APPLICATION OF POPULATION BIOLOGY, CONSERVATION BIOLOGY AND SUCCESSION THEORY TO THE RECLAMATION OF A HIGH ELEVATION COAL MINE[1]

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INTRODUCTION

Alternative reclamation approaches that involve 'minimal intervention' or aftercare may be necessary for high elevation disturbances. For these remote area disturbances, reclamation plans and practices should develop abiotic and biotic conditions that promote 'natural' succession by enhancing invasion and colonization of different microorganisms, plant life-forms and animal species (Brown and Chambers 1990). However, reliance on 'natural' restorative processes for reclamation is constrained by disturbance intensity and size (Pratt and Stevens 1992). Also, the successional status prior to disturbance and species in last occupancy often determines the most likely sequence of arrival and magnitude of colonization by invaders (Mortimer 1987).

Propagules arrive at potential growth sites by various dispersal processes and the configuration of donor sites or sources on the landscape determines frequently the distribution of propagules at the recipient site (Risser 1992). 'Natural' colonization from the periphery of disturbances is dependent upon the presence of sufficiently large populations of species with suitable life histories and the absence of dispersal barriers. Large surface mining activities frequently create landforms, e.g., highwalls and large spoil dumps, which do not have appropriate colonizing species in close proximity or which act as barriers to dispersal. Although colonization of these disturbances has been reported (Macyk et al. 1991), species establishment appears to be inconsistent. Since the recovery rate of primary succession is largely dependent on the rate of propagule arrival and on the reproductive potential of the invaders (Okansen and Ranta 1991), management techniques must be designed to maximize propagule dispersal.

Lessons from biogeography suggest that colonization by some desirable species cannot be left to 'natural processes' and that species with poor dispersal propagules and/or long life histories must be 'artificially' re-introduced (Davis 1986). Dispersal of both plants and animals can be facilitated by managing sites as 'corridors' or 'stepping stones'.

MANAGEMENT MODEL DESCRIPTION

Manipulation of populations is considered the logical choice for 'succession management' (Luken 1990). Therefore, a descriptive model was proposed and is being implemented at a coal mine in British Columbia. The core/satellite management model draws extensively on the stage-based population (metapopulation) dynamics of plants inhabiting patchy environments, metacommunity persistence and landscape ecology processes. The model can be visualized as an array of strategically positioned and intensively managed native seed production and/or wildlife habitat patches embedded within a matrix of seeded agronomic species. The model assumes that multiple disjunct foci or satellites which originate from the introduced or remnant patches (cores) and the adjacent undisturbed landscape will provide colonists for the matrix. In turn, colonization and expansion from the nascent foci (satellites) will facilitate the species replacement process within the matrix. The function of the matrix is soil development, erosion control and facilitation of fauna migration. Establishment of patches and the matrix are designed to be functionally integrated in order to maximize ecological interactions both within the disturbed area and between disturbed and non-disturbed areas. The model attempts to include, where possible, manipulation of all components of the successional process and is based on maximizing satellite colonization of the matrix by patch species as well as stimulating expansionary diffusion from patches. Incorporation of the spatial processes at the landscape level provides

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the opportunity for planning which facilitates colonization and migration throughout the entire post-mining landscape as well as through the adjacent undisturbed landscape. Plant-animal interactions and their manipulation are considered essential.

Relationship of Core/Satellite Colonization Model to Successional Theory

Conceptually, the proposed management model incorporates the theories of species colonization described by Moody and Mack (1988), the patch models of Cz<r<n and Bartha (1992), and the combined pool/corridor model of Merriam et al. (1990). The model is also analogous to the multi-cell loose equilibrium model of DeAngelis et al. (1985) in that it assumes that the entire system operates within a non-equilibrium status although metastability may exist at certain temporal and spatial scales. The non-equilibrium assumption of the model is derived from the low durational stability experienced by small patches (Pickett et al. 1989). The model assumes that persistent ecological entities such as patches have a minimal structure requirement (population size, patch structure and configuration) that permits persistence.

The descriptive model of Moody and Mack (1988) is the first component of the management model and describes the major mechanism of matrix colonization. Multiple disjunct foci or satellites originating from the introduced patches or, if present, from remnant patches or adjacent undisturbed lands, will provide the initial colonists of the matrix. Satellites may be the result of independent introductions from an initial source, of dispersal and repeated establishment of colonists from the initial source, or of a combination of both. The satellites are essentially metapopulations and could establish potentially during each growing season. The factors that contribute to the spread of invading plants are regulated largely by the dynamics of satellite stands rather than by the expansion of the initially large stand. Thus, the rate of spread of desirable species might be enhanced by concentrating resources, e.g., seed and fertilizer, to facilitate the development of satellites that could produce seed for natural dispersal. The establishment of 'intensively managed patches' of native species could function as nuclei for seed production and/or sources of propagules for the surrounding landscape and would facilitate plant successional development over the entire landscape. Furthermore, these patches would stimulate heterotrophic succession through the provision of wildlife habitat.

The model of Moody and Mack (1988) is most applicable, though not restricted, to species with more specialized mechanisms of dispersal where colonization takes place more as isolated individuals. Where the density of seed dispersal declines sharply with distance, it is likely that the population will colonize as an advancing front either through individual colonization or diffusion. The group of processes that involve dispersal or spread are different mechanisms from processes of diffusion where some attribute such as seeds or rametes are dispersed through a fixed population matrix.

The patch models of Cz<r<n and Bartha (1992) address specifically localized or smaller scale interactions of plant populations. The dynamics in this patch model are colonizations and extinctions within and between patches. Patch models assume that populations grow and interact in a number of finite topographical regions (habitat patches) which are separated by a continuous area (matrix) that is uninhabitable but more or less penetrable. Patch models also allow for population diffusion via small scale immigration of seedlings or clonal species expansion from the perimeter of patches.. This concept is important in the expansion and coalescence of patches at a more spatially restricted scale.

At the landscape level, the spatial relationships of the management model can best be described by a combination of the corridor and non-corridor models (Merriam et al. 1990). Corridor models assume patch connectivity and link logically plant succession with heterotrophic succession. Metapopulation size is related not only to quality of the particular patch and the number of other patches to which it is connected but also to the quality of adjacent patches. For those species requiring corridors, connectivity within the post-mining landscape would be facilitated by the continued existence of haul roads functioning as migration routes or as vectors between source and disjunct patches.

Patch Establishment - Plant Species Selection

Plant succession research indicates that the inclusion of different lifeforms (vertical and horizontal structure) in seeding and planting mixtures, together with appropriate amendments may increase phylogenetic and structural diversity of revegetation communities and enhance rates of successional development (Chambers et al. 1988). Since the process of internal regulation is crucial to the maintenance of biotic diversity in ecologically isolated patches (Pickett et al. 1989), the 'functional group' selection and size of each patch must be based on ecosystem as well as metapopulation dynamics. Therefore, species with suitable 'vital attributes' (morphological, physiological, ecological) or those belonging to appropriate 'functional groups' are selected and combined to develop arrays of different 'biotic type' patches (metacommunities).

The accessions used in the metapopulation establishment should mimic the genetic variability of the donor population (Lippitt et al. 1994) in order to reduce the possibility of 'founder effects'. Re-established metapopulation numbers should approximate 10^3 - 10^6 individuals (Shaffer 1987), except where extant *in situ* (remnant patches) or *ex situ* sub-populations are within, or in close proximity to, the surface mine disturbance. In many cases, an effective population size of 500 individuals is adequate (Kesseli 1992).

Patch Establishment - Planning for Colonization and Dispersal

Knowledge of seed dispersal patterns and processes is essential to the spatial configuration design of patches within the matrix. Although reclaimed landscapes seldom correspond spatially to pre-disturbance conditions, there are commonalities which must be considered and planned for when implementing such a management program. 'Natural' as well as post-mining landscapes have spatial diversity with horizontal and vertical boundaries. Understanding the effects of landforms at the landscape ecology level is crucial to the development of a integrative reclamation program (Tueller 1992). As well, the incorporation of temporal and spatial processes external to the mine disturbance are fundamental to the long-term sustainability of reconstructed ecological systems under which minimal management intervention is anticipated.

From a 'controlled colonization' perspective, several management practices can increase propagule dispersal. The most obvious management activity is to increase recruitment by configuring the spatial arrangement of the patches within each landscape type (highwall, dump free face or platform) in order to reduce required seed dispersal distances and increase seed rain density. The direct placement of recently excavated topsoil onto disturbed sites as the pits 'daylight' in mountainous terrain might also re-establish patches of seed bank species.

Since the spatial distribution of species assemblages changes generally from early to later successional stages, replicating the later successional patterns during initial establishment may also enhance recovery. Plants established in 'correct arrays' may require little or no subsequent management due to efficiencies in moisture retention, nutrient availability and through sequestration of mobile inorganics and organics. The provision of suitable habitat for known seed dispersing fauna would facilitate seed dispersal of the appropriate plant species (Archer and Pyke 1991). Large ex-pit spoil dumps exclude effectively many proximal and distal colonists. Therefore, provision of migration corridors and alteration of landscape boundaries is necessary to make them more diffuse to biota migration and colonization (Sven-Olov 1990).

SUMMARY

Reclamation of high elevation surface mine disturbances is constrained by several factors, the most important of which is the availability of appropriate plant materials during the 'controlled colonization' phase. Therefore, 'managed natural' colonization has been proposed as an alternative. The management model is based upon maximizing satellite colonization of the matrix and on stimulating patch expansion.

Application of the core/satellite colonization model should increase beta and gamma diversity in reclaimed disturbances and stimulate heterotrophic succession.

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