TOOLS FOR ARCTIC REVEGETATION: WHAT'S IN YOUR TOOLBOX?

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ABSTRACT

Revegetation in arctic climates is a challenge for many reasons. There are two approaches to arctic revegetation: natural regeneration and active reclamation. Natural regeneration is an inexpensive option that can provide a diversity of locally adapted species. This has been shown to be effective on smaller disturbances at the De Beers Snap Lake Mine. However, natural regeneration can be quite slow and will not work as well on large disturbances where seeds and spores have to travel a long way to populate disturbed areas. Intervention using active reclamation techniques may help accelerate establishment and maturation of reclaimed sites. Determining when and how to intervene can be challenging and can affect the results of reclamation efforts. Erosion, costs, accessibility, diversity, stress factors, size of disturbed area, and rate of succession must be considered and, in some cases, a combination of solutions may be required for specific areas or for a whole site.

Key Words: Revegetation, Natural Regeneration, Active Reclamation, Arctic, Seeding, Ecological Intervention.

INTRODUCTION

Natural resource exploration (mining and oil) in the Canadian North has intensified in the last 20 years, leading to severe environmental disturbances that will need to be reclaimed in the future. Studies of the patterns of disturbance and natural revegetation in various regions have contributed to the body of knowledge on arctic ecosystem recovery. Different approaches to enhance revegetation and ecosystem regeneration (active reclamation) have been described in several studies and reviews (Adams and Lamoureux 2005; Baasch et al. 2012; Drozdowski et al. 2012; Firlotte and Staniforth 1995; Forbes and Jefferies 1999; Jorgenson and Joyce 1994). The numerous examples of natural regeneration and spontaneous succession occurring in disturbed sites suggest that active reclamation may not always be the best answer to regenerate ecosystems after disturbance (Holl and Aide 2011; Prach and Hobbs 2008).

Revegetation programs, in general, have common challenges such as shortage of commercially available native seed, a lack of understanding of propagation protocols (lichens, mosses and vascular plants), a shortage of facilities to propagate native species, and timely and cost effective protocols to determine quality, viability, and vigour of stored seed and propagules. In arctic climates, revegetation is even more challenging due to unique development constraints, including low air and soil temperatures; short growing season; permafrost; irregular surfaces and moisture regimes; limited access to site in the warm, summer season; and the slow growth rate of arctic species (Adams and Lamoureux 2005; Drozdowski et al. 2012; Forbes and Jefferies 1999).

Revegetation is a complex term, often broadly lumped with the terms *restoration*, *re-seeding*, *reclamation*, *land rehabilitation*, and *erosion control*; although related, these terms differ in purpose and definition. For the purposes of this paper, we will use the following definitions (Figure 1).

RE-VEGETATION: replacing or allowing for the establishment of vegetation on a disturbed site

RECLAMATION: returning disturbed land to a useful purpose, in this case a functioning native ecosystem, using active of passive techniques

NATURAL REGENERATION: allowing the establishment of and ingress of vegetation with no active intervention

ACTIVE RECLAMATION: re-vegetation by seeding or planting

SUCCESSION: changes in plant communities over time in both floristic and functional characteristics

INTERVENTION: active reclamation events used to enhance or accelerate natural regeneration

Figure 1. Key Definitions

There are two schools of thought in arctic revegetation methods: natural regeneration and active reclamation. These two extremes each have benefits and drawbacks. Natural regeneration is an inexpensive option that can provide a diversity of locally adapted species; however, it can be quite slow and will not work as well on large disturbances where seeds and spores have to travel a long way to populate disturbed areas. Active reclamation programs provide immediate erosion control and can allow for planting of more mature individuals; however, this method can be expensive and time consuming and there are technical gaps, which could result in lower species diversity than the undisturbed environment. Determining when to intervene with active reclamation techniques be challenging and can affect the results of reclamation efforts. Site ecology, erosion risks, costs, propagation knowledge, accessibility, diversity, stress factors, size of disturbed area, and rate of succession must be considered and, in some cases, a combination of solutions may be required for specific areas or for a whole site.

In this paper, we will discuss some of the issues and suggest potential approaches to maximize reclamation success in the Arctic. We will focus on a case study on the DeBeers Snap Lake Mine site, where natural revegetation has been shown to be successful on small disturbances over a period of several years in the arctic region. We will review the data and discuss what other approaches could be applied to enhance natural regeneration and/or reclamation success in the Arctic.

NATURAL REGENERATION

As mentioned previously, there are generally two major methods which can be used to establish vegetation on disturbed sites; natural regeneration and active reclamation. While the easiest and cheapest method would seem to be to allow natural succession to occur and heal the system, for reclamation projects the success rate and the time needed for a stable system to develop may be unacceptable in the regulatory sense. In addition, stakeholder perceptions of this method tend to be negative. In the following sections we will discuss these methods, their pros and cons, and their rationale for use.

Succession has been defined in various ways, but in this instance it means the changes in plant communities over time in both floristic and functional characteristics. Function as used here, is the collective intraspecific and interspecific interactions of the biota within the ecosystem. Revegetation of disturbed sites involves more than the simple replacement of vegetation. For mining sites where disturbances include the removal of all characteristics of the ecosystem (i.e., vegetation, soil, and topography), the simple replacement of vegetation may not restore function to the systems and reclamation efforts could fail. In early reclamation efforts, vegetation was seen as a means to an end, such as soil stability; what is "green" is recovered. These efforts often utilized standard agricultural or urban revegetation methods in the context of strip mines and pipeline corridors (Adams and Lamoureux 2005; Forbes and Jefferies 1999). While many of these methods were successful at reestablishing vegetation to disturbed areas, these early attempts often resulted in the persistence of nonindigenous species and little establishment of native vegetation (Densmore and Holmes 1987; Johnson 1981). For example, Kentucky bluegrass (*Poa pratensis* var. nugget) and red fescue (*Festuca rubra* var. arctared) were seeded on drilling pads in the Alaska tundra in hopes of stabilizing soils and to act as a surrogate for native species (Younkin and Martens 1987). After 12 years both species persisted, and due to both species having extremely dense root mats and litter layers, less than 15% of the total cover was attributed to native species. The presence of vegetation had been restored, but the function of the ecosystem was not fully developed leaving a system lacking in diversity and ecosystem value and with decreased opportunity for native species establishment. Conversely, when Younkin and Martens (1987) investigated disturbed plots where natural regeneration was allowed to take place, there was an 80% cover of native species after 12 years.

Natural regeneration and active reclamation are "intrinsically linked" since both are mechanisms for recovery and a path to more established or mature ecosystems (Walker et al. 2007). However, natural regeneration relies on an active seed bank (buried seed communities) or seed rain (influx of seed) and an adequate substrate for seedling development. Gartner et al. (1983) found that one of the major factors governing natural revegetation in disturbed tussock tundra was the presence of a viable seed bank and the presence of some organic soils. In areas where long soil stockpiling reduces seed viability or the organic layer is not intact after disturbance, seed rain may be the only alternative for vegetation establishment using natural regeneration. This can be problematic when considering the patch size (i.e., scale) of the disturbance; larger disturbances could have reduced revegetation potential than smaller patches due to limited dispersal of propagules (Forbes et al. 2001). The severity of the disturbance can also impact the ability of the system to recover. The prevalence of mineral-rich soils at most disturbed sites can limit both the reestablishment of species, which originally occurred at sites and species vigor (Gartner et al. 1983). This can impact the time required for natural regeneration to result in a stable ecosystem. Natural revegetation after a disturbance is slow in the arctic. In areas with heavy soil erosion potential, natural regeneration would not provide adequate protection within the first few years of disturbance (Adams and Lamoureux 2005).

The success of natural regeneration on mine sites in the tundra is not well known, since most mines are required to develop and maintain active reclamation efforts at mine closure. However, Kershaw and Kershaw (1987) were able to find 80 un-reclaimed borrow pits in the tundra of northwestern Canada that had been allowed to be revegetated naturally. Disturbances of various ages between 5 to 35 years were observed, and in all cases sites were colonized by native and some non-native species. In general, they found 433 taxa and although most of the successful colonizing species were herbaceous, several woody species (mainly *Salix* spp.) were successful in terms of cover and number of sites established.

A study of natural regeneration of disturbances in the artic is in its early stages at De Beers Snap Lake mine where reclamation plots have been left to regenerate since 2002 with periodic monitoring. The preliminary results of this study are discussed below.

SNAP LAKE MINE

A current study that has been initiated is at the Snap Lake Mine, a diamond mine owned and operated by De Beers Canada Inc. (De Beers) and located approximately 220 kilometres northeast of Yellowknife, Northwest Territories, Canada. Portions of this mine have been removed from operations and have been used in a reclamation monitoring program. Two types of monitoring plots were established; a set of natural plots (control plots) to give a benchmark for recovery, and later a set of plots within disturbed locations (reclamation plots) to monitor vegetation changes to the sites without active intervention. Reclamation monitoring plots were established when a location was released from mine production. Most of the current reclamation plots were last disturbed in the summer of 2002 and include a gravel quarry and a decommissioned camp site. These sites have been allowed to naturally revegetate, and to date (summer 2013) no assisted reclamation has been applied to these plots. Both control and reclamation plots were surveyed in 2004, 2008 and 2013 for vegetation type, vigor and cover. The 2013 data will not be presented in this report.

Figure 2 shows the species richness (i.e., number of species) of vegetation found in both the control and reclamation plots two and four years after disturbance. Only two ecological land classifications (ELC) are found in both the reclamation and control plots; the Tussock Hummock and Heath/Boulder communities. The plots show that, for species richness, the sites display an impressive rate of recovery. It is assumed that all vegetation present on reclamation plots is either from existing soil seed banks or seed rain from the surrounding vegetation communities. The species composition of reclamation plots contained no non-native species and a high proportion of shrubs and moss species compared to grasses. This is similar to the findings of Kershaw and Kershaw (1987). However, when the average percent cover of vegetation within the reclamation plots is considered it is apparent that the vegetation cover is still much less than the control plots (Figure 3). While this cover may not be enough to ward off erosion in areas with steeper slopes, it does indicate that natural regeneration in the tundra can be a valuable tool.

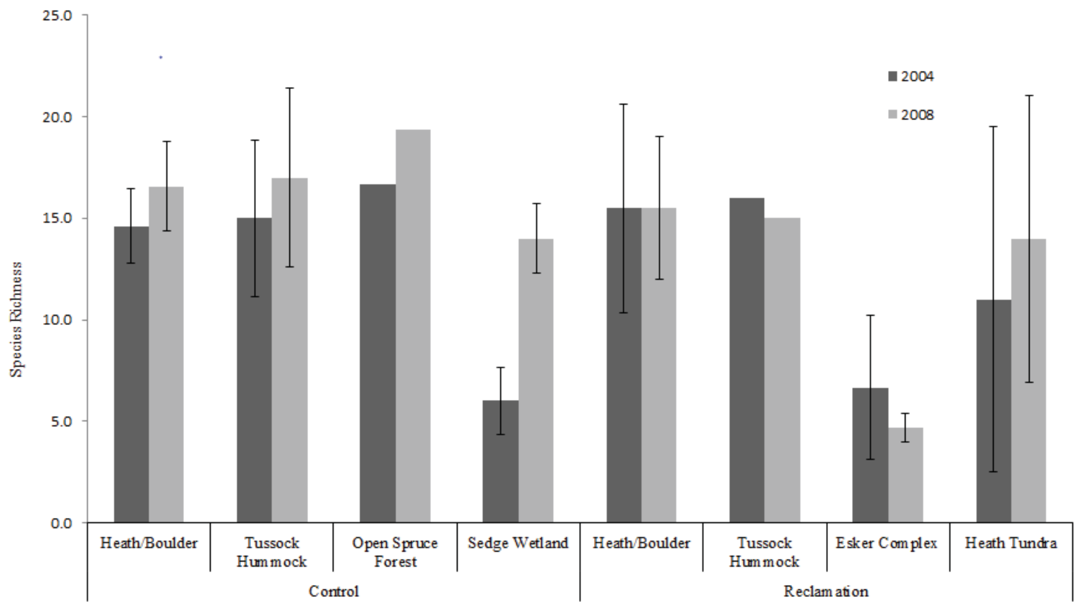

Figure 2. Species Richness (i.e., number of species) For Ecological Land Classifications in Control and Reclamation Plots for the Snap Lake Mine Site

As more sections of the mine are released from production, additional reclamation plots will be added to the reclamation monitoring program. The mine is expected to remain active for at least 20 years and reached full production in 2008. While these plots were not originally designed to investigate natural regeneration, the potential to add more plots and monitor natural change to this disturbance is valuable. However, can natural succession do enough to recover these sites, especially considering that future areas of reclamation are likely to be larger and more intensively disturbed?

THE DECISION PROCESS

Unfortunately, there is not one solution for all revegetation programs in all situations, and in most cases a combination of methods is likely required. The ultimate choice in reclamation approach will depend on the ecology of the site, the type of disturbance and the goals of the reclamation program. There is a spectrum of active intervention in reclamation programs, which is influenced by a large number of factors. Figure 4 shows several of the factors that need to be taken into account when choosing how to revegetate and when to intervene.

Invasives

A site with a large population of invasive or non-native species will be less prone to natural regeneration as there will be increased competition from non-native species reducing the likelihood of functional ecosystems developing without intervention. Interventions may include mechanical or chemical weed control or, in appropriate situations, planting of a "nurse crop" consisting of an annual surrogate, which may help limit invasive establishment. Caution should be taken using this approach as in certain situations surrogates can limit ecosystem development.

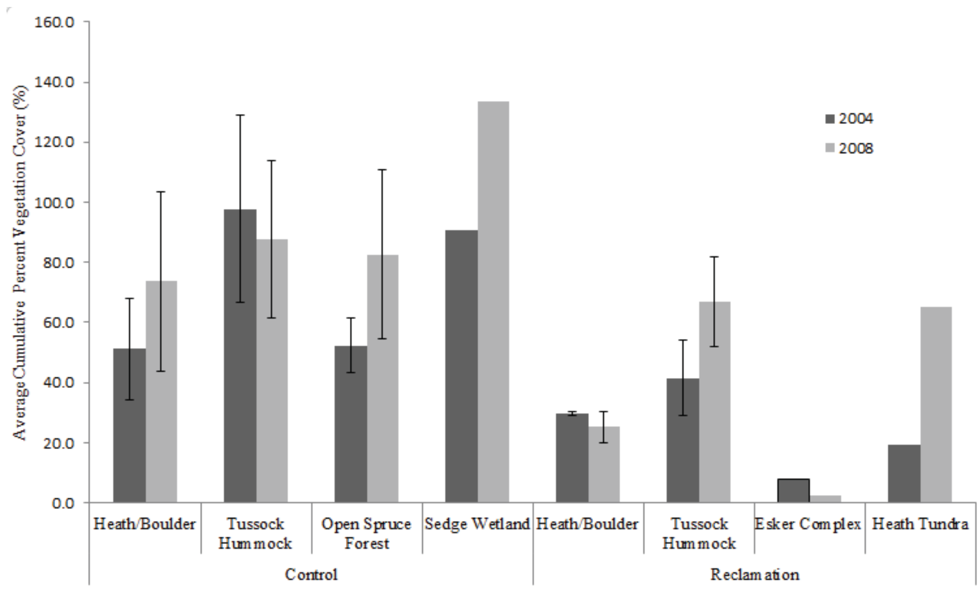

Figure 3. Average Cumulative Percent Vegetation Cover for Ecological Land Classifications in Control and Reclamation Plots for the Snap Lake Mine Site

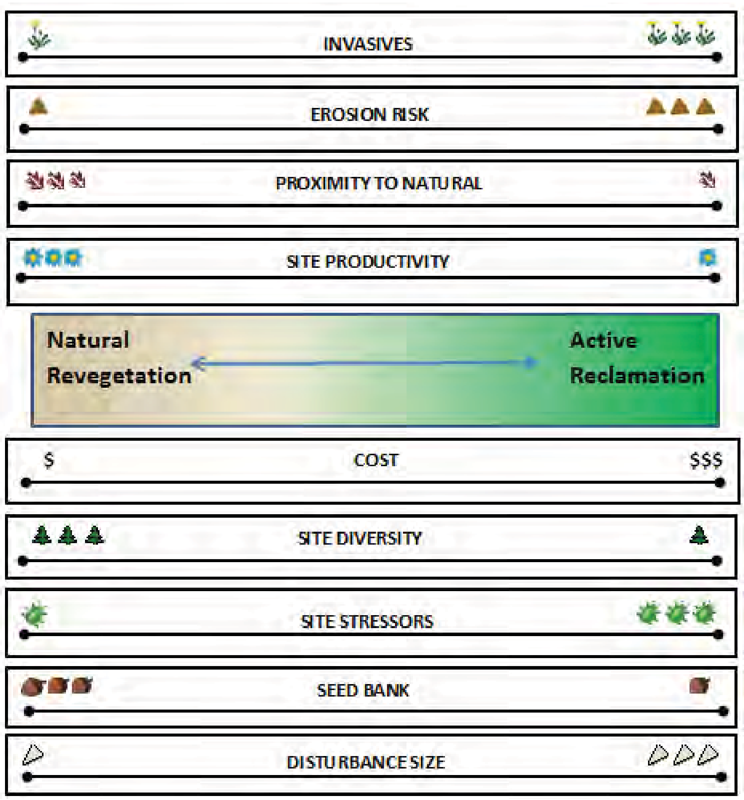

Figure 4. Decision Factors in Choosing Revegetation Methods

<u>Erosion Risk</u>

Natural regeneration can be a slow process especially in arctic climates. In areas with high erosion risk (i.e., steep slopes or loose soils) waiting for vegetation to establish naturally will not provide sufficient protection to conserve soil and maintain landform stability. In these situations, interventions such as planting of plugs, spreading seed, hydroseeding or installation of mechanical controls (e.g., silt fences or geotextile) may help maintain soil integrity while allowing for native species to ingress.

<u>Proximity to Natural or Undisturbed Ecosystems</u>

Ingress of native species through seed rain and vegetative propagation is more likely to occur in a site that is adjacent to an undisturbed ecosystem. This is particularly important in sites that do not have an active seed bank due to long periods of disturbance, impacted soil or spreading of soil that has been stockpiled for long periods of time

(Cooper et al. 2004). Reclamation areas that are surrounded by other disturbances may require intervention to begin vegetation establishment.

Site Productivity

Highly productive sites are more likely to regenerate naturally. High nutrient levels, appropriate moisture conditions and ideal landscape position mean that these types of sites will require little to no intervention to establish a diverse cover of native species in a relatively short period of time. Caution should be taken to monitor these sites regularly as they will also be susceptible to the ingress of non-native or invasive species.

Site Diversity

Generally speaking, moderate sites are the most diverse ecosystems. In these types of situations natural regeneration is preferred as it is more likely to allow for the establishment of a similar diversity of species after reclamation as was found before disturbance. It would be difficult and costly to achieve this level of diversity using only active reclamation; however, a combination of methods may produce excellent results on these types of sites. Arctic ecosystems are a bit of an exception to this rule because they have relatively low diversity, but because the species found in these environments are uniquely adapted to the short growing season and cold winters, they seem to respond well to natural regeneration. This may be partially due to the fact that most arctic species have little to no dormancy, making seeds ready to germinate as soon as they encounter the opportunity (Densmore 1992).

Cost

This is often a factor in choosing reclamation approaches and is usually offset by the time available to achieve reclamation goals. If natural regeneration is possible and several years are available to allow the ecosystems to develop, this method will have very low costs. However, if a site is left to naturally regenerate in the wrong conditions, invasive species, erosion issues and lack of plant establishment can simply defer costs to a later date and extend timelines even further.

Site Stressors

A site that is highly stressed due to disease, insects, contamination or other factors will need some level of intervention to either remediate the stressors or to establish communities that are immune to the specific conditions present on each site. Highly stressed sites can be costly to reclaim and often involve intensive monitoring and ongoing mitigation until the site reaches a self-sustaining state. These are often the situations where novel communities are established as native ecosystems are not suitably adapted to the conditions. Natural regeneration is not preferred in these situations.

Seed Bank Viability

The seed bank in stockpiled soil maintains its viability for a maximum of 15 months (Mackenzie and Naeth 2009). This period may be longer in colder climates, but there is still a relatively short time where stockpiled soil can be placed back and still contribute a viable seed and propagule bank. Seeds banks may also be compromised in areas where soil is compressed, eroded away or contaminated. In these cases natural regeneration may only be possible if there is an adjacent undisturbed ecosystem that can contribute seed rain or vegetative propagation to help the establishment of native vegetation. For large disturbances with a depleted seed bank, some form of intervention is likely required.

Disturbance Size

Large disturbances are more difficult to reclaim due to increased erosion risks and further distance from seed and propagule sources.

Vegetation Propagation Knowledge

Certain species do not propagate well in a greenhouse setting, others are difficult to grow outside their natural habitat (Hagen 2002). The target species may determine if active revegetation is possible at all. In some cases collection, storage and propagation of the seed of target species is not financially or physiologically feasible. The more you know about the species you are trying to grow, the more information you can glean about how reclamation is most likely to be successful.

Intervention

Intervention in reclamation may include any number of activities such as: planting woody species; planting surrogate crops; installing erosion control; fertilization; seeding; recontouring; topsoil building or rehabilitation; thinning; weed control; underplanting; and adding biodiversity and wildlife enhancing features.

Most intervention occurs at the initial reclamation stage through site contouring, soil placement, planting or seeding. Other interventions such as weed control and replanting of unvegetated areas are commonly applied. However, many other potential enhancements are available such as planting understory species when the appropriate successional stage is reached; thinning the overstorey species to accelerate succession; leaving rock piles, brush piles or other refugia on site for wildlife habitat use; and establishment of microsites to increase diversity (Jorgenson and Joyce 1994).

When to use Non-native Species

Direct seeding with either native or non-native species (non-invasive) has been shown to help reduce erosion, reduce dust, retain soil moisture and stabilize ecosystem processes (Adams and Lamoureux 2005; Densmore 1992; Firlotte and Staniforth 1995; Rausch and Kershaw 2007). In areas where topsoil disturbance has reduced the viability of the natural seed bank or where disturbance is so great that surrounding vegetation cannot adequately provide propagules, direct seeding may be needed. The use of indigenous species over introduced species would seem to be the logical choice when it comes to reclamation. Native species have evolved to survive and grow in the local environment while non-native species may not be able to thrive in these conditions. However, native species are generally perennials, not adapted to large soil disturbances and often re-vegetate at a slower rate than non-native species more adapted to early successional conditions (Adams and Lamoureux 2005; Reynolds and Tenhunen 1996). In addition, the lack of commercially available native seed sources limits the practical use of many native species (Rausch and Kershaw 2007).

The assumption that non-native species will make a good surrogate for native species has been used successfully in some reclamation efforts. Chapin and Chapin (1980) successfully used non-native grasses

(*Phalaris arundinacea*, *Poa pratensis*, *Lolium perenne*, *Festuca rubra*, *Phleum pratense* and *Alopecurus pratensis*) in an attempt to recover disturbed tundra. These non-native species established within one growing season, densities dropped off considerably by the third year and were virtually eliminated after five years. During this time native cottongrass (*Eriophorum vaginatum*), Bigelow's sedge (*Carex bigelowii*) and other native species had increased in abundance within disturbed areas. Similar results have been reported by other studies (Densmore and Holmes 1987; Johnson 1981; Webber and Ives 1978).

On the other hand, where non-natives remained in the environment and reduced native species establishment, a number of studies have found a detrimental effect caused by the establishment of non-native species (Cargill and Chapin 1987; Densmore 1992; Forbes and Jefferies 1999; Younkin and Martens 1987). Use of non-native seed species should be done with caution and may be effective in some areas. If time is not of concern, then seeding with native species would be the best solution for recovering disturbance; however in areas with high erosion potential surrogate non-native species may be needed.

OTHER CONSIDERATIONS

Laboratory bench-scale studies could be used to model and optimize approaches to revegetation efforts in the arctic. Studies can be conducted year round, as opposed to a limited time in the field and experimental conditions can be controlled to closely simulate natural soil, temperature, photoperiod and moisture conditions likely encountered by plant species in arctic sites.

There are many factors that may influence the success of reclamation strategies. The quality and viability of seed for native species have a critical impact on the success of revegetation. Although reproduction by seeds is not common in arctic environments, relatively few species have dormant seeds, which allows for germination whenever conditions permit (Bell and Bliss 1980). Seed viability testing can provide an accurate estimate of the potential germination success in the field, which may help determine the condition of the seed bank or the viability of seeds for propagation. Rapid laboratory based seed viability assessment methods such as electrical conductance and tetrazolium (TZ) testing (Miller 2010) can be performed in 2 to 3 days rather than the weeks or months required for full germination studies. Although the TZ test and other rapid screening methods do not account for germinability, factoring in the bulk weight of the seed will provide a measure of the amount of seed required to achieve a desired application rate and potential emergence rate for a given species of seed in the field.

The TZ test has been effectively used to test the viability of several arctic species and methods can be adapted for use with other species as well. Species with established testing protocols include: black spruce (*Picea mariana);* tamarack (*Larix laricina*); white spruce (*Picea glauca*); birch species (*Betula* sp.); small bog cranberry (*Oxycoccus microcarpus*); cranberry, blueberry, bilberry (*Vaccinium* sp.); sedges (*Carex* sp.); and reed grass (*Calamagrostis* sp.). The TZ test is not useful for determining the viability of groundcover species such as lichens and mosses (bryophytes).

CONCLUSIONS

In certain environments, such as the Arctic where species are specialized and conditions are extreme, natural regeneration may be a preferred option. However, innovative approaches are required to enhance and accelerate reclamation through interventions at various stages of development. By taking into consideration site characteristics and the goals of reclamation, specialized approaches can be developed to successfully reclaim disturbed sites in a variety of climates and conditions.

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Overcoming Northern Challenges

Proceedings of the 2013 Northern Latitudes Mining Reclamation Workshop and

38th Annual Meeting of the Canadian Land Reclamation Association

Whitehorse, Yukon September 9 – 12, 2013

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Canadian Land Reclamation Association
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Northern Latitudes Mining Reclamation Workshop

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Polster	Natural Processes: An Effective Model For Mine Reclamation
Dustin	Implementation of contaminated water management system upgrades to allow for dewatering of two open pits at the Vangorda Plateau, Faro Mine Complex, Yukon
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Keefer	Twin Sisters Native Plant Nursery
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Nadeau and Huggard	Restoration Planning and Application of Ecological Succession Principals
Simpson	Defining Disturbance and Recovery - the influence of landscape specific ecological responses to oil and gas linear disturbances in Yukon

NORTHERN LATITUDES MINING RECLAMATION WORKSHOP

The Northern Latitudes Mining Reclamation Workshop is an international workshop on mining, land and urban reclamation and restoration methods. The objective of the workshop is to share information and experiences among governments, industry, consultants, Alaska Natives, northern First Nations and Inuit groups which undertake reclamation and restoration projects, or are involved in land management in the north or in comparable environments.

The first Workshop was held in Whitehorse, Yukon Territory, Canada in 2001 and it has been held every two years since, alternating between Canada and Alaska. The primary sponsors of the Workshop include the Yukon Geological Survey, Indian and Northern Affairs Canada, Natural Resources Canada, US Department of the Interior Bureau of Land Management, and the State of Alaska Department of Natural Resources.

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- To incorporate the advances from research and practical experience into land reclamation planning and practice.
- To collect information relating to land reclamation and publish periodicals, books and leaflets which the Association may think desirable.
- To encourage education in the field of land reclamation.
- To provide awards for noteworthy achievements in the field of land reclamation.

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