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Evaluation of Percent Cover Requirements for Revegetation of Disturbed Sites on Alaska's North Slope

W.J. STREEVER,[1,2] J. McKENDRICK,[3] L. FANTER,[4] S.C. ANDERSON,[1] J. KIDD[5] and K.M. PORTIER[6]

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ABSTRACT. On the North Slope of Alaska, attempts have been made to revegetate areas damaged by development. Some revegetation projects strive to achieve specific performance standards based on percent vegetation cover. This study uses data collected from 60 sites over 16 years to compare revegetating sites and natural reference sites. Results demonstrate that percent cover in most revegetation settings has the potential to reach levels comparable to those of reference sites, depending on how cover is defined. Linear models that explain between 48% and 84% of the variability in data show that planting cultivar seeds and fertilizing can increase cover ($p < 0.05$ for all models) and that cover continues to increase over time ($p < 0.05$ for all models), provided that cover is defined to include all live plants and plant litter. Ordination analysis separates reference sites from most revegetating sites along two significant axes (Monte Carlo tests, $p < 0.01$ with 100 randomizations). Comparison of ordination results with plots of change in plant cover over time shows that plant cover offers only limited insight into plant community development. If percent cover is to be used as a performance standard, it should be clearly defined, and the link between percent cover and restoration objectives should be carefully considered. Although this paper focuses on North Slope revegetation projects, the issues that are addressed have implications for all projects with performance standards calling for specific percent cover by vegetation.

Key words: Alaska, Arctic, North Slope, oil fields, percent cover, performance standards, rehabilitation, restoration, revegetation, tundra

RÉSUMÉ. Le versant Nord de l'Alaska a fait l'objet de tentatives de reverdissement dans des zones endommagées par l'exploitation. Certains projets de remise en état s'efforcent d'atteindre des normes de rendement spécifiques qui s'appuient sur le pourcentage de tapis végétal. Cette étude fait appel aux données collectées à 60 emplacements sur une durée de 16 ans afin de comparer les sites de reverdissement avec des sites témoins laissés à l'état naturel. Les résultats montrent qu'à la plupart des endroits de reverdissement, le pourcentage de tapis végétal a le potentiel d'atteindre des niveaux comparables à ceux des sites témoins, selon la définition du tapis végétal. Les modèles linéaires, qui expliquent entre 48 et 84 % de la variabilité dans les données, montrent que le fait de planter des semences de cultivars et de mettre de l'engrais peut accroître le tapis ($p < 0{,}05$ pour tous les modèles) et que ce dernier continue d'augmenter au fil du temps ($p < 0{,}05$ pour tous les modèles), à condition d'inclure toutes les plantes vivantes et la litière végétale dans la définition du tapis végétal. L'analyse d'ordination permet de distinguer les sites témoins de la majorité des sites reverdis selon deux grands axes (tests de Monte Carlo, $p < 0{,}01$ avec 100 randomisations). La comparaison des résultats de l'ordination avec les courbes de changement dans la couverture végétale en fonction du temps révèle que la couverture n'offre qu'un aperçu limité de l'évolution du peuplement végétal. Si le pourcentage de tapis doit servir de norme de rendement, il faut en donner une définition précise, et examiner en détail le lien entre le pourcentage de tapis et les objectifs de restauration. Si cet article se concentre sur les projets de remise en état du versant Nord, les questions qu'il soulève ont des implications pour tous les projets où les normes de rendement prévoient un pourcentage spécifique de tapis végétal.

Mots clés: Alaska, Arctique, versant Nord, champs pétrolifères, pourcentage de tapis végétal, normes de rendement, remise en état, restauration, reverdissement, toundra

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[1] Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi 39180, U.S.A.

[2] Current address: BP Exploration (Alaska) Inc., Environmental Studies Program, P.O. Box 196612, Anchorage, Alaska 99519; streevbj@bp.com

[3] Lazy Mountain Research, P.O. Box 902, Palmer, Alaska 99645, U.S.A.

[4] U.S. Army Corps of Engineers, Anchorage, Alaska 99506, U.S.A.

[5] ABR, Inc.—Environmental Research and Services, P.O. Box 81934, Fairbanks, Alaska 99708, U.S.A.

[6] Department of Statistics, Institute of Food and Agricultural Sciences and Natural Resources, University of Florida, Gainesville, Florida 32611, U.S.A.

INTRODUCTION

On the North Slope of Alaska, attempts have been made to revegetate areas damaged by activities associated with the oil industry. Some revegetation projects include specific performance standards. In most cases, these performance standards are incorporated within permits issued under Section 404 of the U.S. Clean Water Act (33 U.S.C. 1344). The performance standards used on the North Slope projects, like those used elsewhere (Streever, 1999a, b), have been developed through a trial-and-error process and best professional judgment rather than through careful consideration of data. However, vegetation community data have been collected on North Slope revegetation projects since at least 1984, as part of monitoring schemes and experimental trials of different approaches to fertilization, seeding, and surface manipulation. In general, results of monitoring studies and experiments have been reported case by case in technical reports prepared by industry consultants (e.g., Jorgenson, 1988b; Kidd, 1998). These results have provided important insights regarding establishment of vegetation, especially on abandoned gravel pads, but no attempts have been made to consider accumulated data carefully in the context of performance standards.

This paper summarizes and synthesizes data collected over 16 years to examine trends in plant community development on sites directly affected by oil industry development. Revegetating sites are compared to natural reference sites and discussed in the context of performance standards. To some degree, this paper complements work by Jorgenson and Joyce (1994), Jorgenson (1997), and McKendrick (2000), who considered accumulated data from a number of North Slope projects, as well as a recent synthesis by Forbes and McKendrick (2002). However, here we use additional data that were not available to these authors, and we link results to performance standards. We focus exclusively on revegetation: we do not consider other approaches to land rehabilitation, such as creation of ponds or lakes, or address broader issues of restoration, such as reestablishment of predisturbance hydrology and soil properties. Although this paper focuses on the North Slope of Alaska, its approach could contribute to improving performance standards for revegetation projects elsewhere in the world.

METHODS

Background and Description of Study Area

The Arctic Coastal Plain, or North Slope, covers about 230 000 km^2 north of the Brooks Range and south of the Beaufort Sea. Although annual precipitation is usually less than 18 cm, the combination of low evapotranspiration rates, flat ground, and permafrost results in extensive wetland habitat. At least 15 species of terrestrial mammals, 6 species of marine mammals, and 240 species of birds can be found on the North Slope (Gilders and Cronin, 2000).

The presence of natural oil seeps and promising geological formations on the Alaskan North Slope prompted exploratory drilling as early as the 1940s, but ARCO's 1968 discovery of major reserves at Prudhoe Bay sparked development of oil fields. Infrastructure for drilling, production, transportation, and housing has directly affected about 8793 ha, or 0.04%, of the North Slope (Gilders and Cronin, 2000), while indirect impacts, such as flooding caused by roads that block surface flows and thawing of shallow permafrost caused by dust, have been estimated to affect an area about twice that size (Walker et al., 1987).

Activities leading to a need for revegetation include those involved in 1) gravel pad construction, 2) overburden placement, 3) ice pad construction, and 4) peat stockpiling and construction of peat roads (Fig. 1).

Gravel pads are constructed by piling gravel on top of tundra to heights that can exceed 2 m. The gravel insulates the tundra and limits thawing of permafrost, thereby providing a stable surface. Gravel pads are used for all-season roads and most oil production and housing infrastructure.

Overburden, which consists of sand mixed with gravel and silt, lies beneath surface peat but above underlying gravel in the predisturbance setting (Jorgenson and Joyce, 1994). Digging of gravel mines (which provide material for gravel pads) and reserve pits (which in the past were used to contain drilling mud and other fluids) necessitates stockpiling of overburden. In addition, overburden is sometimes used to backfill abandoned reserve pits.

Ice pads are platforms of ice placed on top of the tundra. Some drilling has been undertaken from ice pads since the 1970s (McKendrick, 1997). Ice pads can be 1 m thick, and they can be insulated through the brief Arctic warm season to permit multi-year use (BP Exploration (Alaska) Inc., 1996). Only ice pads intended for multi-year use cause significant vegetation disturbance.

Disturbed peat results from activities such as construction of peat roads and digging of pits. Peat roads, which have not been used by the oil industry since 1969, were constructed by plowing peat to create road surfaces that were 1–2 m higher than the surrounding tundra. In some cases, peat excavated from mines or reserve pits has been stockpiled.

On the North Slope, many sites on gravel pads, overburden, and disturbed peat have been seeded and fertilized, both experimentally and as a routine land management practice. Seed mixes have included mixes of cultivars imported from areas south of the North Slope and mixes gathered locally from native plants (McKendrick, 2000). Combinations of *Poa glauca* var. Tundra, *Arctagrostis latifolia* var. Alyeska, and *Festuca rubra* var. Arctared (selected for their ability to survive in the Arctic as well as the potential for seed development outside of the Arctic) typically make up cultivar seed mixes, while *Salix* spp., *Artemisia* spp., *Deschampsia caespitosa*, and other species make up native seed mixes (McKendrick, 1991, 2000).

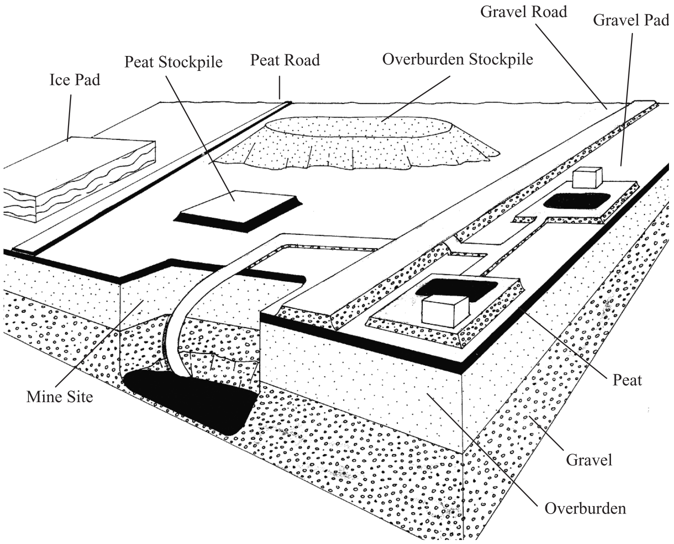

FIG. 1. Conceptual diagram depicting impacts for which revegetation is sometimes required. Adapted from Jorgenson and Joyce (1994). (Sketch by Alison Faulkner.)

The quantity and content of seed mixes applied varies from site to site, apparently according to the best professional judgment of planting contractors and depending on the availability of seed. Fertilizer mixes and application rates also vary from project to project; for example, 8-32-16 (Nitrogen, Phosphorus, Potassium, or N-P-K) was applied at a rate of 400 kg ha^{-1} on the Airport Site (Kidd and Rossow, 1998), and 20-20-10 (N-P-K) was applied at a rate of 500 kg ha^{-1} on the Lake State #1 Site (Jorgenson, 1988b). In addition to seeding and fertilization, surface manipulation (such as plowing of surfaces to reduce the effects of compaction and construction of snow fences to trap moisture) has been attempted at a number of sites. On some gravel pad sites, gravel has been partly or wholly removed before fertilization and seeding. There are also examples of gravel pads, overburden, and disturbed peat on which no fertilization, seeding, or surface manipulation has been undertaken. Abandoned ice pads simply thaw, allowing plants to break dormancy and resume growth.

Throughout the rest of this paper, the phrase "revegetation setting" refers collectively to the various types of damaged areas requiring revegetation because of development, i.e., gravel pads, overburden, disturbed peat, and ice pads. Similarly, the phrase "revegetation approach" refers collectively to the different methods of encouraging revegetation (i.e., combinations of fertilization and seeding with either cultivars or native species).

Examples of Performance Standards

In 1999, a review of Section 404 permit performance standards for revegetation projects on the North Slope was undertaken at the request of the Corps of Engineers Alaska District. Twelve permits with revegetation performance standards for gravel pads, overburden, and ice pads were identified (Table 1). No permits with performance standards for projects on disturbed peat were identified, in part because peat roads, the most common type of disturbed peat, have not been built since 1969. All twelve permits with revegetation performance standards relied heavily on percent cover requirements, although a few permits included other requirements, such as the survival of planted stock or attainment of specific stem densities (i.e., number of stems m^{-2}). Percent cover requirements listed either a specific percent cover to be achieved or a percent cover relative to a reference site. In all cases, permits established a period (usually three years) in which requirements were to be met, and in several cases permits listed requirements for remedial action (typically, application of additional seed and fertilizer) that would apply if performance standards were not met within the specified period. Permits did not specify the methods that were to be used for estimating cover, and they did not differentiate between cultivars and native species. In all but one case, permits did not specify whether or not standing dead plants or plant litter should be included in estimates of cover. No permit specified whether mosses and lichens should be included in plant cover estimates.

Data Sources

Revegetating sites considered in this study were chosen for their accessibility and the availability of information on site history. All sites for which data were available prior to the 2000 field season and which could be accessed by road or by short helicopter flights were included in this study. Reference sites in this study consisted of natural vegetation communities that were not directly affected by oil industry infrastructure but that were generally within 1 km of disturbed sites. Reference sites were selected for their geomorphology similar to that of revegetation sites before disturbance, as well as their proximity to revegetation sites, but it is important to note that enough reference sites were included to at least begin to address variability among sites on the North Slope.

Mean percent cover data from 60 sites were compiled (Table 2 and Fig. 2). For about half the sites, data were collected in more than one year. One data point was recorded for each sampling event (i.e., in each year) for each revegetation approach at each site. On some sites, plots were established and different revegetation approaches were applied to different plots, making it possible for a site to generate more than one data point per year. In total, 169 data points were compiled.

We used a walking point method that recorded vegetation hits at points on a random walk (Owensby, 1973) to collect data during visits to 28 sites in July 2000. In addition, we compiled data from records presented in technical reports submitted to oil companies and regulatory agencies between 1987 and 1999. The data recorded in the technical reports were collected using four methods: (1) the same walking point method that was used during site visits in July 2000; (2) visual estimates of cover within

TABLE 1. Performance standards listed on Section 404 permits for North Slope projects, from a Corps of Engineers internal review undertaken in 1999 and reported in a Memorandum of Record dated 3 March 2000, from Bill Streever (Corps of Engineers, Waterways Experiment Station) to Lloyd Fanter (Corps of Engineers, Alaska District).

Permit Number	Year Issued	Revegetation Setting	Percent Cover Performance Standards
R-820003	1982	Gravel pad	35% cover within 3 years
V-820741	1982	Overburden	60% cover in 3 years
O-820741	1987	Gravel pad	30% cover in 3 years
4-890406	1989	Overburden	30% cover in 3 years
4-910215	1991	Gravel pad	30% cover in 3 years
4-910241	1991	Overburden	30% cover in 3 years
M-910515	1991	Overburden	30% total live vegetation cover or 60% of total live vegetation cover found on adjacent undisturbed area (whichever is less) after 3 years
4-910527	1991	Gravel pad	45% cover in 3 years
4-930426	1993	Ice pad	30% cover in 4 years, or early release if 70% cover is met before 4 years, or early release if cover increases by 10% within 1 year to a level of 50% or more
4-940180	1994	Ice pad	30% cover in 4 years, or early release if 70% cover is met before 4 years, or early release if cover increases by 10% within 1 year to a level of 50% or more
4-960869	1996	Overburden	10% cover within 10 years
O-970705	1997	Gravel pad	60% of cover found in surrounding tundra within 5 years

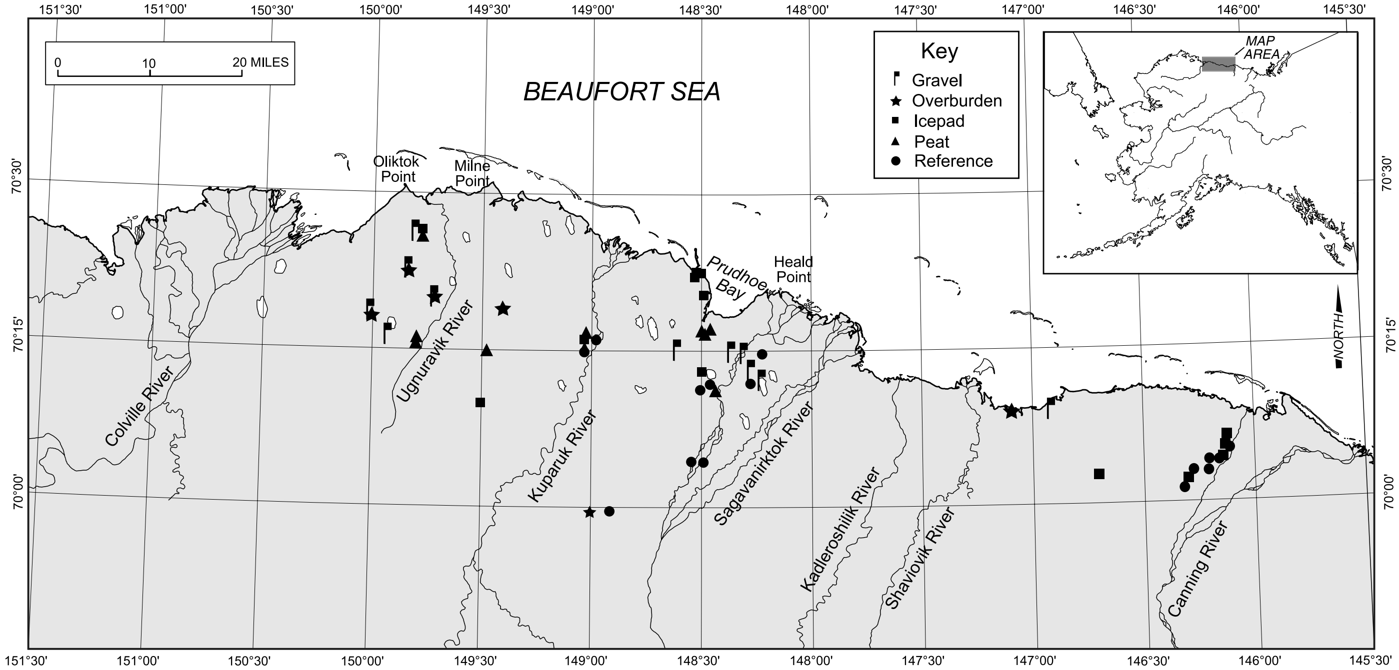

FIG. 2. Approximate locations of study sites on the North Slope of Alaska. Two additional gravel pads are located to the west of the map boundary in the National Petroleum Reserve Alaska (NPRA). Exact locations of sites are available from BP Exploration (Alaska) Inc., Environmental Studies Program, P.O. Box 196612, Anchorage, Alaska 99519, U.S.A.

1 m^2 quadrats (Krebs, 1989); (3) a point-frame method that recorded vegetation hits at 10 cm intervals within a randomly placed 1 m^2 quadrat (Mueller-Dombois and Ellenberg, 1974); and (4) a point-intercept transect method (Jonasson, 1988). In all cases, samples were not collected from areas known to be affected by events that were not representative of the majority of the site. For example, vegetation was absent from portions of some gravel pads because of salt spills, and vegetation was not sampled from these areas.

Differences in the way in which each method of estimating cover was applied could result in different maximum cover values. That is, different maximum cover values, often exceeding 100% cover, could occur even within a single method of estimating cover because of different approaches to counting multiple layers of vegetation. The influence of these differences was mitigated by standardizing all values to a maximum percent cover of 100%, including cover by plant litter and bare ground. For example, if a method could result in a maximum cover of 120%, and plant cover in a plot was reported as 60%, the cover for the plot was standardized by dividing 60% by 120% (= 50% cover).

To mitigate the effects of identification errors and differences in botanical expertise among field personnel, data were collapsed into a single taxonomic group for

TABLE 2. Summary of data sources and methods.

Site	Data source	Number of years	Method[1]
Gravel Pads (total data points from gravel pads = 94[2])			
ARCO 3	Jorgenson, 1988a	1	2
Lake State #1	Jorgenson, 1988b; 2000 field season[3]	5	3, 1
Mine Site D	Jorgenson and Cater, 1992	1	3
2B Access Road	Jorgenson and Cater, 1992	4	3
Inigok Test Well #1	McKendrick et al., 1992	1	1
Lisbourne Test Well #1	McKendrick et al., 1992	1	1
BPOC	Kidd and Rossow, 1998	2	3
Sinclair Exploratory Well	Bishop et al., 1999	4	1, 2
Mine Site F	Bishop et al., 1999	2	3
SE Eileen Exploratory Well	Bishop et al., 1999; 2000 field season	5	1, 3
Drill Site 13	Kidd et al., 1999; 2000 field season	4	1, 3
Airport	Kidd and Rossow, 1998	2	3
North Prudhoe Bay #2	ABR Inc., 1999	5	3
Norgasco	2000 field season	1	1
Washout Creek Road	2000 field season	1	1
East Mikkelsen Bay State 1	2000 field season	1	1
3K Spur Road	2000 field season	1	1
Overburden (total data points from overburden sites = 16)			
Mine Site B	Jorgenson, 1988a	2	2
Sinclair Exploratory Well	Bishop et al., 1999	3	2
Badami Reserve Pit	2000 field season	1	1
Sequoia Reserve Pit	2000 field season	1	1
Mine Site F	Jorgenson and Cater, 1992	2	4
Mine Site D	Bishop et al., 1999	4	4
Ice Pads (total data points from ice pads = 5)			
Yukon Gold	LGL Alaska, 1996; 2000 field season	3	1,3
Sourdough 2	2000 field season	1	1
Sourdough 3	2000 field season	1	1
Disturbed Tundra (total data points from disturbed tundra = 24)			
ARCO Drill Site 5 Road	McKendrick, 1987	1	3
3K Spur Road	Jorgenson, 1988a; 2000 field season	3	1,2
ARCO 3B	Jorgenson and Cater, 1992	2	4
3N	Jorgenson and Cater, 1992	3	4
ARCO 3A	Jorgenson and Cater, 1992	4	4
SE Eileen Exploratory Well	Bishop et al., 1999	4	3
4 unnamed peat roads	2000 field season	1	1
Reference Sites (total data points from reference sites = 30)			
6 Sourdough reference sites	LGL Alaska, 1993	1	3
Yukon Gold	LGL Alaska, 1996; 2000 field season	3	1, 3
N. Prudhoe Bay #2	ABR Inc., 1999; Kidd, 1998	2	3
SE Eileen Exploratory Well	Bishop et al., 1999	1	3
15 unnamed reference sites	2000 field season	1	1

[1] Method 1 = walking point estimates; Method 2 = visual estimates of cover within quadrats; Method 3 = point-frame estimates; Method 4 = point-intercept transect estimates.

[2] The total number of data points for each of the four revegetation settings and natural reference sites is the sum of all samples in all years for all restoration treatments at all sites. Note that in many cases single sites received more than one restoration treatment, so that there may be more data points than sites × years.

[3] 2000 field season data collected by W.J. Streever and J.D. McKendrick as part of this study.

some taxa (Appendix). Because all four of the methods used in this study may not adequately sample infrequently occurring species, records of taxa representing less than 1% cover within a site were removed from the data set (Appendix). Also, because of differences in the way that different field personnel classified plant litter and standing dead plants, these two classes of cover were pooled into a single category, henceforth referred to as plant litter.

For gravel pads, we estimated thickness of gravel (i.e., its height above surrounding tundra). Thermokarsting (i.e., melting of underlying permafrost and subsequent subsidence) and other factors often lead to development of irregular surfaces on abandoned gravel pads, making it difficult to measure average thickness with any degree of precision. With this in mind, estimated mean thickness for each gravel pad was classified as thin (0–50 cm), medium (50–100 cm), or thick (>100 cm). Where survey data were available, selection of pad thickness class was based on the most prevalent elevation for each site. Where survey data were not available, pad thickness was visually estimated.

TABLE 3. Eight interpretations of the meaning of plant "cover." Plant litter includes both standing dead plants and leaf litter.

Category	Definition
All Plants (including mosses and lichens):	
Live cover	All live plants
Live and litter cover	All live plants as well as plant litter
Native live cover	Native plants, excluding cultivars
Native live and litter cover	Native plants as well as plant litter, excluding cultivars
Higher Plants (not including mosses and lichens):	
Higher live cover	All live higher plants
Higher live and litter cover	All live higher plants, as well as plant litter
Higher live native cover	Native higher plants, excluding cultivars
Higher live native and litter cover	Native higher plants as well as plant litter, excluding cultivars

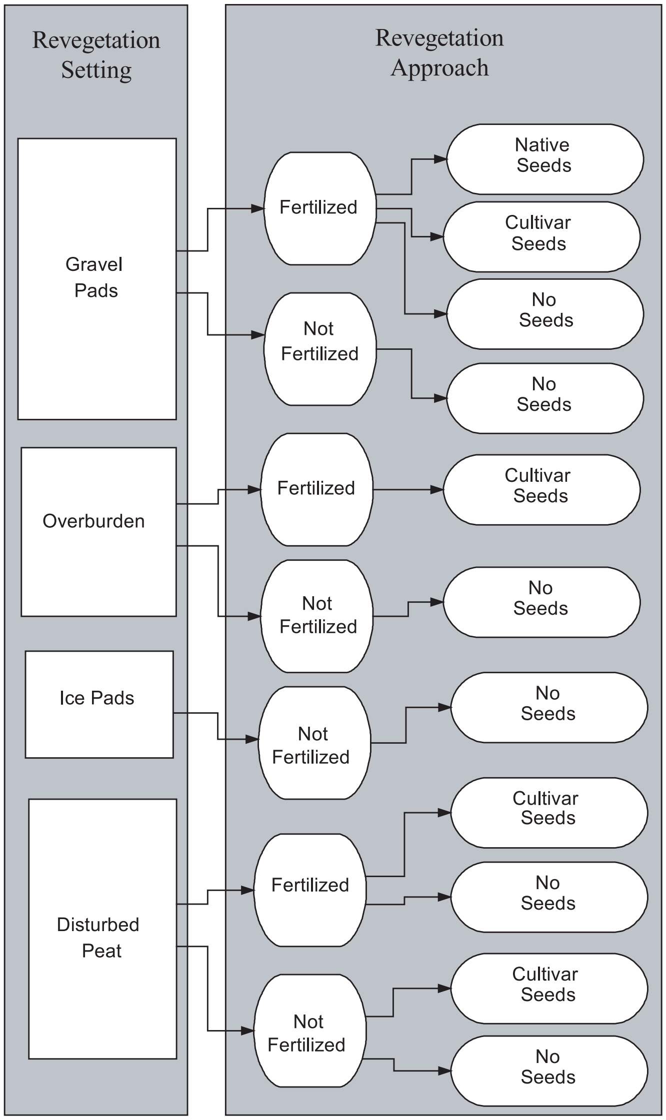

FIG. 3. Revegetation settings and approaches.

Data Analyses

Analyses were intended to allow comparison of vegetation cover in natural reference sites and in different revegetation settings using different approaches to revegetation (Fig. 3). In addition, analyses provide predictive models of changes in vegetation cover over time. Further analyses compared plant community composition and assessed the relationship between composition and cover.

As a first analytical step, plots were generated to allow simple comparisons of percent cover under different conditions. To determine how different interpretations of the meaning of "cover" affected results, plots were generated using eight different interpretations of the meaning of "cover" (Table 3). For the sake of simplicity, gravel pads of different thickness were not separated in the plots.

Because plots did not portray development of vegetation communities over time, an analysis was undertaken to develop a predictive model of percent cover as a function of site age, revegetation approach, and, in the case of gravel pads, pad thickness. A set of hierarchically related regression models was examined in an attempt to identify exactly which factors and factor combinations might produce the best-fitting models (and hence the best predictions). Rather than generating eight models corresponding to the eight different definitions for cover (see Table 3), we chose "live and litter cover" as the definition that would be used in all models; that is, "live and litter cover" was the dependent variable for all models. The most complex model included categorical terms for revegetation approach and pad thickness (for gravel pads only), a continuous term for age, and an interaction term for revegetation approach by age. The interaction term was introduced in an attempt to gauge the strength of evidence for allowing each revegetation approach to have its own linear regression. Where graphical evidence suggested significant nonlinearity, a quadratic for age was also included in the model. *F* statistics were used to test the significance of factors in the model under consideration. Nonsignificant interaction and cross-product terms were removed from the signal part of the model and returned to the error term. Computations were performed using SAS software, primarily the GLM procedure (SAS Institute Inc, 1989).

Both data plots and predictive models examined total percent cover data, irrespective of community composition. Nonmetric multidimensional scaling (NMS), also known as Multiple Dimensional Scaling (MDS), was used to search for patterns that separated revegetating sites and natural reference sites on the basis of community composition. Ordination was based on arcsine square root transformed percentage cover of all taxa of plants, plant litter, and bare ground. NMS was run using the Bray-Curtis distance measure in PC-ORD Version 4 (McCune and Mefford, 1999). One hundred Monte Carlo randomizations were run to test significance of NMS axes.

RESULTS

Data Plots

Figure 4 shows cover, including mosses and lichens, with and without plant litter and with and without cultivars. Reference wetland percent cover had a broad range (22%–94% without plant litter, 62% – 100% with plant litter). For “live cover” and “native live cover,” percent cover ranges for reference sites and revegetation settings overlapped in all cases. However, for “live and litter cover” and “native live and litter cover,” percent cover ranges of revegetation settings and reference sites did not overlap in two cases: 1) gravel pads that were fertilized and seeded with native seeds, and 2) peat sites that were seeded with cultivar seeds but not fertilized. In contrast to the overall range, the mean ± SD for the reference wetlands (i.e., the range that would encompass 68% of the values, assuming a normal distribution (Marks, 1990)) was narrow (51% – 59% without plant litter, 93%–96% with plant litter). Only peat sites that had been neither fertilized nor seeded had mean ± SD that consistently overlapped with those of reference wetlands for all four ways that cover is interpreted. However, both ice pads and overburden planted with cultivars and fertilized had mean ± SD that partially overlapped those of reference wetlands (for “live and litter cover” and “live cover,” respectively).

Figure 5 summarizes cover contributions from mosses and lichens. For reference sites and all revegetation settings, mosses and lichens comprise a substantial part of the plant cover in at least some cases. In many cases, mosses and lichens can comprise almost all of the cover, as seen by comparing the high end of ranges in Figures 4 and 5.

Figure 6 shows “higher” cover, not including mosses and lichens, with and without plant litter and with and without cultivars. Comparison of Figures 4 and 6 shows that overlap in ranges and mean ± SD of reference sites and revegetation settings changes dramatically if mosses and lichens are not included as part of percent cover. Again, reference wetland percent cover had a broad range (18%–77% without plant litter, 40% – 100% with plant litter). For “higher live cover,” percent cover ranges for reference wetlands and revegetating wetlands overlapped in all cases except that of gravel pads that were fertilized but not seeded, but when cultivar cover was removed (i.e., “higher live native cover”), gravel pads that were fertilized and seeded with cultivars also failed to overlap with reference wetlands. For “higher live and litter cover,” ranges for reference wetlands and revegetating wetlands overlapped in all cases except gravel pads that were fertilized and either seeded with native species or not seeded, and removal of cultivars (i.e., “higher native live and litter cover”) had no effect on this relationship. As was true when mosses and lichens were included, the mean ± SD for the reference wetlands was narrow (38% – 43% without plant litter, 77% – 83% with plant litter) relative to the range. No revegetation settings had mean ± SD that consistently overlapped with those of reference wetlands for all four ways that cover is interpreted. However, overlap

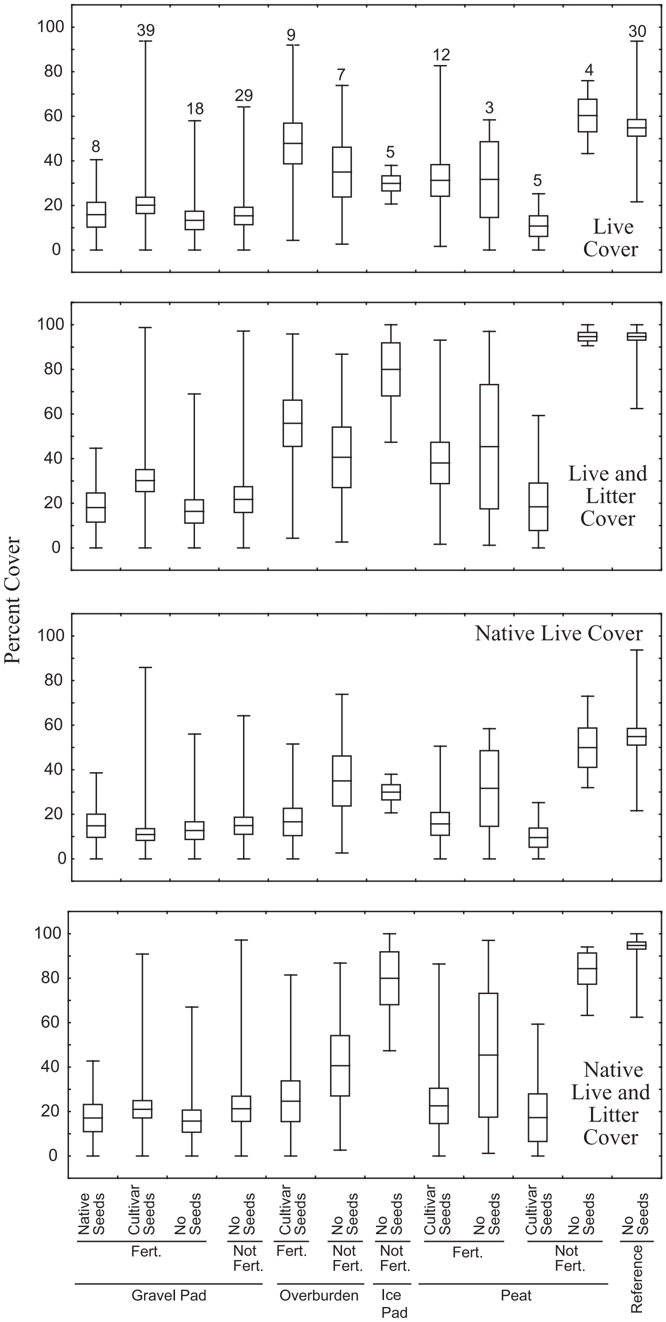

FIG. 4. Percent cover of all plants, including mosses and lichens, with means, standard deviations, and ranges. Numbers above the bars in the top graph indicate sample size. See Table 3 for explanation of cover categories.

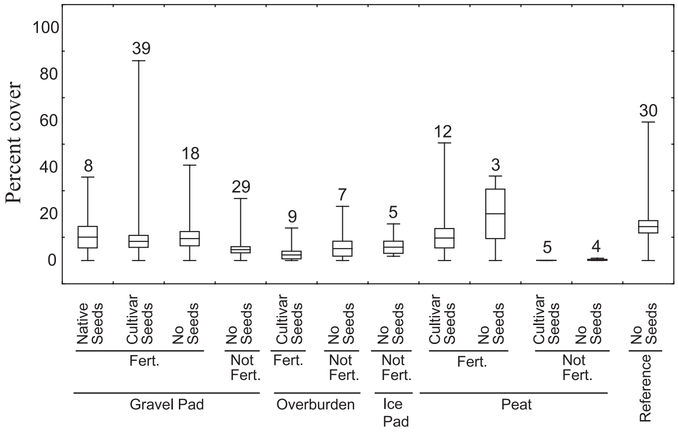

FIG. 5. Percent cover of mosses and lichens only, with means, standard deviations, and ranges. Numbers above bars indicate sample size.

occurred for all revegetation settings except gravel pads in at least one of the four possible interpretations of "cover" that do not include lichens and mosses.

General Linear Models: Development over Time

Table 4 summarizes results of regression analysis for "live and litter cover." None of the interaction terms for revegetation approach by age were significant, so they were dropped from the models. Also, no attempt was made to model disturbed peat sites that were neither fertilized nor seeded because exact ages of these sites were not known (all were more than 30 years old). Models predicting "live and litter cover" explained between 48% and 87% of the variability. Planting cultivars and fertilizing significantly increased "live and litter cover" in all revegetation settings except ice pads, where fertilization and seeding has not been attempted. Gravel pad thickness contributed a significant negative element to the model for thick pads, but did not make a significant contribution to the model for medium pads (i.e., pad thickness did not contribute to a significant difference between thin and medium pads). Age was a significant predictor for all revegetation settings and approaches. Slopes describing the relationship between age and "live and litter cover" were steepest for disturbed peat and least steep for overburden and ice pads.

Ordination: Community Development

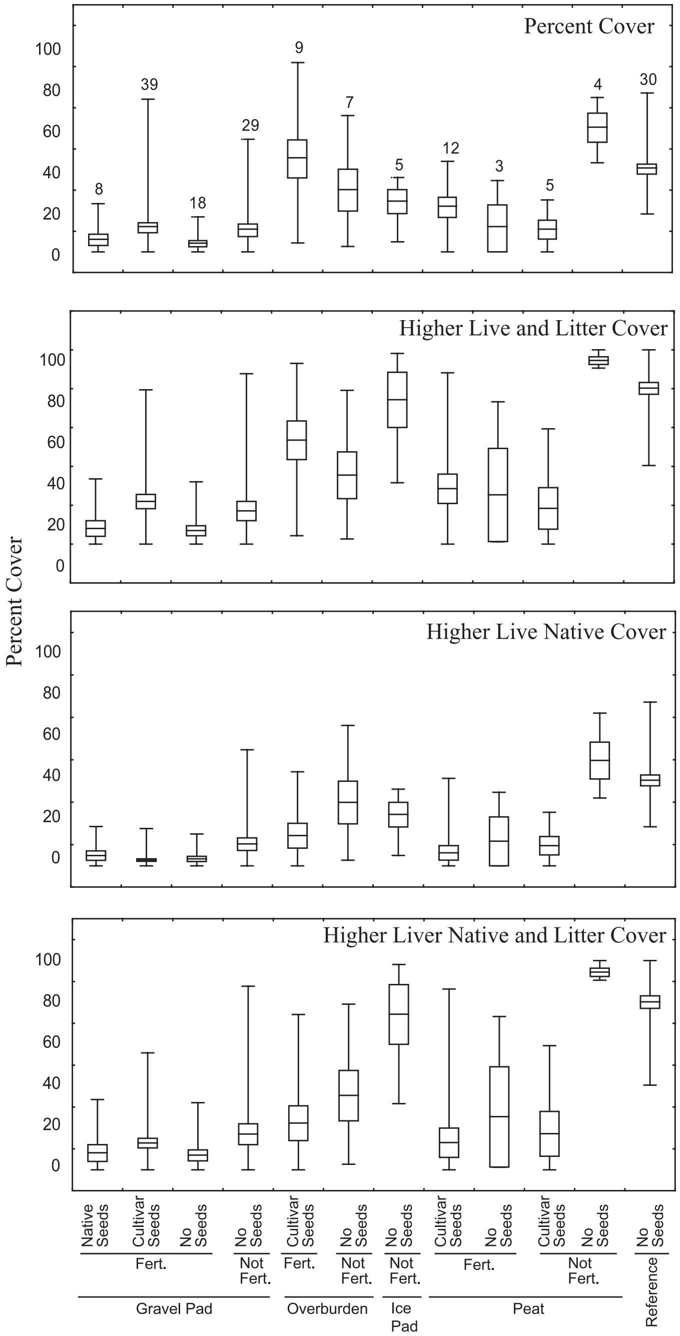

FIG. 6. Percent cover of higher plants, not including mosses and lichens, with means, standard deviations, and ranges. Numbers above the bars in the top graph indicate sample size. See Table 3 for explanation of cover categories.

Cumulative stress values for NMS axes 1, 2, and 3 were 19.8%, 12.6%, and 9.2%, suggesting that interpretation of axes 1 and 2 was appropriate (McCune and Mefford, 1999). Axes 1 and 2 were significant at $p < 0.01$ (Monte Carlo test, n = 100 iterations). There was a slight tendency for reference sites to have somewhat higher values than revegetating sites on axis 1, although there was considerable overlap in the ranges of reference sites and revegetating sites on this axis (Fig. 7). In contrast, there was less overlap in ranges on axis 2, where most of the reference sites were plotted at values above 0.5, while more than 90% of revegetating sites were plotted at values below 0.5. Pearson and Kendall correlation scores (*r* values) indicate that bare ground and *Salix* spp. had the greatest influence on Axis 1 values, while bare ground, litter, *Eriophorum* spp., *Salix* spp., *Carex aquatilis*, *Dryas* spp., and *Carex* spp. had the greatest influence on Axis 2 values (Table 5). However, no large gap between Pearson and Kendall correlation scores separated the taxa exerting the greatest influence from the other taxa.

TABLE 4. Predictive equations for percent “live and litter cover” or ln (% cover). To determine predicted percent cover, enter the age of a site in years and solve the appropriate equation for percent cover.

Revegetation approach	Estimate of cover	Y-Intercept	Correction for revegetation approach	Correction for pad thickness	Correction for age
Gravel Pads (model explains 48% of variability)					
Thin Gravel Pads:					
Fertilizer and native seeds	ln (% cover) =	0.74[a]	+ 0.73	+ 0	+ 0.16 (age)[a]
Fertilized and cultivar seeds	ln (% cover) =	0.74[a]	+ 1.51[a]	+ 0	+ 0.16 (age)[a]
Fertilizer and no seeds	ln (% cover) =	0.74[a]	+ 0.40	+ 0	+ 0.16 (age)[a]
Not fertilized and no seeds	ln (% cover) =	0.74[a]	+ 0	+ 0	+ 0.16 (age)[a]
Medium Gravel Pads:					
Fertilizer and native seeds	ln (% cover) =	0.74[a]	+ 0.73	-0.269	+ 0.16 (age)[a]
Fertilized and cultivar seeds	ln (% cover) =	0.74[a]	+ 1.51[a]	-0.269	+ 0.16 (age)[a]
Fertilizer and no seeds	ln (% cover) =	0.74[a]	+ 0.40	-0.269	+ 0.16 (age)[a]
Not fertilized and no seeds	ln (% cover) =	0.74[a]	+ 0	-0.269	+ 0.16 (age)[a]
Thick Gravel Pads:					
Fertilizer and native seeds	ln (% cover) =	0.74[a]	+ 0.73	-0.99[a]	+ 0.16 (age)[a]
Fertilized and cultivar seeds	ln (% cover) =	0.74[a]	+ 1.51[a]	-0.99[a]	+ 0.16 (age)[a]
Fertilizer and no seeds	ln (% cover) =	0.74[a]	+ 0.40	-0.99[a]	+ 0.16 (age)[a]
Not fertilized and no seeds	ln (% cover) =	0.74[a]	+ 0	-0.99[a]	+ 0.16 (age)[a]
Overburden (model explains 54% of variability)					
Fertilizer and cultivar seeds	ln (% cover) =	1.03	+ 2.27[a]	NA	+0.14 (age)[a]
Not fertilized and no seeds	ln (% cover) =	1.03	+ 0	NA	+0.14 (age)[a]
Ice Pads (model explains 87% of variability)					
Not fertilized and no seeds	ln (% cover) =	3.76[a]	NA	NA	+0.14 (age)[a]
Disturbed Peat (model explains 59% of variability)[c]					
Fertilized and cultivar seeds	ln (% cover) =	0.99[b]	+ 1.15[b]	NA	+0.23 (age)[a]
Fertilized and no seeds	ln (% cover) =	0.798	+ 0.597	NA	+0.21 (age)[a]
Not fertilized and cultivar seeds	ln (% cover) =	0.798	+ 0	NA	+0.21 (age)[a]

[a] Significant at $p < 0.05$.

[b] Significant at $p < 0.1$.

[c] Because percent cover measurements for disturbed peat sites that were neither fertilized nor seeded were available only for 30-year-old sites, this revegetation approach was excluded from the regression analysis.

DISCUSSION

Data Plots

The percent cover values in this study, even for reference sites, are somewhat lower than those typically described in technical reports prepared by industry and other studies reported in the literature (e.g., Kershaw and Kershaw, 1987; Felix and Raynolds, 1989). In this study, all values were standardized to mitigate the effect of using different methods to estimate cover, so that the maximum values for cover, including plant litter, lichens and mosses, and bare ground, was 100%. Other studies often report total cover exceeding 100%, reflecting the possibility of encountering more than one layer of vegetation within a canopy, even on tundra. Before standardization, total cover values in this study often exceeded 100%.

For each revegetation method and setting, the low end of percent cover ranges can be interpreted as representing the worst-case scenario. While the low end of the range for reference sites does not approach 0%, regardless of the way in which cover is defined, the low end of the range for most revegetation settings approaches 0% for at least some definitions of cover. Disturbed peat that is neither seeded nor fertilized is the exception to this generalization, but this may be an artifact of site age and a small sample size—all four disturbed peat sites that were not fertilized and not seeded were more than 30 years old, while most of the other revegetating sites were much younger. For almost all of the other revegetation settings and methods, the low end of the range reflects conditions on sites in their first growing season. The most notable exception occurred on a portion of the airport gravel pad, where total plant cover was 0% after seven years; at this site, flooding caused by thermokarsting had killed plants established in the first three years after planting.

The high end of ranges for percent cover can be interpreted as representing the best case for revegetation in the settings (gravel pads, overburden, ice pads, and disturbed peat) and with the approaches (seeding and fertilization) currently used on the North Slope, with the proviso that cover will typically continue to increase as sites age. In all revegetation settings, ranges for revegetating sites overlapped with those of reference sites for at least some of the definitions of cover, while mean ± SD sometimes overlapped for all vegetation settings except gravel pads. While the high end of ranges represents the best case for revegetating sites, mean values and mean ± SD represent typical revegetation outcomes, again with the proviso that cover will continue to increase with site age. These results demonstrate that revegetation efforts often lead to cover that is comparable to that of reference sites, depending on how cover is defined. For gravel pads, however, vegetation cover is seldom comparable to that of reference sites, regardless of how cover is defined.

It is clear that the way in which cover is defined has a dramatic effect on percent cover estimates (Figs. 4 and 6). For example, there is substantial overlap between gravel pads that have been fertilized but not seeded and reference sites when "live cover" is considered (Fig. 4), but no overlap when "higher live native and litter cover" is considered. Similarly, there is almost perfect overlap in mean ± SD for disturbed peat sites that have been neither fertilized nor seeded and reference sites if "live and litter cover" is considered, but no overlap if "higher live and litter cover" is considered. Importantly, the way in which cover is defined affects different reference sites and restoration settings differently: that is, there is no change consistent among sites when different definitions of cover are used, so that a change in the definition of cover could cause one site's cover to decrease and another site's to increase.

General Linear Models: Development over Time

It is important to understand the limitations of predictive models before considering their practical implications. First, because of the natural log transformation, linear relationships between ln (% cover) and age are actually nonlinear relationships between percent cover and age. Since percent cover cannot be greater than 100%, there will always be a slowing of percent cover increase with time as sites become older and approach the threshold of 100% cover, and the small number of data points for older sites makes the attempt to fit threshold-acting nonlinear models problematic. Second, although the absence of significant interactions between categorical factors and age simplifies model interpretation, the absence of these interactions may be an artifact of small sample size and high unexplained variability in percent cover values. That is, the absence of significant interactions indicates that there is no evidence of an interaction, but it does not indicate that an interaction does not exist. With this in mind, the possibility of interactions between categorical factors and age (e.g., gravel pad thickness and age) should not be entirely dismissed. Third, some of the models account for as little as 48% of the variability in the data, suggesting that a substantial amount of the variability in percent cover results from factors not addressed by the models. Fourth, the models should not be projected for ages beyond those included in the data sets. Fifth, models predict the typical case, but there can be atypical cases; for example, it is possible for cover to increase over time, then decrease dramatically, a phenomenon that has been observed on North Slope revegetation sites but is not predicted by the models.

Despite these caveats to interpretation, the models still provide the best available method for predicting percent cover for various revegetation settings and approaches on the North Slope. Importantly, significance of age in all cases indicates that percent "live and litter cover" typically increases over time in all revegetation settings, regardless of the revegetation approach taken. That is, percent cover will usually increase with time in all revegetation settings and with all revegetation approaches—if time is no object, most sites can meet objectives of increased percent cover. Models also suggest that, for all revegetation settings except ice pads (where only passive revegetation has been tried), the revegetation approach relying on fertilization and planting of cultivars leads to higher percent "live and litter cover." These models indicate that when increased "live and litter cover" is the objective of revegetation, fertilization and planting of cultivars should be relied on in preference to other approaches, bearing in mind, of course, that this may change if the definition of cover is changed. Lastly, these models are reasonably consistent with those of Jorgenson (1997), especially when one considers the differences between the approaches used to generate the models.

Ordination: Community Development

Ordination analysis condenses information about plant community composition in a manner that allows comparison of percent cover values and community composition. In the ordination plot (Fig. 7), there is some overlap between reference sites and all revegetation settings and methods on both axes 1 and 2, just as there is overlap in "live and litter cover" for reference sites and revegetation settings and methods. Furthermore, in cases where data have been collected through several years at a single site, data points for revegetating sites often move increasingly closer to data points for reference sites as they become older (Fig. 8). This convergence in ordination space between revegetating sites and reference sites generally seems to reflect increases and decreases in total plant cover, although the relationship is far from perfect. For example, at Mine Site D, increases in percent cover between years 2 and 3 correspond to a dramatic decrease in the Axis 1 score. Similarly, percent cover can be well within the range of that found in reference sites while ordination scores may still be at the low end of the range for reference sites, especially on Axis 2. In short, "live and litter cover" offers some insight regarding community composition, but if the objective of revegetation is to promote native vegetation communities similar to those of reference sites, some measure other than "live and litter cover" will be needed. At the very least, mosses and lichens should be considered because of the important role they play in Arctic ecosystems.

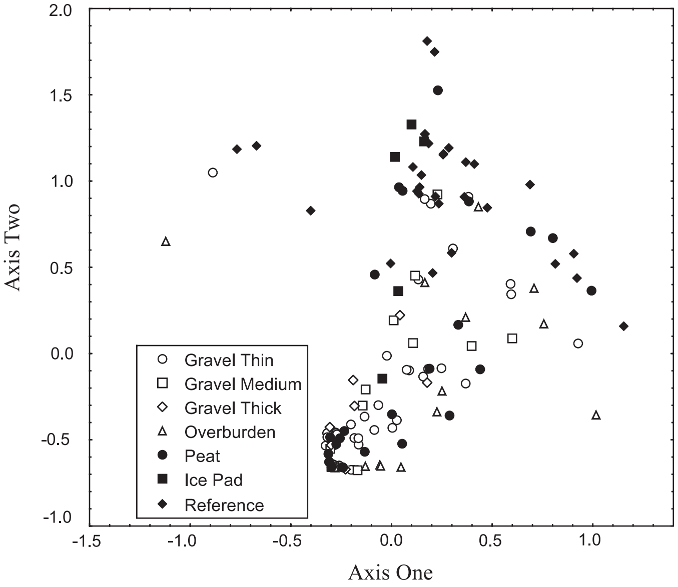

FIG. 7. Nonmetric multidimensional scaling (NMS) plot for North Slope revegetation sites and reference sites based on "live and litter cover" (see Table 5 for explanation).

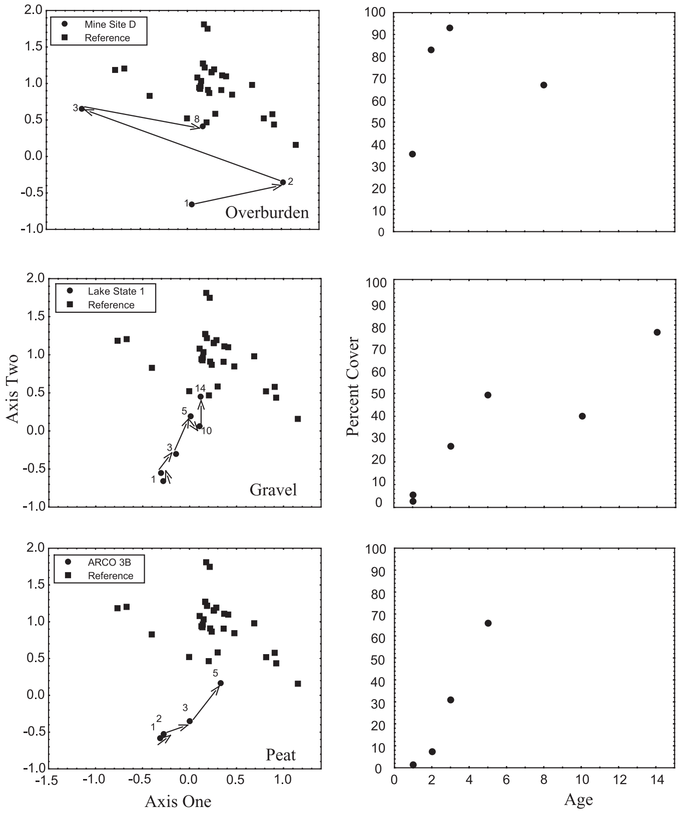

FIG. 8. Partial results of ordination (nonmetric scaling) showing reference sites and individual revegetation sites through time, with numbers indicating site age in years, next to percent cover for the revegetation sites. Juxtaposition of ordination and percent cover plots shows how points move in ordination space as cover increases.

Performance Standards

Clearly, different methods of defining percent cover yield very different results. In the context of performance standards for the North Slope, this finding has important implications: meeting percent cover performance standards depends to a great extent on the way in which cover is defined. While this finding should not surprise anyone who has ever measured percent cover, Figures 4–6 document the extent to which different definitions influence cover estimates. Also, because switching from one definition to another may increase percent cover at one site and decrease it at another, simply linking percent cover requirements in revegetating sites to vegetation cover in reference sites, as is occasionally done (e.g., permit O-970705 in Table 1), is not a panacea for the problems that arise from leaving "cover" undefined when presenting permit performance standards.

The most lenient performance standards on a North Slope permit call for 30% cover within three growing seasons (Table 1). Some permits call for up to 60% cover within five years or link cover requirements to cover found in nearby natural wetlands. Although wording varied among permits, typical wording was as follows: "If after three growing seasons an average of 30% cover has not been achieved the applicant would be required to implement additional fertilization and/or seeding, as directed by the District Engineer." As noted above, meeting percent cover requirements depends in part on how percent cover is defined. However, regression models show that even if the most lenient performance standards are used with the most generous definition of cover, typical gravel pads and disturbed peat sites will not meet performance standards within three years, assuming that cover is measured with the methods used in this study (i.e., standardized to 100%). For example, the model from Table 4 shows that a typical thin gravel pad that is to be fertilized and planted with cultivars will have 15.3% "live and litter cover" after three years, while a disturbed peat site that is fertilized and planted with cultivar seeds will have 17% "live and litter cover" after three years. On the other hand, both overburden sites that are fertilized and planted with cultivar seeds and ice pads will exceed 30% "live and litter cover" in three years, with overburden achieving 41.3% and ice pads achieving 65%.

Two important points regarding model output are worthy of re-emphasis. First, models predict what would occur under typical conditions. Because the models presented here can explain only a small percentage of the overall variability in the data, there will be many cases in which "live and litter cover" is either much higher or much lower than that predicted by the model. Second, models were developed using "live and litter cover" that had been standardized to a maximum of 100% cover. If other methods of estimating cover are used—even if cover is defined as "live and litter cover"—the models are not applicable. Because of this, the models presented here should be seen as an example of how regression modeling can contribute to development of performance standards, with the understanding that new models will have to be developed if and

TABLE 5. Pearson and Kendall Correlation scores (r) for NMS Axes 1 and 2. Absolute value of score indicates the strength of the relationship between the cover category and the axis, while the sign indicates whether the relationship is positive or negative. Only scores with absolute values larger than 0.4 are shown here.

Cover Category	r for Axis 1	r for Axis 2
Bare ground	- 0.651	- 0.945
Litter	–	0.790
Salix spp.	0.542	0.645
Eriophorum spp.	–	0.662
Carex aquatilis	–	0.618
Dryas spp.	–	0.470
Carex spp.	–	0.429

when a standard method of defining and measuring cover is accepted.

The absence of a strong relationship between increasing cover and increasing similarity between revegetating sites and reference sites, as shown by ordination analysis, underscores the importance of linking performance standards and project objectives. If project objectives focus on reestablishment of vegetation communities similar to those of natural sites, as suggested by some regulations (Environmental Protection Agency and the Department of the Army, 1990), percent cover requirements are not appropriate as performance standards. However, literature on North Slope wetland restoration suggests that objectives of revegetation are vague. In the past, revegetation efforts appear to have focused on erosion control, while in more recent times the focus has shifted toward provision of wildlife habitat and improved aesthetics of disturbed sites (e.g., see McKendrick, 1991, 1999). While plant cover in and of itself offers at least a tenuous measure of erosion control and aesthetic value, its link to wildlife habitat will depend on the species targeted by managers and conditions found in and around the site.

CONCLUSIONS

Results of this study indicate that performance standards calling for 30% cover can be achieved within three years for ice pads and overburden, provided that the methods described here are used for estimating cover. However, gravel pads and disturbed peat cannot be expected to meet the minimum performance standards of 30% cover in three years, and some natural reference sites fail to meet the 30% criterion, depending on how cover is defined and how data are collected. Furthermore, results suggest that percent cover and community composition are only loosely linked; if revegetation is undertaken to facilitate development of vegetation communities similar to those that exist in reference wetlands, percent cover is not an adequate measure of performance.

Over the past few decades regulatory agencies and the oil industry have worked cooperatively to minimize impacts on the North Slope, largely through development of techniques that reduce the footprint size of oil industry infrastructure (Gilders and Cronin, 2000). The next step forward will involve further development of rehabilitation practices that can mitigate past impacts and unavoidable future impacts. To take this step, the regulatory agencies and the oil industry need carefully considered, well-articulated performance standards for North Slope rehabilitation projects. Ideally, these performance standards should be closely linked to objectives reflecting the values that society places on Arctic ecosystems in general, but they should be tempered by the realities of economics, engineering, and ecology.

Currently, performance standards reflect the de facto objective of revegetation, but the wording of performance standards is vague. When revegetation to a predetermined level is part of a project's objectives, a standard method of monitoring should be used, thereby allowing straightforward comparisons of data from different projects. Although this study focused exclusively on revegetation, there are other options for rehabilitation that do not rely on revegetation, such as creation of lakes or ponds, and both regulators and permit applicants should consider those options. For example, creation of deep lakes, which are not typical natural features of the North Slope, may be desirable in some circumstances because of the benefits they provide for some species of fish (Hemming, 1989). Even when revegetation is a component of rehabilitation, it may be desirable to move beyond direct measurements of vegetation to look at aspects of ecosystem function, such as wildlife use for grazing or habitat, or at successional trends, such as development of substantial moss cover. Only through careful consideration and open communication will stakeholders come to a meaningful conclusion regarding North Slope rehabilitation objectives, and only then will it be possible to develop meaningful performance standards.

While most of the results presented here are specific to revegetation projects on the North Slope, the issues addressed in this paper have implications for all projects that include performance standards calling for specific cover by vegetation. To single out North Slope projects for criticism would be unjust, as shortcomings with the rationale behind performance standards and the wording of performance standards appear throughout the nation (Streever, 1999a, b). Instead, the results of this study and the comments presented here should be seen as a step toward improving the revegetation process on the North Slope rather than as a criticism of that process, and the methods used here should be viewed as an example that can be applied to test assumptions about percent cover requirements wherever they are used.

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APPENDIX

To mitigate the effects of identification errors and differences in botanical expertise among field personnel, data for some taxa were collapsed into a single group for that taxon, as listed below. In addition, taxa that contributed less than 1% cover to a site were eliminated from the data set. These taxa were *Achillea* spp., *Aster sibiricus*, *Astragalus alpinus*, *Beckmannia syzigachne*, *Caltha palustris*, *Cardamine hyperborea*, *Cassiope tetragona*, *Castilleja* spp., *Chrysosplenium tetandrum*, *Hierchloë alpina*, *Melandrium apetalum*, *Minuartia* spp., *Polemonium boreale*, *Potamogeton* spp., *Pyrola grandiflora*, *Ranunculus nivalis*, *Saussurea* spp., *Senecio atropurpureus*, *Senecio congestus*, *Silene acaulis*, and *Utricularia vulgaris*.

Grasses and Sedges

Carex spp.	Includes *C. atrofusca* (1%), *C. bigelowii* (5%), *C. membranacea* (< 1%), *C. microchaeta* (< 1%), *C. misandra* (< 1%), *C. rupestris* (< 1%), *C. saxatilis* (14%), *C. ursina* (< 1%), and unidentified *Carex* spp. (77%)
Deschampsia spp.	Includes *D. caespitosa* (35%) and unidentified *Deschampsia* spp. (65%), but not the cultivar *D. beringensis*
Eriophorum spp.	Includes *E. angustifolium* (71%), *E. russeolum* (2%), *E. scheuchzeri* (13%), *E. vaginatum* (< 1%), unidentified *Eriophorum* spp. (13%), and unidentified sedge (< 1%)
Festuca spp.	Includes *F. baffinensis* (68%), *F. brachyphylla* (2%), and *F. vivipara* (30%), but not the cultivar *F. rubra*
Juncus spp.	Includes *J. arcticus* (30%), *J. biglumis* (5%), *J. triglumis* (1%), and unidentified *Juncus* spp. (64%)
Luzula spp.	Includes *L. arctica* (11%), *L. confusa* (16%), *L. multiflora* (25%), *L. tundricola* (3%), and unidentified *Luzula* spp. (45%)
Poa spp.	Includes *P. alpigena* (76%), *P. alpina* (< 1%), *P. arctica* (20%), *P. lanata* (2%), and unidentified *Poa* spp. (2%), but not the cultivar *Poa glauca*
Puccinellia spp.	Includes *P. arctica* (15%), *P. langeana* (83%), *P. phryganodes* (1%), and unidentified *Puccinellia* spp. (< 1%)

Forbs

Artemisia spp.	Includes *A. alaskana* (< 1%), *A. arctica* (87%), *A. borealis* (5%), and unidentified *Artemisia* spp. (8%)
Braya spp.	Includes B. *purpurascens* (77%), *B. pilosa* (1%), and unidentified *Braya* spp. (22%)
Draba spp.	Includes *D. cinerea* (2%), *D. hirta* (< 1%), *D. lactea* (< 1%), *D. pseudopilosa* (< 1%), and *Draba* spp. (97%)
Epilobium spp.	Includes *E. davuricum* (< 1%) and *E. latifolium* (99%)
Equisetum spp.	Includes *E. arvense* (17%), *E. scirpoides* (40%), *E. variegatum* (40%), and unidentified *Equisetum* spp. (3%)
Hedysarum spp.	Includes *H. alpinum* (76%) and *H. mackenzii* (24%)
Hippuris spp.	Includes *H. vulgaris* (6%) and *H. tetraphylla* (94%)
Papaver spp.	Includes *P. macounii* (1%) and unidentified *Papaver* spp. (99%)
Pedicularis spp.	Includes *P. kanei* (11%), *P. sudetica* (13%), and unidentified *Pedicularis* spp. (76%)
Polygonum spp.	Includes *P. viviparum* (81%) and unidentified *Polygonum* spp. (19%)
Potentilla spp.	*P. hookeriana* (7%), *P. pulchella* (1%), *P. uniflora* (1%), and unidentified *Potentilla* spp. (91%)
Saxifraga spp.	Includes *S. caespitosa* (< 1%), *S. cernua* (36%), *S. hirculus* (3%), *S. oppositifolia* (38%), *S. tricuspidata* (2%), and unidentified *Saxifraga* spp. (20%)
Stellaria spp.	Includes *S. crassifolia* (6%), *S. edwardsii* (< 1%), *S. laeta* (< 1%), *S. longipes* (2%), *S. humifusa* (4%), *S. monantha* (1%), and unidentified *Stellaria* spp. (87%)

Shrubs

Dryas spp.	Includes *D. integrifolia* (61%) and unidentified *Dryas* spp. (39%)
Salix spp.	Includes *S. arbusculoides* (< 1%), *S. arctica* (30%), *S. fuscescens* (< 1%), *S. lanata* (3%), *S. ovalifolia* (38%), *S. phlebophylla* (< 1%), *S. planifolia* (1%), *S. reticulata* (7%), *S. rotundifolia* (3%), and unidentified *Salix* spp. (18%)

Mosses and Lichens

Mosses	Includes *Aulacomnium* spp. (< 1%), *Bryum* spp. (< 1%), *Distichium* spp. (< 1%), *Drepanocladus* spp. (< 1%), *Funaria hygrometrica* (< 1%), *Hypnum bambergeri* (< 1%), *Marchantia* spp. (< 1%), *Oncophorus wahlenbergii* (< 1%), *Scorpidium scorpioides* (< 1%), *Sphagnum* spp. (7%), *Tomenthypynum nitens* (3%), and unidentified species (83%)
Lichens	*Cetraria* spp. (9%), *Dactylina arctica* (1%), *Peltigera aphthosa* (9%), *Thamnolia* spp. (64%), and unidentified species (17%)

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