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Part I Utilizing natural regimes as models for reclamation and restoration

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1 The changing boreal forest

Incorporating ecological theory into restoration planning

INTRODUCTION

Boreal ecosystems dominate the landscape across much of Canada, Fennoscandia, and Russia. In Canada, they comprise 35% of the total land area and about 77% of Canada's forestland (NRC 2011). These boreal ecosystems are highly variable and consist of lakes, wetlands – especially peatlands – and a variety of upland forest types, all adapted to long, cool winters and short, cool and humid summers. Uplands and peatlands form a mosaic of community types across the landscape, with bogs and fens often forming large peatland complexes, and uplands varying from aspen-dominated deciduous forest to spruce–fir–pine-dominated conifer forests. In the oil sands region of Alberta, peatlands compose 29% of the landscape (Lee and Cheng, 2009) and are an integral part of the functioning landscape. The underlying bedrock, surficial materials, hydrological connectivity, and soils are highly variable within the boreal landscape, and climate is the major controlling factor.

In general, the plant communities of the boreal forest are young in age, and have developed from species northward immigrations since the retreat of the Wisconsinan glaciers – some 12,000 years ago. Across this evolving landscape, the plant and animal communities have continually been influenced by recurring disturbance events. Wildfire has been the most important natural disturbance. In Canada, 2.1 million hectares of boreal forest are burned annually (NRC 2011); however, much has changed over the last century. Disturbances have become larger and more severe. During the early 1900s, the disturbance regime of Canada's boreal forest was dominated by natural disturbances, with human

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influences playing only local roles. Agricultural expansion, escaped local fires, and high-grade logging were the predominant human disturbances. During the latter half of the 1900s, and continuing today, these human disturbances have changed remarkably and include clearing for roads, energy extraction, clear-cutting, peat harvesting, and reservoir creation, set against a backdrop of increasing insect outbreaks, wildfires, and climatic change (Timoney, 2003). The result is two-fold: the disturbances are more severe and larger in scale or occur at higher frequency, and these result in a highly fragmented landscape. As disturbances increase across the boreal landscape, our ability to rehabilitate these disturbed areas also becomes more important, and the principles of ecological succession must guide our actions (Walker and del Moral, 2003). These actions and interventions need to be built around a framework of natural succession. In particular, we must build on restoration theory in order to develop methodologies appropriate for the boreal forest and its unique characteristics. We need to better understand the set of natural ecosystems and recognize that the prevailing disturbance regime of the boreal region has changed.

The change in disturbance regimes for these boreal ecosystems may be a response to the larger-scale phenomenon of global change, resulting from human-induced changes in the physical climate system, land use, and atmospheric pollution (IGBP, 2010). Changes in the disturbance regime, and the resulting ecosystem response, are the consequence of both direct (e.g., oil and gas extraction) and indirect (e.g., climate change) effects of human activity, which vary over time and with local conditions. Understanding the complex relationship between landscape change and ecosystem processes is necessary to predict both the feedbacks to global change and the future resource availability and ecosystem services.

Feedback mechanisms associated with interactions of altered disturbance regimes, vegetation structure and function, and biospheric carbon (C) pools all contribute to the linkages with the atmosphere that are presented in Figure 1.1. Climatic variables and atmospheric deposition of nutrients are important ecosystem-driving variables that affect processes such as plant distribution, composition, and growth. Site-specific conditions and small-scale processes determine the relative importance of these variables. Of particular importance are the changes in: (1) vegetation composition and distribution; (2) net C fluxes via plant production and decomposition (Houghton, 2003); and (3) water and energy fluxes altered by precipitation, evapotranspiration (Amiro et al., 2010), and runoff (Lal, 2008). The processes controlling these factors are highly sensitive to

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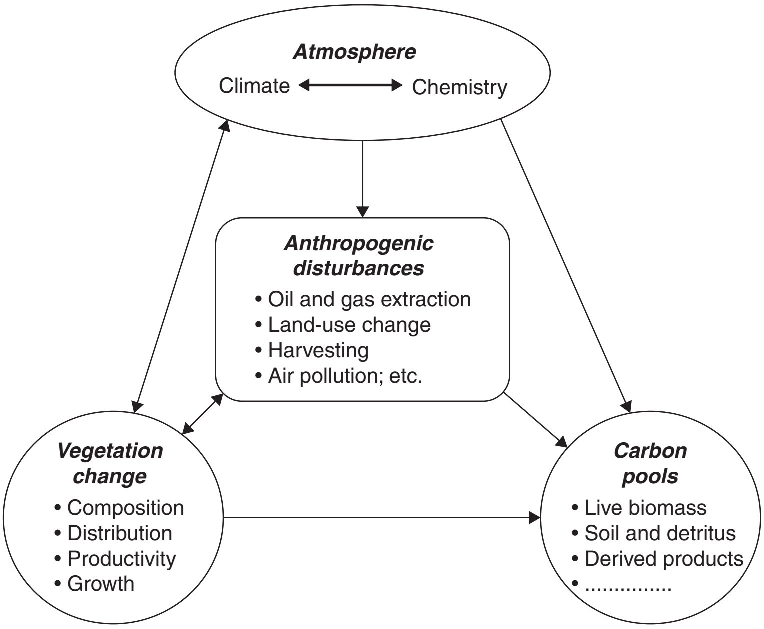

Figure 1.1. The relationship between forest/peatland ecosystem components, their interactions, and atmospheric-climate feedbacks. (Modified from Bhatti et al., 2001.)

environmental change and response at leaf, tree, and stand levels and occur within days to decades (Shugart and Smith, 1996).

A key factor affecting vegetation structure and function is the natural or anthropogenic disturbance regime (Yade et al., 2011b). This regime alters processes that affect ecosystem structure and function at large, and spatial and temporal scales. Alterations in resource availability and its partitioning among biotic components, changes in ecosystem structure, and changes in disturbance regimes are three ways by which changes at the stand or biome level occur. These changes may not be immediately observed and instead may occur over an extended period of time–from years to decades or centuries. Changes in forest structure, both in terms of age–class structure (Kurz et al., 2008, Yade et al., 2011b) and spatial distribution can modify the local, regional, and global scale climate through alteration of albedo, humidity, and ground level wind patterns (Canadell et al. 2007). Yade et al. (2011a) have shown that stand-replacing disturbances play a complex, but very important role in determining the annual exchange of CO_2 with the atmosphere.

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As expected, the impact of global change is a significant alteration of the frequency and timing of disturbance events in northern forests (Flannigan et al., 2009). Metsaranta et al. (2010) demonstrated that frequent large-scale forest disturbances such as wildfires could accelerate forest biome adaptation to changing climate conditions. With increased frequency of stand replacement disturbances recently, it is important to understand what are the principal ecological processes governing variability of boreal ecosystems and their inhabitants, as well as their resilience to disturbances; how do we maintain resilience in boreal ecosystems and still maintain viable resource extraction industries? Successful restoration is a key component to the future of this complex boreal landscape and restoration is dependent on understanding how ecosystems and communities change over time.

Biological science has also changed. As Keddy (1999) has described, we have reached the end of an era of exploration and description. The era of discovering the diversity of life and documenting species richness set the stage for our understanding of the species pools from which communities are composed. It also set the stage for relating the patterns of species occurrence to environmental gradients. Biomes were described, species distributions related to elevational and latitudinal gradients, and many of our theories in community and ecosystem ecology proposed. In comparison, the present focus is the search for mechanisms and interrelationships of a multitude of ecosystem components. Unfortunately, ecology is complicated and patterns are often messy, leaving one dissatisfied and wondering if rules do, indeed, exist. Even though they may be disguised, they do exist, and furthermore, they are important for our understanding of natural patterns. As we explore the rules for structure and function of natural communities and ecosystems, we also need to recognize that these same rules govern the restoration of disturbed areas, and in particular, we must utilize these rules to rebuild communities on the boreal landscape.

Ecologists have long been interested in how communities change over time (Pickett et al., 2008). Perhaps the earliest studies were those of Henry Cowles, who observed floristic changes from lakeshore inland along Lake Michigan and interpreted these as representing community change through time (Cowles, 1899). Somewhat later, Frederick Clements (1916) and Henry Gleason (1917) provided a foundation of competing ideas on community succession and laid the groundwork for modern successional theory. Clements' view of discrete assemblages of species arriving, assuming dominance, and shifting in discrete phases until a final "climax" community was attained in a predictable manner was

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quite different from Gleason's view of individual species arriving and responding dynamically to their environments, with a variable, nonpredictable successional progression and endpoint. In 1977, Connell and Slatyer proposed three general models of succession focusing on life history traits of species. In general, they argued that the interactions of resource availability and site history provide a set of circumstances for a set of species arrivals; these arrival species establish, grow, and interact with one another. The result of these events is: (1) facilitation, whereby species modify their surroundings and make conditions suitable for the next group of species; (2) tolerance, whereby late-arrival species are not affected by early arrivals; or (3) inhibition, whereby early arrivals suppress or exclude late-arriving species.

A FRAMEWORK

From a reclamation/restoration point of view, we can utilize many of these ideas to build a theoretical framework for reclamation and restoration in the western boreal forest. This framework encompasses four ecological filters, and each can be translated into a set of operational protocols necessary for successful restoration planning (Figure 1.2).

- **Site history and resource availability:** disturbed sites have basic resource levels, determined by position on the landscape, local and regional hydrology, and chemical and physical limits of the substrate. Additionally, sites are varied in size and positioned along unique portions of resource gradients. Sites are strongly affected by regional climate and its annual variation. Our detailed understanding of the key environmental drivers at each restoration site is the first step in developing operational protocols and engineering the site for species arrivals.
- **Species availability:** the availability of arriving species is controlled by the abilities of diaspores to be dispersed from surrounding areas and the available regional species pool. Size of the disturbance, number of potential contributing species, and resource limitations of the recipient site are all-important thresholds to be crossed. Seed, spore, and bud banks are important determinants that have the potential to limit the arriving species pool. Operationally, it may not be sufficient to depend on species arrivals from natural existing donor sites; species may need to be selected and introduced (Brudvig and Mabry, 2008). In applied contexts, it is critical to understand how species respond to important environmental gradients (Gignac et al., 1991).

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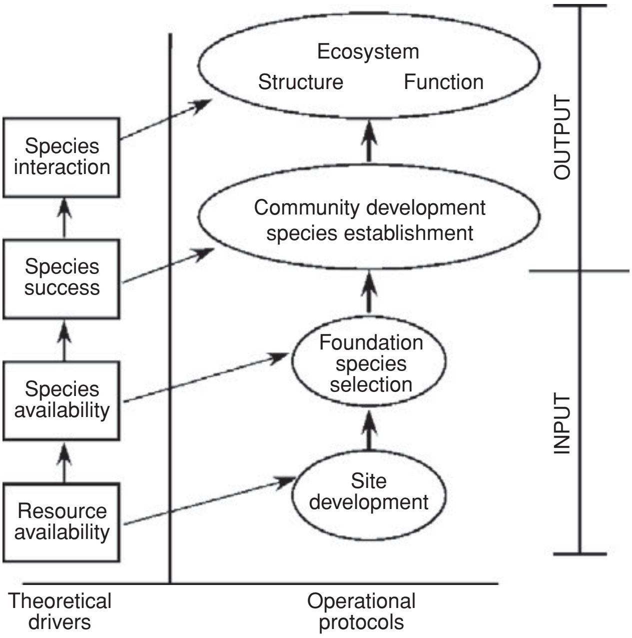

Figure 1.2. Four ecological filters taken from successional theory (left side) and the resulting actions and findings required for restoration of large-scale or frequent disturbances.

Both site preparation and species selection are inputs to successful restoration and lead to a series of potential results or outputs (Figure 1.2).

- **Species performance:** arriving species must establish, grow, and reproduce. Establishment and growth are important early stage indicators of species success, while reproduction, both sexual and asexual, is important later on. Early regeneration dynamics such as seedling mortality and narrow environmental requirements may form a "bottleneck" for successful establishment (Poorter, 2007). The initial establishment and success of foundation species leads to early community development. Species success is manifested in the development of community structure, wherein species are sorted into a variety of vegetational layers. Operationally, the system must be carefully monitored for individual species responses and also for structural complexity and development.
- **Interspecific interactions:** once species are established and structural attributes begin to form, biotic interactions such as competition, herbivory, and invasions of aggressive species are factors that determine the eventual outcome of species succession.

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These biotic interactions determine the eventual success of individual species, but do not determine the functional integrity of the community. If the correct foundation species are present, then, with time, additional species arrivals will increase the species diversity. These complex species interactions provide the backdrop for the return of ecosystem function, and successful restoration requires the assessment of both community richness and ecosystem functions.

In summary, this framework outlines four key processes that act as ecological filters and that must be recognized in any reclamation or restoration project. These translate to: (1) site development utilizing natural analogues; (2) species selected from comparative natural situations; (3) species performances based on clear natural benchmarks; and (4) development of community stabilization, species richness, and ecosystem function, again based on natural analogues.

These four ecological filters and associated operational protocols form the framework for restoration of boreal disturbances. The chapters in this book provide answers and background to some of these. Much of what we have learned and presently utilize in boreal restoration is practically based. It is time that we develop these operational protocols from ecological theory, theory that has resulted from decades of exploration and experimentation. The chapters in this book attempt to provide insights into a number of key areas. In particular, the stage is set by a series of chapters exploring the use of natural regimes as baselines for site and species inputs. Second, several authors review what we have learned over the past few decades about implementing successful planting regimes, introducing regional species, and early site development. Third, we learn how successful some of the restorations have been, and how we can attempt to manage C in a changing world of C offsets. Having read these reviews of what we know of restoration across the boreal regime, we are left with many questions; some of these are presently being answered by research programs already in place, while others remain for the future.

POSSIBLE FUTURE SURPRISES AND THE PATH FORWARD

Five research themes would strengthen scientific understanding of future restoration efforts.

- **Significant data and knowledge gaps exist**. Although we have cleverly engineered sites for control of water and chemistry, we

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still know little about how species and the system as a whole will respond. We have just scratched the surface of understanding community development or how species diversity can be installed into restoration plans. The surprise may be that we can, indeed, restore (not reclaim) landscapes.

- **Histories**, or developing a series of meaningful benchmarks to know if we are successful, have been a nagging problem for a decade. Is it correct to compare our three- to five-year-old "fen" with one that has been functional for millennia? Unlikely, but where are the correct benchmarks on the landscape? The surprise may be that adequate function may be achieved before we know that we have it.
- **Hydrology** provides the necessary conditions for both wetlands and uplands to function; however, climate also plays a key role. There are clear research needs to quantify the roles of temperature and precipitation under a changing climatic regime and to learn more of how these relate to regional hydrology. Unfortunately, the surprise is that global climate change may have an overriding local effect.
- **Carbon cycles** must be better understood. We need to better quantify C fluxes and sequestration at early stages of restorations. We know much about C stocks and C fluxes, and we need to better develop C offset baselines–we may be surprised by what we learn about C management.
- **Models** are needed to better predict how our short-term restoration efforts will play out over the next decades. These models need to be climate-linked and able to detect threshold dynamics as well as internal feedbacks.

The message from chapters in this book is clear: reclamation and restoration cannot be afterthoughts to operations. Operational protocols that are in line with the limiting ecological filters must be in place in the early planning stages of operations. We have learned that the addition of organic material to help develop the soils and introduce diaspores is extremely beneficial, but the timing of this introduction is also critical to the long-term site development and C cycling. Time is of the essence in restoration, and the development of reclamation protocols that incorporate ecological theory into site engineering is the key to success. Finally, peatlands have their own set of ecological services and play a pivotal role on the landscape. As such, peatlands are equal partners in achieving landscape restoration.

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