk of concealing treatment details of ecological relevance.

The use of commercial seed mixtures has been a standard treatment for quick establishment of a vegetation cover for several reasons, such as erosion control, the prevention of weeds or invasive species, visual preferences, or for the preparation of long-term succession in slow-growing ecosystems (Hagen et al., 2014). Seeding is an easy and cheap treatment, however, ecological effects of commercial seed mixtures are context dependent, and commercial seeds might outcompete and limit the recovery of native species (Forbes and Jefferies, 1999; Hagen et al., 2014). In addition, other factors such as soil conditions, can be more important for the long-term establishment of a vegetation cover (Rydgren et al., 2013). Reuse of original topsoil (stored during construction and redistributed on top when construction period terminates) has been the emerging alternative to seeding during the last two decades, and soil provides conditions for colonisation from adjacent intact vegetation (Farrell et al., 2020; Mehlhoop et al., 2018; Rivera et al., 2014; Skrindo and Halvorsen, 2008). Despite the documentation of seeding not being an ecologically preferred solution, as also confirmed in this study, this measure is still in use, likely because it is easy and a tradition. This confirms other studies which show, that past experience and input from co-workers are crucial factors to determine practitioners' decisions in restoration and mitigation (Cooke et al., 2018; Pullin et al., 2004).

4.3. *Time is most important factor explaining vegetation recovery*

Time (years since treatment) is the most important factor to explain the establishment of vegetation cover in this study. The recovery from totally degraded land into mature vegetation is a slow process in most northern ecosystems, and time as an explanatory factor of vegetation development is expected. We find the same pattern for all plant groups in our study, both fast-growing grasses and slow-growing shrubs and

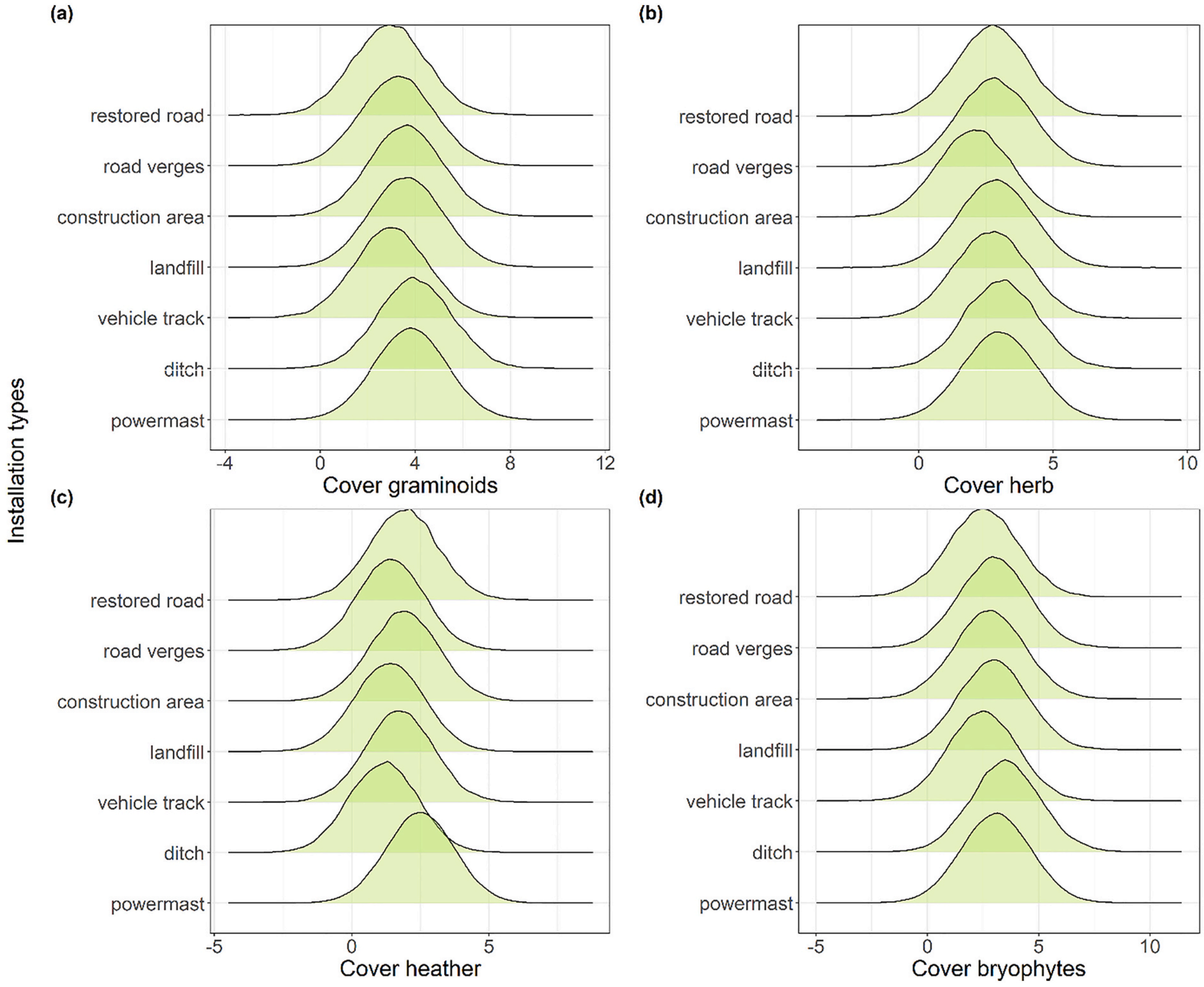

Fig. 9. Probability of vegetation cover for the most important functional plant groups (a-d), for each installation type (restored roads, road verges, construction area, landfill, vehicle track, ditch, powermast).

heather species, although the level of recovery (in terms of cover) is higher at all stages for graminoids.

Overall, vegetation cover showed very similar response to all treatments (commercial seeding, topsoil treatment, added gravel and natural recovery) in the sites, including total vegetation as well as each plant group separately; graminoids, herbs, bryophytes and heather. The cover of shrubs and trees is generally very low, and can be explained by the relatively short time of recovery combined with slow growth rates for these plant groups. Graminoids are, as expected, the most common group overall and in all treatments. Grass species are quick colonisers, fast-growing, produce plenty of seeds, and are strong competitors in disturbed soils (Gómez-Aparicio, 2009). We found the non-seeded sites to have the same cover of graminoids as seeded sites, indicating that seeding does not promote the fast establishment of a grass cover, and that seeds dispersed from the intact surroundings are sufficient for establishment of new vegetation (sensu Hagen et al., 2014; Rydgren et al., 2017). Our screening method only includes cover of functional plant groups, and a more detailed study, including species abundance, could reveal if species diversity or species composition differ between treatments. Lower species diversity has been reported in seeded compared to non-seeded sites using commercial seeds (Hagen and Evju, 2013; Hagen et al., 2014; Rydgren et al., 2013). There are indications that native seeds are less competitive in alpine sites (Hagen et al., 2014), and also have genetic and ecological advantages compared to commercial seeds for ecological restoration (Van der Mijnsbrugge et al., 2010; Durka et al., 2017). Native seeds have not been available for the contractors to use in any of the sites in this study. As our results show that seeding with commercial seeds does not improve vegetation cover, this treatment seems superfluous and could be avoided in the future.

Soil type contributed to explaining variation in plant functional group composition across sites, particularly separating sites with mixed mineral soils from other soil types. Mixed mineral soil likely has less water holding capacity and nutrients, compared to organic soil, and hence leads to a lower vegetation cover (Baldock and Skjemstad, 1999; Mehlhoop et al., 2018).

The sites in this study are distributed along a latitudinal gradient of 12°, representing different climatic conditions, temperatures, growing season length, and vegetation history. Region is detected as important in the Bayesian Network of all sites (Fig. 8), which is also reflected in the results of the functional plant group composition (Fig. 10), where the second axis separates sites along the east-west gradient, and the third axis separates southern and northern sites. We would expect that sites in the most favourable climates (south/east and west) have an advantage for vegetation recovery. Even though it is difficult to interpret recovery from an ordination, sites from region East and West are located on the same area of the axis, which is associated with higher vegetation cover. Vegetation recovery can be explained by a variety of factors, and the relative importance of these are difficult to disentangle in our data. The individual site itself is important for the vegetation cover in our study, each representing a combination of ecological conditions (including soil, moisture, slope, etc.), severity of impact from the construction (level of degradation, size of installation, etc.) and vegetation treatment. In this

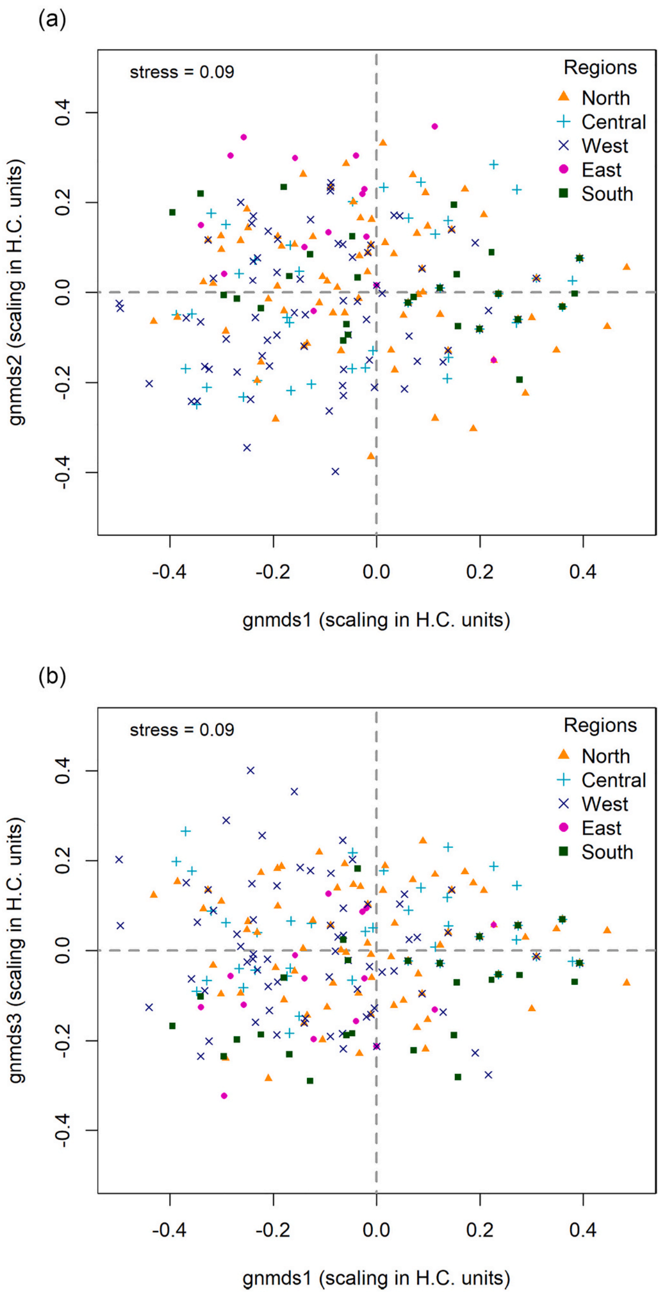

Fig. 10. Ordination biplots based on global non-metric multidimensional scaling (NMDS; with Bray-Curtis dissimilarity, four dimensions) of the plant functional group composition in the sites. Panel a) shows site placement along axes 1 and 2, while panel b) shows site placement along axes 1 and 3. Each region (North, Central, East, South, and West) is represented by different colours and symbols.

study the relative importance of geographic region does not override the contribution from other factors to explain vegetation cover. Our results show that both installation type and revegetation measure are important for explaining plant functional group composition. Smaller installations, such as powermasts and ditches, seemed to be more similar than larger installations. Further, particularly seeding, but also gravel, resulted in different composition than the other treatments, as was also shown by the mean vegetation cover class for functional plant groups (Fig. 6), with particularly lower cover of heather in these treatments. Even though time is clearly the most important factor explaining variation in vegetation cover in our restoration sites, this is not the only factor important to vegetation recovery. The boruta algorithm even indicate that attributes related to individual sites can explain the total plant cover. We have tested a screening approach to evaluate the effect of revegetation treatments, and prioritized to collect a large number of sites at the cost of detailed species assessments at each site. Hence, total vegetation cover, which is a much-used indicator for vegetation condition, was selected as an indicator (Ruiz-Jaen and Aide, 2005). Individual species frequency is a more accurate indicator to detect effects and interactions between ecological factors (Mehlhoop et al., 2022). A large number of evaluated sites is favourable, but our findings support that more detailed studies will contribute to more accurate evaluations of different vegetation treatments (Nilsson et al., 2016; Cooke et al., 2018; Evju et al., 2020).

4.4. Implications for development of future procedures for vegetation treatment in construction sites

Lack of documentation during implementation, as well as absence of systematic design and monitoring, are huge obstacles to perform relevant mitigation in construction projects. The implementation stage of mitigation measures is normally described in general terms in the individual project documents and reflect the similar general guidelines from large developers (Evjen et al., 2021; Statens Vegvesen, 2016; Statnett, 2020). There are no procedures for reporting or documenting the details on how actual measures were performed at the site, and hence, this information is only available in the mind of the executives. Only rarely are biologists present in core project groups of such projects. Furthermore, there is a need to explore how to choose a reference area for the evaluation, as in large construction sites there are likely several habitats under influence, and the recovery is highly dynamic in time and space (Hiers et al., 2016). The definition of realistic and achievable targets for the restoration measures towards some reference is important for long-term management (Mehlhoop et al., 2022).

The screening approach is an attempt to assess what level of details is required for documentation and evaluation of mitigation efforts. The screening suggested here can be performed by other professions than trained biologists, such as landscape architects or planners. However, the need for evidence-based experiments (e.g. randomised controlled trials; Pywell et al., 2011; Pywell et al., 1995) and well-designed monitoring to develop reliable methods and procedures for restoration has recently been clearly addressed (Cooke et al., 2018; Legg and Nagy, 2006). Our study shows that there is no quick-fix to evaluate the outcome of vegetation treatments and identify cost-effective mitigation measures in development projects. This implies the need for a more detailed overview of measures carried out, as well as replicated data on species abundances and soil characteristics, and data on landscape factors. This is required to generalise from idiosyncratic, site-specific case-study results to a predictable science for restoration (Brudvig, 2017; Brudvig, 2011).

5. Conclusion

The dynamics and complexity of ecosystems recovery following human interventions is complicated, yet essential to understand and plan mitigation and restoration measures (Jordan et al., 1987; Walker and Wardle, 2014). The impact on landscape and vegetation from the construction of powerlines has much in common with other infrastructure development, such as road construction, renewable energy and recreation facilities, as they occur in the same diversity of habitats and include heavy degradation of landscape and ecosystems. Sharing experiences and knowledge between large developers related to planning, mitigation and restoration is thus highly relevant. This can be done through systematic documentation of mitigation efforts and output under different ecological or technical conditions, and we suggest this should be mandatory in development projects, and included in the permissions in line with the documentation of technological, risk, safety, and economic matters (Loosemore et al., 2005). The developers' use of mitigation measures as promotion of more eco-friendly and sustainable

Table 5

Parameter estimates and confidence intervals from the linear models of the plant functional group composition GNMDS axes 1 to 4 as a function of installation type (powermasts in the intercept), time since restoration, soil type (mixed organic in the intercept), region (North in the intercept), and restoration treatment (topsoil in the intercept).

	Mean gnmds 1		Mean gnmds 2		Mean gnmds 3		Mean gnmds 4	
Predictors	Estimates	CI	Estimates	CI	Estimates	CI	Estimates	CI
(Intercept)	0.135 ***	0.063–0.208	0.017	−0.014–0.049	0.083 ***	0.038–0.129	0.000	−0.018–0.017
Installation								
ditch	0.004	−0.117–0.124	–	–	−0.083 *	−0.153 to −0.013	–	–
vehicle track	0.160 **	0.061–0.259	–	–	0.003	−0.054–0.059	–	–
landfill	0.073 *	0.004–0.142	–	–	−0.048 *	−0.090 to −0.005	–	–
construction area	0.112 **	0.033–0.191	–	–	−0.077 **	−0.123 to −0.031	–	–
road verges	0.101 *	0.023–0.179	–	–	−0.043	−0.089–0.002	–	–
restored roads	0.111	−0.018–0.241	–	–	−0.007	−0.082–0.069	–	–
Time since restoration	−0.054 ***	−0.069 to −0.038	–	–	−0.011	−0.022–0.001	–	–
Soil type								
mix mineral	0.130 ***	0.065–0.194	–	–	–	–	–	–
gravel	0.021	−0.146–0.187	–	–	–	–	–	–
mix	0.060	−0.070–0.189	–	–	–	–	–	–
peat	−0.003	−0.068–0.062	–	–	–	–	–	–
Region								
East	–	–	0.144 ***	0.071–0.217	−0.053	−0.124–0.018	–	–
Central	–	–	−0.031	−0.075–0.012	0.019	−0.019–0.058	–	–
South	–	–	−0.016	−0.070–0.037	−0.075 **	−0.123 to −0.027	–	–
West	–	–	−0.056 **	−0.097 to −0.016	0.02	−0.022–0.061	–	–
Restoration treatment								
gravel	–	–	0.121 *	0.002–0.239	−0.126 *	−0.231 to −0.021	−0.087	−0.186–0.013
none	–	–	−0.042 *	−0.079 to −0.005	−0.022	−0.055–0.011	−0.029	−0.059–0.002
seeded	–	–	0.053 *	0.002–0.103	−0.040	−0.087–0.006	0.077 ***	0.035–0.119
unknown	–	–	0.071	−0.024–0.167	−0.010	−0.095–0.075	0.019	−0.061–0.098
Observations	278		278		278		278	
R^2 / R^2 adjusted	0.235 / 0.203		0.157 / 0.132		0.203 / 0.158		0.081 / 0.067	

Significant *p*-values are noted as stars behind the estimates; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

projects can easily be criticised as “greenwashing” if the ecological outcome can be questioned, and if the measures are used to legitimate new land degradation (Marchi et al., 2020). Only by taking the total mitigation hierarchy seriously the impact on nature values can be reduced, and greenwashing avoided.

Credit author statement

Dagmar Hagen, Ellen Torsæter and Magni Kyrkjeeide conceived the idea for the study, with support from Anne Catriona Mehlhoop. Dagmar Hagen, Ellen Torsæter, Magni Olsen Kyrkjeeide and Anne Catriona Mehlhoop collected and compiled data. Anne Catriona Mehlhoop, Marianne Evju and Mattew Grainger performed the statistical analysis. Dagmar Hagen wrote the manuscript with major contributions from all co-authors (Torsæter, Kyrkjeeide, Grainger and Evju).

Declaration of Competing Interest

No potential conflict of interest was reported by the authors.

Data availability

Data will be made available on request.

Acknowledgement

This study was supported by The Research Council of Norway (grant number 282327) and Statnett. We are grateful to Eline Hildrum, Hanne Bjørnås Krogstie and Nellie Henriette Nilsen for assistance during field work. Thanks to Lars Rød-Eriksen for producing Fig. 1. We appreciate the constructive comments from three anonymous referees.

Appendix A. Ordination biplots based on global non-metric multidimensional scaling of the plant functional group composition

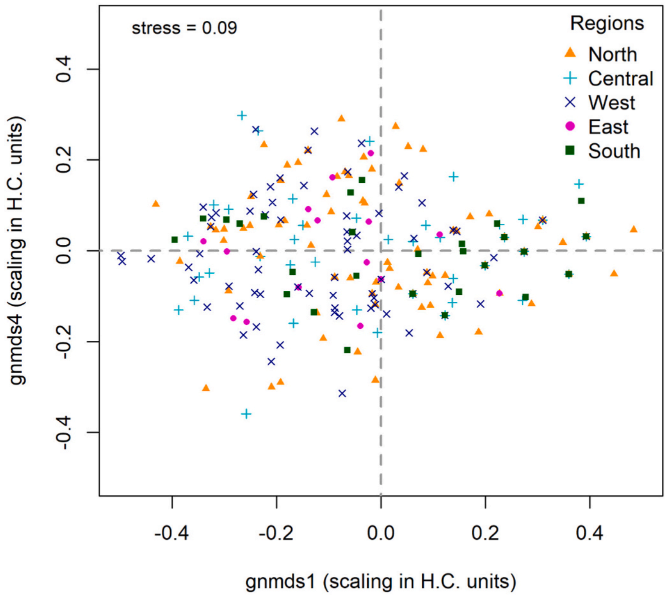

Fig. A1. Ordination biplot based on global non-metric multidimensional scaling (NMDS; with Bray-Curtis dissimilarity, four dimensions) of the plant functional group composition in the sites. Site placement along axes 1 and 4 with each region (North, Central, East, South, and West) represented by different colours and symbols.

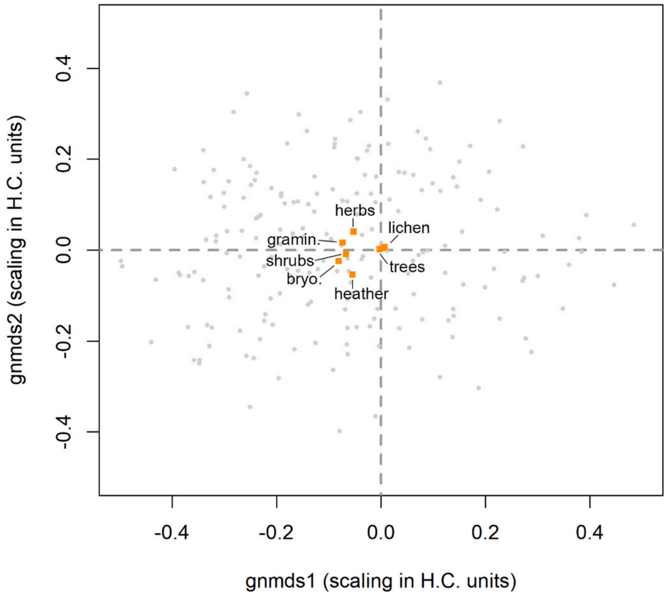

Fig. A2. Ordination biplot based on global non-metric multidimensional scaling (NMDS; with Bray-Curtis dissimilarity, four dimensions) of the plant functional group composition in the sites. Site placement along axes 1 and 2 with each site represented as grey dots, and centroids of the different plant functional groups as orange squares. Gramin. = graminoids, bryo. = bryophytes.

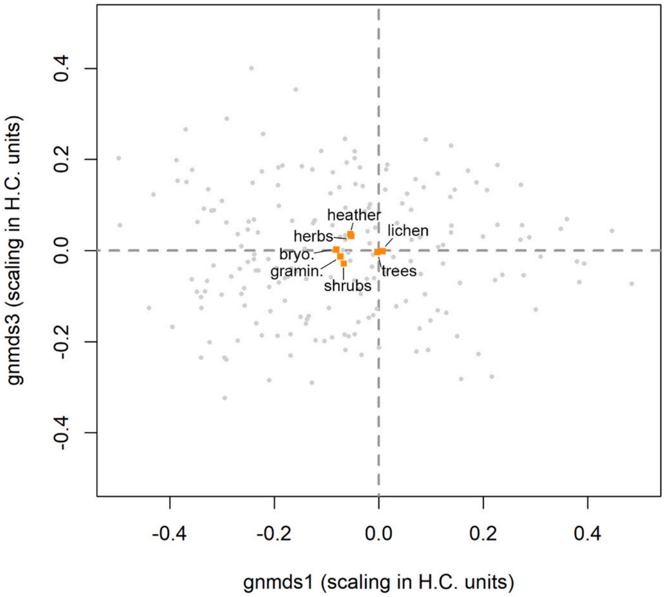

Fig. A3. Ordination biplot based on global non-metric multidimensional scaling (NMDS; with Bray-Curtis dissimilarity, four dimensions) of the plant functional group composition in the sites. Site placement along axes 1 and 3 with each site represented as grey dots, and centroids of the different plant functional groups as orange squares. Gramin. = graminoids, bryo. = bryophytes.

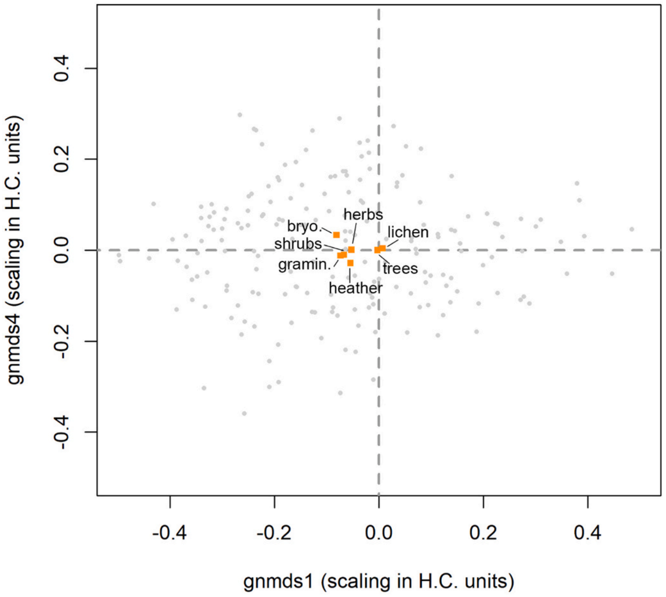

Fig. A4. Ordination biplot based on global non-metric multidimensional scaling (NMDS; with Bray-Curtis dissimilarity, four dimensions) of the plant functional group composition in the sites. Site placement along axes 1 and 4 with each site represented as grey dots, and centroids of the different plant functional groups as orange squares. Gramin. = graminoids, bryo. = bryophytes.

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