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Strategies for revegetation of disturbed gravel areas in climate stressed subarctic environments with special reference to Churchill, Manitoba, Canada: a literature review

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ABSTRACT: In the vicinity of Churchill, Manitoba, Canada, dry heath tundra is restricted to elevated gravel deposits such as beach ridges and eskers. These sites have been utilized for gravel excavation and extraction as well as for building and road construction. Vast areas of open gravel resulting from human activities scar the landscape and reduce the amount of undisturbed dry heath tundra. When left alone these gravel areas may remain devoid of vegetation for many decades due to the severity of the climate. Nothing has been done to restore them to their pre-disturbance vegetation cover. Their soils are characterized by low nutrient availability, poor moisture retention capabilities and limited seed banks. The current paper reviews literature regarding manipulation of chemical and physical properties of gravel substrates in order to facilitate the development of cover by native plants. A planned revegetation project is presented. This project would provide ecological and aesthetic benefits as well as enhance conservation and tourism in the area.

KEY WORDS: Revegetation · Tundra · Gravel · Colonization

INTRODUCTION

Churchill, Manitoba, Canada (58° 47′ N, 94° 11′ W) is an easily accessible community in the High Subarctic and has been greatly affected by human activity. European settlement began in the 18th century with the building of Fort Prince of Wales, continuing with construction of an army base, rocket launch and residential and commercial properties to the present day (Hochbaum 1970, Walker 1970). Usually gravel was required for the foundations of buildings and for protecting the underlying permafrost (Sugden 1982, Bishop & Chapin 1989). Gravel has been excavated from ancient beach ridges and from eskers in the vicinity of Churchill. This quarrying has caused considerable environmental damage and yet nothing has been done to alleviate it.

Gravel excavation required removal of overlying soil and vegetation ('the overburden') to expose the underlying gravel and allow assessment of its quality and quantity. The overburden was frequently burned or, more often, left as a heap adjacent to the open pit.

Exposed gravel in the open pits when combined with the severity of the subarctic climate provides a severe habitat for colonization by plants. In addition to climatic factors, other factors which limit colonization may include: soil moisture, nutrient supply, absence of organic particles or finer-grained mineral particles in the soil and an inadequate seed bank or seed rain (Wilson 1966, Miller 1982, Bradshaw 1983, 1984, Shaver & Chapin 1986, Arnalds et al. 1987, Johnson 1987, Klokk & Rønning 1987, Runolfsson 1987, Svoboda & Henry 1987, Bishop & Chapin 1989, Kohn & Stasovski 1990, Salonen 1990). Artificial modification of topography and/or changes to the substrate may make gravel pits more hospitable to colonizing vegetation invasion (Johnson 1987).

NUTRIENT AVAILABILITY AND FERTILIZER TREATMENTS

Quantities of nitrogen and phosphorus are often limiting factors in arctic soils (Wilson 1966, Haag 1974, Miller 1982, Shaver & Chapin 1986, Klokk & Rønning 1987, Truett & Kertell 1992). The application of NPK fertilizer to restore the nutrient balance in denuded sites has been undertaken in many studies, with positive results (Chapin & Chapin 1980, Skriabin 1981, Gartner et al. 1983, McKendrick 1991, Schoenholtz et al. 1992). Chapin & Chapin (1980) applied 2 different fertilizer combinations, a high nitrogen compound (20-10-10) and high phosphorus compound (8-32-16), at the rate of 444 kg ha^{-1} to a vegetation-free organic mat in an *Eriophorum vaginatum* tundra community. Ten years after the initial disturbance and fertilizer application, a complete vegetation cover dominated by *Carex* sp. and *E. vaginatum* was established (Chapin & Chapin 1980). Gartner et al. (1983) found that application of NPK fertilizer (25 g m^{-2} N as NH_4NO_3, 25 g m^{-2} P as P_2O_5 and 32 g m^{-2} K as K_2O) enhanced natural recovery by stimulating growth of *Carex* sp. and grass seedlings on disturbed tundra sites. Schoenholtz et al. (1992) applied inorganic N fertilizer temporarily (1 growing season). The result was improved herbaceous biomass on mined soils, which minimized erosion (Schoenholtz et al. 1992). Phosphorous fertilizer improved native grass invasion and seedling establishment on barren areas (McKendrick 1987). McKendrick (1987) found areas without phosphorous fertilizer treatment averaged 65% canopy cover while fertilized areas had 100% canopy cover following 10 yr of recovery time. It has been found that natural recovery of vegetation on disturbed gravel sites continues in the absence of fertilizer application; however, the recovery rate was considerably slower than in treated areas (Chapin & Chapin 1980, Skriabin 1981, McKendrick 1991).

WINTER DROUGHT AND SNOW COVER MANIPULATION

Snow cover may provide important protection and moisture for the colonizing vegetation (Carlsson & Callaghan 1991, McKendrick 1991). Ice crystals and strong winds cause abrasion and desiccation of any plant parts which are exposed above the snow surface (Savile 1972, Miller 1982). Lack of spring moisture where snow cover is sparse may restrict colonizing vegetation (McKendrick 1987, Kohn & Stasovski 1990). Restoration of vegetation may be enhanced by trapping snow on open gravel areas to protect the pioneer vegetation during winter. This may be done by utilizing snow fences on or adjacent to denuded areas.

Snow cover may protect plants from destruction caused by vehicle movements. The restriction of construction to the winter months may minimize damage to plant cover (Hayhoe & Tarnocai 1993). The use of winter roads serves to protect vegetation and permafrost from damage due to heavy traffic (Adam & Hernandez 1977).

SOIL TEXTURE AND ORGANIC MATTER APPLICATIONS

Removal of organic surface layers to facilitate gravel extraction is detrimental to future plant colonization in dry tundra sites. The lack of organic matter and fine soil particles results in an area with little moisture holding capability and low levels of available nitrogen and phosphorous (Runolfsson 1987, Bishop & Chapin 1989). The replacement of the organic matter is a primary goal of restoration (Johnson 1987). Pioneer vegetation fosters the accumulation of dead biomass and leaf litter which will decay over time and provide nutrients to the area as well as increase moisture holding capacity (Savile 1972, Freedman et al. 1982, Chapin & Shaver 1989, Chambers et al. 1990). Under natural circumstances primary colonizers of disturbed gravel areas are usually cushion- or mat-forming species, such as *Dryas integrifolia*. Plants with these growth forms are able to accumulate organic matter (McCarthy 1992). The natural accumulation of an organic layer in the soil is a slow process; therefore, its artificial enhancement would increase the rate of vegetation recovery and also reduce the risk of erosion (Cargill & Chapin 1987).

Skaller (1981), Bradshaw (1983), Gartner et al. (1983) and Street (1985) have shown that damage due to quarrying often can be reduced by stockpiling and redistributing the overburden onto the excavation site or the pit when gravel excavation has ended. Such treatment would be least expensive if undertaken immediately after excavation while heavy earth equipment is on site. In arctic areas where the overburden has not been stockpiled complete reconstruction can be very costly (Bradshaw 1983). Application of mulch on gravel areas has been ineffective since wind effects can easily remove it with no vegetation to hold it in place (Chambers et al. 1990). Planting grass in strips to induce organic accumulation on the gravel area can enhance natural revegetation (Runolfsson 1987). Manipulation of the vegetation cover can be an economic alternative to complete soil replacement.

SEED AVAILABILITY AND ENHANCEMENT OF SEED APPLICATION

It is crucial for the colonization of denuded gravel areas that propagules arrive at the site (Bradshaw 1983). Seed production in these areas is often limited due the large investment of energy required throughout the growing season (Urbanska & Schültz 1986, Diemer & Prock 1993). Though limited, seed production is largely determined by the length and quality of consecutive growing seasons, hence a series of harsh years may result in decreased seed yields (Archibold 1984). Colonization of barren areas such as old gravel pits usually relies on the presence and proximity of a nearby seed source (Fridriksson 1987) or a viable seed bank (Archibold 1984).

The availability of seeds is partly determined by the proximity and composition of surrounding vegetation (Bishop & Chapin 1989, Salonen 1990). Gravel areas may become totally dependent on incoming seed rain because of the absence of an overlying organic mat and its seed bank (Cargill & Chapin 1987). Undisturbed areas adjacent to open gravel pits can provide a seed source for natural recovery (Salonen & Setälä 1992). Decreased seed availability can be alleviated in 2 ways: by applying fertilizer to adjacent undisturbed areas to increase their seed production and by applying seeds directly to affected areas.

Fertilizer has been used to successfully increase seed production in adjacent undisturbed areas, with the result that the seed rain has significantly increased into the disturbed site (Chapin & Chapin 1980). Chapin & Chapin (1980) found that flowering density in adjacent sites increased by 25% after application of phosphorus and potassium. This resulted in the release of over 1000 seeds m^{-2} and a germination rate of 50% (Chapin & Chapin 1980).

Seeding a gravel area may improve the rate of revegetation (Hernandez 1974). Exotic plant species have been used to achieve an initial vegetation cover to prevent erosion during pipeline construction (Webber & Ives 1978, Chapin & Chapin 1980, Densmore & Holmes 1987). The use of introduced southern species like Nugget Kentucky bluegrass are thought to have more negative than positive effects on these gravel pads (Cargill & Chapin 1987, Younkin & Martens 1987, Densmore 1992, Forbes 1992). Complete vegetation cover is reached very quickly but the invasion by native species is restricted by the thatch created when the southern species die (Younkin & Martens 1987). Native species should be preferred since they are adapted to the local environment, unlike the introduced southern species (Skriabin 1981, Elliott et al. 1987, Johnson 1987).

Utilization of native arctic species in revegetation projects is increasing. Companies commercially produce seeds and make them available to the public. As native arctic species are adapted to these harsh climatic conditions it only makes good sense to use a genotype which has evolved in the area to return it to a natural community cover (Elliott et al. 1987).

PROPOSED RESTORATION STRATEGIES FOR THE CHURCHILL AREA

In the Churchill area, revegetation of disturbed gravel areas would provide ecological and aesthetic benefits and enhance tourism and conservation. In an attempt to examine these denuded areas and the contributing environmental limitations inhibiting restoration, a research project is currently under way, with the following 4 objectives:

(1) To produce a map of damaged areas in the Cape Churchill region. This will allow a quantitative estimation of disturbance in dry tundra areas.

(2) To determine the sequence of natural succession toward the climax dry tundra community and its rate from the initial disturbance.

(3) To set up permanent study sites in gravel quarries to attempt different revegetation strategies.

(4) To derive from data a ranking scheme of plants which can then be utilized in selecting appropriate species for the restoration of damaged dry tundra areas.

A more complete understanding of the natural processes occurring on disturbed dry tundra and the extent of damage will allow for the implementation of an appropriate restoration strategy for the area. Indeed this is only the beginning of restoring the gravel areas in the Churchill region.

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