DEVELOPING REFERENCE CONDITIONS FOR ECOLOGICAL RESTORATION OF FORESTS IN SUB-BOREAL BRITISH COLUMBIA

by

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ABSTRACT

It is widely accepted that timber harvesting has lead to changes in the forests of sub-boreal British Columbia, Canada, but these changes are difficult to quantify and characterize. If ecological restoration of these forests is a management objective, then developing historical reference conditions to compare with contemporary conditions is a prerequisite. To characterize historical forest condition as a foundation for a sustainable forest management plan, oral and written records were used to describe land use patterns in and around the John Prince Research Forest (JPRF), in sub-boreal British Columbia. Historical aerial photography and current forest inventory data were compared to quantify changes in landscape structure between 1947 and 1999 on the JPRF, and to define landscape level reference conditions. Written historic records and data from current remnant stands were integrated to define stand level reference conditions for mature Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) leading stands. These stands are important both ecologically and economically on this landscape. The results indicate that there has been a significant decline in mature coniferous forest, and that the remaining forest has become increasingly fragmented. Three key factors related to land use in this region have lead to changes in landscape structure, including: harvesting effects, mechanical innovation, and silviculture system used. The study indicates that there is a need for ecological restoration in areas of the JPRF heavily impacted by past timber harvesting, but further analysis into the natural range of variation for the forest is needed before restoration can begin.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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- Chapter 1 -

Thesis Introduction

SUSTAINABLE FOREST MANAGEMENT

The primary goal of ecosystem management in forests is to address economic and social concerns while concurrently sustaining biological diversity (or, biodiversity) and ecosystem productivity (Cissel et al. 1994, Irland 1994, Salwasser 1994). It has been suggested that ecosystem management is the only way to conserve floral and faunal organisms and biological associations in managed ecosystems (Franklin 1993). The concept is based on managing processes and connections that occur naturally in the ecosystem (Galindo-Leal and Bunnell 1995). One approach to maintain and enhance biodiversity in forests is through planning conducted over larger areas and longer time periods (Franklin 1993, Irland 1994). Additionally, a key component of ecosystem management is gaining site specific knowledge about the area in question (Kohm and Franklin 1997).

Further, sustainable forest management involves a movement away from managing sustained yields in forests, and incorporates environmental, economic, and social aspects into forest management (Kneeshaw et al. 2000). In Canada, sustainable forest management involves the dynamic interplay of environmental considerations, socio-economic and cultural benefits, and implementing and monitoring appropriate sustainable forest management initiatives (CCFM 1997).

Criteria and indicators provide framework for developing forest management strategies, and serve as a tool to monitor progress towards sustainable forest management (CCFM 1997). A *criterion* is a category of conditions or processes by which sustainable forest management may be assessed, and is characterized by a set of related *indicators*, which are monitored periodically to assess change. An indicator is a quantitative or qualitative variable which can be measured or described and can be observed periodically to monitor trends (CCFM 1997). Criteria and indicators are a tool used to define sustainable forest management goals, and national criteria and indicators (CCFM 1997) use this approach as a framework to assess forest sustainability. Specifically, criteria used to monitor sustainable forest management in Canada include the (1) conservation of biological diversity, (2) ecosystem condition and productivity, (3) conservation of soil and water resources, (4) global ecological cycles, (5) multiple benefits of forests to society, and (6) accepting society's responsibility (CCFM 1997). In the context of ecological restoration, developing criteria and indicators based on reference information can be used to define targets for "natural" forest conditions during the planning process. Tools and approaches from restoration ecology, landscape ecology and historical ecology can be used to support ecosystem management planning and implementation, and establish a framework for sustainable forest management.

Restoration Ecology

Ecological restoration is a deliberate activity that initiates or accelerates the recovery of ecosystem health, integrity or sustainability (SER 2002). Restoration ecology (the science) also embraces the social, economic, cultural, and political elements of ecological restoration. This involves restoring the structure and function of an ecosystem to the condition present some prior point in time by managing, and accelerating, the natural ecological processes within the ecosystem (Jordan et al. 1987, Hobbs and Norton 1996). Ecological restoration has been defined by the Society for Ecological Restoration Science and Policy Working Group (2002) as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed". In this context, ecological integrity is defined as the critical range of variability in biodiversity, ecological processes and structures, regional and historical context and sustainable cultural practices. Restoration ecology is a relatively new scientific discipline that incorporates concepts from ecosystem management, preservation and conservation.

The principals of restoration ecology can be employed on a continuum of management problems (Hobbs and Norton 1996). At one end of the continuum is the re-creation of ecosystems from sites that have been completely altered from their original state, and at the other end is the management of ecosystems on sites that have been relatively unmodified (Hobbs and Norton 1996). Good restoration involves expanding the scope from one focused solely on science and technology to one which incorporates historical social, cultural, political, aesthetic and moral aspects (Higgs 1998).

In the past, ecological restoration has been criticized for not placing adequate emphasis on developing a structured methodology (Wyant et al. 1995, Hobbs and Norton 1996, Michener 1997). For example, ecological restoration projects frequently do not identify causes of degradation, and this oversight results in continued impact from degrading factors. Also, projects are often established with broad and ill-defined goals, and lack a method for determining the successes and/or failures of the initiative. Finally, ecological restoration is most often applied on a site-specific basis, with little or no focus given to the development of standard theories and/or principals (Hobbs and Norton 1996). This lack of direction is due to two main factors. First, there has often been insufficient communication between managers and the appropriate scientific specialists (Wyant et al. 1995) leading to ecological restoration based on 'best-guess management decisions' rather than on scientific research. Second, ecological restoration has often been implemented with little or no attention to how the area in question fits into a larger context on the landscape (Wyant et al. 1995, Bell et al. 1997).

In an attempt to alleviate the problem of the lack of structured methodology in ecological restoration, Hobbs and Norton (1996) have introduced a protocol by which ecological restoration may proceed. These essential steps include: (1) identifying the processes that have lead to ecosystem degradation, (2) developing methods to reverse the cause of degradation, and (3) determining goals for re-establishing species and functional ecosystems while recognizing both the ecological limitations on ecological restoration and the socio-economic and cultural barriers to its implementation. To address some of these limitations in practice, a link can be made between ecological restoration and the theories from the field of landscape ecology (Bell et al. 1997).

Landscape Ecology

Landscape ecology examines the structure, function and changes in landscape patterns and the responses of biological organisms to these factors (Forman and Godron 1986). Analytical techniques have been developed to quantitatively interpret landscape patterns and support landscape ecology studies (Rossi et al. 1992). These techniques address practical issues in ecological restoration (Bell et al. 1997). Ecological restoration has traditionally focused on small areas and expanding the scope to encompass larger areas allows for setting goals at the landscape level (Bell et al. 1997). This approach provides a context for more specific activities (Mitsch and Wilson 1996). Developing a historical perspective of ecosystem structure and function, understanding changes at the landscape level, and identifying ecological restoration target areas using the principals of landscape ecology are key elements of incorporating ecological restoration principals into forest management and planning.

Historical Ecology

The first step of a successful ecological restoration program involves developing an accurate picture of the structure and function of the ecosystem to be restored, and understanding both the natural and anthropogenic (human-caused) disturbance influences on an ecosystem is also important for ecological restoration (Jordan et al. 1987, Hobbs and Norton 1996). This information can be used to characterize the natural range of variability in ecosystems prior to human impact (Swetnam et al. 1999). Historical ecology offers a methodology for locating and analyzing historical information sources to support ecological restoration (Russell 1997, Egan and Howell 1999), which may be used to establish reference conditions for ecological restoration

(Covington et al. 1997, Fulé et al. 1997, White and Walker 1997, Moore et al. 1999) and for sustainable ecosystem management. Although skepticism remains around the extent to which historical information accurately portrays conditions of the past (Landres et al. 1999, Millar and Wolfenden 1999), it is clear that understanding the past is important for make informed decisions about the future (Christensen et al. 1996). One of the most useful aspects of historical ecology is that it provides a context for understanding present conditions in the face of industrial land management and climate change (Swetnam et al. 1999). Humans have been using landscapes in a sustainable manner for thousands of years (Anderson 1996, McCann 1999b, Turner et al. 2000, Anderson 2001) and historical ecology can assist in developing an understanding of the extent to which current human impact on the landscape is within the range of natural variation (Christensen et al. 1996, Swetnam et al. 1999). Historical ecology and ecological restoration are both concerned with understanding and studying past ecosystems, but ecological restoration expands the perspective to include restoring altered ecosystems (Egan and Howell 2001).

Natural Range of Variability

The historical, or natural, range of variability is a concept used to describe the dynamic nature of ecosystems undergoing constant change (Morgan et al 1994). Most species have adapted to a particular disturbance regime within the ecosystem they inhabit (Mutch 1970) and when ecosystem conditions have moved outside the natural range of variability, biodiversity may be compromised (Morgan et al. 1994). Understanding the range of variability that naturally occurs within an ecosystem will assist managers in determining whether the current forest conditions fall within the natural range (Landres et al. 1999).

Currently in British Columbia, Canada, two-thirds of the province (approximately 59 million ha) is designated public (crown) land, and 12% of this land has been designated as parks and protected areas as a result of increased public pressure regarding the need for conservation and maintenance of biodiversity (Fenger 1996). In addition to the increasing number of parks and protected areas, the Forest Practices Code (FPC) exerts jurisdiction over all crown forests in British Columbia (British Columbia Ministry of Forests 1995). The FPC came about as a result of debates between government, industry and other stakeholders (Ward 2001) and the Biodiversity Guidebook (British Columbia Ministry of Forests and British Columbia Environment 1995) of the FPC presents an ecosystem based approach to the conservation of biodiversity in managed forests (Fenger 1996). The Biodiversity Guidebook attempts to conserve a variety of natural habitats at the landscape level, and promotes forest management practices at the stand level that sustain key ecological processes and attributes. Through the Biodiversity Guidebook natural disturbance patterns dictate the land management practices that must be in place for the conservation of biodiversity. The Biodiversity Guidebook provides recommendations for forest conditions based on natural disturbance regimes. In ecosystems that have undergone substantial human disturbances, understanding the conditions that developed under the influence of natural disturbance processes and patterns is therefore critical.

In addition to historical disturbance regimes (natural or cultural) in forests, it has long been recognized that changes in climate influence vegetation at multiple levels. Assumptions that climate is a stable entity for the purpose of simplifying management will lead to inaccurate interpretations of natural variation in ecosystems (Millar and Woolfenden 1999). Without some consideration of the effects of changes in climate, the establishment of dynamic reference conditions for ecological restoration may be incorrect, and incorporating knowledge of changes in climate with historical records of vegetation can increase our understanding of the natural range of variability (Millar and Woolfenden 1999).

STUDY OBJECTIVES

It is widely accepted that in the past century timber harvesting has lead to changes in the forests of sub-boreal British Columbia, Canada. Specifically, past harvesting practices are believed to have altered landscape structure and function, and forest managers have identified ecological restoration as a potential means of ameliorating changes. This thesis demonstrates the links between ecological restoration, landscape ecology and historical ecology to address the issue of ecological restoration in the forests of sub-boreal British Columbia. The specific objectives of this study, therefore, are to:

1. Identify the sources of culturally-derived historical information that may be used to support ecological restoration in British Columbia.
2. Characterize the patterns of industrial land use for a study area in sub-boreal British Columbia using the sources identified in Objective 1.
3. Link the fields of landscape ecology and restoration ecology to quantitatively analyze changes in landscape structure in a forest in sub-boreal British Columbia.
4. Define the reference conditions for ecological restoration based on culturally-derived historical information, quantitative analysis and field surveys in remnant stands.

STUDY AREA

The study area for this research is the 13,032 ha John Prince Research Forest (JPRF), situated on an east-west oriented isthmus located approximately 50 km north of the village of Fort St. James in sub-boreal British Columbia (Figure 1-1). The JPRF is situated between Tezzeron Lake to the north and Pinchi Lake to the south, and is located within the traditional territory of the Tl'azt'en Nation. The JPRF was established in 1999 as a co-managed, working research forest by the University of Northern British Columbia and Tl'azt'en Nation, under license of the crown[1].

The JPRF lies within the Nechako Plateau physiographic region, on a geology of flat or gently dipping volcanic rock, with moderately well drained soils, and an elevational range between 700 and 1267 m asl. The JPRF is located within the montane zone of central British

[1] John Prince Research Forest (JPRF). 1999. John Prince Research Forest Management Plan: 1999-2004. Unpublished Report.

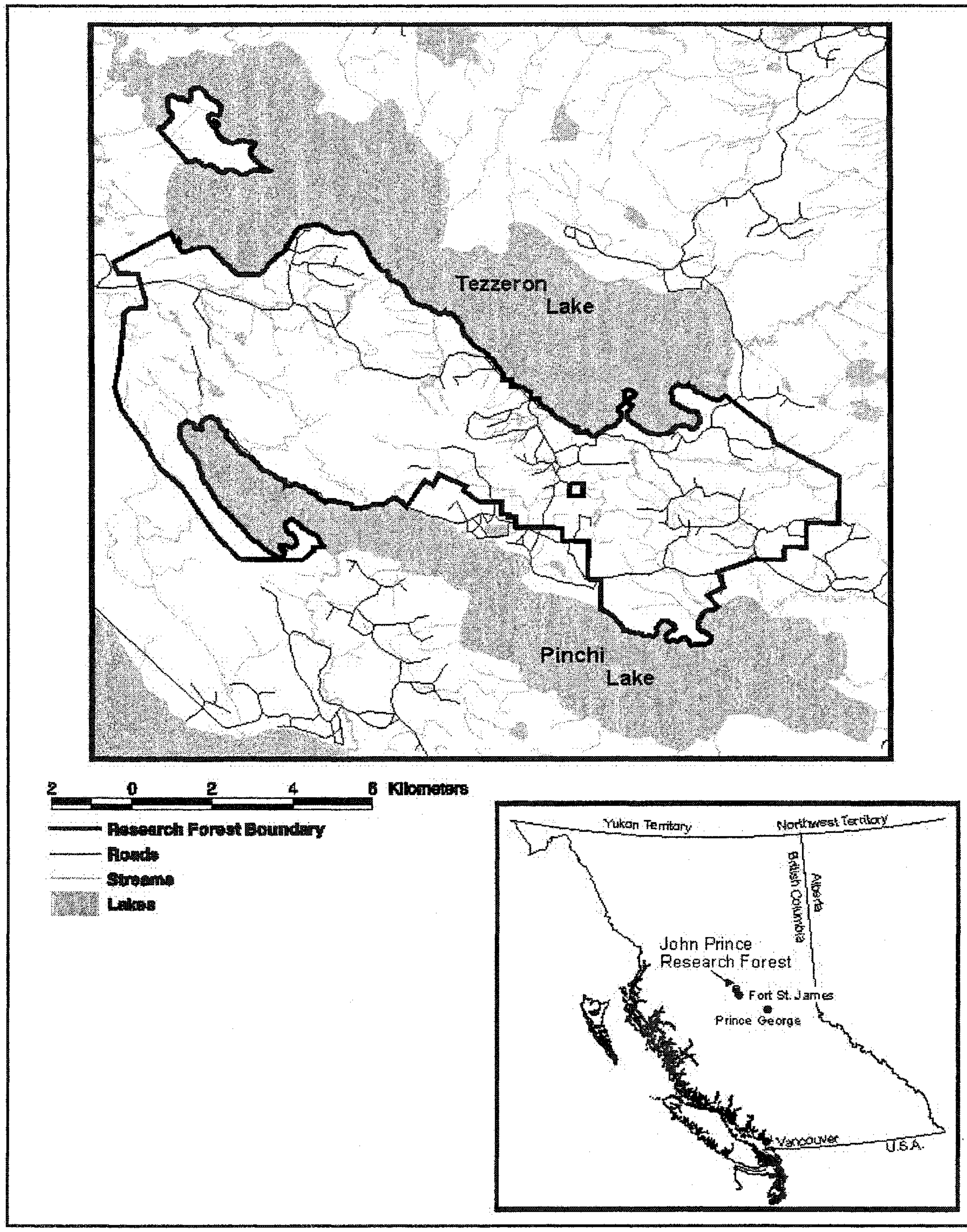

Figure 1-1 Map illustrating the location of the John Prince Research Forest (JPRF) in sub-boreal British Columbia, Canada.

Columbia in the Sub-Boreal Spruce (SBS) Biogeoclimatic Zone (Meidinger and Pojar 1991). The SBS biogeoclimatic zone is situated in the Canadian Boreal Forest Region (Krajjina 1965) and is the transitional region between true montane Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) forests to the south; the dry, cold pine-spruce forests to the southwest; northern boreal forests; and the high elevation subalpine forests (Meidinger and Pojar 1991). Upland coniferous forests dominate the landscape, with interior spruce (*Picea glauca* [Moench] voss, *Picea engelmannii* Parry ex. Englm., and their naturally occurring hybrids) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt) as the dominant climax tree species. Lodgepole pine (*Pinus contorta* Dougl. ex. Loud.), paper birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx.) are widespread pioneers in seral stands. Douglas-fir persists on dry, warm, rich sites in the SBS, and is a long-lived seral species. Black spruce (*Picea mariana* (Mill.) B.S.P.) also occurs intermittently as a component in the climax upland forest (Meidinger and Pojar 1991).

The SBS is characterized by seasonal extremes of temperature and moderate annual precipitation. Mean annual temperature of the SBS ranges from 1.7 to 5°C, while the average daily temperature is below 0°C for 4 to 5 months of the year, and above 10°C for 2 to 5 months of the year. Mean annual precipitation in the SBS ranges from 440 to 900 mm, with approximately 22 to 25% of this precipitation falling as snow (Meidinger and Pojar 1991).

Natural Disturbances

Fire is the most important disturbance process that influences the sub-boreal forest (Johnson 1992, Delong and Tanner 1996). In the SBS, wildfires occur primarily in the spring and summer months. In general, low temperatures in the SBS create slow decomposition rates, resulting in significant accumulations of forest litter which provide potential fuel. During the spring, the retreat of the Artic air mass allows the Pacific airstream, which is warmer and more unstable, to flow over the interior of British Columbia. This event results in the increased drying of fuels and increased thunderstorm activity, increasing the frequency of fires (Johnson 1992). Also, increased fire activity is associated with the extended periods of drought which may occur during the summer months (Hawkes 1993).

Most fires in the SBS are medium to high intensity surface and ground fires (Parminter 1990). Surface fires consume forest litter and debris within several meters of the forest floor, and often burn in combination with higher intensity crown fires that consume wood and foliage in the forest canopy (Parminter 1990). Ground fires (i.e. fires which burn at low intensities and are confined to the forest floor) are not common in the sub-boreal forest (Johnson 1992, Delong and Tanner 1996). In the SBS, fire size is highly varied (Parminter 1990), where fires range in size from small spot fires to large fires that covered tens of thousands of hectares. Parminter (1990) estimates the historic fire size in the SBS at 50 to 500 ha, and Delong and Tanner (1996) estimate the historic fire size in the SBS at greater than 500 ha. The fire return interval in the SBS is estimated between 75 and 250 years, with an average return interval of 100 to 150 years (Parminter 1990, Delong 1996) in the dryer regions of the SBS, such as the area occupied by the JPRF.

Under natural conditions in the SBS, it was typical for remnant patches of mature forest to remain standing in burned areas, creating a matrix of even aged stands ranging from a few to thousands of hectares in size, with mature remnant patches interspersed within them. These mature remnant patches had an important role in increasing the structural complexity of the forest. In forests dominated by Douglas-fir, the number and size of remnant patches increased due to the resistence of this species to wildfire, providing added structural diversity (British Columbia Ministry of Forests and British Columbia Environment 1995). In 1947, the dominant age cohort on the JPRF was age class seven (141 to 250 years), and so it may be inferred that a widespread natural disturbance (most likely a fire) occurred in this area between 1807 and 1827 leading to the establishment of the current forest[2].

In addition to fire, other processes such as insects, disease and wind play a role in maintaining the forest mosaic in the SBS. For an insect or disease to impact forest condition, three factors must be satisfied simultaneously. First a pathogen or insect must be present at an infectious stage in its life history. Next, there must be a susceptible host for infection or attack. Finally, their must be the appropriate environmental conditions for infection or attack to occur. Insects and diseases that are common throughout the SBS include the mountain pine beetle (*Dendroctonus ponderosae*), Lophodermella needle cast (*Lophodermella concolor*), Douglas-fir beetle (*Dendroctonus pseudotsugae*), spruce beetle (*Dendroctonus rufipennis*), tent caterpillar *Malacosoma* spp.), satin moth (*Leucoma salicis*), and large aspen tortrix (*Choristoneura conflictana*) (Humphreys and Van Stickle 1996).

Cultural History

In addition to the natural disturbance history described above, the JPRF also has a rich cultural history. The JPRF is located within the traditional territory of the Tl'azt'en Nation, and the Tl'azt'enne (Tl'azt'en people) have managed the flora and fauna of their territory for subsistence, medicinal and spiritual purposes prior to the initiation of industrial development in the region. Many of these uses continue today. Tl'azt'enne organized their territory into *keyohs*, or family use areas, and the JPRF includes portions of three *keyohs* that are now defined by government delineated traplines (Karjala and Dewhurst, in press). Five permanent village sites are located within Tl'azt'en territory, but there is no evidence that permanent village sites existed within the boundaries of the JPRF (Morris 1999). Land claim settlements between Tl'azt'en Nation and the provincial and federal government are not yet settled, and currently the majority of Tl'azt'en

[2] Grainger, 2002. Analysis of historical photography to support ecological restoration. Terrestrial Ecosystem Restoration Program, Forest Renewal British Columbia. *Unpublished Report.*

territory is currently under tenure to industrial forest companies. This includes an area-based tree farm license northwest of the JPRF, which is Tl'azt'en owned and operated (Booth 1993)

Tl'azt'en people managed the land primarily for hunting, gathering and harvesting of salmon, whitefish, char, berries, small birds and mammals (Morris 1999). Trapping was focused on small mammals, and members of Tl'azt'en Nation concentrated trapping activities in riparian areas, and on old roads and trails (Morris 1999). Hunting took place throughout the territory, and was focused on large mammals (e.g. moose, deer, wolf and bear) (Morris 1999).

The extent to which Aboriginals used fire in the SBS, and in the JPRF more specifically, is unknown. We can, however, use evidence of Aboriginal use of fire in other regions of northern Alberta and British Columbia to make inferences about how the Tl'azt'en Nation may have used fire. In North America, Aboriginals used restricted, local, fires for warmth, cooking, drying and smoking foods, smoke-tanning hides, preparing medicines, felling trees and wood working (Pyne 1984, Turner 1991). Fires were also used for light, as a method of communication, to ward off insects, and for cultural and entertainment purposes (Pyne 1984). In addition to these small fires, Aboriginals also used "landscape burning" for large-scale intentional vegetation burning (Turner 1991). In this context, fire yards refer to openings or clearings within a forested area that are maintained by burning, while fire corridors refer to areas that make up grass fringes of streams, sloughs, ridges, or trails, and are also maintained by burning (Pyne 1984, Lewis and Ferguson 1988). Cultivation and harvesting of natural grasses was facilitated by broadcast fires, and the use of fire for hunting was one of the most ancient uses of fire. Along similar lines, Aboriginals also used fire to create new habitat for large mammals (Pyne 1984).

In northwestern Alberta, Aboriginals used fire to clear large openings to create prairie habitat. Also in northwestern Alberta, Aboriginals used fire to manage the plant and animals associated with trapping and trapline hunting, and fire was used to manage the relative abundance of both. Fire was also used in this region to maintain trails and corridors to facilitate travel (Lewis and Ferguson 1988).

In northwestern British Columbia, the Gitxsan and Wet'suwet'en peoples used burning as a tool to manage vegetation for the renewal of the berry species black mountain huckleberry (*Vaccinium menbranaceum* Dougl.) and lowbush blueberry (*V. caespitosum* Michx.). The Gitxsan and Wet'suwet'en peoples also used burning to clear area around village sites (Johnson 1994). The Aboriginal use of fire to manage vegetation has also been recorded in the Pemberton Valley region of the interior plateau of British Columbia (Turner 1991).

In some areas within Tl'azt'en traditional territory (including the Pinchi Lake area), there have been reports that Aboriginals traditionally burned wild hay meadows for horse and cattle grazing. In general, the impacts of Aboriginal management practices such as fire have often been understated (Denevan 1992) and we tend to generalize these activities despite the site-specific impacts on the land (Russell 1997). This is also true of the JPRF, where the extent to which past traditional activities have influenced the past and current landscape condition is largely unknown.

Over the last century, the area of British Columbia in which the JPRF lies has been heavily exploited for timber harvesting, and the effects of past industrial land use are evident across the landscape (Bernsohn 1981). Forty-one percent of the JPRF has been harvested over the last 60 years using a variety of silviculture systems[1], and this has led to changes in the structure, and possibly the ecological functioning, of the forest. Community members and forest managers have expressed concern regarding these changes (Lousier and Kessler 1999) and ecological restoration is considered a management option for some areas in the JPRF. This thesis, therefore, looks in depth at the issue of ecological restoration on the JPRF.

THESIS STRUCTURE AND ORGANIZATION

This thesis is organized as three manuscripts with supporting materials, and is structured into six chapters (Figure 1-2). The six chapters include:

- Chapter 1 – Thesis Introduction
- Chapter 2 – Historical Information to Support Ecological Restoration
- Chapter 3 – Using Land Use Patterns to Guide Restoration
- Chapter 4 – Using a Landscape Ecology Approach to Support Restoration
- Chapter 5 – Defining Reference Conditions for Ecological Restoration
- Chapter 6 – Overall Summary and Conclusions

Chapters 3, 4 and 5 were written as manuscripts to be submitted for publication, and the remaining chapters serve to further support the issue of ecological restoration on the JPRF. Chapter 2 highlights the sources of culturally-derived historical information available to support ecological restoration in British Columbia, and identifies sources available and methods for collecting historical information. Chapter 3 presents a methodology for considering land use patterns to guide ecological restoration, and relates land use history to specific ecological restoration needs in forested landscapes. In Chapter 4, the concepts of landscape ecology and historical ecology were integrated to quantitatively identify changes in landscape structure that have resulted from past land use. Some evidence is provided for the need for ecological restoration on the JPRF, and candidate areas for ecological restoration treatments are identified. Chapter 5 demonstrates an approach for developing reference conditions using stand level historical information and reference sites for an area targeted for ecological restoration. Finally, Chapter 6 provides an overall summary of the findings, general conclusions, and implications for sustainable forest management in sub-boreal British Columbia.

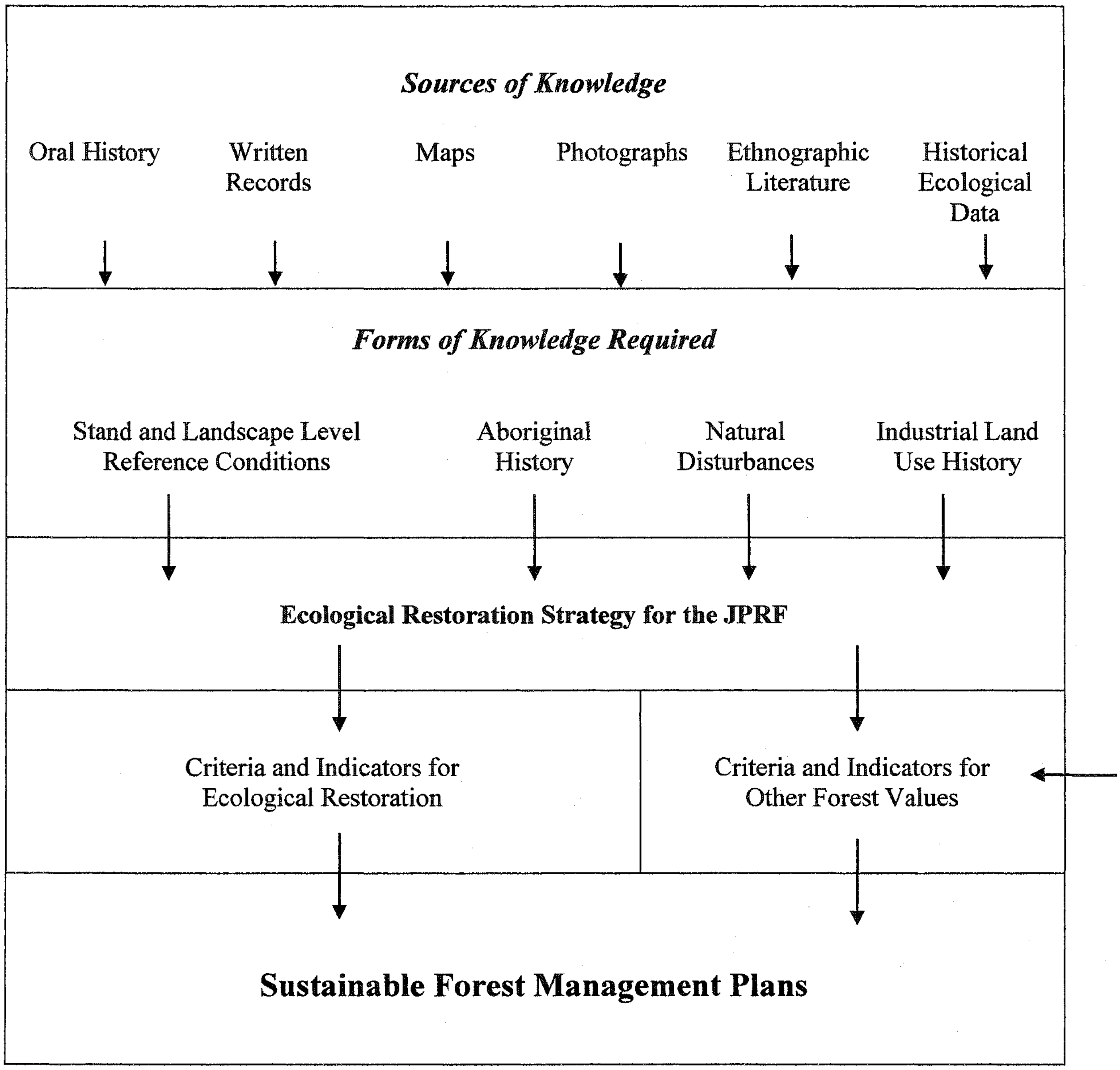

Figure 1-2 Range of information required to support ecological restoration, and the process for integrating the information into sustainable forest management planning of forests in British Columbia.

- Chapter 2 -

Historical Information Available to Support Ecological Restoration in British Columbia

INTRODUCTION

Reference information is essential in ecological restoration, as it is a form of information that defines the condition of the historical ecosystem, and identifies the factors that have resulted in changes to the ecosystem. Reference information also assists in defining the actions needed to accomplish ecological restoration, and identifies criteria used to measure the successes and/or failures of ecological restoration treatments (White and Walker 1997, Swetnam et al. 1999). The extent to which reference conditions derived from historical evidence should be applied to forest management is not yet clear, but it is agreed that understanding the past is a critical element of defining sustainable resource management (Swetnam et al. 1999).

Historical evidence available for use in defining reference conditions for ecological restoration falls into two general categories: culturally-derived (or "documentary") evidence, and biological (or "natural") evidence (Swetnam et al. 1999, Egan and Howell 2001). Culturally-derived evidence includes written documents, maps, photographs, oral histories and Aboriginal histories. Biological evidence includes remnant stands of trees, growth cycle analysis (e.g. tree rings or corals), animal deposits (e.g. packrat middens) or remains, sediments (e.g. pollen, charcoal, microfossils and phytoliths), soil profiles and ice cores (i.e. layered records). The degree to which reference conditions developed from historical ecological research addresses the issue of natural variation in ecosystems is still unclear, but the need to integrate a variety of sources and techniques to develop the most dynamic and complete picture of past conditions is evident (White and Walker 1997, Foster and Motzkin 1998).

Both culturally-derived and biological evidence have limitations, as each type of evidence is subject to a unique form of "filtering" (Swetnam et al. 1999). Biological and physical processes filter natural records, and our ability to reconstruct natural conditions depends on the degree to which the nature of the filtering process is understood, and the extent of the filtering. For example, environmental factors influencing an ecosystem may change over time, or responses to similar environmental disturbances may differ between sites (Swetnam et al. 1999). Culturally-derived evidence and documentary records undergo a form of cultural filtering, where records vary in availability and technical quality (Swetnam et al. 1999). For example, during the mid 19th century, timber harvesting in British Columbia occurred preferentially near waterways, as water was the primary means of transporting logs (Drushka and Konttinen 1997). Inland forests therefore were not often harvested, and their condition not documented. As such, most inland forest that are not close in proximity to lakes or rivers lack historic records on vegetation.

Over time, there has been considerable variation in the culturally-derived evidence documenting resource use. This variation reflects changes in societal attitudes on the environment, the issues viewed as "constructive" to study at the time, and the types of observations which were commonly recorded (Russell 1997). As the questions being asked by today's researchers are different than those considered important by resource users in the past, it is unlikely that sources that were developed and maintained in a systematic fashion will be located. Rather, the sources available tend to exist as a range of fragmentary evidence.

One author has equated this work to a puzzle, where researchers are familiar with the product, but not the manner by which the pieces were assembled (Russell 1997). In this context, the pieces of the puzzle are the pieces of reference information, or culturally-derived evidence. The completed puzzle is the "picture" of the historical, or natural, ecosystem, or the goal for ecological restoration. Viewing the puzzle as old, with many pieces missing or broken, may further extend this analogy. It is therefore necessary to interpolate the gaps in the picture using the fragmentary pieces of evidence available.

HISTORICAL INFORMATION FOR THE JPRF

A number of historical sources were collected to support ecological restoration on the JPRF, namely: ethnographic literature, manuscripts and government reports, oral histories, maps and photographs. Each source has strengths and weaknesses when considered within the context of supporting ecological restoration. Documentary information available for the JPRF dates back to the establishment of the Pinchi Mercury Mine in 1940. It is known that prior to 1940, the Tl'azt'en Nation lived in and managed the area for subsistence purposes, and Tl'azt'enne continue to utilize the area for hunting, trapping and cultural activities (Morris 1999). Information regarding traditional use exists primarily as recorded oral histories. Evidence regarding the activities of early European explorers, traders and trappers has not been located for the JPRF.

Locating Culturally-Derived Evidence

Historical information to support ecological restoration on the JPRF has been found at the local, regional and provincial levels. At the local level community museums, district government offices, archives and libraries contained a limited amount of information concerning forest operations and past land use on the JPRF. Also, First Nations frequently have information documenting traditional use and historic landscape conditions. Experiential knowledge holders are individuals who have gained knowledge through direct and indirect land use, and include both Aboriginal and non-Aboriginal community members. These individuals were a rich source of information for this study, as several had retained written records and/or maps of the area, or they were aware of where such information could be located. At the regional level, museums and archives, district and regional government offices also house information on local forest history. At the provincial level, government offices, museums and archives hold a diverse range of historical forest information. These include forest harvesting records that covers many of the major forestry centres (past and present) in British Columbia, including the region which contains the JPRF. A wide-ranging search for historical information to support ecological restoration on the JPRF was conducted that focused on the aforementioned locations. The following is a generic description of the information collected, and the information available in British Columbia.

FORMS OF CULTURALLY-DERIVED EVIDENCE IN BRITISH COLUMBIA

Historical evidence, or information collected was organized into four broadly defined categories, including: (1) Aboriginal history, (2) written records, (3) oral history, and (4) maps and photographs. Although distinct categories were established for purposes of facilitating data analysis, sources were by no means mutually exclusive, and considerable overlap occurs between each source. For example, although maps and written documents are distinct categories, most of the maps used in this study were found within written documents. Or, although Aboriginal history and oral history are separate categories, a key form of Aboriginal history includes oral history.

Aboriginal History

Aboriginal land use and management practices have profoundly influenced ecosystems at multiple levels (Anderson 1996, McCann 1999a, McCann 1999b). Both plants and animals were harvested and managed sustainably (Turner and Kuhnlein 1983). The knowledge gained from the close ties Aboriginal peoples have to the land is termed Traditional Ecological Knowledge (TEK). Many authors consider TEK information complementary to scientific and other forms of information (e.g. Berkes 1999). Ecological restoration may not be complete if it fails to consider the rich knowledge, traditions and practices of Aboriginal cultures (Soulé and Kohm 1989, Anderson 2001). TEK can provide evidence of the biological richness of historical ecosystems, and provide models for sustainable resource use (Jordan et al. 1988, Jordan 1994, Turner et al. 2000). According to Anderson (2001), Aboriginal history may be further classified as (a) oral histories and participant observations with Aboriginals, (b) ethnographic literature, (c) museum artifacts, (d) ecological field experiments, and (e) plant and animal remains in an archaeological context. In this work, several sources of ethnographic literature are used to support ecological restoration on the JPRF.

The JPRF is situated in the traditional territory of the Tl'azt'en Nation, located north of the village of Fort St. James in the Fraser River watershed (Morris 1999). Unlike many Aboriginal communities which have not yet documented their experience and knowledge of the land, Tl'azt'en Nation have compiled an extensive body of oral and cartographic information related to their cultural experience and knowledge.

Tl'azt'en Nation granted access to several information sources housed in their Natural Resources and Administration offices, located in the community of Tache, British Columbia. The first source was a collection interviews from Dr. Annie Booth, examining the Tl'azt'en Nation's Tree Farm License (TFL) 42[3]. This source provided a significant body of information including interviews with elders, Band Council members, forest workers, individuals linked with TFL 42 and other community members. While the focus of this research was on TFL 42, discussions included traditional land management in Tl'azt'en traditional territory, and industrial land use history within the JPRF. The second information source included summaries of interview and focus group transcripts conducted with Tl'azt'en elders between 1978 and 1995, which concentrated on traditional life in Tl'azt'en territory prior to 1950.

Written Records

Written records are useful for evaluating change in species composition, age distribution and landscape structure over time (e.g. Bourdo 1956, Loeb 1982, Kettle et al. 2000, Axelsson and Östlund 2001, McGarigal et al. 2001). An extensive body of written records exists documenting

[3] Forest Renewal British Columbia Research Grant. Annie L. Booth, Principal Investigator; Gail Fondahl, Co-Investigator. June 1997-May 1999. Linking Forestry and Community in the Tl'azt'en Nation: Lessons for Aboriginal Forestry.

past land use practices and natural history of British Columbia, and written records that support ecological restoration on the JPRF include both manuscripts and government records.

Manuscripts include unpublished, non-government records generated by individuals, families, organizations or businesses. Access was granted by experiential knowledge holders to several unpublished reports regarding land use practices in and around Fort St. James.

Three permanent sawmills are known to have existed on the JPRF, and access was granted to original documents produced by Industrial Forestry Services (IFS), a consulting company with a long operating history in central-interior British Columbia. These records relate to one licensee who operated on the JPRF and surrounding areas. The first report focused on the timber supply for operations based on Tezzeron Lake, which specifies a tentative harvesting plan and the timber potential throughout the JPRF[4]. The second report includes a cruise and partial logging plan for a timber sale on the JPRF. This report contains a detailed description of stand conditions prior to timber harvesting and provides supplemental information regarding land use practices[5]. Next, an inventory of the area encompassing the Tezzeron Lake operation summarizes the volume of merchantable trees in the area where Park Brothers Ltd. was operating, including the JPRF[6]. The fourth report details the quality and quantity of mature forest available for harvest throughout the Stuart Lake Public Sustained Yield Unit (PSYU) and operations which persisted within the Stuart Lake PSYU in the mid 1960s[7]. Finally, an evaluation of waste details trees that were cut but not hauled to mill sites on two timber sales on the JPRF[8]. Also, access was granted

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[4] Industrial Forestry Service (IFS). 1962. Park Brothers Limited: timber supply for Tezzeron Lake operation. Industrial Forestry Services, Prince George, BC. *Unpublished Report.*

[5] Industrial Forestry Service (IFS). 1956. Park Brothers Limited: cruise and partial logging plan for TSX65876. Industrial Forestry Services, Prince George, BC. *Unpublished Report.*

[6] Industrial Forestry Service (IFS). 1965a. Park Brothers Limited: summary of timber values within operational areas In the Stuart Lake PSYU. Industrial Forestry Services, Prince George, BC. *Unpublished Report.*

[7] Industrial Forestry Service (IFS). 1965b. Park Brothers Limited: inventory of Tezzeron Lake operating unit. Industrial Forestry Services, Prince George, BC. *Unpublished Report.*

[8] Industrial Forestry Service (IFS). 1966. Park Brothers Limited: waste evaluation – TSX65876 and TSX69349. Industrial Forestry Services, Prince George, BC. *Unpublished Report.*

to several unpublished reports produced by an experiential knowledge holder which describe land use history in the Prince George and Fort St. James areas, and silvicultural systems employed in these areas.

Unfortunately, the value of written records for understanding forest history and for supporting ecological restoration in British Columbia is generally not well known or appreciated. For example, the owner of one lumbering company which operated on the JPRF disposed of all records relating to past timber harvesting one year prior to this research.

> *"Just a year ago I took out, I had all the old timber sales contracts, and maps and that stuff just exactly a year ago I took it out and put it into a bonfire" – Owner/operator Cassiar Forest Products, 2001*

Government records include documents created by provincial government departments or ministries. Those records that are particularly relevant to ecological restoration include records that relate to land and resource management. These include timber records (e.g. reconnaissance, cruising and sales), Department of Agriculture records, lot registers, water rights records and park records. Government records contain information about government policy regarding land management, the types of vegetation in an area, agricultural practices, land settlement and division, and decisions surrounding resource use and conservation. Although records relating to mineral exploration associated with the Pinchi Lake Mercury Mine are believed to exist, it was not possible to obtain these records for use in this research.

Two key forms of government records were used in this study. First, access was granted to an inventory of abandoned sawmill sites in the area, as prepared by the Fort St. James Forest District. This inventory contains maps and photographs of abandoned sawmill sites and was useful for understanding how sawmills were distributed across the JPRF[9].

[9] Turner, T. 1997. Sawmill inventory and preliminary investigation. MO8199701, Fort St. James Forest District, Fort St. James, BC. *Unpublished Report.*

The second form of government records used in this research includes timber sale files. Timber sale files were created to document timber allocation and harvesting activities from 1912 through the 1970s in British Columbia. These files vary in technical quality, but generally contain information on land cover, management practices, ownership, physical features and timber yield within the bounds of the timber sale. Timber sale files present an opportunity to extract detailed information about land use and landscape structure at relatively large spatial scales. Eighty-six timber sale files were uncovered for the JPRF, spanning a 35 year period (1940 to 1975). Timber sale files were accessed through the British Columbia Forest Service, Inventories Division, in Victoria. The files were organized chronologically and an index summarizing the files was compiled. A summary of the documents contained within each file was created and included in the index. Additionally, an ecological summary based on any ecologically relevant information contained in the file was written for each timber sale and included in the index.

Oral Histories

Many users of the land have considerable knowledge about land use history and historical ecosystem conditions, but few individuals have recorded this information (Fogerty 2001). When working within the bounds of an oral history, however, people are often able to recall this information. An oral history is a structured conversation between an interviewer, who is pursuing a specific range of topics, and an interviewee, who holds the information related to those topics (Fogerty 2001). To date, oral sources have most often been used to develop an understanding of land use history, and less often been used to interpret historical ecological conditions. In the context of this research, oral histories include new interviews conducted to support this study.

Candidate interviewees were selected to represent a diversity of perspectives related to past land management practices and historical ecology on the JPRF. Additional interviewees were identified using the snowball sampling method, where the interviewee is asked about other potential interviewees. In total, ten individuals were interviewed using a semi-structured interview guide to organize the interview-discussion (McCracken 1988).

When individuals agreed to participate, they were sent a detailed letter explaining the project, rationale for their selection, and the ethical considerations related to the project. After the information package had been received and read, interviewees were contacted again to arrange an interview and clarify any of the interviewees' questions.

Overstory and understory vegetation, roads, riparian areas, fire, insects and diseases were important forest condition themes identified from the literature, and interview questions were designed to generate discussion about these specific forest characteristics. Questions were also asked about land use practices and land use history to generate discussion about changes in forest condition. Interviewees were requested to disclose demographic information to determine which particular geographic areas they were familiar, and to what time period their information could be applied.

Interviews were transcribed in full following the interview. When possible, both the interviewer and interviewee edited the transcripts (Caunce 1994). Interviewees were given the opportunity to omit any portion of the conversation and to ensure names and facts were correct to the best of their knowledge. The edited versions of the transcripts were used for analysis. Transcripts were analyzed to summarize information related to criteria described above, and ecological summaries from each interview were combined to identify similarities and differences in information. Interviewees were also grouped according to geographic expertise and time period of experience.

Maps and Photographs

Maps and photographs present the most obvious source of information regarding past landscape conditions where details are spatially comparable over time (Reithmaier 2001). This comparison is possible because maps and photographs have natural landmarks such as hills, lakes and streams that are very similar to landscape features that exist today. Details such as vegetation types may be interpreted, if the researcher has an understanding of the map-making standards at the time the map was produced (Russell 1997). Maps used in this research generally accompanied written records, such as timber sale files, and in these cases it was possible to extrapolate the information from written records to specific areas on the map.

Direct evidence of the past can be found in photographs, and comparisons may be made between photographs taken of the same area, at a similar scale, over different time periods (Kilgore 1972, Vankat and Major 1978). Photographs are a selective record of the past, as attractive scenes or culturally significant sites have a higher likelihood of being photographed (Stephenson 1999). Also, photographs represent the three-dimensional world in only two dimensions. Several still photographs have been uncovered which depict the natural environment and land management practices on the JPRF. The photographs taken of natural areas, however, were not specific enough to permit repeat photography of the area. The photographs documenting management activities offer visual insight into the activities and practices which caused changes on the landscape, such as sawmill equipment and harvesting practices.

Changes in landscapes are also visible through vertical aerial photography (Russell 1997, Egan and Howell 2001); however, in some cases aerial photographs may postdate the desired time period for restoration activities (Duncan et al. 2000). Changes in vegetation can be digitally analyzed over time using aerial photography, digital image processing and geographic information systems (GIS) (Mast et al. 1997, Hessburg et al. 1999, Cameron et al. 2000, Jenkins and Parker 2000). Aerial photographs became generally available in British Columbia during the 1930s, using technology developed during World War I. Aerial photographs may present problems of interpretation depending on the level of vegetation classification desired and scale of the photos, but are useful in recording landscape changes over time and establishing boundaries of land use (Kettle et al. 2000), and are particularly useful when combined with ground surveys. Stereoscopic aerial photographs taken in 1947 were obtained for the JPRF. An orthophotograph was created from these aerial photographs, and the forest vegetation was classified to current standards using manual and automated aerial photograph interpretation techniques.

SUMMARY

Subsequent chapters of this thesis describe, in detail, methods for using the aforementioned sources to support ecological restoration on the JPRF.

- Chapter 3 -

Using Land Use Patterns to Guide Ecological Restoration in Sub-Boreal British Columbia[10]

INTRODUCTION

Human influence can change natural landscapes through the alteration of natural ecosystem cycles, habitat loss and fragmentation (Noss et al. 1997). In many areas, industrial land use is the leading cause of habitat degradation, and contributes to rapid decline in biological diversity (Walters 1992, Hunter et al. 1995). Over the past 70 years, human influence has resulted in significant changes in the forests of North America (Jenkins and Parker 2000). The effects of long-term climate change (Millar and Woolfenden 1999), as well as short-term changes from land use and management practices, persist within forests (Kettle et al. 2000), and are known to influence processes of ecological succession (Myster and Pickett 1990). In human-dominated ecosystems, land use is a major determinant of landscape structure and composition (Pan et al. 2001), and these changes are influenced by both social and economic factors (Robiglio 2000).

By understanding the cumulative effects of past management practices on a landscape, it is possible to better understand the ecological impacts of these practices (Axelsson and Östlund 2001). If ecological restoration of landscapes that have been altered by land use is a management objective, a successful ecological restoration program involves identifying the processes leading to landscape decline, to ensure the deleterious forces are controlled (Hobbs and Norton 1996). If the processes are not controlled, they may continue to cause degradation following ecological restoration. The most important role of land use history in ecological restoration is the identification of the anthropogenic forces acting on the ecosystem.

[10] A version of this chapter has been submitted for publication under the following authorship: M.K. MacGregor and S.M. Dewhurst.

Understanding land use history in the context of ecological restoration is complicated by the fact that forests may retain a "natural" appearance following industrial management. In spite of their appearance, however, these systems may have undergone significant structural and/or ecological change that is outside the natural range of variability. For example, the *Pinus ponderosa* Dougl. ex. Laws. (ponderosa pine) ecosystems of the southwestern United States have undergone substantial changes resulting from the century-long practice of controlling fires in the interests of protecting timber and other resource values (Covington et al. 1994). These forests are naturally regulated by fire, and the exclusion of fire has resulted in increase in live and dead tree biomass, decline in productivity of herbaceous plants, increasing susceptibility to insect and disease and an increase in crown fires (Fulé et al. 1997). Understanding the natural and anthropogenic disturbance history and subsequent landscape change in these, and other, ecosystems sets the stage for more effective ecological studies, natural resource management and environmental modeling (Cissel et al. 1994, White and Walker 1997, Swetnam et al. 1999, Kettle et al. 2000, Egan and Howell 2001).

An additional role for historical studies in ecological restoration is in the characterization of the location, intensity and duration of past natural disturbance patterns. It is important to understand natural disturbance processes acting on the landscape, or processes which no longer play a key role (e.g. fire in areas where fire suppression has been a management practice). Understanding the natural disturbance regime under which the species, or ecosystem, in question evolved is key to evaluating the ecological consequences of forest management (White 1979). In sub-boreal British Columbia, Canada, forest ecosystems have undergone significant changes since the initiation of industrial timber harvesting and forest management (Ward 2001). Prior to the initiation of industrial land use, this region was heavily influenced by aboriginal management (Turner et al. 2000), and was infrequently disturbed by catastrophic natural events, such as fires.

Following European settlement in British Columbia during the mid-1800s, forest ecosystems were influenced by timber harvesting and livestock grazing. Simultaneously, many forest ecosystems were indirectly altered through fire suppression. In much of sub-boreal British Columbia, late successional tree species were harvested using selective harvesting and diameter-limit logging practices. These practices have resulted in serious challenges for ecological restoration, conservation and forest management.

Attempts to quantify landscape changes that result from anthropogenic causes are numerous (e.g. Bromly 1935, Bourdo 1956, Moore et al. 1999, Stephenson 1999, Duncan et al. 2000, Jenkins and Parker 2000, Axelsson and Östlund 2001, Pan et al. 2001); however, published accounts describing changes in forested ecosystems resulting from land use in sub-boreal British Columbia have focused on changes in landscape structure, and not the processes leading to these changes (e.g. Sachs et al. 1998). This paper describes sources of historical information relevant to understanding the industrial land use history of forests in sub-boreal British Columbia. This information is used to describe three key factors which have influenced change in landscape condition in sub-boreal British Columbia.

STUDY AREA

This study was conducted on the John Prince Research Forest (JPRF) located in sub-boreal British Columbia. A detailed description of the study area can be found in Chapter 1 of this thesis.

INFORMATION SOURCES AVAILABLE

Oral histories and government reports were used to analyze trends in land use on the JPRF between 1940 and 1970. This includes the period between the initiation of industrial harvesting activities and the availability of modern records.

Oral histories were collected from local knowledge holders who lived or worked in the JPRF and surrounding areas between 1940 and 1975, and the interview transcripts were analyzed for words, phrases or themes related to land use history. Interviewees were selected to represent a diversity of perspectives related to industrial land management activities. In addition, a collection of interview transcripts completed with members of Tl'azt'en Nation and other resource professionals were reviewed. Oral histories were used to corroborate information from government reports, and helped to clarify information in records and helped understand conventions used in the past.

Timber sale files were obtained and analyzed for the JPRF. Timber sale files are a form of government report documenting timber harvesting activities in British Columbia. These files were examined to characterize the distribution of management activities, to determine ownership patterns and to understand changes in management conventions (e.g. rules and standards). In British Columbia, timber sale files are the most consistent and accessible record of land use history in forests. Information from oral histories and timber sale files were correlated, and combined with data from unpublished reports. The data was compiled into a composite land use history for the JPRF.

An understanding of industrial land use practices, and the resulting changes on the landscape structure is critical for developing reference conditions for ecological restoration. On the JPRF we define three factors have strongly influenced industrial land use history in the forests of that region, and the degree of anthropogenic landscape change, including: (1) harvesting effects, (2) mechanical innovation, and (3) silviculture trends.

HARVESTING EFFECTS

Between the early 1900s and the mid-1970s, area-based timber sales were typically used to assign timber-harvesting rights. In a process similar to that used for mining claims, licensees located a merchantable stand of timber and made a written request to obtain rights to harvest the area. If approved, the British Columbia Forest Service would allocate the rights to harvest the timber to the applicant. On the JPRF, the likelihood that an area was harvested depended on the historical market demand, proximity to waterways, and terrain.

Historical Market Demand

Two different forms of market demand drove harvesting on the JPRF: processing activities related to the development of cinnabar deposits on Pinchi Lake, and lumbering operations on Tezzeron Lake.

Development of Cinnabar Deposits at Pinchi Lake - The Pinchi Mercury Mine is located adjacent to the JPRF on the north-shore of Pinchi Lake (Figure 3-1). The Consolidated Mining and Smelting Corporation of Canada (Cominco) developed cinnabar deposits located in the area. When cinnabar is harvested it releases elemental mercury, which was used to construct fuses, batteries and precision instruments during World War II. Cordwood was harvested from stands east of the mine, and this wood was used to fuel a crusher, kiln and condenser for the production mercury from the ore. In 1944, the Allies secured supplies of mercury from Spain and Italy, and the Pinchi Mercury Mine was subsequently closed. It was later re-opened in the 1960s, and lumbering operations, continued in the area into the early 1950s and beyond (Morris 1999).

Lumbering operations at Pinchi Lake in the 1940s focused on harvesting Douglas-fir trees for building permanent structures associated with mine operations. Also, cordwood was harvested as fuel for the mine, and harvesting associated with the Pinchi Mercury Mine was less-selective than harvesting that occurred in other areas of the forest. All available tree species were harvested for cordwood; however, operators preferred Douglas-fir and *Betula papyrifera* Marsh. (paper birch). Paper birch emitted intense heat, but was relatively uncommon in the area. Douglas-fir was readily available and emitted substantial heat, and was therefore the predominant species harvested.

Lumbering Operations on Tezzeron Lake - During the 20 years following World War II, Douglas-fir and *Picea glauca* (Moench) voss., *Picea engelmannii* Parry ex. Englm., and their naturally

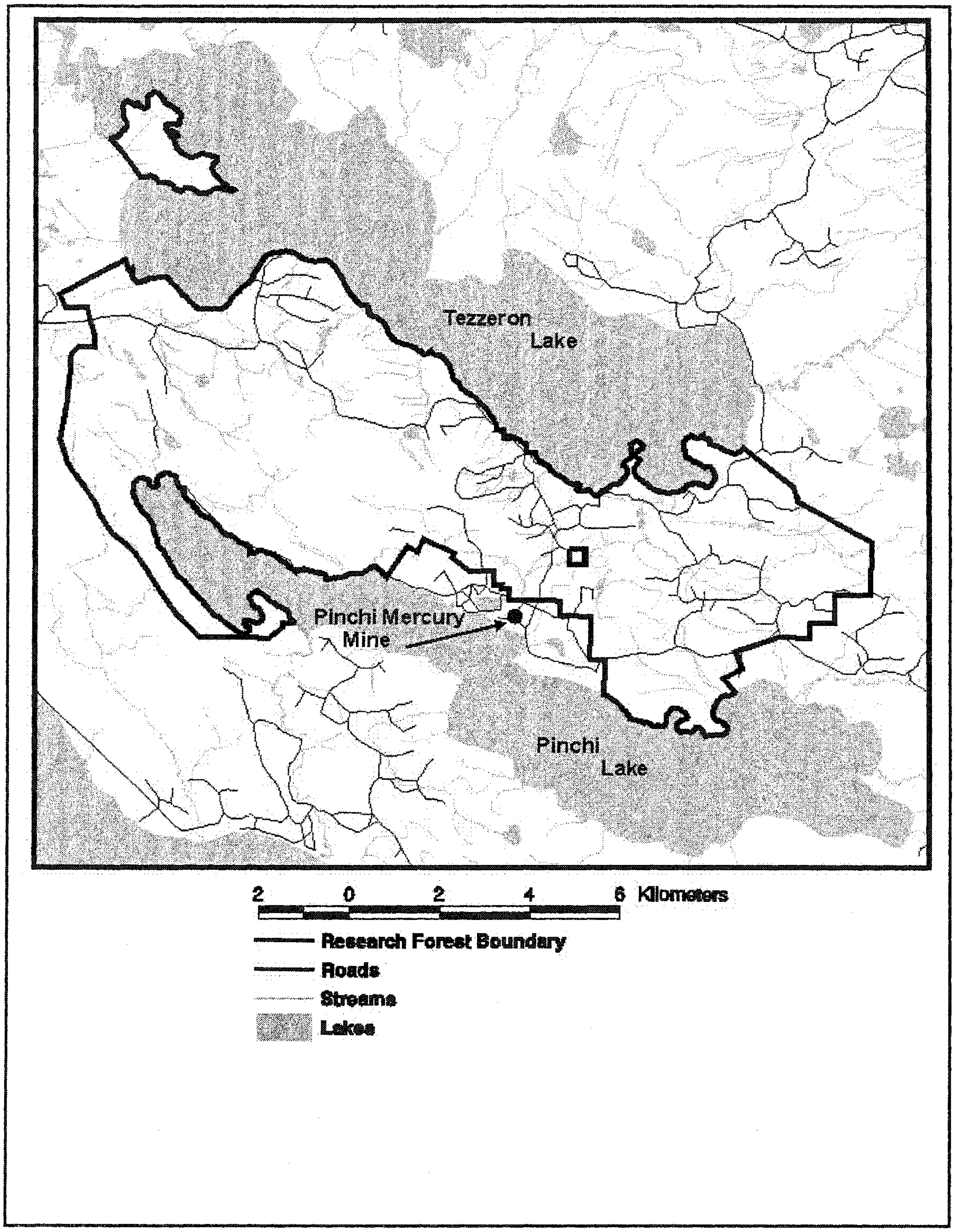

Figure 3-1 Map illustrating the location of the Pinchi Mercury Mine located adjacent to the John Prince Research Forest in sub-boreal British Columbia, Canada.

occurring hybrids (interior spruce) were the preferred commercial species in sub-boreal British Columbia, and on the JPRF. As the cost was high to haul lumber in remote areas (e.g. the area that is now occupied by the JPRF), licensees sought out prime stands of timber to cover high costs associated with transportation. Records indicate the Douglas-fir forest cover in the northern part of the JPRF near Tezzeron Lake was of a very high quality and consequently this species and interior spruce were harvested in that area. Patches of *Pinus contorta* Dougl. ex. Loud. (lodgepole pine) and *Abies lasiocarpa* (Hook.) Nutt (subalpine fir), although merchantable, were generally avoided due to the low commercial value of these species at the time.

Proximity to Waterways

Historically, water was the most readily available means of transporting logs, and industrial activities developed in close proximity to rivers, lakes and oceans (Drushka and Konttinen 1997). The JPRF is an isthmus (i.e. surrounded by water on two sides) significantly affected by timber harvesting. Trees were harvested from stands near lakeshores and transported by water to the sawmills. Close proximity to such large bodies of water increased harvesting activities on the north and south sides of the JPRF. This trend is reflected in the location of permanent sawmill and in the location of timber sales.

Landings were built on the shore of the lake near an active timber sale. Felled trees were hauled to landings and cut into smaller lengths. Operators often cut logs on the ice during the winter and left wood on the ice. When the lake ice melted in spring, logs would float on the water, and sawdust and other debris would settle to the bottom of the lake. Throughout the spring and summer a boom (i.e. a chain of floating logs which was secured together and enclosed other free-floating logs) was moved to the sawmill with a tugboat or river barge.

Permanent mills on the JPRF were built on lakes near the highest quality and most accessible stands of timber. When timber sales were at a considerable distance from the sawmill, the damage inflicted to the trees by dragging trees during skidding was substantial, reducing the value of the logs. Therefore, operators used water to transport logs over long distances.

Terrain

Many areas of the JPRF are characterized by steep terrain. Limitations in available equipment made logging difficult in these complex areas, and moving logs down steep grads was extremely dangerous and therefore avoided. For example, areas like Pinchi Mountain (in the center of the JPRF) were not heavily impacted by timber harvesting in part because of the steep and difficult terrain, and because of the distance from the water.

MECHANICAL INNOVATION

In this context, mechanical innovation refers to the impacts that result from different forms of harvesting equipment. As advances in mechanical equipment ensued, changes in landscape condition on the JPRF. Changes in mechanical technology on the JPRF included advances in sawmill technology, advances in wood transportation, and road construction technology.

Advances in Sawmill Technology

There were both portable and permanent sawmills on the JPRF (Figure 3-2). Sawmills responded to market definitions of premium tree species and sizes, and trees were harvested accordingly. Throughout the 1950 and 1960s, there were approximately 20 to 25 portable sawmills in the forests north of Fort St. James, many of which were situated between Pinchi and Tezzeron Lakes on what is now the JPRF (Figure 3-3). Portable mills were small operations, producing approximately 18,000 to 20,000 board feet (62.6 to 69.6 m^3) of lumber daily. These mills were moved from one timber sale to the next, and scrap wood and other waste was left behind. Remnants of sawdust piles can provide evidence about the distribution of sawmills on the landscape (T. Turner, personal communication). Portable mills were often established in heavily

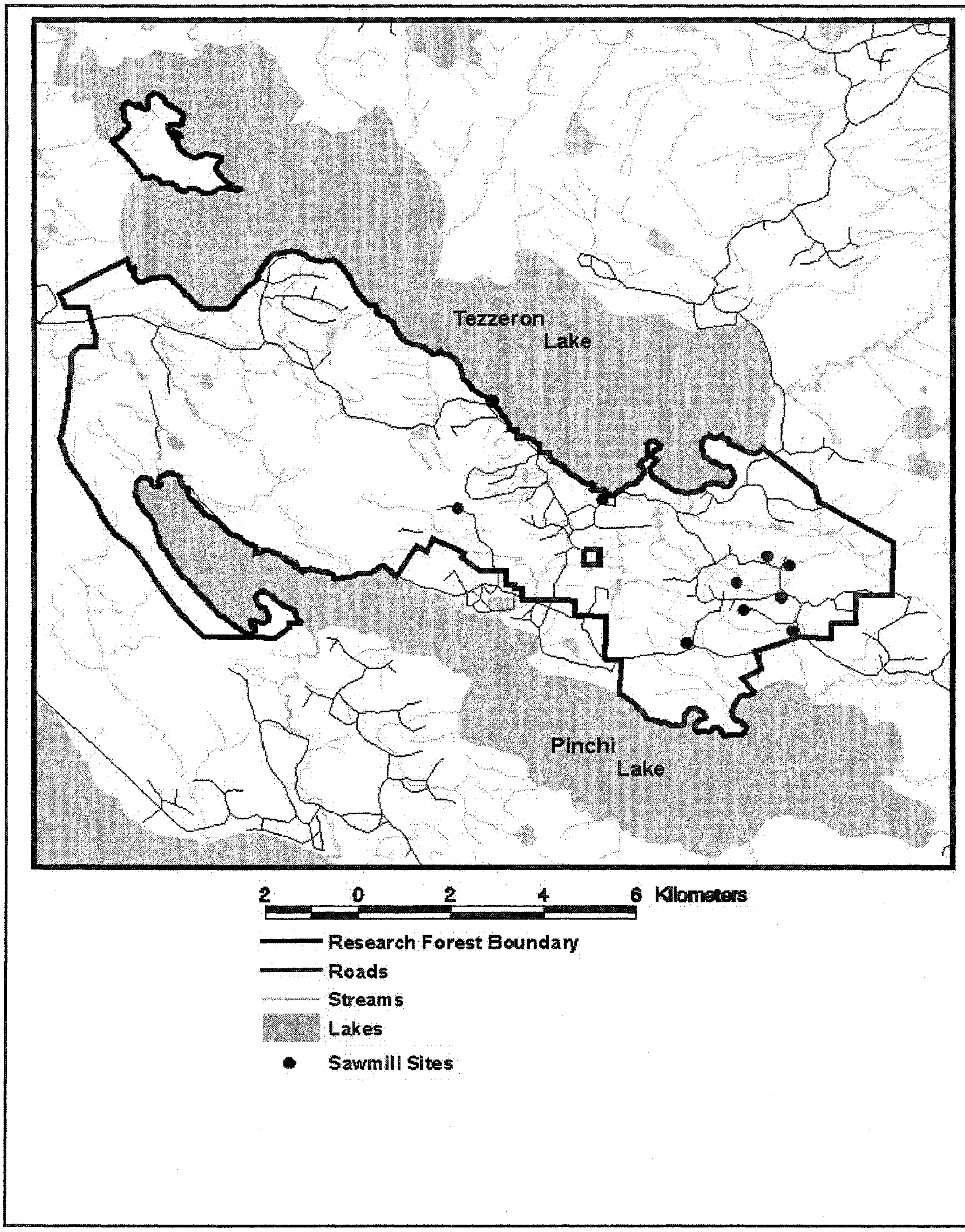

Figure 3-2 Map illustrating the location of the permanent and temporary sawmill sites on the John Prince Research Forest in sub-boreal British Columbia, Canada[8].

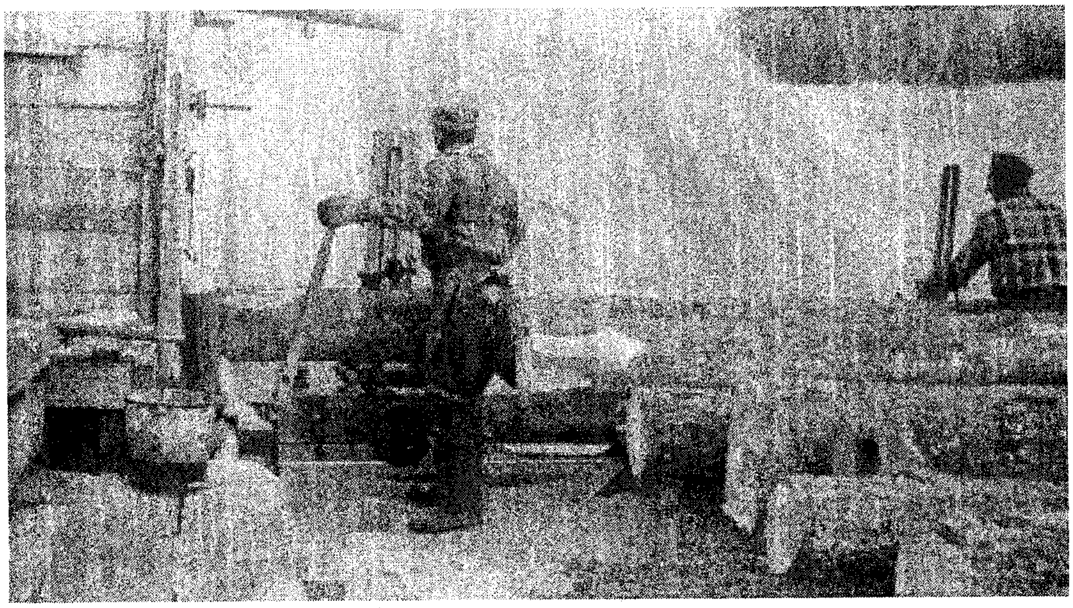

Figure 3-3 One permanent sawmill located on Tezzeron Lake on the JPRF in the 1950s (photograph courtesy of L. Williamson).

forested areas away from significant waterways. Skidding logs to these mills was restricted to a distance of about ¼ mile (0.4 km). As a result of the limited scale on which portable mills could operate, these mills were dismantled, moved and reassembled at a new timber sale each season. These practices resulted in relatively small areas of the forest being impacted by harvesting.

Three permanent sawmills were known to have operated on the JPRF. The first was located on Pinchi Lake, near the Pinchi Mercury Mine. This was a small operation, which held approximately four small timber sales at one time, and employed approximately 20 individuals. The second, Cassiar Forest Products, was erected on Tezzeron Lake near Sunshine Island in 1955. This mill operated and produced dimensional lumber until 1964 when it was out competed by larger mills in the area. Through its nine year operation, the mill expanded from five to 37 employees. A resort was established on the mill site after the mill was closed which operated until 2002 when it was aquired by the JPRF for a research and training facility.

The third permanent mill was owned and operated by Park Brothers Ltd. and ran between 1955 and 1969. This mill produced approximately 50,000 to 60,000 board feet per day (174 to 209 m^3), and was considered the most stable lumbering operation on the JPRF. Trees were cut to size and length at the mill on Tezzeron Lake, and logs were shipped to a planing mill in the town of Vanderhoof (approximately 100 km away) to be sorted, have the bark peeled, and cut into lumber. Cassiar Forest Products and Park Brothers Ltd. focused harvesting activities on the northern side of the JPRF and harvested primarily Douglas-fir and interior spruce. Park Brothers Ltd. was taken over by Canadian Forest Products Ltd. in 1969, after which processing operations were centralized in the town of Fort St. James.

Sawmills on the JPRF increased in size to increase production of lumber and compete with larger mills. Impacts that resulted from the higher capacity mills on the north side of the JPRF was different than the impacts that resulted from the smaller portable mills that were interspersed over the landscape.

Advances in Wood Transportation

Harvesting on the JPRF occurred during the winter and logs were skidded to haul roads with a team of horses and loaded onto sleighs. Ice roads were built to help pull sleighs, and significant attention was focused on creating the most efficient logging operations using horses and sleighs. The introduction of the crawler tractor led to the expansion of lumbering operations on the JPRF. Crawler tractors were used for a diverse range of tasks, and replaced horses as the dominant log skidding technology. A winch was fastened to the crawler tractor, and logs were dragged behind the machine. The increased power offered by the crawler tractor allowed operators to skid logs up to ¼ mile (0.4 km) and haul larger loads (often more than one log at a time depending on tree size). Wagons and sleighs, formerly drawn by horses, were adapted for use with crawler tractors, and the addition of a blade to the front of the crawler tractor assisted with road construction.

The next major change for harvesting operations was the introduction of the arch truck (Figure 3-4). The arch was a device mounted on the back of a truck to elevate one end of the logs during skidding. Like the crawler tractor, the arch truck allowed operators to move logs over longer distances and handle significantly heavier loads. These two systems expanded harvesting into previously inaccessible areas, increasing the volume of wood harvested.

Road Construction Technology

Prior to industrial land use the JPRF was very isolated, with no evidence of roads. Aboriginal users describe an intricate trail system in the area that facilitated foot transportation from settlement areas to the *keyohs*, or family hunting and trapping grounds. The first evidence of road building came with the establishment of the Pinchi Mercury Mine. Road development increased in the southern portion of the JPRF with mine expansion and the establishment of several sawmill operations. The first road to Tezzeron Lake was constructed in 1951, and a second road to Tezzeron Lake was built in 1956. Park Brothers Ltd. built most of the roads on the JPRF between 1955 and 1969 to ease accessibility to timber sales.

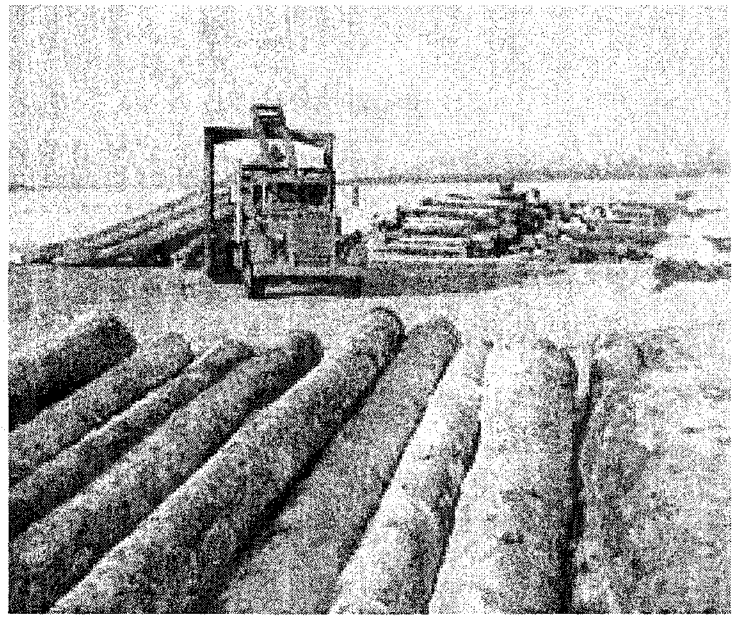

Figure 3-4 Arch truck in the 1950's transporting logs on Tezzeron Lake (photograph courtesy of L. Williamson).

The majority of the roads that existed prior to 1970 on the JPRF were winter roads. It was difficult to build summer roads in many areas, due to inadequate equipment and the wet terrain common in valley bottoms where road building was most economical. When roads were built in wet areas, the builders used non-merchantable deciduous species to stabilize roads (corduroy roads). Also, when harvesting in areas characterized by difficult terrain and steep grades, roads were often built through creek bottoms. When Canadian Forest Products Ltd. took over operations on the JPRF in 1969, several winter roads were upgraded to create permanent roads, some of which still exist today (Figure 3-5). Other roads that were not upgraded by have become inaccessible or inactive.

SILVICULTURE TRENDS

Historical timber harvesting was undertaken with the same intent as silviculture is typically applied today. The term silviculture refers to the "treatments applied to forests to maintain and enhance their utility for any purpose" (Smith et al. 1997). Historically silviculture on the JPRF was primarily focused on short-term profit and job creation. Silvicultural practices during this time were experimental and based on trial and error. Near Pinchi Lake, where timber was harvested to fuel the mine, small clear-cuts dominated the landscape. Where the forest was selectively logged for Douglas-fir and interior spruce near Tezzeron Lake, the stands that remained distinct in character.

In selectively harvested areas, utilization standards for tree species and size underwent many changes from the 1940s to the 1970s, and records of past harvesting operations on the JPRF reflect these changes. Single-tree selection was the predominant silvicultural method used in the 1940s, and this practice changed to diameter-limit harvesting. Diameter-limit harvesting was the dominant silvicultural practice documented on the northern portion of the JPRF. Diameter-limit harvesting involves removing the highest quality and most vigorous trees greater than a set

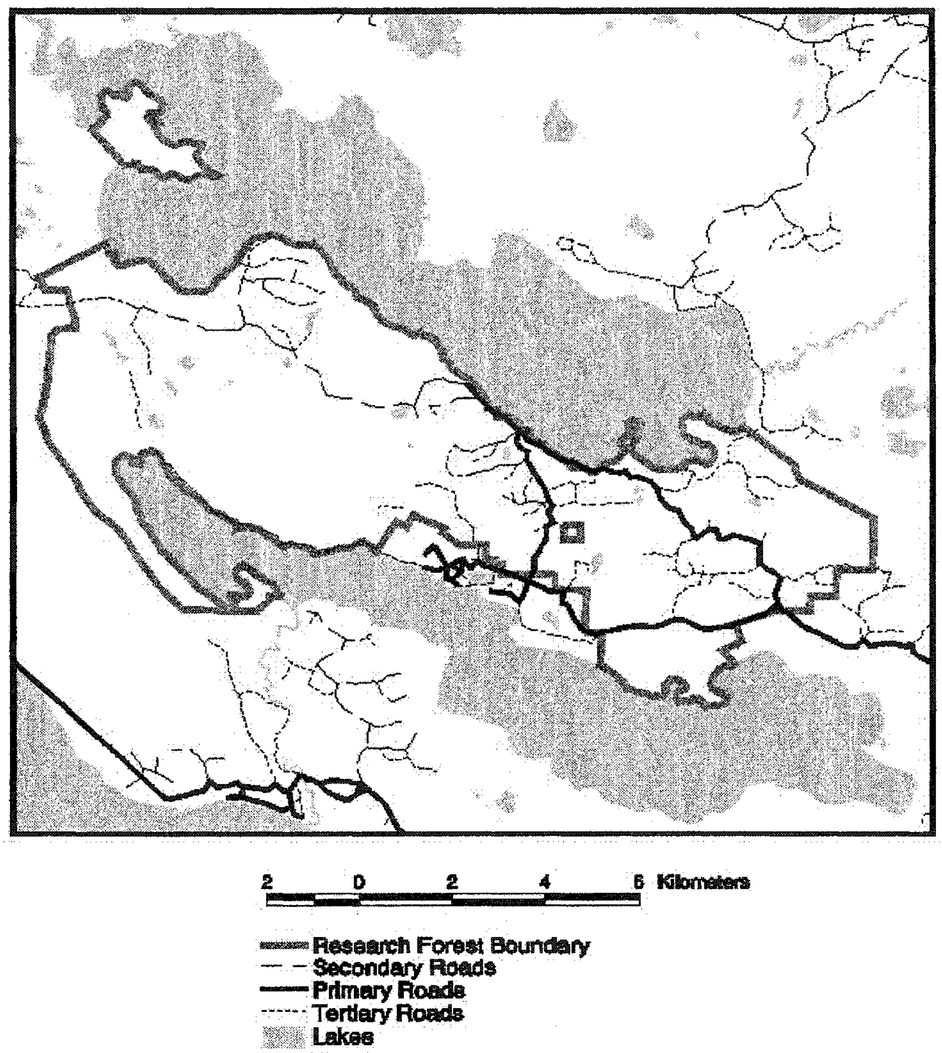

Figure 3-5 Map illustrating the location of primary, secondary and tertiary roads on the John Prince Research Forest in sub-boreal British Columbia, Canada in 1999.

diameter from a site, leaving the suppressed understory and poorer quality trees to naturally restock the site where conditions were favourable (Smith et al. 1997). These practices generally do not consider future stand conditions, altering patterns of regeneration and succession. During the 1950s and 1960s, operators were not permitted to harvest trees <140 years. The diameter limit originally established by the Forest Service was 18 inches, thus trees smaller than 18 inches (46 cm) in diameter were not harvested. The diameter limit was later reduced to 16 inches (41 cm), indicative of the increasing scarcity of large trees, and changes in technology and markets. As time progressed, the diameter limit continued to decrease, and operators were permitted to harvest smaller trees. Multiple waves of harvesting occurred in the northern portion of the JPRF, as harvesting rules changed and the diameter limit was reduced, increasing the range of merchantable trees. For example, in the mid 1950s strip cutting was introduced, where harvesting was done in strips and "leave strips" were left behind to naturally regenerate the forest. When possible, operators included Douglas-fir and interior spruce in harvested strips and lodgepole pine and subalpine fir remained in leave strips. When a wider variety of species and sizes became merchantable operators returned to harvest leave strips. During this time, Douglas-fir was the most commercially valuable species in the region, and harvesting focused on this species altered the representation of Douglas-fir in these forests today.

DISCUSSION

Research focused forest restoration or management must consider the historical context in which past communities developed, and subsequent changes brought about by industrial land management (Kettle et al. 2000). This study marks the first in-depth attempt to understand the industrial land use patterns that have impacted landscape structure in sub-boreal British Columbia. Through this work we have identified and described three factors that have dictated land use patterns on the JPRF, including: harvesting effects, mechanical innovation, and silviculture trends. These factors are not mutually exclusive and all three factors have lead to changes apparent on the JPRF, creating the primary disturbance regime.

Reference periods vary for different landscapes, depending on the natural rotation of the forest, and the time period when industrial land use activities occurred. The early 1940s were selected as a suitable point in the natural forest rotation to study, as industrial management was the primary factor leading to observed degradation on the JPRF. Also, information sources were available for the 1940s, but not before.

Stands that were not harvested were left to develop naturally. These stands were often small remnant patches of the original forest, and such stands are often were heavily impacted by edge effects (White and Walker 1997). Also, unharvested areas often occur on less productive sites or in inaccessible sites. Understanding where and how harvesting impacted the landscape is important for establishing target areas for ecological restoration, but one must recognize that unharvested areas may not be representative of natural forest conditions.

The JPRF is located within Tl'azt'en traditional territory. Tl'azt'en Nation managed the flora and fauna of the region prior to 1940 and concurrently with industrial management in the years following 1940. A question that needs to be answered to better understand natural landscape structure is the role of traditional land management on the JPRF. This study has focused on industrial land management; however, cultural practices of aboriginal people are known to have altered ecosystems prior to this time (Anderson 1996, McCann 1999b). This information is of great importance, as ecological restoration must not only reintroduce the structure of the historic ecosystem and eliminate deleterious forces, but also reproduce the disturbances (natural and anthropogenic) that shaped the ecosystem (Anderson 1996). A more comprehensive understanding of traditional land management on the JPRF is critical to understanding the forces which shaped the ecosystem.

Industrial land use in forests of sub-boreal British Columbia has resulted in changes in landscape condition (i.e. landscape composition and landscape configuration). Landscape composition refers to the variety and abundance of patch types on a landscape, while landscape configuration refers to the spatial distribution of these patch types (McGarigal and Marks 1995). Specifically, mechanical innovation impacts both landscape composition and configuration, as technological advances influence the species and size of trees harvested (composition), and increase the areas where harvesting was possible by facilitating movement into previously inaccessible areas (configuration). Factors affecting the likelihood of a stand being harvested also impact landscape composition and configuration. Historic market conditions dictated the species and size of trees harvested (composition), and proximity to water and terrain dictated which stands were harvested on the landscape (configuration). Finally, the silviculture systems employed also impact both composition and configuration, as changes in silviculture practices primarily determined changes in size of trees harvested and left behind (composition). Different silviculture systems also leave different patterns on the landscape (configuration).

This paper demonstrates how land use patterns have impacted landscape structure on the JPRF. Understanding how forests have been influenced by past land use is essential to sustainable management of forests. The oral sources obtained were instrumental in reconstructing past land use patterns on the JPRF. It is critical to understand if these changes that have come about as a result of industrial land use are within the natural range of variation for this ecosystem. Quantitatively analyzing changes in landscape structure at the landscape level will further assist in defining goals for ecological restoration on the JPRF.

- Chapter 4 -

Quantifying Effects of Land Use on Landscape Structure in Sub-Boreal British Columbia [11]

INTRODUCTION

The rate and direction of changes resulting from industrial land use in forests over the past century may be outside the natural range of variability (Covington et al. 1994), and these changes may result in habitat loss and fragmentation (McGarigal and McComb 1995, Fahrig 1997, Villard et al. 1999). In contrast to natural disturbances in forests, industrial land use tends to create simplified patches (Meffe and Carroll 1997), causing a reduction in patch size, an increase in patch isolation (Bennett 1999), and more edges (Meffe and Carroll 1997). As changes in landscape structure have direct impacts on ecological function, it is important to maintain large tracts of the landscape with representative seral stages, species distribution, patch sizes and corridors if natural ecosystem functioning is to be sustained (McGarigal and Marks 1995). This may be accomplished in part through sustainable forest management, and through the allocation of parks and protected areas. Although there is some uncertainty (Wennergren et al. 1995), it has been shown that changes in landscape pattern resulting from industrial land use may lead to the decline of many forest-dependant species (Noss 1995). Using natural, or at least historical, forest structure (i.e. forest composition and configuration) to design management regimes and to guide ecological restoration may assist in maintaining natural ecological functioning, and therefore maintain natural levels of biodiversity (Baker 1992, Hunter et al. 1995, Noss 1995, White and Walker 1997, Fulé et al. 1997).

In sub-boreal British Columbia, ecological responses to changes in landscape structure resulting from industrial land use are largely unstudied. Available studies of impacts of forest

[11] A version of this chapter will be submitted for publication under the following authorship: M.K. MacGregor, S.M. Dewhurst, S. Grainger and A.G. Sicotte.

management over large areas of interior of British Columbia indicate these forests are in the early stages of fragmentation (Sachs et al. 1998). Studies of the impacts of forest management at larger spatial scales (i.e. over smaller areas) are limited. It is widely accepted that ecological restoration of landscapes impacted by industrial land use and other anthropogenic disturbances requires an understanding of the changes that have resulted from the cumulative impacts of land use (White and Walker 1997, Fulé et al. 1997). It is important, therefore, to further understand the extent of changes in landscape condition resulting from industrial land use in sub-boreal British Columbia, and to evaluate the need for, and relevance of, ecological restoration in these forests.

In British Columbia, natural resources are an important contributor to the economy, and forestry is the predominant sector. As a result, timber harvesting and related road construction constitute the dominant form of development in forests (Ward 2001). In the relatively recent past, forest resources in British Columbia were considered abundant, and as a result the forests were harvested with a limited vision for the future forest condition (Ward 2001). Prior to 1970, timber leases were short-term, and replanting following selective harvesting was not common. Harvested stands were left to naturally regenerate, and as a consequence these forests retained little of the natural landscape condition. For example, the past half-century of forest management in sub-boreal British Columbia has focused on harvesting Douglas-fir (Lousier and Kessler 1999). This species reaches the northern extent of its natural range in the interior of British Columbia, and concern has been expressed regarding changes in the representation of Douglas-fir in the forests. Selectively cut Douglas-fir stands often become dominated by more shade-tolerant understory species, such as subalpine fir, while clearcut Douglas-fir stands are often replanted with lodgepole pine or interior spruce. Understanding the extent to which the characteristics and distribution of Douglas-fir and other tree species has changed as a result of forest management and other industrial land use activities is important for guiding ecological restoration in sub-boreal British Columbia.

Road construction is another form of development that occurs in forests along with timber harvesting, and the presence of extensive road networks may alter natural ecosystem functioning (Forman and Alexander 1998, Trombulak and Frissell 2000). These impacts may have more significant ecological implications than the habitat loss that results from timber harvesting, as roads create high contrast edges and cause fragmentation (Reed et al. 1996, Tinker et al. 1997). Natural processes such as soil erosion, sedimentation and landslides may be increased with the presence of roads, and roads may change natural disturbance cycles (Norse et al. 1986). By enhancing access into forests, roads increase the frequency of fires caused by humans (Franklin and Forman 1987) and increase hunting activities (Lyon and Jensen 1980, McClellen and Shackleton 1988). Roads also increase the movement of exotic species through otherwise remote areas (Benninger-Traux et al. 1992), and create a barrier against species dispersal (Forman 1995). In some forests, roads have been shown to have a more lasting impact on landscape structure than timber harvesting (McGarigal et al. 2001).

A practical method for quantifying these and other changes in landscape condition in forests is through the analysis of historical records (e.g. Bourdo 1956, Axelsson and Östlund 2001, McGarigal et al. 2001). Changes in landscape structure can be measured directly using permanent sample plots, however these plots must have been established during the past and require continued monitoring over time (Philip 1994). Aerial photography, topographic and planimetric maps are historical records that may also be used to illustrate changes in landscape structure over time (Mast et al. 1997, Sachs et al. 1998, Cameron et al. 2000, Axelsson and Östlund 2001, Cousins 2001). Improved aerial photography technology for mapping, inventorying and monitoring vegetation and landscape features (Howard 1991), combined with progress in the production of orthorectified aerial photographs in digital form, make it possible to monitor changes in landscape structure over long temporal and large spatial scales (i.e. over long time periods and relatively small areas). Until recently, the analysis of these historical sources, and black and white aerial photography in particular, has been limited to visual interpretation.

The introduction of digital image processing and geographic information systems (GIS), however, allow for the detection and quantitative analysis of changes in landscape structure within ecosystems and along ecosystem boundaries (Mast et al. 1997).

Criteria and indicators provide framework for developing forest management strategies, and serve as a tool to monitor progress towards sustainable forest management. A *criterion* is a category of conditions or processes by which sustainable forest management may be assessed, and is characterized by a set of related *indicators.* The latter are monitored periodically to assess change. An indicator is a quantitative or qualitative variable and can be measured or described which can be observed periodically to monitor trends (CCFM 1997). In this context, landscape indices may be used as criteria and/or indicators for ecological restoration, and to measure changes in landscape structure and function that have been altered by industrial land use practices.

Landscape indices are used to quantify landscape structure. Response variables (process rates) are used to measure ecological processes. Landscape indices are related to response variables, and make certain predictions about them, allowing researchers to indirectly measure ecological processes (Tischendorf 2001). These indices are especially useful for interpreting spatial changes in landscape structure over time making certain, limited, predictions about ecological processes (Schumaker 1996, Giles and Train 1999, Tischendorf 2001). With respect to the limitations of the indices, for example, it has been previously demonstrated that many indices are redundant (McGarigal and McComb 1995, Riitters et al. 1995, Cain et al. 1997) or ambiguous (Gustafson and Parker 1992, Hargis et al. 1998).

It is generally accepted that a small, parsimonious set of landscape indices offers the most insight into both landscape patterns and ecological processes (Giles and Train 1999, McGarigal et al. 2001, Tischendorf 2001). Spatial evidence of landscape structure from historical records such as aerial photography will assist forest managers assess natural and/or human induced changes in landscapes over time (Hester et al. 1996). The purpose of this study is to use historic aerial photography with image processing and GIS to quantify changes in landscape structure on the John Prince Research Forest (JPRF) between 1947 and 1999. The intent of this paper is to provide insight into changes in landscape structure that have incurred in selectively harvested forests of sub-boreal British Columbia and to characterize changes at the landscape level which may have implications for ecological functioning.

METHODS

This study was conducted on the 13,032 ha JPRF, located approximately 50 km northwest of the village of Fort St. James, in sub-boreal British Columbia. A detailed description of the study area may be found in Chapter 1 of this thesis.

Data Preparation and Development

Contemporary Forest Conditions (1999) - Two sources of data were used to describe contemporary forest conditions on the JPRF. The first source was the British Columbia Ministry of Forests forest cover inventory database, which contains spatial data on forest cover and associated attributes. This was used to assess the extent of timber resources. The second source was Terrain Resource Inventory Mapping data (TRIM II), obtained through the Geographic Data British Columbia Branch of the Ministry of Environment, Lands and Parks. TRIM II provides topographic data, cultural features, land cover, surface features (cliffs, scarpes, eskers), transportation features (roads, railways, pipelines, bridges) and water features (lakes, rivers, wetlands) at a scale of 1:20,000.

Historical Forest Conditions (1947) - Historical forest conditions were characterized using 1:15,840 black and white aerial photography. British Columbia has been extensively covered with aerial photography since the 1920s, providing a source of historical data for most of the province. Panchromatic aerial photography from 1947 was obtained from the JPRF, and the photographs were converted into digital images. Ground control points from TRIM II data were used to rectify photographs to the Universal Transverse Mercator (UTM) map projection, and the images were further geometrically corrected using a digital elevation model to create an orthophotograph (Figure 4-1). An orthophotograph is a rectified photograph that presents objects in true planimetric arrangements (Novak 1992, Baltsavias 1996), where distortions due to tilt, variations in height and topography are removed. Orthophotographs are geometrically equivalent to conventional line maps (or TRIM II) and can be used to analyze distances, angles, positions and areas (Cameron et al. 2000). The orthophotograph was timber-typed using current forest inventory standards. The resulting database was converted to GIS maps for analysis. Polygons were delineated based on species composition, age class, height class, stocking class and crown closure. Additional landscape features such as lakes, swamps, streams, landslides, rock, clearcuts, roads, non-commercial or non-productive brush, and clearings were also defined. Industrial Forestry Service Ltd. (Prince George, British Columbia) converted the photographs into digital format and performed the timber typing.

Data Stratification

The historical and contemporary data was stratified for this analysis using three schemes: (1) vegetation cover type, (2) seral stage, and (3) a combination of vegetation cover type and seral stage. The vegetation cover type map was stratified based on leading species (i.e. the dominant tree species in the stand) (Table 4-1). Leading species was defined as the species with the greatest abundance on a forest inventory label by species composition. The "brush" stratum includes polygons classified as non-productive or non-commercial brush. The seral stage map was created by reclassifying inventory age classes into four seral stages, corresponding in part to seral stage definitions for Natural Disturbance Type 3 (within which the JPRF falls) in the Biodiversity Guidebook (British Columbia Forest Service and British Columbia Environment 1995). The following age ranges were used: early (<40 years), mid (40-99 years), mature (>100

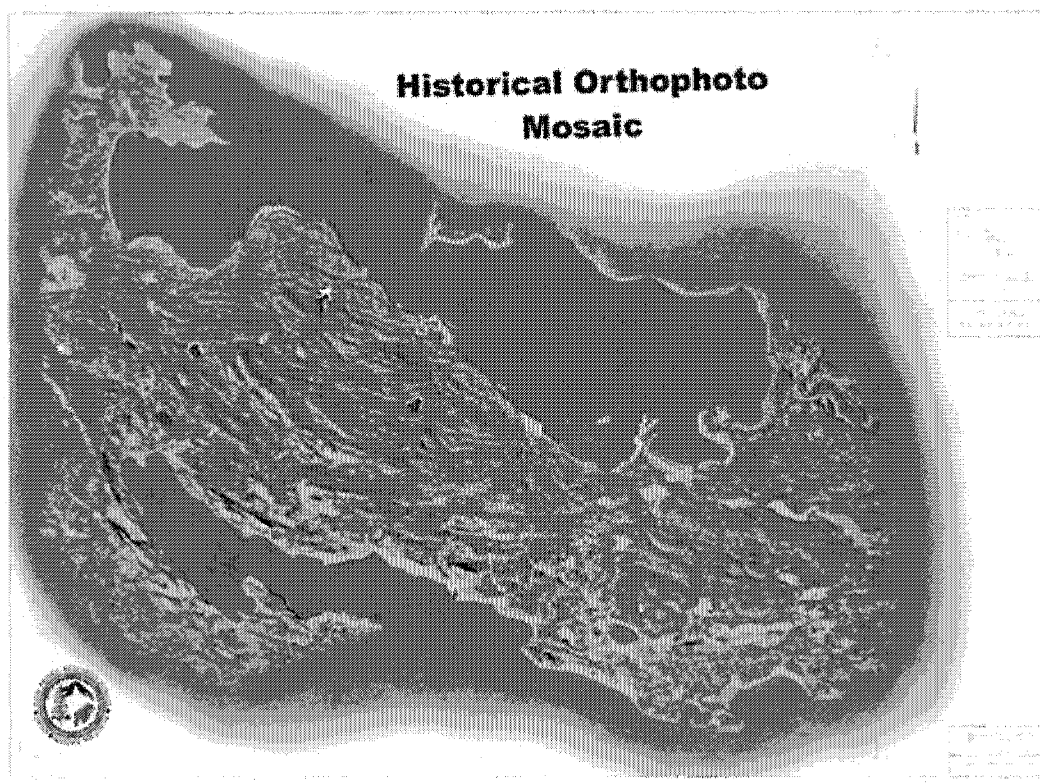

Figure 4-1 Orthophotograph of the John Prince Research Forest created from 1947 aerial photography.

Table 4-1 Vegetation cover type stratification scheme based on leading species for the John Prince Research Forest.

Vegetation Type	Description
Coniferous strata	
Douglas-fir	Douglas-fir leading stands (lodgepole pine, interior spruce, or deciduous secondary)
Interior spruce	Interior spruce leading stands (Douglas-fir, lodgepole pine, or deciduous secondary)
Lodgepole Pine	Lodgepole pine leading stands (Douglas-fir, interior spruce or deciduous secondary)
Subalpine fir	Subalpine fir leading stands (lodgepole pine, Douglas-fir, interior spruce or deciduous secondary)
Black Spruce	Black spruce leading stands (Douglas-fir, interior spruce, lodgepole pine or deciduous secondary)
Deciduous strata	
Black cottonwood	Black cottonwood leading stands (coniferous or deciduous secondary)
Paper birch	Paper birch leading stands (coniferous or deciduous secondary)
Trembling aspen	Trembling aspen leading stands (coniferous or deciduous secondary)
Other Strata	
Brush	Non-commercial or non-productive brush
Lakes and wetlands	Lakes, swamps, marshes, fens, etc.
Logged (clearcut)	Forests harvested using clearcut silviculture systems

years), and old (>140 years) (Table 4-2). Although the mid seral stage is not defined in the Biodiversity Guidebook (1995), it was included here. The combined vegetation cover and seral stage distribution map included 26 strata, with all deciduous species – black cottonwood (*Populus trichocarpa* Torr. & Gray), paper birch and trembling aspen - combined into one vegetation type. The maps were converted to raster format with a cell size of 25 m for analysis.

Data Analysis

Landscape structure (composition and configuration) was characterized for the six aforementioned maps using FRAGSTATS (McGarigal and Marks 1995) and the results from 1947 and 1999 were compared. A set of landscape indices were used to quantify elements of landscape structure based on the assumption that limited predictions regarding ecological processes (i.e. response variables) can be made by analyzing landscape structure (Forman and Gordon 1986, Tischendorf 2001). In this context, criteria used to assess sustainable forest management with respect to ecological restoration include landscape composition and landscape configuration (Table 4-3). Landscape composition refers to the area, in percent or hectares, of the landscape analysis unit comprised of a particular stratum, and is typically used to estimate the extent of available habitat and by inference the degree of biodiversity. Landscape configuration refers to the arrangement of these strata across the landscape, and can be interpreted as indices of fragmentation (Forman and Godron 1986, McGarigal and Marks 1995).

Area by stratum was used as an indicator of landscape composition. Specifically, class area (ha) tabulates the amount of the landscape composed of each stratum. Habitat loss is a fundamental concern with landscape change, and it is important to understand the amount of habitat (to the limits of what can be inferred from the vegetation type and seral stage) that exists on the landscape (Fahrig 1997). Percentage of the landscape occupied by each stratum was computed to quantify area in relative terms as percent of total landscape area.

Table 4-2 Seral stages stratification scheme for the John Prince Research Forest. Seral stages are based upon guidelines for Natural Disturbance Type 3 in the Biodiversity Guidelines (British Columbia Environment and British Columbia Ministry of Forests 1995).

Seral Stage Delineation	Description
Early	Stands <40 years; age class 1, 2
Mid	Stands 41-99 years; age class 3, 4, or 5
Mature	Stands >100 years; age class 6, 7, 8 or 9
Old	Stands >140 years; age class 8, or 9

Table 4-3 Criteria and indicators for landscape level ecological restoration in sub-boreal British Columbia.

Criteria	Indicator
Landscape Composition	Class area (ha)
	Percentage of landscape
Landscape Configuration	Patch density (# patches per 100 ha)
	Mean patch size (ha)
	Mean shape index
	Co variation of Euclidean Nearest Neighbour
	Road length (km)

The remaining indices were used as indicators to measure of landscape configuration. Patch density (i.e. number of patches per 100 ha) and mean patch size (ha) (i.e. average patch size in a given cover type) were used to measure landscape fragmentation. An increase in patch density reflects a more fragmented landscape (McGarigal and Marks 1995). Similarly, a landscape with a smaller mean patch size may also be considered more fragmented.

The complexity of patch shapes as compared to a standardized shape (i.e. a circle) was analyzed using mean shape index. Patch shape influences several ecological processes (Forman and Godron 1986), however the most important influence appears to be related to edge effects. The edge of a patch can have a significantly different environment than the patch interior, resulting in a different array of species. Different organisms show variable responses to changes in the edge of a patch. For example, the American marten (*Martes americana*) (Buskirk 1994), an interior forest species, demonstrates a negative response to an increase in edge, where other species such as white-tailed deer (*Odocoileus virginianus*) thrive when edge habitat is increased (Halls 1984).

The co-variation of Euclidean nearest neighbor (ENN) distance refers to the distance between two patches of the same cover type based on an edge-to-edge comparison. The most significant interpretation co-variation of ENN relates to patch isolation and patch connectivity. It has been demonstrated that an increase in patch isolation, demonstrated by an increase in co-variation of ENN, explains why fragmented landscapes contain fewer bird species that contiguous habitats (Forman and Gordon 1986).

As road development that occurred in conjunction with timber harvesting may have significant (and independent) ecological impacts, a preliminary analysis of road development on the JPRF was conducted. To access changes in road development resulting from industrial land use between 1947 and 1999, road length (km) was measured and compared between the two time periods.

RESULTS

Changes in Vegetation Cover Type

Landscape Composition - There have been changes in vegetation cover type on the JPRF between 1947 and 1999 (Figure 4-2). Landscape composition was measured using class (or strata) area, and percentage of the landscape occupied by that stratum. On the JPRF, there have been decreases in the representation of strata that were harvested for timber. For example, the representation of lodgepole pine has decreased (34% to 14%), and the representation of Douglas-fir has decreased (28% to 24%), and the Douglas-fir component has shifted from the northern portion of the JPRF to the interior. The relatively small decrease in the extent of Douglas-fir, which was heavily impacted by harvesting and often not replanted or regenerated, may be an artifact of natural successional processes. Mixed lodgepole pine/Douglas-fir stands have matured since 1947, and the longer-lived Douglas-fir has begun to dominate these stands as the shorter-lived lodgepole pine has become overmature and subsequently died out. This may also partially explain the precipitous drop in the extent of lodgepole pine dominated stands. Also, the decrease in lodgepole pine may be related to fire suppression, and the difficulty naturally regenerating lodgepole pine in the absence of fire.

Although interior spruce was harvested for timber, there has been an increase in the composition of that species (20% to 32%) likely due to replanting of interior spruce. The increase in subalpine fir (0.8% to 9%) may reflect the release of this suppressed understory species when Douglas-fir and interior spruce overstory were removed through harvesting practices. There has been an increase in area classified as brush (1% to 2%), which may have been created by selective harvesting when merchantable species were removed (Douglas-fir, interior spruce, and a lesser extent lodgepole pine and subalpine fir) and other species were left to naturally regenerate. There have not been significant changes in the composition of those strata that which were not harvested for timber, including black spruce, black cottonwood, paper birch, trembling aspen, and lakes and wetlands (Table 4-4).

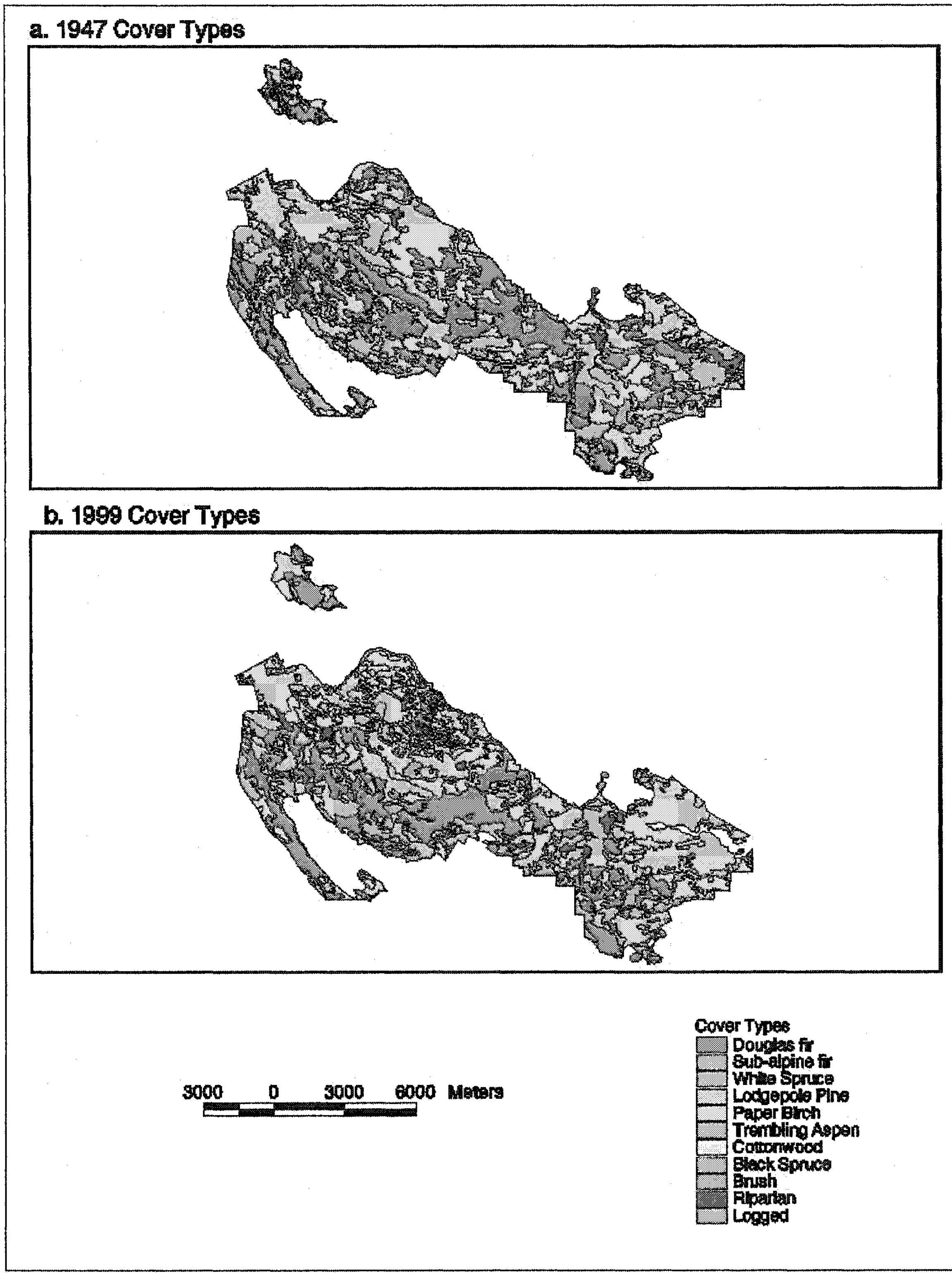

Figure 4-2 Maps illustrating changes in vegetation cover type on the John Prince Research Forest between 1947 and 1999.

Table 4-4 Changes in area (ha) and percentage of the landscape in each cover type between 1947 and 1999 on the John Prince Research Forest. Percent change represents the difference in percentage of the landscape between 1947 and 1999 where negative values signify a decrease in that patch type and positive value signify an increase.

	1947		1999		
Type	Area (ha)	% of JPRF	Area (ha)	% of JPRF	% Change
Douglas-fir	3670.9	28	3141.6	24	-14
Interior spruce	2587.9	20	4073.1	32	60
Lodgepole pine	4382.9	34	1734.0	14	-59
Subalpine fir	108.2	0.8	1186.8	9	1025
Black spruce	88.1	0.7	167.9	1	43
Black cottonwood	46.8	0.4	18.1	0.1	-75
Paper birch	65.3	0.5	650.9	5	900
Trembling aspen	1185.8	9	1030.4	8	-11
Brush	180.3	1	231.4	2	100
Lakes & wetlands	343.8	3	349.9	3	0
Logged (clearcut)	276.8	2	178.3	1	-50

Landscape Configuration – There has been an increase in fragmentation in strata where timber harvesting occurred, indicated by an increase in patch density and a decrease in mean patch size. Douglas-fir and lodgepole pine strata became increasingly fragmented between 1947 and 1999. Although there is only a relatively small area occupied by subalpine fir and paper birch on the JPRF, these stand types also demonstrated an increase in fragmentation. Changes in interior spruce are ambiguous as this stratum shows an increase in patch density and a decrease in patch size indicating a move towards increased fragmentation. This contradicts observed patterns on the JPRF where the number of interior spruce leading stands in larger patches has increased resulting from reforestation practices. Black cottonwood shows a decrease in patch density and an increase in patch size, but the small overall representation of this stratum on the landscape makes interpretation difficult. It is possible that changes in black cottonwood is a result of the subjective nature of the inventory methods used, rather than a real change in the stratum (Figure 4-3 a, b).

All vegetation cover types (except black spruce) have undergone a decrease in patch complexity, based on the mean shape index. The decrease in patch complexity indicates a decrease in available edge habitat, and a movement towards less complex patches in harvested stands. This change has different ecological implications depending on the species in question (Figure 4-4 a). Also, vegetation types heavily impacted by timber harvesting have become less connected. For example, in Douglas-fir and lodgepole pine leading stands there has been an increase in patch isolation as measured by the co-variation of ENN. Also, there has been an increase in patch isolation in subalpine fir and paper birch leading stands as measured by the co-variation of ENN, despite the overall increase in the representation of these stands across the landscape. As there was not significant enough area occupied by subalpine fir and paper birch leading stands in 1947, there was no value recorded for co-variation of ENN at that time (Figure 4-4 b).

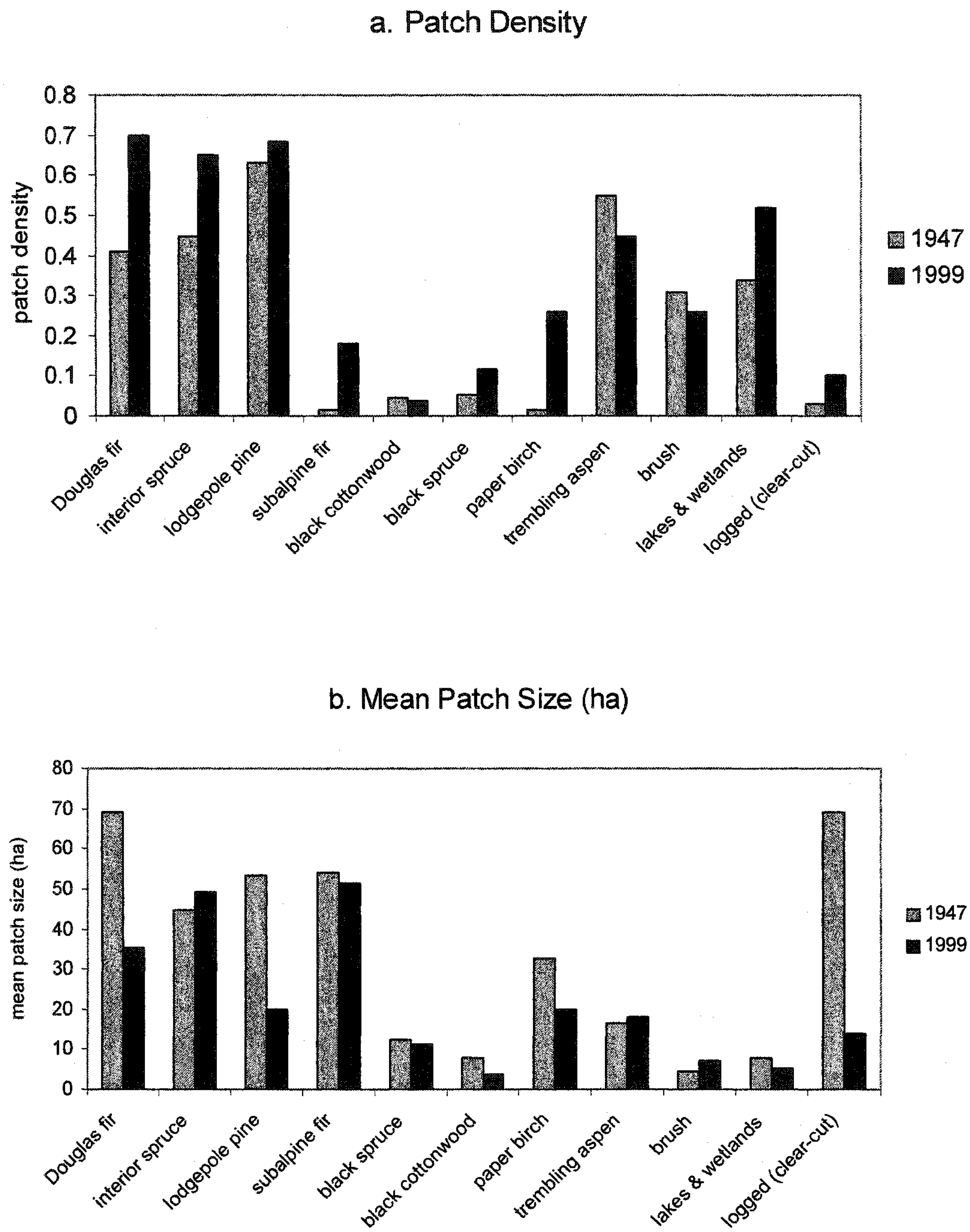

Figure 4-3 Changes in (a) patch density and (b) mean patch size (ha) between 1947 and 1999 for leading species on the John Prince Research Forest.

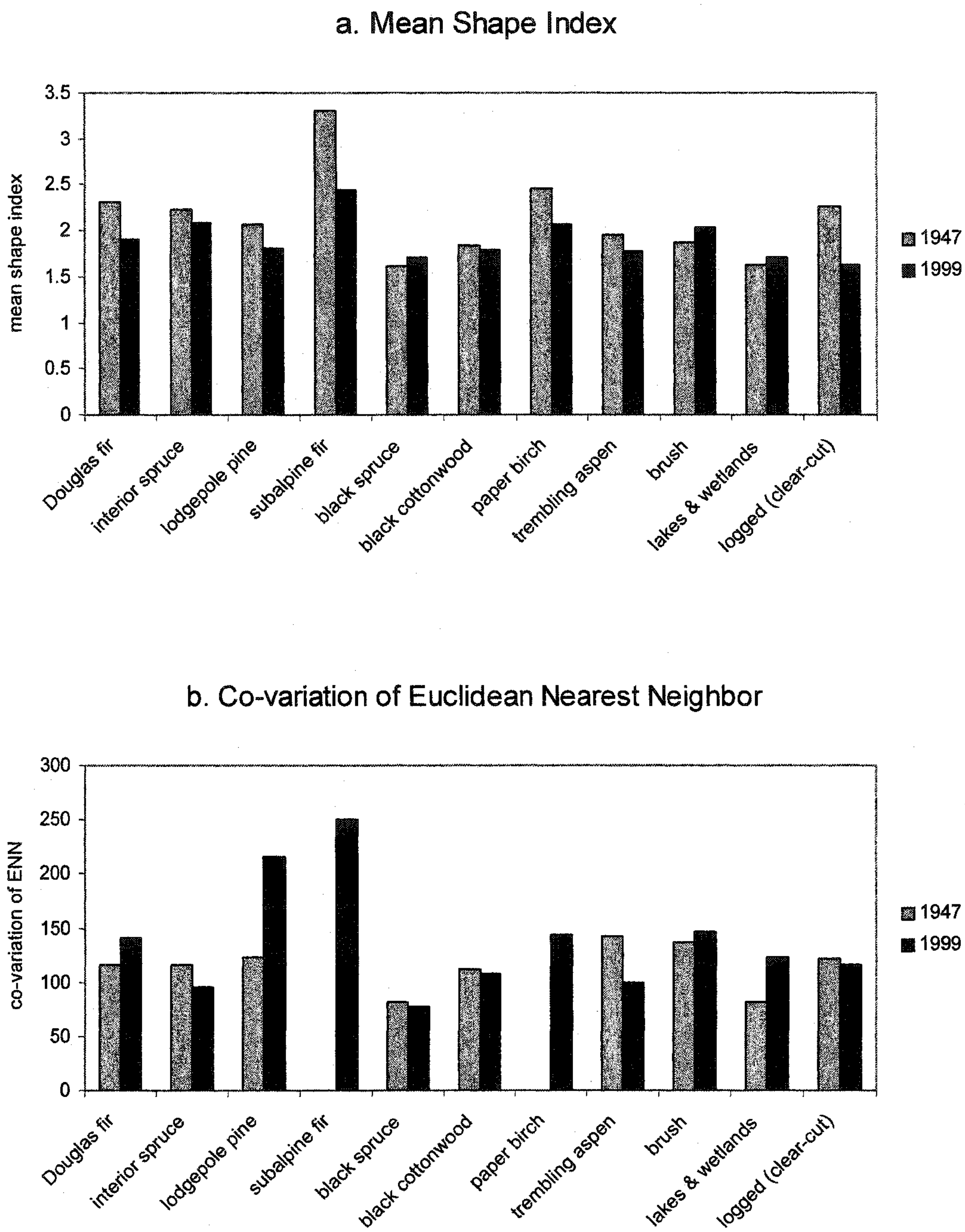

Figure 4-4 Changes in (a) mean shape index and (b) co-variation of ENN between 1947 and 1999 for leading species on the John Prince Research Forest.

In addition to changes in vegetative strata, there has been a change in the lake and wetland strata where patch density has increased and mean patch size has decreased, indicating increased fragmentation. Also, the increase in co-variation of ENN indicates a decrease in connectivity in this stratum. As the changes in area classified as lake and wetlands are minute (343 ha to 349 ha), the changes reported here are not believed to be significant. There have been changes in the strata harvested using clearcut silviculture systems between 1947 and 1999. Because there is no data on the areas selectively harvested it is difficult to make assumptions about this stratum.

Changes in Seral Stage Distribution

Landscape composition – The seral stage distribution on the JPRF has changed between 1947 and 1999 (Figure 4-5). There has been a decline in seral stages subjected to timber harvesting on the JPRF, including mature seral stages (63% to 48%) and mid seral stages (20% to 16%). Natural and artificial regeneration in harvested stands has lead to an increase in the representation of early seral stages (14% to 31%). This increase in early seral stages does not appear to be of the magnitude observed when the mature cohort that dominates the forests was established (i.e. the increase in early seral stages is not of a magnitude that would indicate the beginning of a new rotation). Old seral stages have also increased (0.7% to 33%) and this may be the fire suppression policies combined with the ageing of stands in unharvested areas (Table 4-5).

Landscape Configuration – There has been a dramatic increase in fragmentation of old-seral stages as reflected by an increase in patch density. Also, mature-seral stages have become increasingly fragmented as shown by an increase in patch density and a decrease in mean patch size. Early seral stages have become considerably less fragmented as reflected by a decrease in patch density and an increase in patch size. Changes in mid seral stages were not substantial (Figure 4-6 a, b).

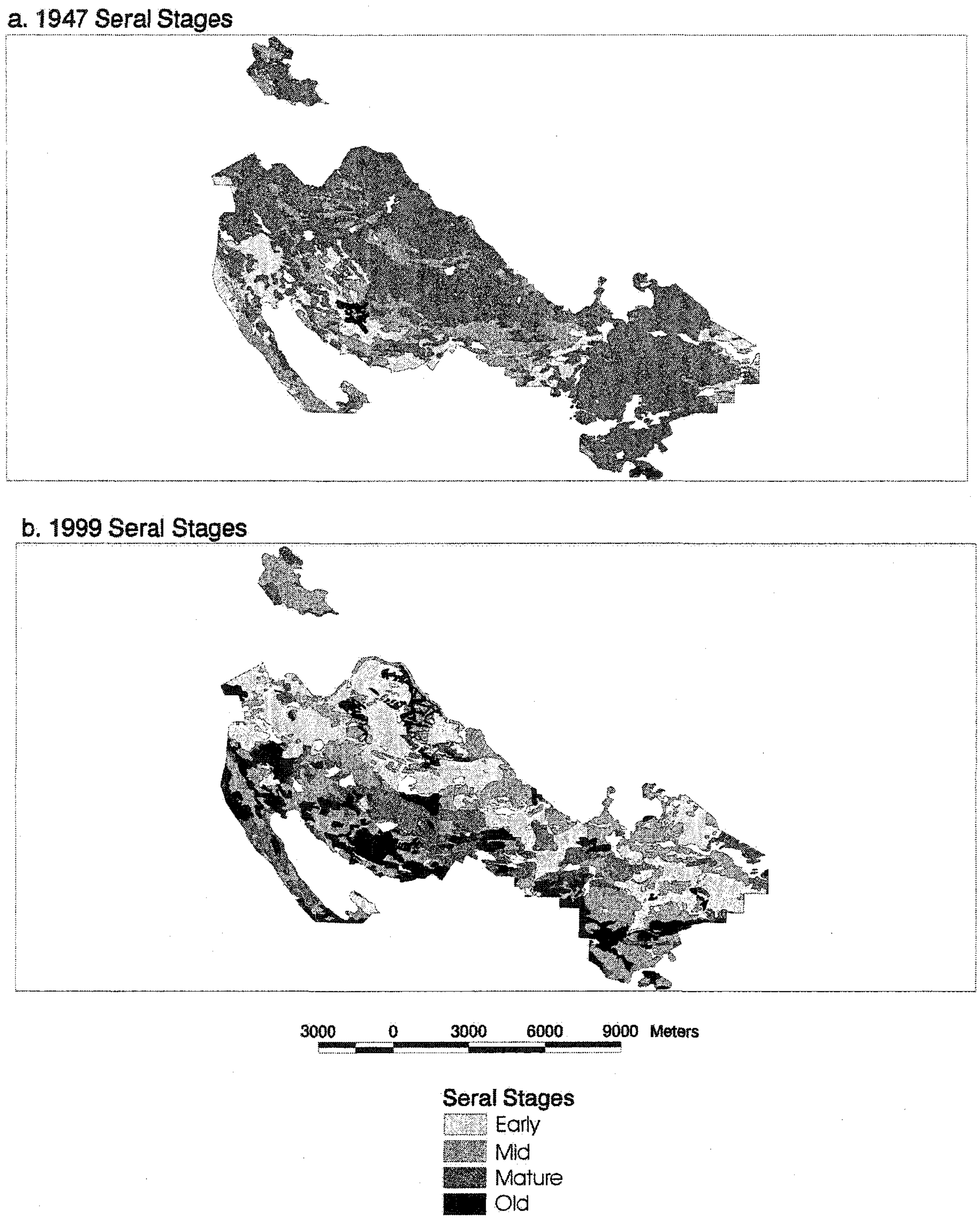

Figure 4-5 Maps illustrating changes in seral stage distribution on the John Prince Research Forest between (a) 1947 and (b) 1999.

Table 4-5 Changes in area and percentage of the landscape represented for each seral stage between 1947 and 1999 on the John Prince Research Forest. Percent change represents the difference in percentage of the landscape between 1947 and 1999 where negative values signify a decrease in the representation of that patch type and positive value signify an increase in the representation of that patch type.

	1947		1999		
Seral Stage	Area (ha)	% of JPRF	Area (ha)	% of JPRF	% Change
Early	1737.1	14	3847.9	31	121
Mid	2470.6	20	2053.6	16	-20
Mature	7909.2	63	6101.6	48	-24
Old	90.9	0.7	4153.3	33	4614

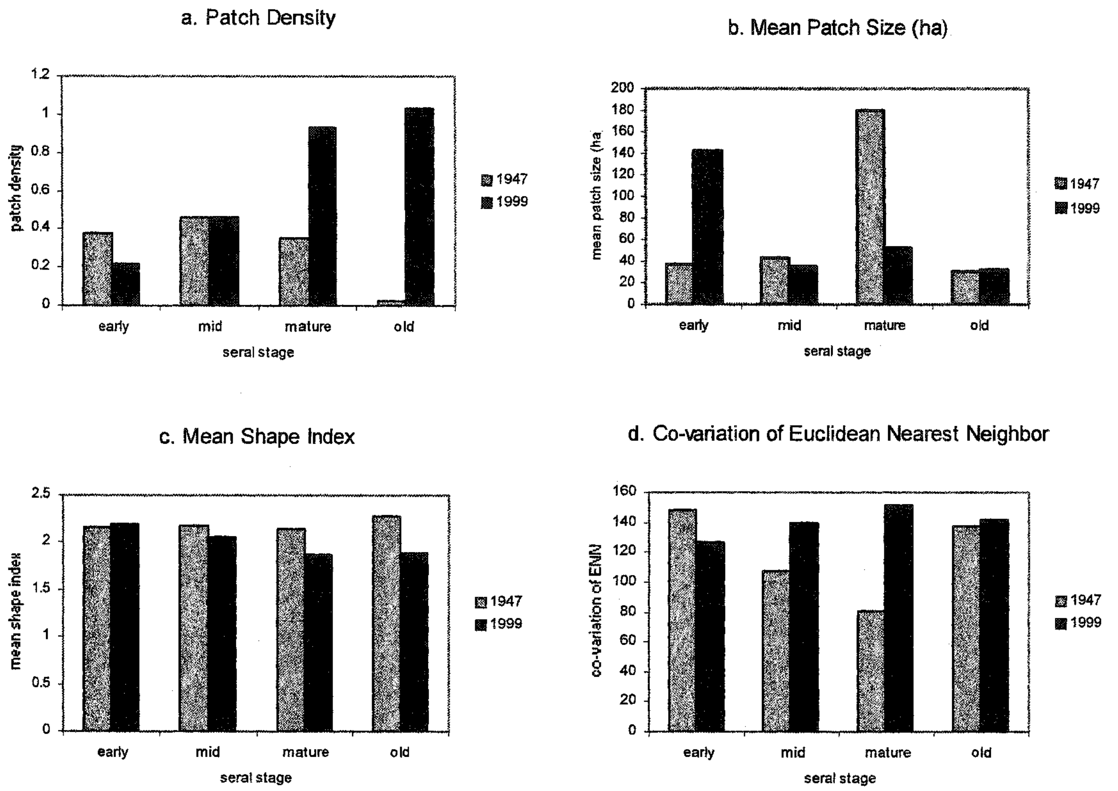

Figure 4-6 Changes in (a) patch density, (b) mean patch size (ha), (c) mean shape index, and (d) co-variation of ENN between 1947 and 1999 for seral stage on the John Prince Research Forest.

As a result of timber harvesting, mid, mature and old seral stages have undergone a decrease in patch complexity as measured by a decrease in mean shape index. In early seral stages mean shape index has increased resulting in an increase in patch complexity, and therefore in edge habitat (Figure 4-6 c). Ecological consequences of this change may have positive impacts on species such as white-tailed deer, which thrive in edge habitat and young forests (Halls 1984).

In strata heavily impacted by timber harvesting there has been a considerable decrease in patch connectivity. For example, co-variation of ENN has increased in mid, mature and old seral stages, indicating an increase in patch isolation and thus a decrease in connectivity (Figure 4-6 d).

Changes in Vegetation Type and Seral Stage Distribution Combined

Landscape Composition - Changes in seral stage representation by vegetation type can be characterized by combining leading species and seral stage (Figure 4-7). As Douglas-fir, interior spruce and lodgepole pine leading stands constitute the greatest proportion of the JPRF in 1947, the discussion is focused on these cover types.

Commercially valuable conifers have undergone a decline in mature seral stages as a result of timber harvesting in these age classes. For example, there has been a decrease in the representation of mature Douglas-fir (22% to 21%), a decrease in the representation of mature interior spruce (17% to 16%), and a decrease in the representation of mature lodgepole pine (20% to 8%). As well, all commercially valuable conifers have shown an increase in old seral habitat essentially showing this forest becoming older. For example, there has been an increase in old Douglas-fir (0.7% to 15%), an increase in old interior spruce (0% to 14%), and an increase in old lodgepole pine (0% to 4%). This trend may be attributed to fire suppression policies and may have significant implications for increased susceptibility to insects and fire (Table 4-6). Although it is not uncommon to find Douglas-fir in the old seral stage (>140 years), due to the natural rotation age of the species, it is not common to find lodgepole pine or interior spruce in the old seral stage in this area of British Columbia.

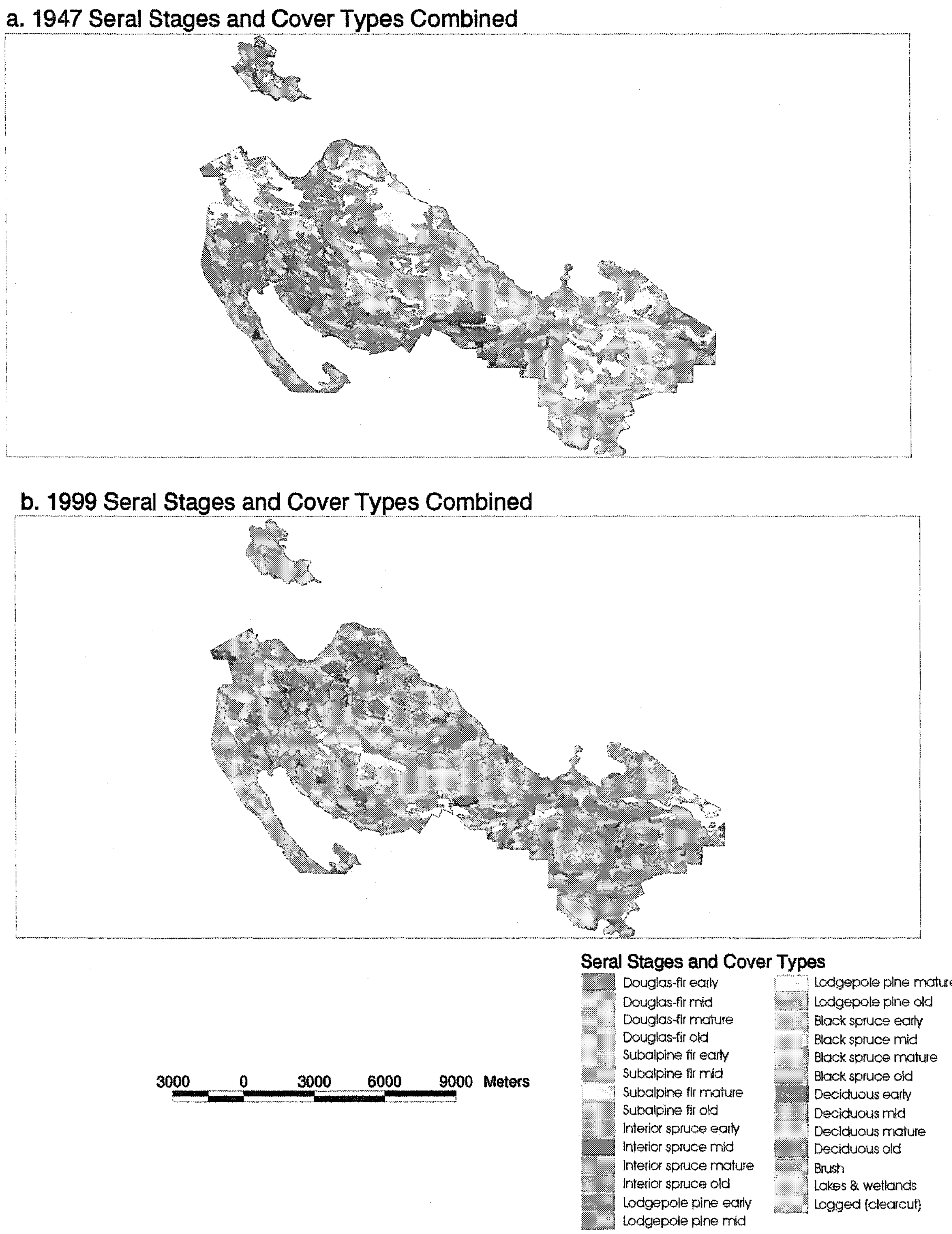

Figure 4-7 Map illustrating changes in vegetation cover type and seral stage distribution combined on the John Prince Research Forest between 1947 and 1999.

Table 4-6 Changes in area and percentage of the landscape for cover type in each patch type between 1947 and 1999 on the John Prince Research Forest. Percent change represents the difference in percentage of the landscape between 1947 and 1999 where negative values signify a decrease in that patch type and positive value signify an increase.

	1947		1999		
Type	Area (ha)	% of JPRF	Area (ha)	% of JPRF	% Change
Douglas-fir					
Early	157.0	1	30.9	0.2	-80
Mid	638.4	5	418.2	3	-40
Mature	2866.4	22	2692.4	21	-5
Old	90.9	0.7	1862.2	15	2043
Interior spruce					
Early	116.1	0.9	1705.6	13	1344
Mid	308.1	2	346.8	3	50
Mature	2153.4	17	2020.4	16	-6
Old	0	0	1746.4	14	-
Lodgepole pine					
Early	774.5	6	631.1	5	-17
Mid	1006.1	8	146.9	1	-88
Mature	2602.6	20	956.0	8	-60
Old	0	0	476.4	4	-
Subalpine fir					
Early	0	0	858.2	7	-
Mid	0	0	223.0	2	-
Mature	108.3	0.8	105.8	0.8	0
Old	0	0	45.0	0.4	-
Black spruce					
Early	9.9	0.1	52.1	0.4	300
Mid	73.9	0.6	115.9	0.9	50
Mature	4.2	0	22.8	0.2	-
Old	0	0	0	0	-
Deciduous					
Early	679.2	5	621.5	5	0
Mid	444.3	3	866.8	7	133
Mature	174.2	1	211.0	2	100
Old	0	0	0.9	0	-
Other strata					
Brush	180.3	1	231.4	2	100
Lake & Wetlands	343.8	3	350.0	3	0
Logged (clearcut)	276.8	2	178.4	1	-50

Results indicate that interior spruce, lodgepole pine, black spruce, subalpine fir and deciduous species were not represented in the old seral stage in the 1947 data. This trend likely reflects of the natural rotation ages of the species. During natural successional processes these species are not generally represented in old seral stages, whereas Douglas-fir is known to be a component of the older forest. This trend may also be an artifact of different classifications used on the 1947 and 1999 data. When classifying aerial photography it is difficult to discern the difference between mature and old seral stages, especially in the older, poorer quality photography from 1947.

Landscape Configuration – In addition to observed changes in landscape composition, changes in landscape configuration were observed when vegetation cover type and seral stage were combined. Most notably, harvesting focused on mature Douglas-fir, interior spruce and lodgepole pine forests has resulted in a substantial increase in fragmentation in remnant patches (Figure 4-8 and 4-9). In Douglas-fir, interior spruce and lodgepole pine leading stands patch density has increased in the mature seral stages, indicating an increase in fragmentation. In Douglas-fir leading stands patch density has increased in mid seral stages and has increased considerably in old seral stages, indicating an increase in fragmentation. In Douglas-fir leading stands, patch density has decreased in the early seral stages. In interior spruce leading stands, patch density has increased in all seral stages, reflecting an increase in fragmentation in all seral stages. In lodgepole pine leading stands, patch density has increased in late seral stages and decreased in early and mid seral stages (Figure 4-8).

Changes in mean patch size (ha) were variable. In Douglas-fir, interior spruce and lodgepole pine leading stands mean patch size has decreased in mid and mature seral stages, indicating an increase in fragmentation in these seral stages. In Douglas-fir leading stands, mean patch size has decreased in all seral stages, indicating an increase in fragmentation in all strata. In interior spruce leading stands, mean patch size has increased in early and old seral stages

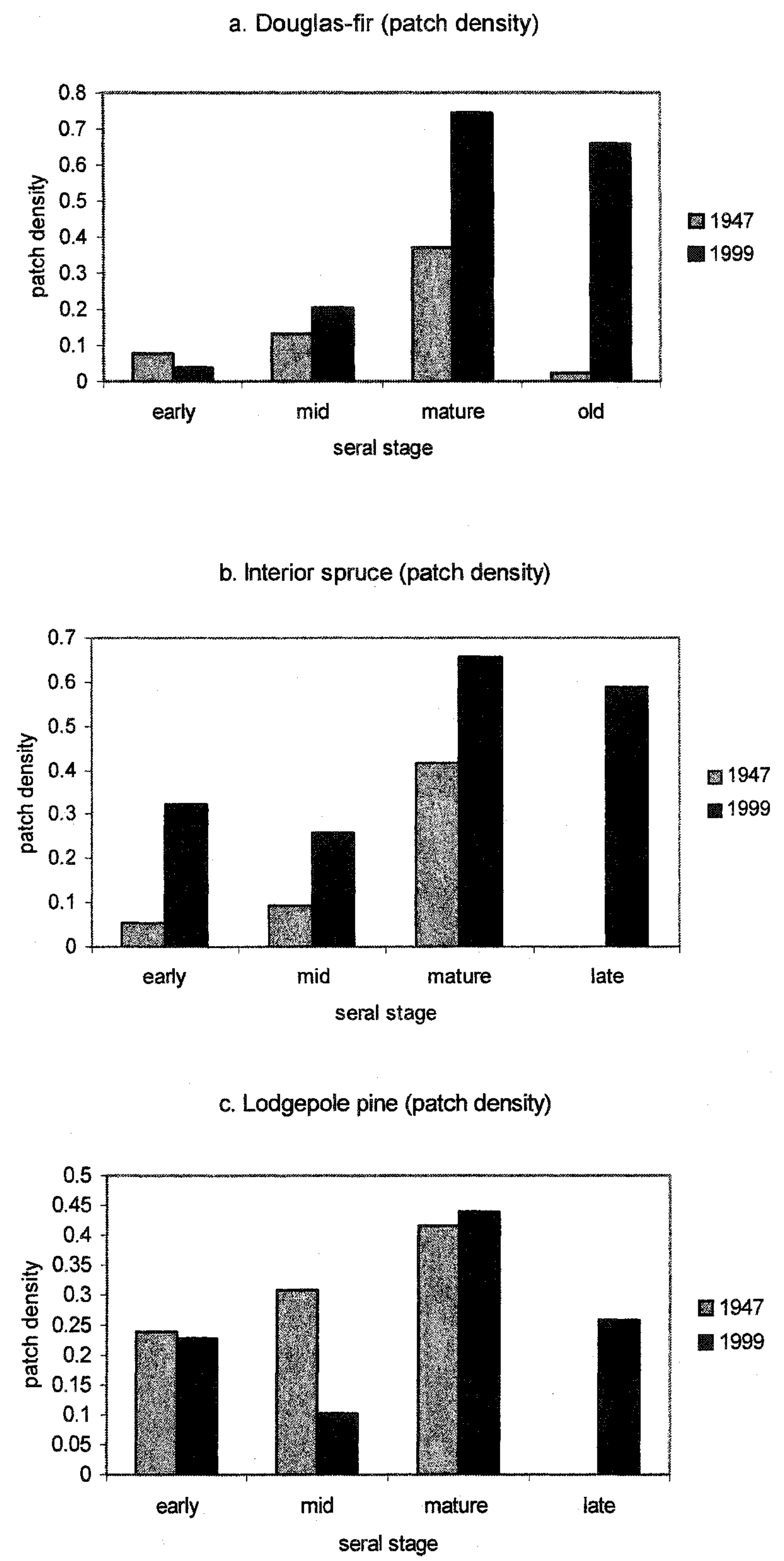

Figure 4-8 Changes in patch density between 1947 and 1999 for (a) Douglas-fir, (b) interior spruce, and (c) lodgepole pine leading stands on the John Prince Research Forest.

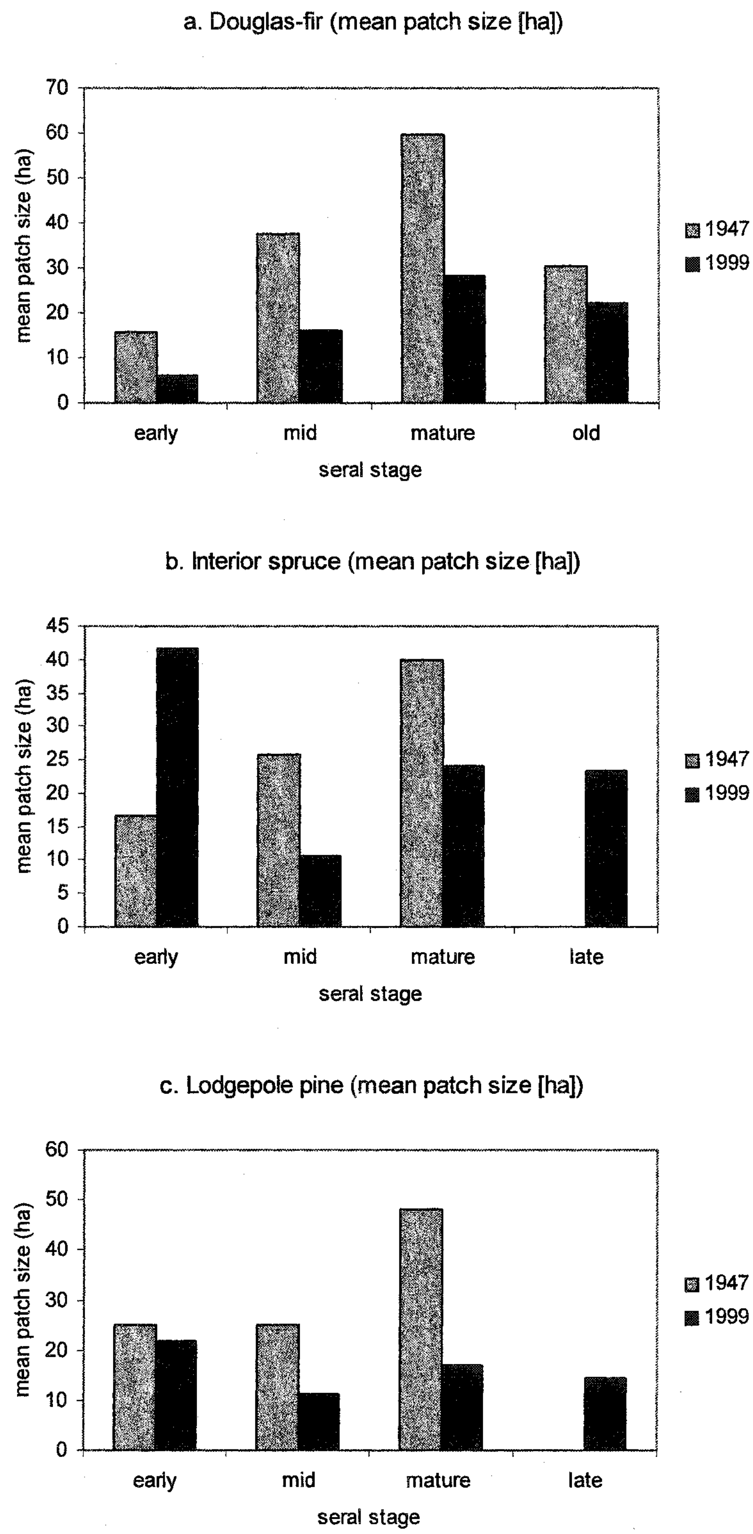

Figure 4-9 Changes in mean patch size (ha) between 1947 and 1999 for (a) Douglas-fir, (b) interior spruce, and (c) lodgepole pine leading stands on the John Prince Research Forest.

indicating a decrease in fragmentation in these seral stages. In lodgepole pine leading stands, mean patch size has increased in old seral stages indicating a decrease in fragmentation in these seral stages (Figure 4-9).

Changes in mean shape index were also variable. In Douglas-fir leading stands, mean shape index has decreased in all seral stages, indicating a decrease in edge. In interior spruce leading stands, mean shape index has decreased in mid and mature seral stages and increased in early and old seral stages. In lodgepole pine leading stands, mean shape index has decreased in early, mid and mature seral stages; and increased in old seral stages (Figure 4-10). Co-variation of ENN increased in early and mature seral stages reflecting an increase in patch isolation. Co-variation of ENN decreased in mid and old seral stages. In interior spruce leading stands, co-variation of ENN increased in early, mid and old seral stages and decreased in mature seral stages. In lodgepole pine leading stands, co-variation of ENN increased in all seral stages (Figure 4-11).

Changes in Road Length

Road length on the JPRF has increased by approximately 95%, from 9.1 km in 1947 to 179.4 km in 1999. In 1947 roads were located in the southern portion of the JPRF associated with the Pinchi Lake Mercury Mine. In the years following, road expansion occurred throughout the JPRF.

DISCUSSION

Over the past 60 years on the JPRF, there have been changes in landscape composition and configuration. These changes are thought to have occurred primarily as a result of industrial management in the form of timber harvesting and road construction. There has been a decline in mature seral stages in Douglas-fir, interior spruce and lodgepole pine leading stands likely resulting from timber harvesting in these forest types. The increase in old seral stages may

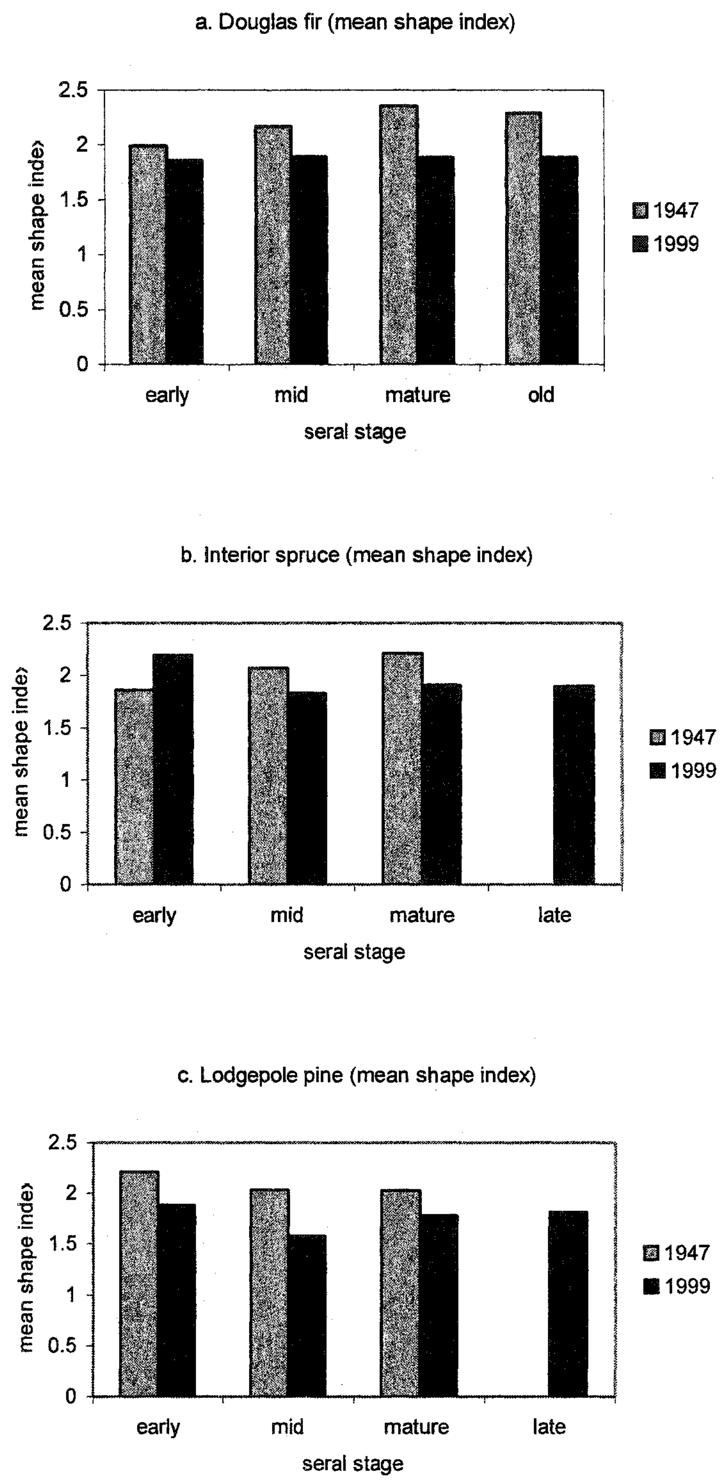

Figure 4-10 Changes in mean shape index between 1947 and 1999 for (a) Douglas-fir, (b) interior spruce, and (c) lodgepole pine leading stands on the John Prince Research Forest.

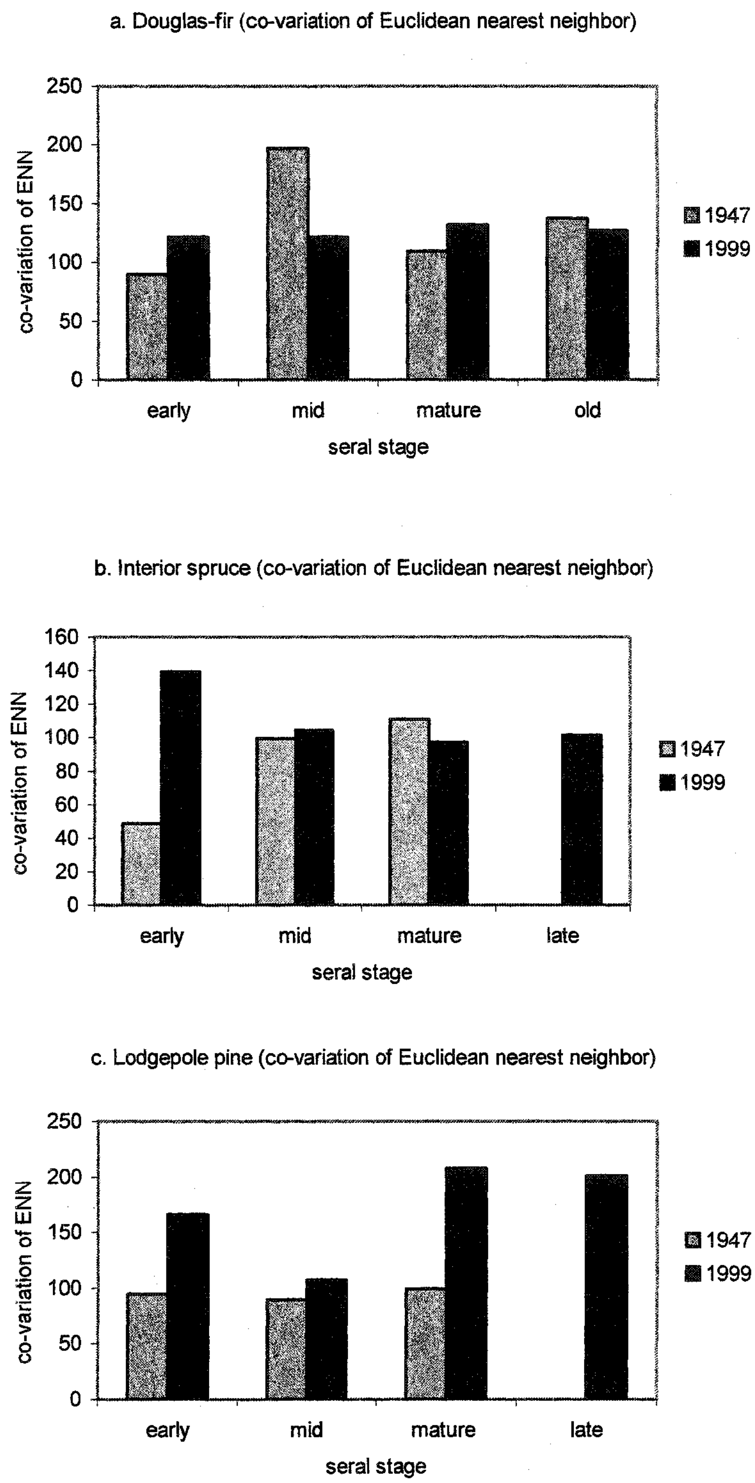

Figure 4-11 Changes in co-variation of Euclidean Nearest Neighbor (ENN) distance between 1947 and 1999 for (a) Douglas-fir, (b) interior spruce, and (c) lodgepole pine leading stands, on the John Prince Research Forest.

represent the ageing of unproductive or inaccessible mature stands that were not harvested, and the increase in young seral stages may be the result of harvest and subsequent regeneration (natural and artificial) in young forests. Over the past half century, seral stage distribution is moving towards an increase in the youngest and oldest age classes. These, and other changes, changes may have significant implications for future ecological function including changes in wildlife habitat, risks of insects and disease, and changes in fire risk.

In areas on the JPRF where diameter-limit harvesting occurred, stands were frequently converted to subalpine fir as a result of the release of this shade tolerant species by partial cutting. These types often regenerated into mixed stands, especially with a deciduous species as a component. Following the 1970s, some of the stands that were harvested earlier using diameter-limit harvesting were later clearcut and frequently were artificially regenerated with interior spruce, and to a lesser extent lodgepole pine. The decline in lodgepole pine in the old seral stage may be partially the result of a successional shift in mixed stands from lodgepole pine leading stands to the longer-lived Douglas-fir as the leading type. Also, as lodgepole pine was primarily located in the north and eastern portion of the forest, these types may have been cut down along with Douglas-fir which was a highly valuable species at that time. This would be especially relevant as utilization standards became more inclusive, and therefore species such as lodgepole pine became increasingly valuable and were targeted.

While the increase in young interior spruce indicates the natural and artificial systems employed to regenerate this species were successful, the decline in young Douglas-fir may reflect the difficulty of successfully regenerating Douglas-fir at the northern extent of its range (Lousier and Kessler 1999). This decline may reflect fire control in the area and the difficulty regenerating Douglas-fir in the absence of fire.

Since 1987, licensees in British Columbia have legally assumed the responsibility for the establishment, maintenance and production of a free growing stand. In this context, a free growing stand is a plantation that is not impeded by brush, is healthy with respect to insects and disease, contains advanced regeneration with the potential of becoming sound and merchantable timber at the time of rotation, and meets a minimum height requirement (British Columbia Ministry of Forests 2000). The decline in young Douglas-fir stands on the JPRF may reflect policies for free growing stands implemented by the British Columbia Ministry of Forests. In this region of British Columbia, it has been common to reforest with lodgepole pine or interior spruce, as opposed to Douglas-fir, as these species (especially lodgepole pine) have faster initial growth rates than Douglas-fir and generally perform better when planted, therefore reach a free growing stand faster (British Columbia Ministry of Forests 2002). The reluctance to reforest with Douglas-fir also results because of the limited technology to process Douglas-fir in this region of British Columbia. This move away from Douglas-fir as a merchantable species is also related to reducing management risk of the species that is prone to attack by the *Dendrotonus* bark beetle.

On the JPRF, fragmentation has increased in the coniferous forest over the last half century. As well, the coniferous forest is composed of more simplified patches with less edge which have become increasingly isolated. An important result of increased fragmentation in mature coniferous forests is the conversion of interior forest to smaller patches with an increased amount of edge (Reed et al. 1996, Tinker et al. 1997). Industrial land use, and the creation of smaller patches, creates high contrast edges which may influence adjacent stands for tens to hundreds of meters. Increased edges may obstruct species dispersal, divide the population and increase competition in the patches that remain (Saunders et al. 1991). In Douglas-fir forests, smaller patches experience increased rates of windthrow, reduced humidity and altered hydrological patterns (Meffe and Carroll 1997, Bennett 1999). An increased amount of edge may also impact tree growth rates, elevate rates of tree mortality, reduce stocking density and impact conifer regeneration (Chen et al. 1992). Although this study shows an increase in fragmentation on the JPRF (which in turn results in an increase in edge effects), the mean shape index decreased, indicating a decrease in patch complexity and fewer edges. In essence, this means that although there has been an increase in the number of patches, each individual patch has become less complex, and therefore the total amount of edge has decreased. This result may be, in part, a function of straight edges on clearcuts.

The quantity of mature coniferous forest habitat on the JPRF has declined and the remaining habitat has become increasingly fragmented. One species in particular, the American marten, is known to inhabit the forests of this region and is negatively impacted by the changes that result from the conversion from mature, contiguous forest to younger, more fragmented forest. This species selects mature, contiguous forest habitat for predator avoidance, special habitat features and the abundance of prey (Buskirk 1994). The changes in this habitat type that have occurred over the past 60 years on the JPRF may have negative and lasting impacts for the American marten, and other interior forest species.

In some forests road development has been shown to leave a more lasting impact on the landscape condition than changes that have resulted from timber harvesting (McGarigal and Marks 2001). In this study it was shown that between 1947 and 1999 there has been a 95% increase in roads constructed to facilitate timber harvesting on the JPRF. Although these roads are still obvious on the forest, some of the roads have become overgrown with vegetation and are impassable to vehicular traffic. Nevertheless, an increase in roads potentially leads to increased fragmentation, increased natural geological process (i.e. soil erosion and sedimentation), increased access for recreational activities such as hunting, and changes in species dispersal patterns. Any ecological restoration initiatives on the JPRF must consider the impact of roads on the ecological integrity of the forest. Because of the nature of the operations on the JPRF, however, these considerations must be balanced with the need for access onto the forest for social, economic and educational purposes.

Limitations of Data

The scale and variable quality of older aerial photography impacts the quality of interpretation possible when using this type of data, and the quality of the available photography is the primary constraint on applications using historical aerial photographs to interpret past landscape structure (Cameron et al. 2000). Similar limitations exist with current inventory data. Integrating aerial photography data with other forms of historical information helps to address this limitation.

To test the quality of the database created from the 1947 aerial photography, polygons were selected and ground sampled[9]. Since 1947 over 40% of the JPRF has been harvested, and many remaining areas that were not harvested have limited access and were not sampled. Therefore, only 16 polygons were sampled throughout the JPRF with three plots each, to represent the diversity of types identified in the 1947 database. Due to the limited number of samples the sampling was not expected to provide statistical accuracy but rather to give an indication of database quality[9].

From the 1947 data, leading species was correctly identified in 62.5% of the polygons. In those polygons where leading species was incorrectly identified differences may be explained by successional changes over the past 60 years, or differences in ordering of leading and secondary species. Age classes were correctly identified in 50% of the polygons. The incorrect polygons underestimated by one age class. Height classes were 75% accurate. In the 1999 database 48% of polygons were accurately identified with respect to species composition. Similar to the 1947 data, in polygons incorrectly identified, differences may be the result of successional shifts, or incorrect ordering of leading and secondary species. Only 25% of the age classes in 1999 database were correct, with the remainder showing inaccuracies of 22 years[9]. It is important to consider these inaccuracies when making assumptions about changes in landscape structure.

Natural Range of Variability

The primary limitation of this work involves the use of a single point in time (i.e. the year 1947) to reference the landscape condition on the JPRF prior to industrial management. As the landscape has undoubtedly changed over time in response to natural disturbances, using measurements from a single point in time to characterize pre-industrial conditions is a limited approach. Using multiple points over time to quantify the range of variation that naturally occurs in these forests, and comparing the current condition to this natural range, would assist in interpreting the changes reported here. However, the 1947 data does represent a point on the natural trajectory of the forest from which some indications of landscape change may be derived.

In general, there are a lack of established values for determining the natural range of variation in ecosystems, and therefore a lack of a framework with which to interpret changes in landscape structure. To partially overcome this limitation, the 1947 and the 1999 data were compared to recommendations for patch size distribution and seral stage distribution from the Biodiversity Guidebook (British Columbia Ministry of Forests and British Columbia Environment 1995). The Biodiversity Guidebook, a document developed to support implementation of the Forest Practices Code of British Columbia (Government of British Columbia 1994), presents an ecosystem based approach to the conservation of biodiversity in managed forests (Fenger 1996). A basic tenant of the Biodiversity Guidebook is the more a managed forest resembles the historical forest which existed prior to European contact, the more likely natural species and processes will be maintained (Fenger 1996). As such, the Biodiversity Guidebook recognizes differences in natural disturbance patterns and processes in the forests of British Columbia, and provides basic management recommendations based on indicators such as patch size and seral stage distribution.

Comparisons between the recommended and observed patch size distribution were distinctly different (Table 4-7). Specifically, both the 1947 and 1999 data sets contain patches >250 ha in size, whereas the Biodiversity Guidebook does not include recommendations for these larger patches. The rational behind setting an upper limit on patch size in the Biodiversity Guidebook reflects societal values, using the assumption that creating large patch sizes through practices such as clear cutting may have negative effects on wildlife habitat, watershed conditions and recreational value in the short term (Delong 1998). These are untested assumptions, and there may be benefits to promoting a greater amount of larger patches in areas such as the JPRF.

Table 4-7 Comparison between patch size distributions based on seral stages on the John Prince Research Forest. Data from 1947 and 1999 was compared to recommended range of variation from the Biodiversity Guidebook (British Columbia Ministry of Forests and British Columbia Environment 1995) and observations by Delong (1998).

	Percent of Forest Within Landscape Unit			
Patch Size (ha)	Biodiversity Guidebook	1947	1999	Delong (1998) [b]
<40	20-30	9.7	12.4	9
40-80	25-40	5.1	8.9	3
80-250	30-50	11.3	13	10.4
>250 [a]	N/A	73.9	65.7	77.6

[a] Biodiversity Guidebook (1995) does not include recommendations for patch sizes >250 ha.

For example, road density is drastically reduced when an equivalent amount of area is harvested in large, as opposed to small, patches. The 1947 and 1999 data sets were also compared to published data on patch size distribution for this ecosystem type (Delong 1998). Delong (1998) suggests the patch size distribution recommended by the Biodiversity Guidebook for this ecosystem type could be improved based on his findings, and data presented here tends to support that conclusion. This issue emphasizes the need to obtain site-specific data to define natural, or at least historical conditions, for the study area and not to rely solely on recommendations provided by the Biodiversity Guidebook.

The seral stage distribution for both the 1947 and the 1999 data fall within the recommendations from the Biodiversity Guidebook (1995) for maintaining high levels of biodiversity (Table 4-8). This indicates that with respect to seral stage distribution, changes that have occurred on the JPRF between 1947 and 1999 have remained within the natural range of variation.

Species composition is one component of natural landscape change that has not been quantified within the context of the Biodiversity Guidebook. Without this frame of reference it is difficult to determine whether the changes in species composition that have resulted over the past 60 years on the JPRF are within the natural range of variation for the ecosystem. It is recognized, however, that the changes in species composition that have occurred on areas with high timber value are of a greater magnitude than those areas that were not as accessible and therefore not harvested. For example, in the northern portion of the forest, near Tezzeron Lake, was heavily impacted. Based on descriptions of the natural ecosystem from the Biodiversity Guidebook, data from 1947 aerial photographs, and oral and written records, these changes are believed to be outside the natural range of variation. As such, ecological restoration initiatives should be focused in areas that have undergone substantial changes, such as on the northern portion of the JPRF.

Table 4-8 Comparison between seral stage distributions on the John Prince Research Forest. Data from 1947 and 1999 was compared to recommended range of variation from the Biodiversity Guidebook (British Columbia Ministry of Forests and British Columbia Environment 1995).

	Biodiversity Guidebook Recommendations [a]				
Seral Stage	Low	Intermediate	High	1947	1999
Early	N/A	<54	<40	13.9	30.6
Mature	>11	>23	>34	63.4	48.5
Old	>11	>11	>16	0.7	33.0

[a] Biodiversity Guidebook (1995) recommendations seral stage distribution for the SBS (percent of forested landscape within the landscape unit), including low, intermediate and high biodiversity options.

Issue of Temporal and Spatial Scale

The perception of natural variability in ecosystems is dependant both on the method of observation (as previously discussed), and on the scale that the observation was made (White and Walker 1997). In an ecological system, the patterns detected are a function of the scale, both in terms of the grain and the extent of the analysis (Forman and Godron 1986). When observing landscape change the spatial scale is defined by the size of the smallest patch (grain) and by the geographic extent of the landscape, while the temporal scale is constrained by the time when the original sample (grain) was taken and by the entire time period (extent) that is being considered. These constraints limit the interpretations of the results in studies such as this as ecological patterns cannot be detected below the grain or beyond the extent that was studied (Forman and Godron 1986, White and Walker 1997, McGarigal et al. 2001).

In terms of temporal scale, the period of time during which the landscape was studied has an impact on the changes detected and the subsequent interpretations made. In this case, as the period studied encompassed the time during which the most extensive harvesting was known to have been occurring on the JPRF, and therefore the changes that were observed documenting the cumulative impacts of timber harvesting and road construction during this time were significant. Alternatively, if the landscape was studied over incremental periods between 1947 and 1999 (e.g. over 10 year periods) undoubtedly the changes observed would not be as obvious. Similarly, if 10 year periods were studied over the past 200 years the conclusions would be very different. To a certain degree, the knowledge of land use practices gained from oral and written historical records offers insight into the changes that occurred over shorter time periods (e.g. 5 or 10 year periods) between 1947 and 1999. For example, from these records it is known know that intermediate utilization standards (i.e. selective harvesting) were used between 1940 and 1970, and clearcutting was the primary silviculture system used between 1970 and 1999. Clearly, the spatial changes that would have occurred on the landscape under these different silviculture systems would be quite different. However, without spatial data from incremental periods between 1947 and 1999 it is not possible to discuss these spatial changes quantitatively.

In terms of spatial scale, it is not possible to draw conclusions from the data beyond the smallest patch size (or polygon) studied (grain), or beyond the total geographic extent of the JPRF. As such, caution must be exercised when comparing results from this study with other published studies, as values obtained for metrics using different scales are not comparable. For example, Sachs et al. (1998) determined that between 1975 and 1992 forested landscapes in the interior of British Columbia were in the early stages of fragmentation. However, the landscape in question was of a different size than the JPRF, and the time periods were different, it is not possible to compare the quantitative results from Sachs et al. (1998) to the results reported in this work. Therefore, it is not possible to make conclusions about the changes in landscape structure in the interior of British Columbia by combining the data or comparing the metrics from these two studies.

The years 1947 and 1999 were selected for analysis as data was available for the study area during these periods. It appears, however, that the late 1930s would have been a more appropriate reference period, as management activities on the JPRF affiliated with the Pinchi Mercury Mine had already begun in 1940. Thus, harvesting activities in the southern portion of the JPRF were already in progress prior to 1947. The primary area of concern for ecological restoration on the JPRF, however, is in the northern portion of the forest. As harvesting activities began in that area in the mid 1950s the results from this work will prove useful in that effort. That is, it is possible to use changes reported here to justify further work into the potential need for ecological restoration in this portion of the JPRF. Further, a range of data that reflects pre-management conditions is necessary to definitively establish trends that have industrial management on the JPRF, and to distinguish these changes from those that would result naturally.

Previous studies have shown that changes in landscape condition in forests are more apparent at larger scales, and this issue of scale is relevant when considering a relatively large areas (Sachs et al. 1998, McGarigal et al. 2001). Additionally, greater and potentially more ecologically significant changes in landscape structure are evident in smaller areas composed of merchantable timber (McGarigal et al. 2001). That is, when studying changes over large areas it is possible that the changes observed become masked to a certain degree, and these are more apparent when looking at smaller areas, which are currently, or were at some time, composed of high quality timber. This trend is apparent on the JPRF. Specifically, the northern portion of the JPRF was heavily impacted by timber harvesting because of the high quality and quantity of timber, suitable terrain and close proximity to Tezzeron Lake. In particular, Timber Sale (TS) X65876, (approximate area, 2000 ha) located in the northern portion of the JPRF, was reportedly an area of high timber value. As a result timber harvesting activities on the JPRF during the 1950s and 1960s were focused to a large extent on this area. Therefore, changes in landscape structure are much more prevalent in this and other similar areas of the JPRF. An analysis at the resource management zone level provides insight into landscape changes in smaller areas of the JPRF[9]. More specifically, performing spatial analysis on areas which have been harvested (such as on TSX65876) may result in more obvious changes in landscape structure than have been reported here, and thus highlighting the need for ecological restoration.

Conclusion

The image processing and GIS techniques demonstrated in this study provide information for improved forest management on the JPRF, and for other forests in sub-boreal British Columbia which have been subjected to similar land management patterns. These techniques have analytically quantified changes in landscape structure and composition over time. This information provides the necessary measures for better understanding the sustainability of management practices and for defining reference conditions for potential ecological restoration efforts.

- Chapter 5 -

Defining Reference Conditions for Ecological Restoration in Sub-Boreal British Columbia[12]

INTRODUCTION

Historically, in British Columbia, natural disturbances (i.e. fire, insects, disease, and wind) and Aboriginal management activities were the dominant factors that shaped forests, but in the past half-century industrial land use has become an additional disturbing agent (British Columbia Ministry of Forests and British Columbia Environment 1995, Delong and Tanner 1996). To date, ecological restoration in forests of British Columbia has primarily focused on urban development issues in Garry Oak (*Quercus garryana* Dougl. ex Hook.) ecosystems, management of fire risk in dry interior forests, management of parks and protected areas, and watershed restoration (Holt 2001). Sustainable forest management initiatives in British Columbia place importance on understanding the natural character of forests, and ecological restoration in forests altered by diameter-limit harvesting practices is an issue that is potentially relevant to forest managers throughout much of the province.

Landscape structure in forests (i.e. species composition, age distribution and spatial arrangement) has changed as a result of timber harvesting, road construction and the alteration of natural disturbance regimes (Baker 1992, Fulé et al. 1997, Moore et al. 1999). While many of these changes have been the topic of previous research, changes in forests resulting from diameter-limit timber harvesting and other selective harvesting practices are less obvious and have received less attention. In the sub-boreal forests of the central interior of British Columbia Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) reaches the northern extent of its natural range, and diameter-limit logging and other selective harvesting practices has lead to a decline in the representation of Douglas-fir on the landscape (Lousier and Kessler 1999). A recent study in the

[12] A version of this Chapter will be submitted for publication under the following authorship: M.K. MacGregor and S.M. Dewhurst.

region concludes Douglas-fir is at risk in this area, as it is being lost to forest harvesting and insects faster than it is being replaced[13]. There is an ongoing perception that Douglas-fir can not be successfully regenerated in this region, and therefore after harvesting more "reliable" species, such as interior spruce and lodgepole pine are often replanted. Even if harvesting in Douglas-fir stands were to cease in the near term, losses due to forest insects would remain high.

Douglas-fir plays a key ecological role in forests of sub-boreal British Columbia. Douglas-fir trees can grow to very large sizes, relative to other species in the region, lives a very long time, and a slow rate of decay. The species is associated with areas rich in biodiversity, and as such has been identified as a target species for retention in this region. To date, no work has been published which develops theories and guidelines for ecological restoration in forests impacted by diameter-limit and other selective harvesting practices.

Broadly speaking, guidelines for ecological restoration have been well researched and documented (e.g. Jordan et al. 1987, White and Walker 1997). It is generally accepted that effective ecosystem restoration requires: (1) a characterization of the current conditions in the area targeted for ecological restoration, (2) a detailed description of the structure and function of a suitable reference condition, (3) a management strategy based on ecological restoration objectives, and (4) a framework for continued monitoring and research. Characterizing reference conditions requires gathering and analyzing data at both the landscape and stand levels (Moore et al. 1999). However, there is generally a lack of detailed knowledge of the character of natural forests impacted by industrial land use at the stand level (Angelstam et al. 1997). Therefore, describing reference conditions at the stand level is important for depicting the natural variability within the ecosystem (Morgan et al. 1994) and offering site specific and practical goals for ecological restoration (White and Walker 1997).

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[13] Oneil, E., L. Beaudry, C. Whittaker, W. Kessler, and D. Lousier. 1997. Ecology and Management of Douglas-fir at the Northern Limits of its Range: A Problem Analysis and Interim Management Strategy. University of Northern British Columbia, Unpublished Report.

Culturally-derived historical information plays an important role in interpreting and defining reference conditions for ecological restoration (White and Walker 1997). However, it is often difficult to locate historical information relevant to a specific area, and define reference conditions based on that information (Fulé et al. 1997). Historical information has many limitations, including insufficient detail, poor resolution, and biases (White and Walker 1997), but comparing multiple sources of information will help overcome these limitations (Foster et al. 1990, Moore et al. 1999, Swetnam et al. 1999). Although historical information does not present a definitive description of desirable ecosystem characteristics, it does provide critical reference points and creates a basis for ecological restoration (Falk 1990). Multiple lines of culturally-derived historical information exist in British Columbia to support ecological restoration, including ethnographic information, oral histories, written records, maps and photography. These sources have been described in detail in Chapter 2. Culturally-derived historical information generally provides information to support the ecological condition at a broad scale (i.e. the landscape or stratum level), and additional sources of information are necessary to describe historical conditions at the stand level.

Reference sites (i.e. areas that have not been directly impacted by management) also provide insight into the character of historic ecosystems at the stand level (Fulé et al. 1997, Stockwell 1999, Swetnam et al. 1999). These sites, however, are generally small in size, located a considerable distance from the area targeted for ecological restoration, and may provide a biased sample of past conditions (i.e. they tend to be located in less productive or inaccessible areas) (White and Walker 1997). Despite these limitations, reference sites provide an additional source of information for describing the character of the historical ecosystem on a different, larger scale. Given the limitations of, and differences in scale between, reference sites and historical information, a comparison between sources is necessary to define reference conditions at multiple scales. In this paper, multiple sources of reference information were used to define reference conditions for ecological restoration on a forest in sub-boreal British Columbia.

METHODS

Study Area

The study area for this work is the 13,032 ha JPRF, located approximately 50 km northwest of the village of Fort St. James in sub-boreal British Columbia[1]. A detailed description of the JPRF can be found in Chapter 1 of this thesis. This area has been heavily impacted by industrial land use in the form of diameter-limit and other harvesting activities over the past half century (Chapter 3). The need for further exploration of ecological restoration at a larger scale is highlighted by changes in forest condition at the landscape level (Chapter 4). Using knowledge of land use patterns obtained from oral and written records (Chapter 3), and through an analysis of change in landscape structure from historical aerial photography and geographic information system (GIS) technology (Chapter 4), a target area for ecological restoration was identified on the JPRF. An area approximately 2000 ha in size in the northwest portion of the JPRF, which has been heavily impacted by industrial land use since the mid 1950s, was selected (Figure 5-1). The area was formerly Timber Sale (TS) X65876, and was selected because the most relevant and abundant sources of historical information for the JPRF exists for TSX65876, and it has been previously established that ecological restoration efforts on the JPRF should be focused in this general area[1].

Timber sale X65876 is located in the Stuart Dry Warm Sub-Boreal Spruce (SBSdw3) biogeoclimatic zone, which occupies approximately 91% of the JPRF[1]. The SBSdw3 is composed of a varied mixture of Douglas-fir, paper birch, subalpine fir, lodgepole pine and interior spruce (Meidinger and Pojar 1991). In these forests natural disturbances leave remnant Douglas-fir patches that, over time, develop increased structural diversity and therefore increased biodiversity (Lousier and Kessler 1999). Based on the ecological and social significance of the species, Douglas-fir remnant patches were used to explore methods for integrating stand level data from reference sites for these remnant forest types with landscape level reference information.

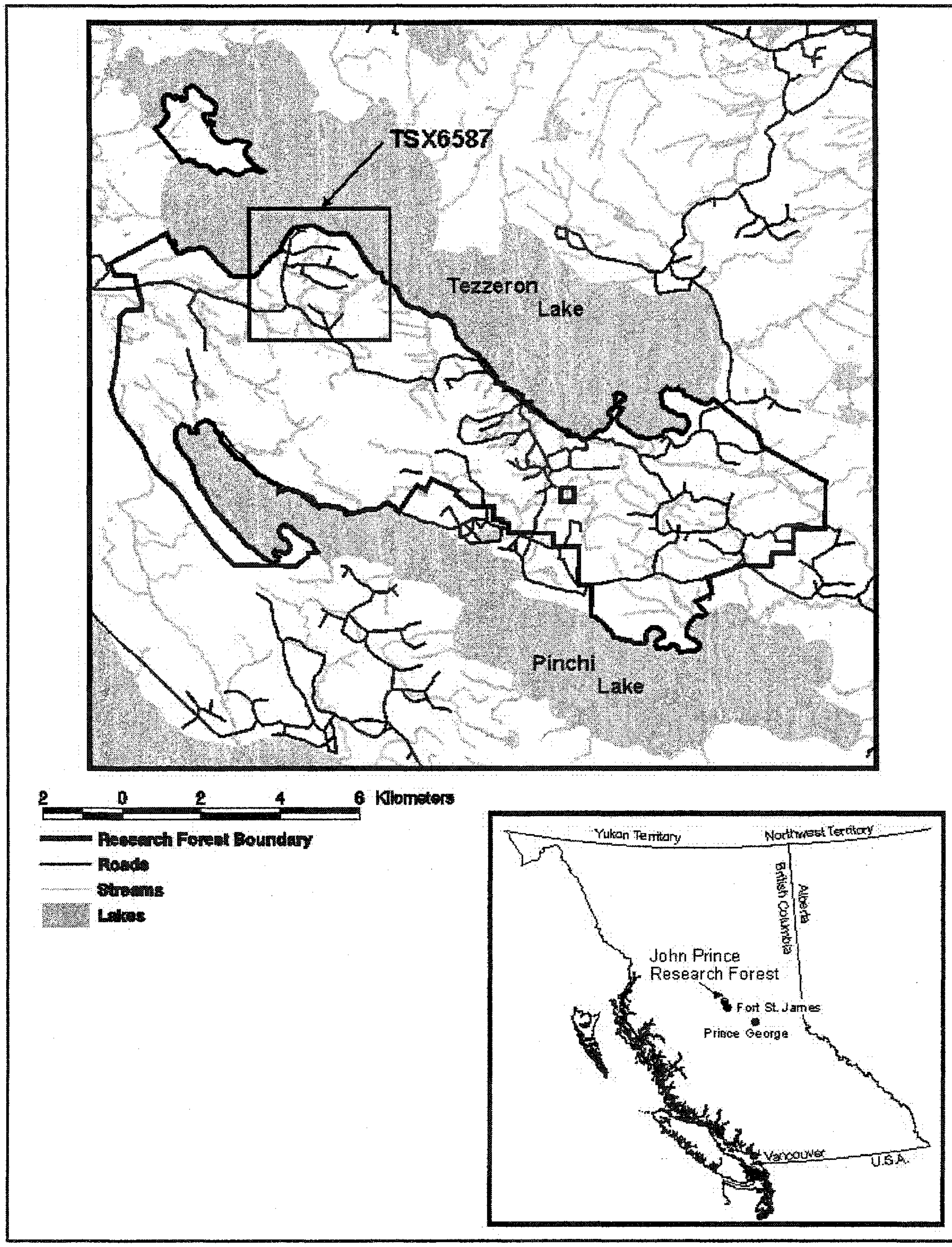


Figure 5-1 Map of the province of British Columbia (inset) and the John Prince Research Forest. Timber Sale (TS) X65876 is outlined in the upper left portion of the map.

In the Sub-Boreal Spruce (SBS) biogeoclimatic zone, wildfire, insects and disease were the primary factors that drove natural landscape dynamics (British Columbia Ministry of Forests and British Columbia Environment 1995). These natural disturbances resulted in extensive variation in landscape pattern due to vegetation, topography and the stochastic nature of natural disturbances. Where coniferous species dominate in the SBS, the mean fire interval was ca. 125 years, and remnant patches of mature forest typically remained in burned areas. In forests dominated by Douglas-fir, the number and size of remnant patches increased due to resilience of the species to wildfire, providing added structural diversity (British Columbia Ministry of Forests and British Columbia Environment 1995).

The study area was historically influenced by traditional activities of the Tl'azt'en Nation (Morris 1999, Karjala 2001). A detailed description of natural disturbances and cultural history for the area can be found in Chapter 1 of this thesis. Over the past half century, industrial land use has replaced both natural disturbances and traditional activities becoming the key disturbance agent in the SBS (British Columbia Ministry of Forests and British Columbia Environment 1995, Delong and Tanner 1996). A detailed description of the land use history on the JPRF can be found in Chapter 3 of this thesis.

Landscape Level Changes on the JPRF

An analysis of digital orthophotographs allowed the characterization of changes in landscape structure on the JPRF between 1947 and 1999 (Chapter 4). Data from the 1947 orthophotographs was used to define reference conditions at the landscape level on the JPRF. A detailed description of techniques used and results are provided in Chapter 4. In 1947, the JPRF was dominated by lodgepole pine (34%), Douglas-fir (28%), and interior spruce (20%) leading stands, and the remainder of the forested area was a combination of subalpine fir, paper birch, trembling aspen and black cottonwood (Table 5-1). Mean coniferous patch size averaged between 12 and 69 ha, with the Douglas-fir type comprising the larger patches (Table 5-2).

Table 5-1 Species composition by leading species on the John Prince Research Forest in 1947 based on data from historical aerial photographs (Chapter 4).

	1947	
Leading species	Area (ha)	% of JPRF
Douglas-fir	3670.9	28
Interior spruce	2587.9	20
Lodgepole pine	4382.9	34
Subalpine fir	108.2	0.8
Black spruce	88.1	0.7
Black cottonwood	46.8	0.4
Paper birch	65.3	0.5
Trembling aspen	1185.8	9
Brush	180.3	1
Lakes & wetlands	343.8	3
Logged (clearcut)	276.8	2

Table 5-2 Mean patch size by leading species on the John Prince Research Forest in 1947 based on data from historical aerial photographs (Chapter 4).

Leading Species	Mean Patch Size (ha)
Douglas-fir	69
Interior spruce	45
Lodgepole pine	53
Subalpine fir	54
Black spruce	12

Seral stages were defined by reclassifying inventory age classes into four seral stages using the following age ranges: early (<40 years), mid (40-99 years), mature (>100 years), and old (>141 years). In 1947, the forest was predominantly a mature, coniferous forest (63%), with a relatively low proportion of the forested area in early (14%), mid (20%) and old (0.7%) seral stages (Table 5-3). The majority of the mature coniferous forests were of Douglas-fir (22%), lodgepole pine (20%), and interior spruce (17%) forest types (Table 5-4). Early, mid and old forest patches were relatively small compared to the large mature patches (Table 5-5).

Historical Data Sources

The purpose of this study is to characterize landscape structure and define reference conditions on TSX65876. To do so, two primary sources of written documents were used: (1) the Cruise Report for Timber Sale X65876, British Columbia Forest Service, 1955[14], and (2) the Park Brothers Ltd. Cruise and Partial Logging Plan of TSX65876, Industrial Forestry Services, 1956[3]. Oral histories provided a more detailed understanding of historical inventory methods and aided in interpreting report content.

Forest Inventory Methods - The methods used for forest inventory in central British Columbia during the 1950s and 1960s varied based upon local standards, and special conditions of each timber sale. The below general method for completing a forest inventory during this period in this region was used by government and the forest industry. Transects were placed 10 chains (201.2 m) apart and plots were measured at every 10 chains (201.2 m) along the transect.

Plots were 1 chain (20.1 m) wide and 4 chains (80.5 m) long, and plot centers were offset 5 chains (100.6 m) from the adjacent transect, resulting in a 0.4 acre plot (0.2 ha) and a 4% cruise. Trees over 11.1 inches diameter at breast height (DBH) (28.2 cm) were tallied in 2 inch (5.1 cm)

[14] British Columbia Forest Service. 1955. Cruise report for Timber Sale X65876. British Columbia Forest Service, Victoria, British Columbia. Unpublished Report.

Table 5-3 Seral stage distribution on the John Prince Research Forest in 1947 based on data from historical aerial photographs (Chapter 4).

	1947	
Seral Stage	Area (ha)	% of JPRF
Early	1737.1	14
Mid	2470.6	20
Mature	7909.2	63
Old	90.9	0.7

Table 5-4 Seral stage distribution by leading species on the John Prince Research Forest in 1947 based on data from historical aerial photographs (Chapter 4).

	1947	
Leading species	Area (ha)	% of JPRF
Douglas-fir		
Early	157.0	1
Mid	638.4	5
Mature	2866.4	22
Old	90.9	0.7
Interior spruce		
Early	116.1	1
Mid	308.1	2
Mature	2153.4	17
Old	0	0
Lodgepole pine		
Early	774.5	6.0
Mid	1006.1	8
Mature	2602.6	20
Old	0	0
Subalpine fir		
Early	0	0
Mid	0	0
Mature	108.3	0.8
Old	0	0
Black spruce		
Early	9.9	0.1
Mid	73.9	0.6
Mature	4.2	0
Old	0	0
Deciduous		
Early	679.2	5
Mid	444.3	3
Mature	174.2	1
Old	0	0
Other strata		
Brush	180.3	1
Lake & Wetlands	343.8	3
Logged (clearcut)	276.8	2

Table 5-5 Mean patch size by seral stage on the John Prince Research Forest in 1947 based on data from historical aerial photographs (Chapter 4).

Seral Stage	Mean Patch Size (ha)
Early	40
Mid	43
Mature	180
Old	32

classes. Two sub-plots were established to measure smaller trees. A plot 10 chains (201.2 m) wide was established along the same transect, 3.3 feet (1 m) on either side, to tally smaller trees at least 4.5 feet (1.4 m) high. Trees on this 0.04 acre (0.02 ha) sub-plot were tallied in 2 inch (5.1 cm) classes. Trees in the 0.4 acre (0.2 ha) and 0.04 acre (0.02 ha) plots were tallied by species and classified as either "suspect" or "residual" depending on evidence of decay or damage. Trees less than 4.5 feet (1.4 m) high were tallied by number and species in a 0.001 acre (.0004 ha) sub-plot at the plot centre.

Tree height and age was recorded for approximately 30 dominant and co-dominant trees of each major species. Samples were selected to represent the range of diameters present and were not necessarily located within the inventory plots. For each sample tree, DBH was measured using a diameter tape and recorded to 0.1 inches (0.2 cm) and height measured to 1 foot (0.3 m) using a chain and clinometer. Age was estimated by adding several years to the counted age from tree cores based on the width of early growth rings. Radial increment was recorded for the last 10 years and 20 years to 0.1 inch (0.25 cm). Stands whose increment had not begun to decline were classified as "thrifty" and left to continue growing.

Timber volume per tree (board feet) was obtained using site index based volume tables, and average volume per acre was determined for each type based on the samples within that type. Overall volumes were determined by calculating areas of each type. Defect was estimated in the compilation process (in the 5% to 20% range) based on the relative numbers of residual and suspect trees.

Government Documents – The Cruise Report for Timber Sale X65876 was produced by the BC Forest Service in 1955[12]. This document will hereafter be referred to as the "cruise report". The cruise report was located in the government file containing records of harvesting activities on TSX65876 between 1955 and 1972, and was obtained from the British Columbia Archives in Victoria, British Columbia. The purpose of the cruise report was to inventory and advertise the sale of merchantable timber on TSX65876. The cruise report classified the area into seven types (or strata), three of which were classified as merchantable timber (Table 5-6). Stand tables included in the cruise report provide inventory data for the three merchantable strata (Table 5-7), and the map included with the report illustrates the spatial distribution of the strata (Figure 5-2). This map was digitally enhanced to aid in interpretation (Figure 5-3). Two of the three merchantable strata represent Douglas-fir leading stands by volume. Inventory data from the two Douglas-fir leading stands defined in the cruise report was compared to data from 2001 reference sites.

The cruise report also details: (1) a rudimentary soil classification for the merchantable strata, (2) a method for designating species and size to be harvested and methods for brush disposal, (3) silvicultural considerations, (4) a general description of the area, (5) logging and agricultural possibilities, and (6) the economic and legal constraints affecting the sale. The cruise report is of limited direct ecological value, as only merchantable strata were inventoried, and it is likely that using only three merchantable strata would not fully describe or represent stand variation.

Industry Documents – The Cruise and Partial Logging Plan for TSX658767 was produced by IFS in 1956[3]. This document will hereafter be referred to as the "logging plan". The purpose of the logging plan was to inventory and describe commercially valuable stands, and to outline the logging plan to be implemented over the next several years. The logging plan includes cull factors (i.e. an evaluation of waste), a description of the timber sale boundary and a description of the topography. The logging plan describes a partial cutting harvesting plan to be implemented over a 10 year period, road plans, and the location of the permanent sawmill. A map is referenced that illustrates the location and extent of each stratum, the timber sale boundary and a partial road plan, but the map could not be located for use in this study. The stand tables in the logging plan describe 23 types (or strata), and present data on stand density (trees per acre), stand

Table 5-6 Classification of Timber Sale (TS) X65876 on the John Prince Research Forest according to the Cruise Report for Timber Sale X65876[12]. Area is presented in both imperial (acres) and metric (ha) units, and the percent of total area represented by each stratum is given.

Classification of Area	Area (acres)	Area (ha) [a]	Percent of Total Area (%) [b]
Merchantable	3877	1569.0	81
Non-merchantable (scrub)	137	55.4	3
Immature reproduction	488	197.5	10
Non-commercial and swamp	250	101.2	5
Non-productive	36	14.6	1
Total Area	4788	1937.7	100

[a, b] Data was not included in original cruise report.

Table 5-7 Merchantable timber types by area within Timber Sale (TS) X65876 on the John Prince Research Forest according to the Cruise Report for Timber Sale X65876[12]. Area occupied by each strata is presented in imperial (acres) and metric (ha) units. Volume of merchantable timber cubic feet by species is also given. Types in bold are Douglas-fir leading by volume, and were compared to data from 2001 reference sites.

			Area		Vol. of Merchantable Timber (cubic feet)				
Type	Name	Abr. [e]	Acres	Ha [f]	Total	Spruce [a]	Pine [b]	Fir [c]	Balsam [d]
1	Spruce-Fir-Pine	FS1	2368	958.3	5644	3114	966	1359	205
2	**Fir-Spruce-Pine**	**FS2**	**1396**	**564.9**	**2966**	**948**	**550**	**1379**	**53**
3	**Fir-Pine-Spruce**	**FS3**	**113**	**45.7**	**249**	**14**	**65**	**169**	**1**
Total			3877	1569.0	8859	4112	1571	2907	259

[a] Inferred species interior spruce; [b] Inferred species lodgepole pine; [c] Inferred species Douglas-fir; [d] Inferred species subalpine fir.
[e,f] Data not included in the original report.

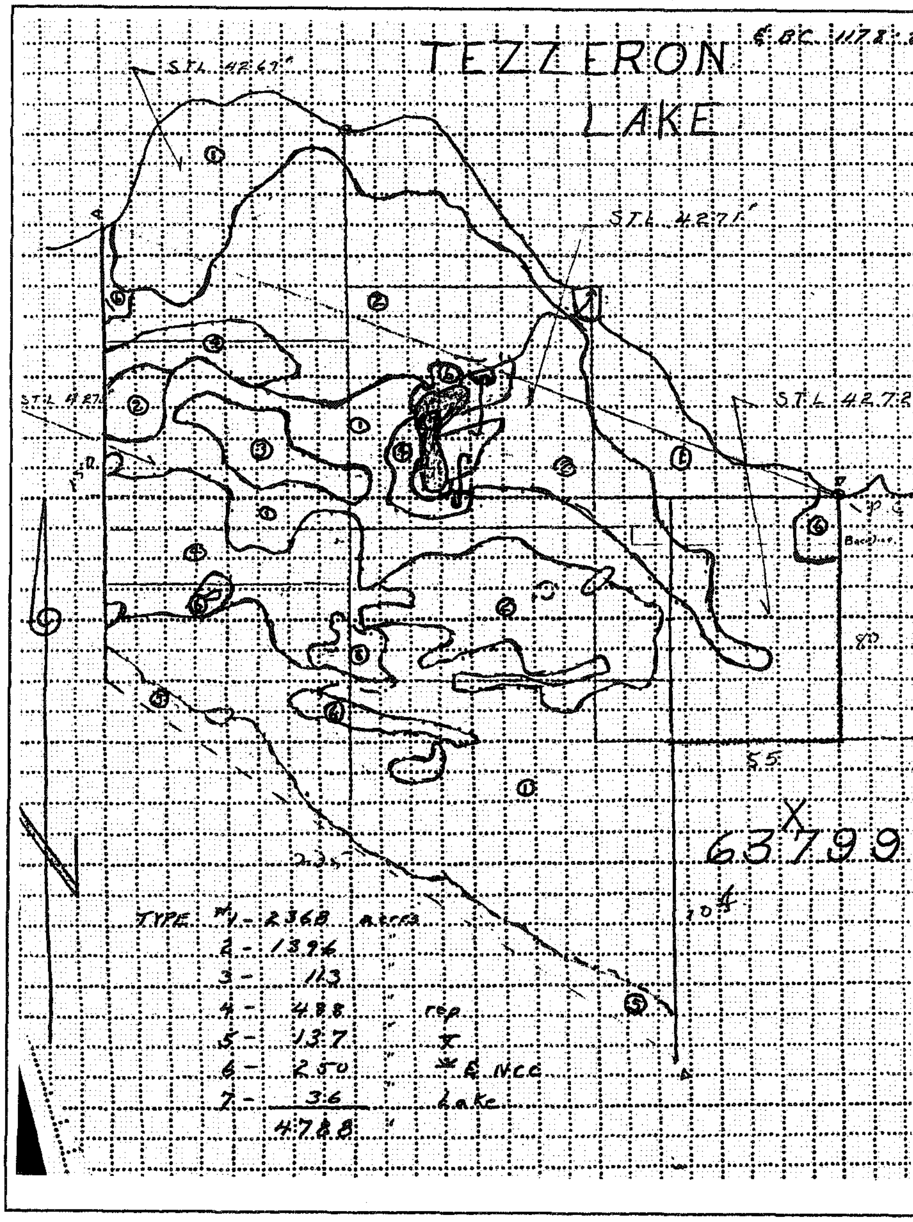


Figure 5-2 The original map for Timber Sale (TS) X65876 on the John Prince Research Forest from the Cruise Report for Timber Sale X65876[12]. The area is divided into seven types (or strata) listed by area (acres) at the bottom left of the figure.

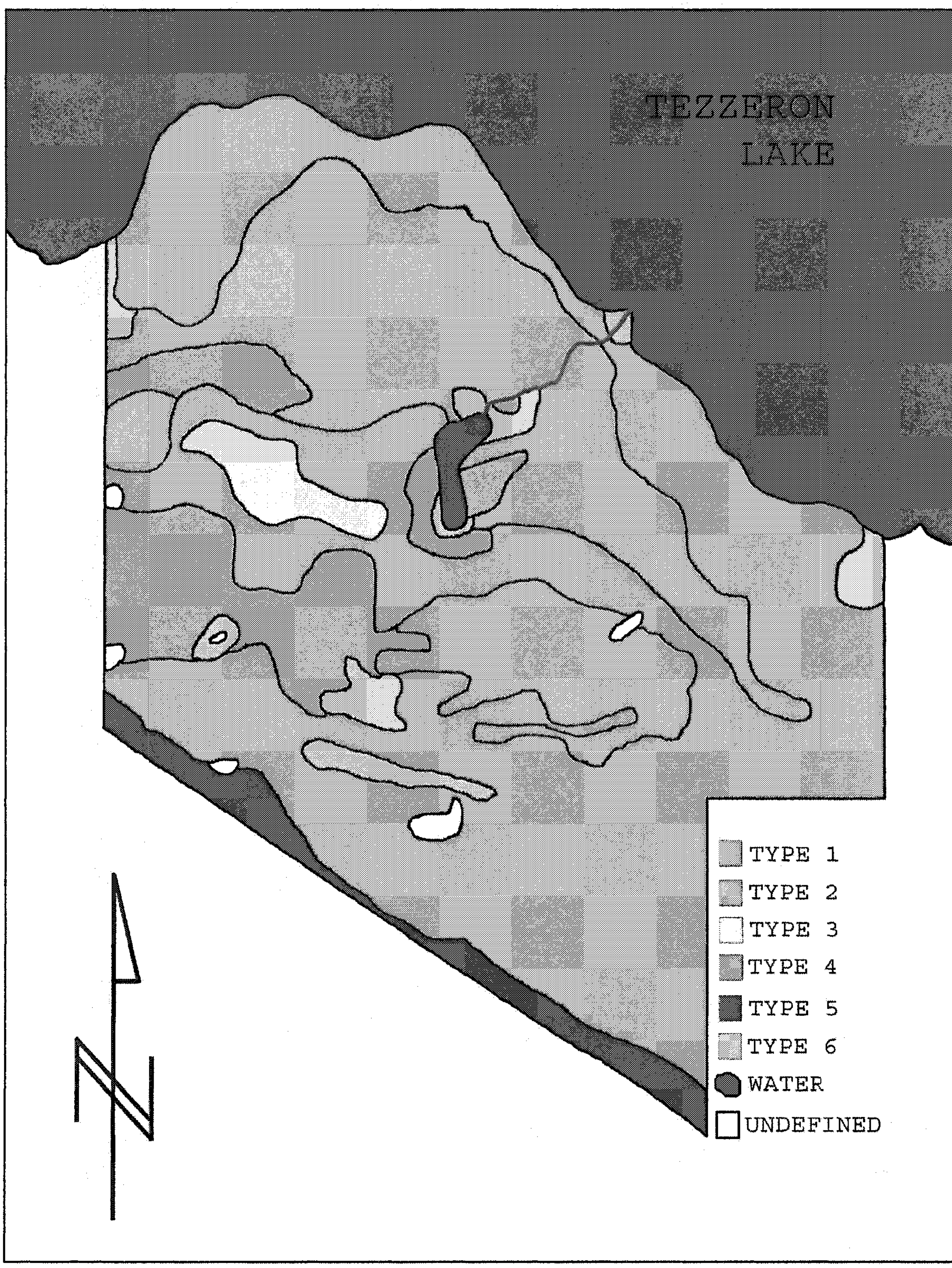


Figure 5-3 Digitally enhanced version of Timber Sale (TS) X65876 on the John Prince Research Forest based on the original map defining seven types from the Cruise Report for Timber Sale X6587612.

volume (volume per acre), gross volume, cull factor, area occupied by each stratum and stand age (Table 5-8). The characteristics of the 13 major strata, the recorded strata name and original survey notes with the approximate strata location and the inferred site series are described in Table 5-9. Thirteen of the 23 strata were designated major types (i.e. occupying >55 acres), and eight of the 23 strata were Douglas-fir leading by volume. Several stand tables describe representative trees by species, diameter, age, height, radial increment and crown class. Inventory data from the eight Douglas-fir leading stands from the logging plan was compared to data from 2001 reference sites. While the logging plan provides the most detailed account of vegetation prior to harvesting, stand level data included in the report is of limited ecological value, as it is biased towards merchantable trees. For example, for all 23 strata inventoried, there are no records of trees smaller than 12 inches diameter at breast height (DBH). Also, tree species are recorded by colloquial name (e.g. "swamp spruce"), rather than scientific name (most probably *Picea mariana*). Given the known characteristics of SBSdw3 ecosystems and the descriptions included in the logging plan, it is possible to infer the scientific name of the tree associations. However, as indicator plant species and moisture regimes of the sites were not described, this method of defining site series is limited.

Analysis of written records - A description of landscape condition on TSX65876 during the mid 1950s was developed based on data from the cruise report[12] and the logging plan[3]. Stand level data from the written documents is not presented here, as it was not possible to locate original data collected (i.e. the cruise cards) as I only had access to aggregate stand tables. The characterization is therefore limited to the interpretations made from strata descriptions. Aggregate stand tables from the cruise report[12] and the logging plan[3] were compared with data from 2001 reference sites.

Table 5-8 Classification of Timber Sale (TS) X65876 on the John Prince Research Forest according to the Cruise and Partial Logging Plan for TSX65876[3]. Type number, abbreviations (abr.) used in this study, name, inferred scientific name and area by each type (in acres and ha) are included. Types in bold (9-16) are Douglas-fir leading by volume, and were compared to data from 2001 reference sites.

Type	Abr.[a]	Name	Inferred Scientific Name [b]	Area Acres	Area Ha [c]
1	I1	Spruce	*Picea glauca* x *engelmannii*	1260	509.9
2	I2	Small Spruce	*Picea glauca* x *engelmannii*	56	22.7
3	I3	Swamp Spruce	*Picea mariana*	125	50.6
4	I4	Spruce Fir	*Picea glauca* x *engelmannii – Pseudotsuga menziesii* var. *glauca*	389	157.4
5	I5	Spruce Pine	*Picea glauca* x *engelmannii – Pinus contorta* var. *latifolia*	238	96.3
6	I6	Scrubby Spruce Pine	*Picea glauca* x *engelmannii – Pinus contorta* var. *latifolia*	8	3.2
7	I7	Spruce Pine Fir	*Picea glauca* x *engelmannii – Pinus contorta* var. *latifolia - Pseudotsuga menziesii* var. *glauca*	10	4.0
8	I8	Small Pine Spruce Fir	*Pinus contorta* var. *latifolia - Picea glauca* x *engelmannii - Pseudotsuga menziesii* var. *glauca*	13	5.2
9	**I9**	**Fir**	***Pseudotsuga menziesii* var. *glauca***	**332**	**134.4**
10	**I10**	**Scrubby Fir Pine**	***Pseudotsuga menziesii* var. *glauca - Pinus contorta* var. *latifolia***	**30**	**12.1**
11	**I11**	**Fir Spruce**	***Pseudotsuga menziesii* var. *glauca - Picea glauca* x *engelmannii***	**514**	**208.0**
12	**I12**	**Scrubby Fir Spruce**	***Pseudotsuga menziesii* var. *glauca - Picea glauca* x *engelmannii***	**9**	**3.6**
13	**I13**	**Fir Pine**	***Pseudotsuga menziesii* var. *glauca - Pinus contorta* var. *latifolia***	**270**	**109.3**
14	**I14**	**Fir Spruce Pine**	***Pseudotsuga menziesii* var. *glauca - Picea glauca* x *engelmannii - Pinus contorta* var. *latifolia***	**32**	**13.0**
15	**I15**	**Fir Pine Spruce**	***Pseudotsuga menziesii* var. *glauca - Pinus contorta* var. *latifolia - Picea glauca* x *engelmannii***	**40**	**16.1**
16	**I16**	**Semi open Fir Pine Spruce**	***Pseudotsuga menziesii* var. *glauca - Pinus contorta* var. *latifolia - Picea glauca* x *engelmannii***	**29**	**11.7**
17	I17	Pine	*Pinus contorta* var. *latifolia*	505	204.4
18	I18	Small Pine	*Pinus contorta* var. *latifolia*	114	46.1
19	I19	Pine Spruce	*Pinus contorta* var. *latifolia - Picea glauca* x *engelmannii*	322	130.3
20	I20	Pine Fir	*Pinus contorta* var. *latifolia - Pseudotsuga menziesii* var. *glauca*	91	36.8
21	I21	Pine Spruce Fir	*Pinus contorta* var. *latifolia - Picea glauca* x *engelmannii - Pseudotsuga menziesii* var. *glauca*	88	35.6
22	I22	Immature & Scattered Mature Spruce	*Picea glauca* x *engelmannii*	12	4.9
23	I23	Spruce Fir & Cottonwood	*Picea glauca* x *engelmannii – Pseudotsuga menziesii* var. *glauca – Populus balsamifera* spp. *trichocarpa*	3	1.2

[a, b, c] Data was not included in the original logging plan.

Table 5-9 Data on the major strata (i.e. occupying >55 acres) from the Cruise and Partial Logging Plan[3] including the recorded strata name, survey notes and location on TSX65876, John Prince Research Forest. Inferred biogeoclimatic subzone site series is also included. Types in bold are Douglas-fir leading by volume.

Type	Recorded Name	Original Survey Notes	Inferred Site Series [a]
1	Spruce	This is the best timber type on the area. Spruce averages 20" DBH and is generally tall and clean. As can be seen on the type map the major portion of this type is *in the south-east portion of the timber sale.*	06/07
2	Small Spruce	This type contains spruce averaging 14" DBH and 95 ft high. Volumes per acre are considerably less than those of type No. 1	06/07
3	Swamp Spruce	The spruce in this type is medium sized (averaging 16" DBH) and of fairly good quality. The *ground is very swampy in all cases* and logging should be considered for winter only for this type	10
4	Spruce-Fir	A large portion of this type is *on the hill within 20 chains of the shore of Tezzeron Lake.* Trees of both species are tall and clean and generally of good quality	08
5	Spruce-Pine	This type occurs *in small patches over the entire area.* Spruce averages 20" DBH and pine nearly 16" DBH	06/07/08/09
9	***Fir***	**A type composed of small to medium sized fir with minor quantities of spruce and pine. Although the trees are not large they are fairly clean (for 2 logs) and sound. The type occurs *on very dry ground (south slopes and tops of knolls, etc.).***	**04/02**
11	**Fir-Spruce**	**This type contains fairly good quality large fir and spruce. The main position of this type is *on the steep hillside in the extreme south-western corner of the sale.***	**04/02**
13	**Fir-Pine**	**This type is found *on knolls and dry south slopes* and is composed of medium sized fir and pine of fair quality (some low limbs)**	**01/04**
17	Pine	Medium sized pine trees of very good quality from this type, which is found *on dry flats and ridges throughout the sale.*	03
18	Small Pine	This type is found *in similar areas to type (17)* but the trees are much shorter and average only about 10" DBH. Logging would not likely be profitable in this type.	04
19	Pine-Spruce	This type is composed of good quality, medium sized pine and spruce trees *on moist flats and ridges.*	01/04
20	Pine-Fir	This type is very similar to type (13), but pine volume is much greater than that of fir.	01/04
21	Pine-Spruce-Fir	This type contains almost equal quantities of each species. Trees of all species are of good quality (except large fir) and the volume per acre is high.	01/04

[a] Data was not included in original report.

Field Methods in Reference Sites

Field measurements in Douglas-fir leading stands were obtained to begin to incorporate reference conditions at the stand level into the ecological restoration framework for the JPRF. Reference conditions defined at the stand level can be used as a basis for defining silvicultural strategies for ecological restoration. In this context, remnant Douglas-fir stands were used to provide stand-level reference conditions for TSX65876 as it was typically Douglas-fir remnant patches that remained following natural disturbances (British Columbia Ministry of Forests and British Columbia Environment 1995). Also, Douglas-fir leading stands were selected because of the observed decline in representation of that species throughout the region (Lousier and Kessler 1999). However, planting of Douglas-fir is increasing in the Prince George Timber Supply Area (Prince George, Vanderhoof, and Fort St. James Forest Districts) over the past five to six years, and therefore in 20 years young stands will have a different composition than young stands in the current inventory. It is important to note that a comprehensive ecological restoration management plan would also incorporate stand level analysis for each stratum, and not only Douglas-fir.

Field measurements were obtained in the summer of 2001 to characterize remnant Douglas-fir leading stands. Four sites within the SBSdw3 with Douglas-fir leading stands in age class 8-9 (>140 years, old seral stage) were selected as reference sites. Site 1 was located in the northwest part of the JPRF, accessible via gravel road and a 5 km trail. Three sites were located in Tree Farm License #42, located approximately 40 km northwest of the JPRF, on the south shore of Trembleur Lake. Site 2 was located the furthest east on Trembleur Lake, Site 3 was located furthest west on Trembleur Lake. Site 4 was situated between Sites 2 and 3 (Figure 5-4).

Preliminary site boundaries were delineated using aerial photographs and current forest cover maps. Transects were laid out 50 m apart through each study site, and site series was described at a sampling intensity of one site per 100 m along the transect. Species composition and percent cover for shrub, herbs and mosses were inventoried using a 5.64 m^2 fixed area plot

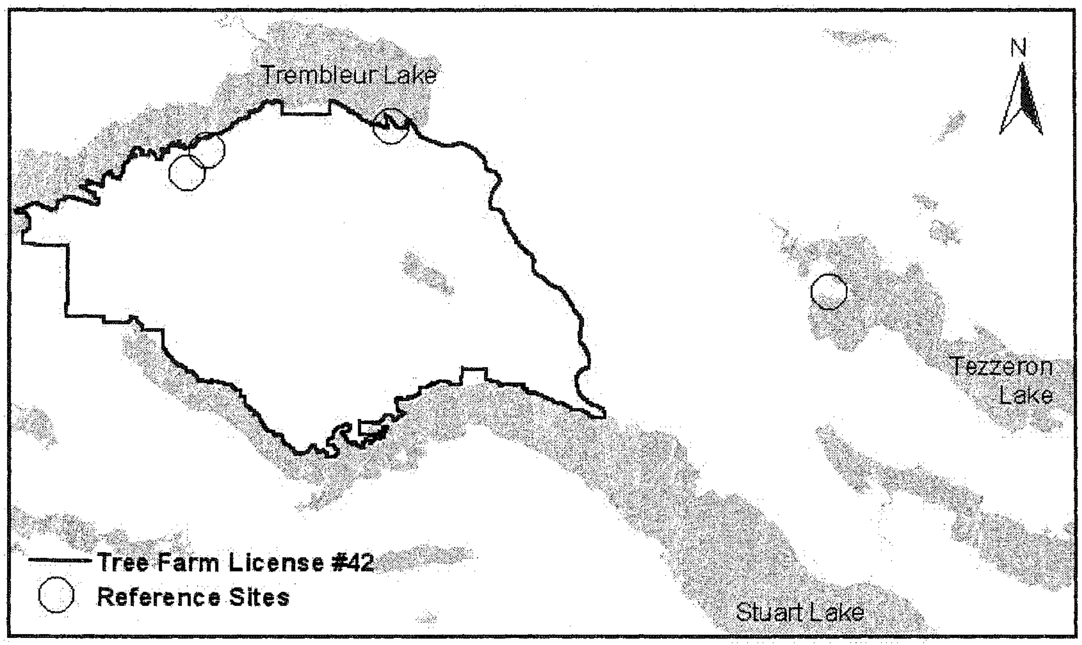


Figure 5-4 Location of four reference sites in the John Prince Research Forest and Tree Farm License #42.

(0.01 ha). Biogeoclimatic zone, subzone, variant and a description of site series was recorded for each site, in addition to elevation and slope. Variable radius plots were established using a basal area factor (BAF) 6 prism, and tree species, DBH (mm) and height (m) for each species was measured and recorded. To determine stand age an increment core was obtained at breast height for the largest tree of each species in each plot. A total of ten plots were inventoried in Site 1, nine in Site 2, six in Site 3, and six in Site 4 for a total of 31 measured plots. Data from all plots on each site were compiled to characterize species composition, density, DBH and basal area. Data was analyzed using a one-way ANOVA to test for similarity in stem density, DBH and basal area between the four sites. Reference conditions for Douglas fir leading stands were defined based, in part, on these data.

Comparison Between Written Records and Reference Sites

Two of the three merchantable strata defined in the cruise report[12] were Douglas-fir leading by volume (Table 5-7), and eight of the 23 strata defined in the logging plan[3] were Douglas-fir leading by volume (Table 5-8). These ten strata were used to define structure (in the mid 1950s) of Douglas-fir remnant stands prior to industrial management. This data was compared to data from the four reference sites inventoried in 2001. The strata from the written records were abbreviated based on the source. For example, "Type 2" defined by the cruise report[12] was abbreviated as "FS2", and similarly "Type nine" defined by the logging plan[13] was abbreviated as "I9" (Table 5-7 and 5-8).

To make comparisons between the two forms of information, data from reference sites were summarized into volume acre^{-1} by species (using only Douglas-fir and interior spruce stand components) based on standards used in written records. The 2001 reference data were more detailed, and the original measurements for these data were available. As a result, it was more feasible to reclassify the 2001 measurements to standards found in historical records than to reclassify the historical records to modern standards (and units of analysis). Therefore, data in this section was presented in imperial units.

The strata descriptions in the written records do not include trees less than 12 inches DBH, and thus trees less than 12 inches DBH from the 2001 reference sites were not included in the analysis. Also, as historic strata descriptions only include merchantable species, deciduous species measured in 2001 reference sites were omitted.

By using the characteristics of reference sites, and comparing these to historic descriptions of Douglas-fir leading stands as found in historical forest inventory data, it is possible to determine the extent to which data from reference sites can be used to define stand level reference conditions in Douglas-fir leading stands described in historical records.

RESULTS

Landscape Level Reference Conditions for TSX65876

From the cruise report[12] and the logging plan[3], three major vegetation strata by volume were identified on to have dominated TSX65876 in the mid 1950s, including: (1) Douglas-fir, (2) interior spruce, and (3) lodgepole pine leading stands. Douglas-fir leading stands occupied 26% to 32% of TSX65876, interior spruce leading stands occupied 41% to 49% of TSX65876, and lodgepole pine leading stands occupied 0% to 22% of TSX65876. The strata were defined based on the relative portions of Douglas-fir, interior spruce, lodgepole pine, sub-alpine fir and deciduous species. The merchantable forest originally covered approximately 80% of TSX65876, with the remaining 20% of the area classified as water, brush or swamp.

Within TSX65876, Douglas-fir leading stands dominated dry slopes, the tops of knolls and along steep ridges. Lodgepole pine occurred in relatively small patches on dry flats. Interior spruce dominated moist low-lands and along the shore of Tezzeron Lake. In the valleys, black spruce stands replaced interior spruce. Road development occurred on TSX65876 with the initiation of timber harvesting and prior to development the area was described as an isolated, mature, coniferous forest.

Stand Level Reference Conditions for TSX65876

Site 1 was situated in the SBSdw3/04 (Ricegrass) variant, and Sites 2, 3 and 4 were situated in a mixture of SBSdw3/01 (Pinegrass) or SBSdw3/04 (Ricegrass) variants. A tree layer dominated by Douglas-fir with interior spruce as a co-dominant species characterizes both variants. The primary difference between the two variants was the more developed shrub layer in the SBSdw3/04 (Figure 5-5). The successional stage of each site was climax forest that is continuing to mature. Field studies provided insight into micro-site conditions, and shrubs, herbs and mosses present were described. A total of 252 live trees were measured in the 31 measured plots.

Trees <1.37 m tall were essentially absent from the plots. Table 5-10 presents species composition by percentage for each site. Stands were dominated by Douglas-fir, with variable components of interior spruce, subalpine fir and paper birch. Based on species composition, ecological restoration targets for average percentage occupied by each species could include a 42% to 69% (mean 59%) Douglas-fir component, a 2% to 48% (mean 26%) interior spruce component, a < 34% (mean 10%) subalpine fir component and a 4% to 12% (mean 6%) paper birch component.

Stand Density – The average density for all trees ranged from 146 to 910 stems per hectare (sph), and for Douglas-fir the range was from 8 to 75 sph (Table 5-11). There was no significant difference ($F = 2.98$, $P = 0.520$) in the average densities in each plot among the four sites when making comparisons among all species. When the average densities for Douglas-fir in each plot among the four sites were compared using an ANOVA, no significant differences were detected ($F = 2.98$, $P = 0.289$). Based on these data ecological restoration targets for average stand density

Figure 5-5 Photographs from two different plots within Site 3. The top photograph illustrates the more developed shrub layer present in the SBSdw3/01 and the bottom photograph illustrates the less developed shrub layer in the SBSdw3/04. The structure in both was a mature to old forest.

Table 5-10 Species composition by percentage for Sites 1, 2, 3 and 4.

		Species Composition (%)			
Site	# trees	Douglas-fir	interior spruce	subalpine fir	paper birch
1	69	42	48	0	12
2	84	64	28	2	4
3	56	59	2	34	5
4	52	69	17	8	6
Average	252	59	26	10	6

Table 5-11 Average stand density (sph), average DBH (cm) and basal area (m^2 ha^{-1}) for all trees and only Douglas-fir in Site 1, 2, 3 and 4.

Site	Average density (sph)		Average DBH (cm)		Basal area (m^2 ha^{-1})	
	All	Douglas-fir	All	Douglas-fir	All	Douglas-fir
1	146	8	40	65	47	42
2	910	75	36	46	55	36
3	279	36	49	67	56	33
4	255	59	45	57	52	36

would be between 146 and 910 sph for all trees, and between 8 and 75 sph for Douglas-fir trees (Table 5-12).

Diameter – The DBH for all trees measured ranged from 6 to 156 cm, and for Douglas-fir the range was from 8 to 156 cm. The mean DBH for all trees measured ranged from 40 to 49 cm, and the average DBH for Douglas-fir trees ranged from 46 to 67 cm (Table 5-11). DBH for all species was different among sites (F=8.28, P=0.026). The mean diameter for all trees varied significantly between Site 1 and Site 2 (F=7.44, P=0.007), between Site 2 and Site 3 (F=8.28, P=0.004), and between Site 3 and Site 4 (F=7.44, P=0.007). DBH for only Douglas-fir trees was also different among sites (F=7.23, P=0.0001). The mean diameter for Douglas-fir trees varied significantly between Site 1 and Site 2 (F= 12.22, P=0.0006), between Site 2 and Site 3 (F=17.04978, P=0.00006), and between Site 2 and Site 4 (F=4.31, P=0.040). Mean diameter by species for the four reference sites is presented in Figure 5-6. Based on these data ecological restoration targets an average DBH for all trees between 40 and 49 cm, and between 57 and 67 cm for Douglas-fir trees (Table 5-12). Data from Site 2 was omitted for consideration, as trees size was different in this site.

Basal Area – The total basal area for each plot varied from 12 to 96 m^2 ha^{-1}, and the total basal area for each plot represented by Douglas-fir varied from 12 to 96 m^2 ha^{-1} (Table 5-11). There was no significant difference in basal areas of all trees (F = 2.975, P = 0.720) or basal areas of only Douglas-fir trees among the four sites (F = 2.975, P = 0.852). Based on these data ecological restoration targets would reflect an average of between 47 and 56 m^2 ha^{-1} total basal area, with 33 to 42 m^2 ha^{-1} of the basal area Douglas-fir (Table 5-12).

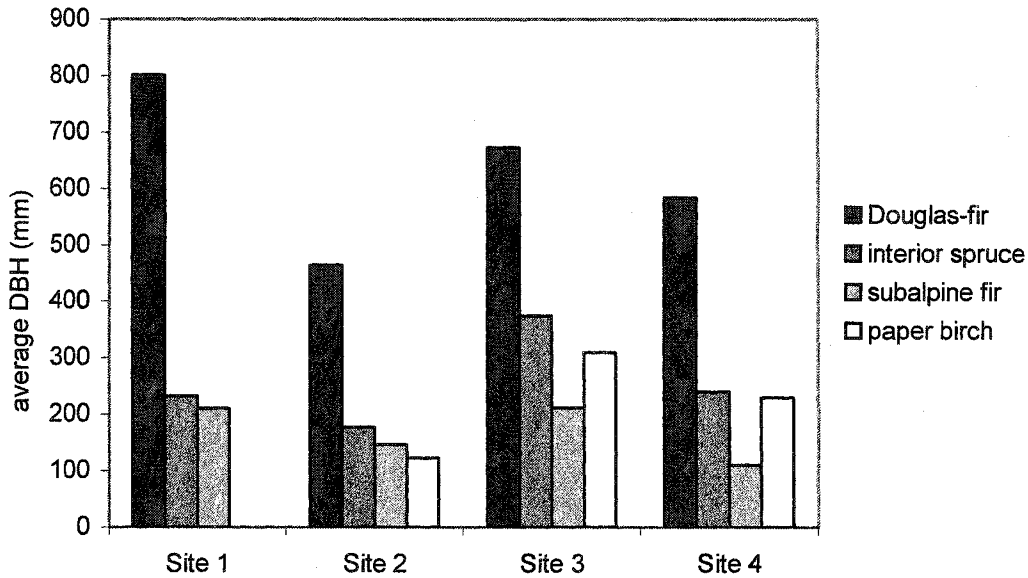


Figure 5-6 Mean diameter (cm) by species for Sites 1, 2, 3 and 4.

Table 5-12 Ecological restoration targets for TSX65876, on the John Prince Research Forest, based on data from 2001 reference sites. Targets were established for average stand density (sph), average DBH (cm) and basal area (m^2 ha^{-1}).

	Average stand density (sph)	DBH (cm)	Basal area (m^2 ha^{-1})
All trees	146-910	40-49	47-56
Douglas-fir trees	8-75	57-67	33-42

Comparison between reference sites and written records

Species composition differed somewhat between the strata described in written records and the data from the 2001 reference sites. For example, reference sites yielded no lodgepole pine components, which infers the reference sites have forests with slightly different composition than that described in the written records. These differences in species composition may reflect differences in site conditions or differences in available seed sources. As coarse woody debris was not measured in reference sites it is not possible to determine if lodgepole pine was a prior component of these stands that has been lost in natural successional processes over the past 60 years.

The Douglas-fir component from each of the four reference sites was compared to the Douglas-fir component in the two Douglas-fir leading stands defined in the cruise report and the eight Douglas-fir leading stands defined by the logging plan[3]. Although the data from reference sites does not provide an exact replicate of types described in written records, these sites were similar in some respects and are useful for defining silvicultural strategies with respect to Douglas-fir remnant forest patches (Figure 5-7).

The four reference sites were not comparable to the two Douglas-fir leading sands defined in the cruise report[12]. This may be the result of the broad approach used to define strata in the cruise report. Also, with respect to volume acre^{-1} Site 4 was not comparable to strata described by the cruise report[12] or in the logging plan[3] (Figure 5-8 b). This site was located a considerable distance from TSX65876 on the south side of Trembleur Lake, and this may partially explain the differences. Also, the site was a small, remnant forest patch in relatively atypical conditions (i.e. with significant lake influence). The location of this site was considerably different than the locations described in the written records.

The Douglas-fir component from Site 1 was similar to the Douglas-fir component from Type 15 (scrubby fir spruce = 3.64 ha) defined by the logging plan[3] (Figure 5-8 a). The Douglas-fir component from Site 2 was similar to the Douglas fir component from Type 9 (Fir = 134 ha),

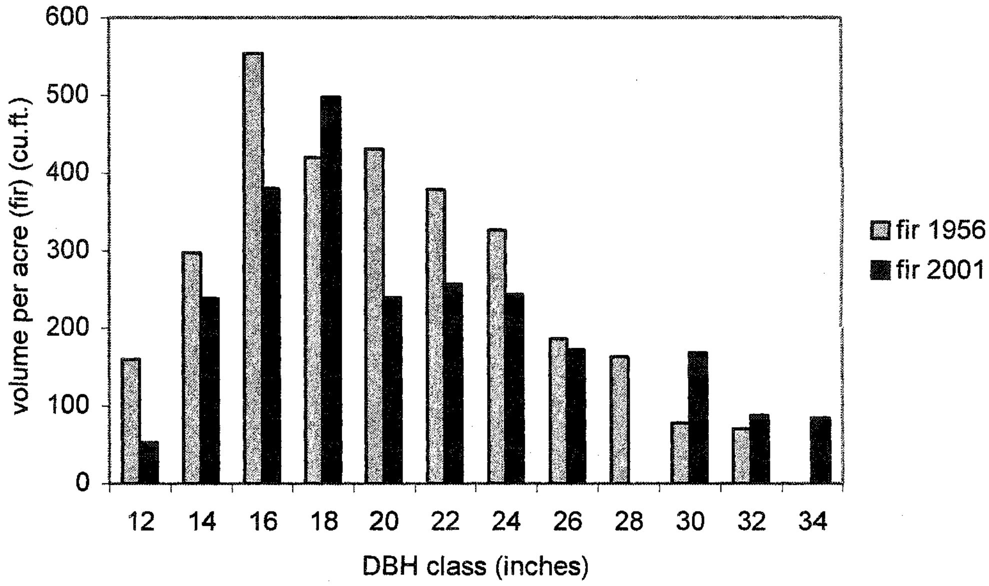


Figure 5-7 A comparison between volume per acre for the Douglas-fir component of Site 2 measured in 2001 and Type 9 as defined by the logging plan[3].

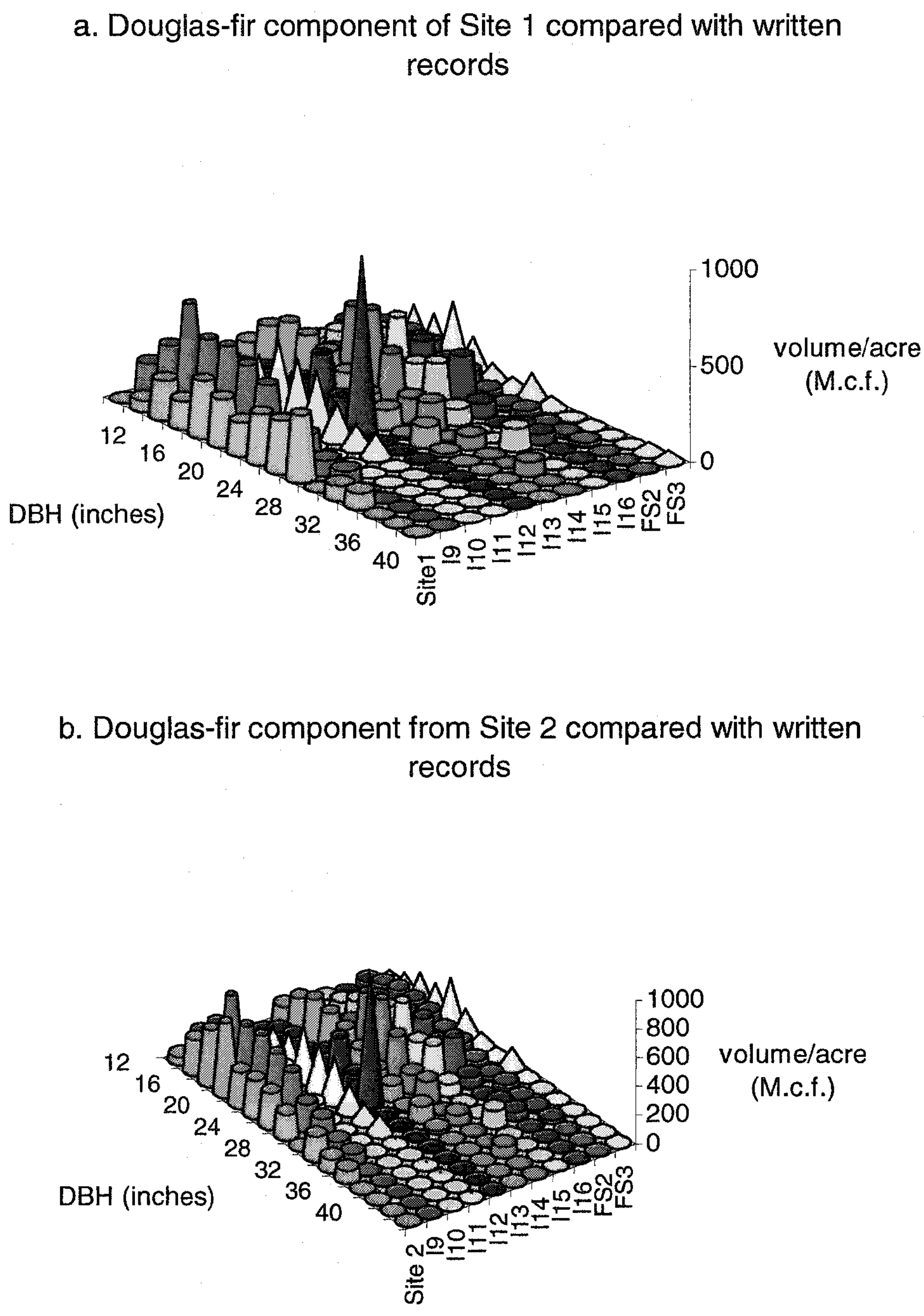


Figure 5-8 Comparison between volume per acre (cubic feet) for Douglas fir component in (a) Site 1, and (b) Site 2 with strata described in the cruise report[12] and in the logging plan[3].

and Type 15 (fir pine spruce = 13 ha) defined by the logging plan[3]. The Douglas-fir component from Site 2 appears to be a younger version of Type 11 (fir spruce = 208.01 ha) defined by the logging plan[3] (Figure 5-8 b). The Douglas-fir component from Site 3 was similar to several types defined in the logging plan[3]. This site appears to be an older version of Type 9 (fir = 134.36 ha), Type 11 (fir spruce = 208.01), and Type 15 (fir pine spruce = 13 ha) (Figure 5-9 a).

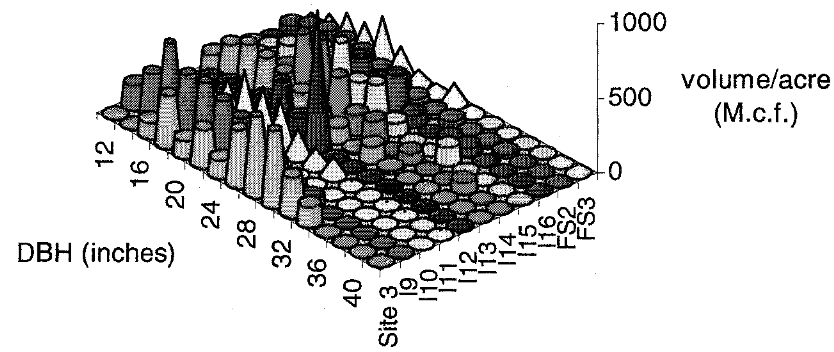
The interior spruce component from the written records was different from the spruce component from Sites 1, 2 and 3 (Figure 5-9 a, b; Figure 5-10). However, the interior spruce component in Site 4 appears to be a younger version of the spruce component from Type 9 (fir = 134 ha) and Type 12 (scrubby fir spruce = 3.64 ha) (Figure 5-11).

DISCUSSION

Reference information has been used in the past for defining reference conditions for ecological restoration at the landscape and stand levels (e.g. Fulé et al. 1997, Moore et al. 1999, Stephenson 1999, Axelsson and Östlund 2001). Most retrospective studies on forests, however, emphasize a landscape level approach, and analysis at the stand level has been largely overlooked (Spies et al. 1994, Frelich and Reich 1995, Wallin et al. 1996). Accurately identifying changes in forests that have resulted from patterns of industrial land use requires an analysis at a variety of scales, including both the landscape and the stand level (Axelsson and Östlund 2001). This study marks the first attempt to define reference conditions at both the landscape and stand levels for forests impacted by diameter-limit harvesting in sub-boreal British Columbia.

Available technology dictated patterns of land use on the JPRF, and these influences are evident in trends on the landscape today. With water the dominant means of transporting logs to sawmills during the 1940s to 1960s, the northern portion of the JPRF was heavily impacted because of the close proximity to Tezzeron Lake. Without access to waterways to transport logs to the sawmill, the interior portion of the JPRF remained relatively untouched (Chapter 3).

a. Douglas-fir component from Site 3 compared with historical data



b. Douglas-fir component from Site 4 compared with written records

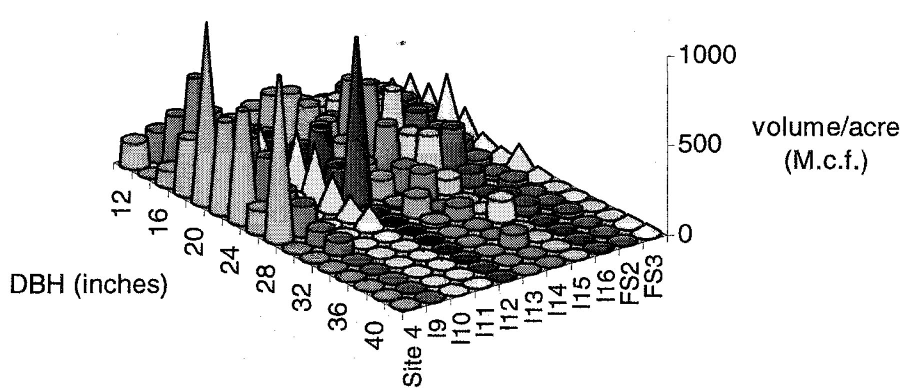


Figure 5-9 Comparison between volume per acre (cubic feet) for Douglas fir component in (a) Site 3, and (b) Site 4 with strata described in the cruise report[12] and in the logging plan[3].

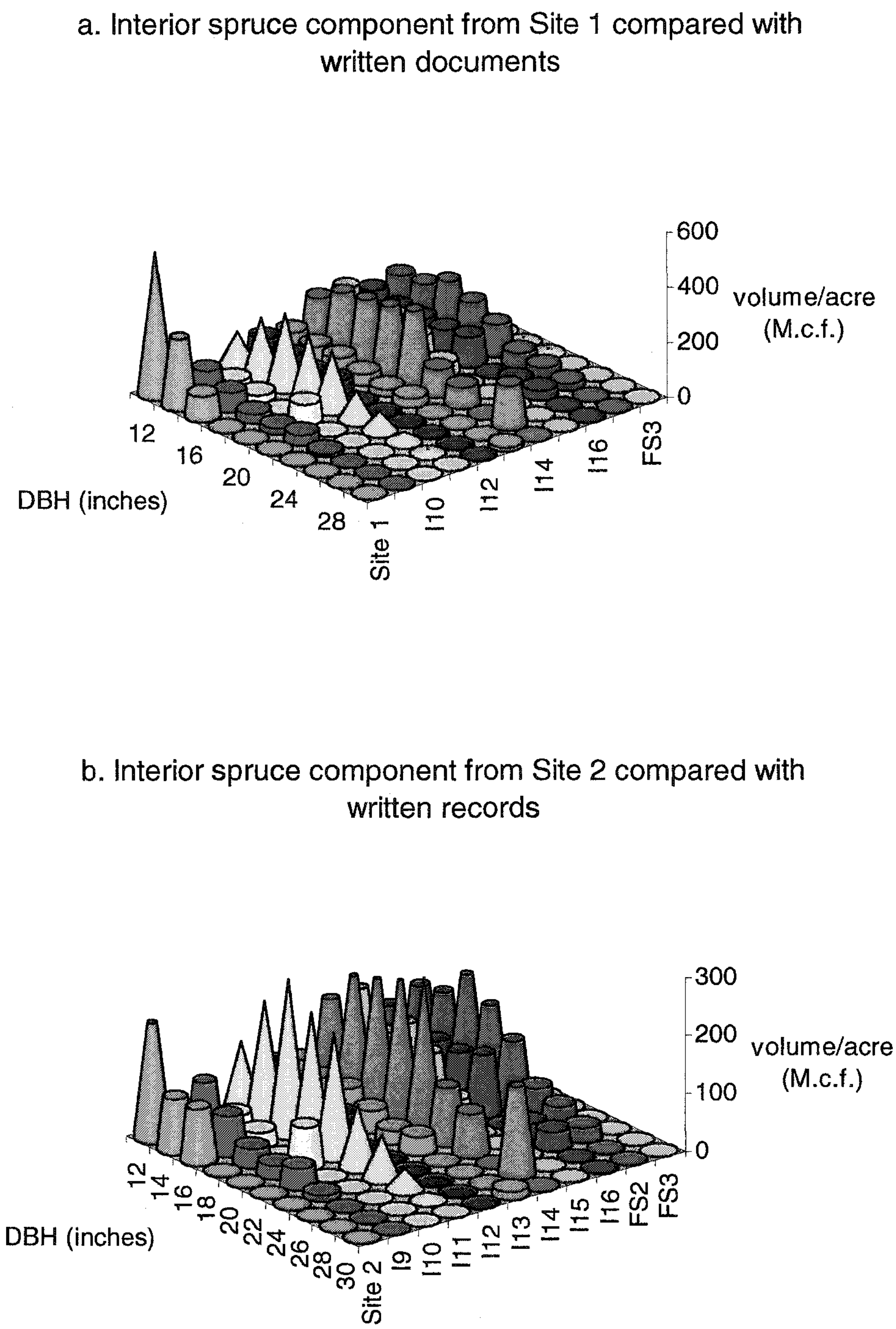


Figure 5-10 Comparison between volume per acre (cubic feet) for interior spruce component in (a) Site 1, and (b) Site 2 with strata described in the cruise report[12] and in the logging plan[3].

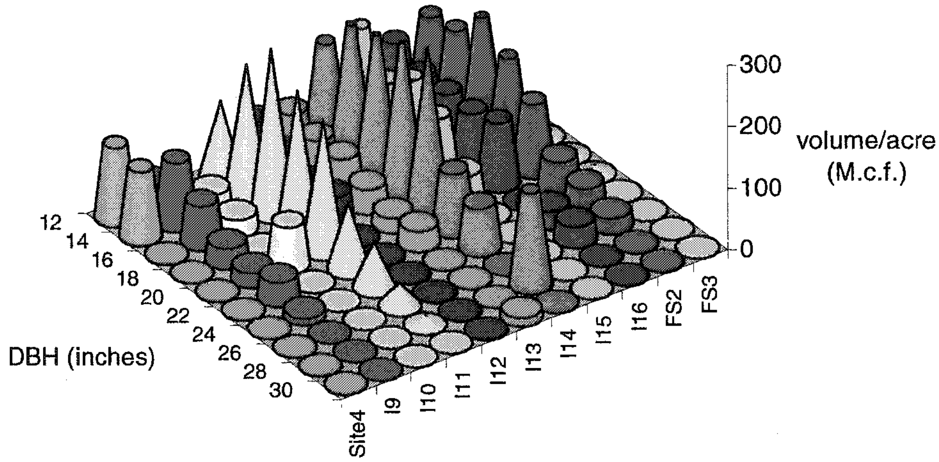


Figure 5-11 Comparison between volume per acre (cubic feet) for interior spruce component in Site 4 with strata described in the cruise report[12] and in the logging plan[3].

In 1947 the JPRF was dominated by mature coniferous forest, comprised of lodgepole pine (34%), Douglas-fir (28%) and interior spruce (20%) leading stands with variable components of subalpine fir, trembling aspen, paper birch and black cottonwood. As well, from the historical written records it is known that, in the mid 1950s on TSX65876 the landscape was dominated by mature and old coniferous species – Douglas-fir, interior spruce and lodgepole pine - with a minor percent classified as water, brush or swampy areas. Specifically, TSX65876 was predominantly occupied by interior spruce leading stands (41 to 49%), with a lesser amount of Douglas-fir (26 to 31.5%) and lodgepole pine (0 to 22%) leading stands.

Over the past half century, industrial land use has changed the landscape composition and configuration of the JPRF with respect to both seral stage distribution and species composition. Although changes in seral stage distribution are believed to be within the natural range of variability for the JPRF, it is unknown whether changes in species composition fall within the natural range of variation. In general, the northern portion of the JPRF has undergone a general shift from mature and old Douglas-fir, lodgepole pine, and interior spruce leading stands to young and mature stands dominated by deciduous species and subalpine fir. Consequently, it is recommended that ecological restoration efforts should focus on the north side of the JPRF, where a significant proportion of the area was previously occupied by TSX65876.

Ecosystem Structure Versus Ecosystem Function

In some ecosystems (e.g. the giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz) groves in the Sierra Nevada), the restoration of natural processes can be used to restore forest structure and composition, and active management may not be necessary for ecological restoration (Stephenson 1999). Restoring forest conditions by the reintroduction of natural disturbance regimes alone requires a comprehensive understanding of the impacts these processes had on the ecosystem (Stephenson 1999), but this approach may not be practical particularly in the case of restoring remnant patches of Douglas-fir on the northern portion of the JPRF. Due to the difficulty of naturally regenerating Douglas-fir it is believed that harvesting and artificial planting will be necessary to restore the Douglas-fir component to stands in TSX65876. If the area is left to naturally regenerate itself, particularly in the absence of a natural fire regime, Douglas-fir will not likely be a key component of the ecosystem as it was in the past. More shade-tolerant, if less fire tolerant, species such as interior spruce and subalpine fir will likely be favored by prevailing fire suppression and other management policies. Achievement of ecological restoration objectives in the harvested areas of the JPRF, formerly dominated by Douglas-fir, will require active management intervention. The information derived from historical information and stand-level reference sites can assist in characterizing remnant Douglas-fir patches and landscape level management goals.

Stand level reference conditions: Douglas-fir remnant forest patches

In the SBS, remnant Douglas-fir patches that remained following natural disturbances provided increased structural diversity and had important function maintaining natural levels of biodiversity in sub-boreal spruce forests (British Columbia Ministry of Forests and British Columbia Environment 1995, Delong and Tanner 1996). It is well established that natural disturbances maintain the structural complexity in forest stands promoting diversity in the plant and animal communities (e.g. Baker 1992, Landres et al. 1999, Egan and Howell 2001). Therefore, mimicking the structural complexity that results from natural disturbances in managed forests is one way of promoting biodiversity in managed stands (e.g. Jordan et al. 1988, Cissel et al. 1994, Morgan et al, 1994, Spies et al. 1994, Galindo-Leal and Bunnell 1995, Covington et al. 1997, Swetnam et al. 1999). Maintaining remnants of older forest stands in managed forests provides both wildlife habitat and seed source for natural regeneration (Eberhart and Woodward 1987), and this is true in Douglas fir dominated forests in the SBS.

Today, remnant stands of the mature Douglas-fir type on the JPRF occur in smaller patches than those that existed in the late 1940s (i.e. mean patch size has decreased from 69 to 28 ha over the last 60 years), in the mature seral stage (>100 years). Remnant stands inventoried in 2001 were comprised predominantly of Douglas-fir, with variable components of interior spruce, subalpine fir and paper birch. With respect to the Douglas-fir component, these stands were similar in structure with respect to basal area, stand density and DBH. Specifically, there was no significant difference between density and basal area of Douglas-fir trees in the four study sites. Also there were no significant differences between DBH of Douglas-fir trees in Sites 1, 3, and 4. The trees in Site 2, however, were significantly smaller than the trees in the other three sites. This difference is likely due to the variable topography and non-optimal growing conditions of areas in Site 2, which was comprised largely of ridges and talus slopes.

Several measures of forest structure – abundance of large trees, variation in tree size, abundance of understory plants, amount of coarse woody debris, and density of snags – have been presented as indicators of mature and old forests (Spies and Franklin 1991, Hansen et al. 1991, Acker et al. 1998, Niemelä 1999). Data from 2001 reference sites provides baseline data for characterizing tree structure in remnant Douglas-fir forests on the JPRF. As several of these sites were comparable with respect to volume per acre with Douglas-fir leading stands described in historical records, the management recommendations that follow would represent, in part, characteristics of Douglas-fir leading stands that persisted on TSX65876 prior to industrial management. While reference sites were not exact replicates of strata described in the written records, information from reference sites is useful for establishing targets for ecological restoration at the stand level.

Although the abundance of understory plants, the amount of coarse woody debris, and the density of snags were not specifically measured in this study they will be discussed here in a general context. Based on reference conditions, and general recommendations about structure in remnant forest stands, an ecological restoration prescription for remnant Douglas-fir stands on the northern portion of the JPRF would be based on the following general framework:

(1) Develop silviculture prescriptions to allow managing Douglas-fir on long rotations (>141 years) to assist in achieving old growth and biodiversity goals.

An important modification to traditional management practices that will more closely mimic natural disturbance regimes on the JPRF is to increase the number of remnant Douglas-fir stands (Fries et al. 1997). Leaving groups of trees unharvested and lengthening rotation between the harvest in Douglas-fir stands will accelerate the development of old-growth structure in remnant Douglas-fir stands (Vora 1994). In areas where Douglas-fir is no longer represented, and is not regenerating naturally, replant Douglas-fir to ensure the continuation of this species on the landscape. Also, reintroducing prescribed burning under Douglas-fir remnant stands more closely mimics natural disturbances than impacts resulting from mechanical scarification (Fries et al. 1997).

Many remaining Douglas-fir stands on the JPRF are infested with *Dendroctonus* bark beetles, and retaining mature and old Douglas-fir may have implications for forest health issues[1]. Mature Douglas-fir stands are increasingly susceptible to attack by *Dendroctonus* bark beetles due to changes in stand structure resulting from fire suppression, changes in local temperature and changes in the global climate. These trends are expected to further promote insect pests such as the *Dendroctonus* bark beetles on the JPRF. Currently, 848 ha of the JPRF show some level of attack by *Dendroctonus* bark beetles, and 700 ha are at high to extreme risk of attack[1]. It will be important for JPRF managers to consider this increase in susceptibility to attack by *Dendroctonus* bark beetles when managing Douglas-fir on longer rotations on the JPRF.

(2) Leave all remnant Douglas-fir trees and stands (>100 years), harvest in larger patches where possible, and build larger patch structures through sequential harvesting entries

Forest conditions in 1947 contained larger, more contiguous patches than those that exist on the JPRF today. Currently, there is an upper limit to patch size based on the social unacceptability of large openings in forests. Also there are assumptions that large patch sizes will compromise wildlife habitat, watershed conditions and recreational values in the short term, but these assumptions remain untested (Delong 1998). In this region, larger patch openings may be more representative of natural forest conditions. Prior to establishing an allowance for larger patch sizes, however, it will be critical that recommendations are put in the context of natural landscape patterns for the harvested area.

(3) Retain and promote an abundance of large Douglas-fir trees, and variation in tree size, typical of remnant stands.

Limiting tree density in Douglas-fir stands in the first several decades of management will accelerate mature stand structure (Acker et al. 1998). This may be achieved through the thinning of dense regenerating stands (Vora 1994). Developing complex stand structure in Douglas-fir remnant stands primarily involves putting emphasis on increasing the heterogeneity of tree sizes and increasing canopy layering within the stand (Acker et al. 1998). Further research should be conducted to characterize the natural complexity of stand structure in the forest types present in this region.

Data from 2001 reference sites are somewhat representative of Douglas-fir stands described in the cruise report[12] and the logging plan[3], and is used here to define reference conditions for overstory structure. Based on measurements from reference sites, ecological restoration targets for average species composition in remnant Douglas fir stands could include a 42% to 69% (mean 59%) Douglas-fir component, a 2% to 48% (mean 26%) interior spruce component, a < 34% (mean 10%) subalpine fir component and a 4% to 12% (mean 6%) paper birch component. To determine if lodgepole pine was previously a component of these stands that died out through natural successional processes a survey of coarse woody debris should be completed.

(4) Establish reference conditions for understory species, and structural elements such as coarse woody debris, wildlife trees, etc. Maintain structural elements such as coarse woody debris and wildlife trees in remnant and managed stands.

Levels of understory diversity, coarse woody debris and numbers of wildlife trees were not measured in this study, however the importance of retaining coarse woody debris in managed stands is certainly recognized. Wildlife trees are standing live or dead trees with special characteristics that provide valuable habitat for a variety of species (Spies and Franklin 1991, Fenger 1996). Coarse woody debris is downed wood and provides habitat, and an influx of energy and nutrients in mature or old forests (Spies and Franklin 1991). The density of coarse woody debris and snags are generally more abundant in older, remnant stands, and promoting these attributes in managed stands will promote biodiversity (Hansen et al. 1991, Acker et al. 1998). Typically, more organic matter is left following natural disturbances than following timber harvesting, and it is important to incorporate coarse woody debris and other residual material in all managed stands, not only remnant forest patches (Hansen et al. 1991, Niemelä 1999). It is not critical to allow natural development of coarse woody debris in managed stands. Large trees may be felled, speeding up the natural cycle, and left in managed stands to create increased structural diversity and the influx of nutrients (Vora 1994).

Further work is needed to establish reference conditions for these elements of forest structure on the JPRF.

Limitations of Data from Reference Sites

Reference sites can provide a sample of the original, unmanaged forest, but these sites are often remnant patches of the original habitat, impacted by edge effects, and may occur in less productive and/or inaccessible areas of the forest (White and Walker 1997). But, these inaccessible stands may still offer the most potential for describing reference conditions. Since the mid 1950s, recognition has grown of the lack of suitable reference sites in some areas (Bourdo 1956), and with the passage of time this issue becomes increasingly important, as reference sites become limited to more remote and isolated areas with the inexorable expansion of industrial management activities.

Most accessible stands (i.e. those stands near water and on suitable terrain) of valuable merchantable timber in the JPRF area were harvested between 1950 and 1980, the rare reference sites that do persist are generally unproductive, inaccessible or unrepresentative of the historical forest. Although it is possible to describe stand structure in Douglas-fir types using this approach, caution must be exercised in recognizing conditions affecting the reference sites which are not necessarily representative of the natural range of variability that would have been found in harvested portions of the forest. This information may therefore be integrated to some extent with historical records to define reference conditions for the JPRF. Interviewees were frank with respect to the possibility of finding remnants of the former forest:

> *"You would almost have to be in a park. I mean, we looked for those kinds of stands, and we found them." Forest Worker, 2001*

> *"If they were available, they wouldn't be available. They would have been logged already." Forest Worker, 2001*

> *"They were pretty prime stands so there would have to be some reason why it wasn't logged." Forest Worker, 2001*

> *"There was some fantastic Fir in those days. At Pinchi there, it was not unusual to get five or six foot bucked at the bottom. Trees that you will never see now or you very rarely do if you get back in some hole or something that hasn't been touched." Forest Worker, 2001*

Although it is possible to describe stand structure in Douglas-fir types based on data from reference sites, caution must be exercised when selecting and using data from reference sites to describe reference conditions. Historical oral and written records help to explain why data from reference sites may not be sufficient to describe reference conditions, and these sources provide additional information from which reference conditions may be defined. Conditions affecting the reference sites may not necessarily be representative of the natural range of variability that would have been found in harvested portions of the forest. This information should be integrated with other sources of information to define reference conditions for the JPRF.

Limitations of Historical Information

The most significant limitation of historical research in forests is the fragmentary and brief nature of historical records (Swetnam et al. 1999). Both the complexity and the reliability of historical information decrease as time passes, but this limitation can be addressed in part by using a reference period defined in part by the most reliable and complete historical record available (Swetnam et al. 1999). In this study an area on the JPRF was selected where ecological characteristics and historical management practices indicate ecological restoration may be appropriate, and reference conditions are based on the period for which the most detailed historical record was available.

Early forest inventory data for sub-boreal British Columbia is biased, given its focus on merchantable timber near water. Younger, non-merchantable and inland stands were typically avoided and it is rare to locate forest inventory data for these stand types. Ironically, these are the areas which are most often available for use as reference sites today. Data for the merchantable stands, however, remains useful for defining reference conditions in stands impacted by industrial land use, as these stands would now be likely candidates for ecological restoration. Therefore, data from non-merchantable stands is useful for defining reference conditions in stands not impacted directly by management, but not necessarily in stands that were harvested.

Information gained through interviews with individuals who worked in the forest industry have a similar bias, as these individuals gained much of their experience and knowledge from harvesting merchantable stands of timber.

> *"If we were looking for Fir we would go and pick a place where we could get Fir. If we were looking for Spruce, we would get a place [that had Spruce]."* Forest Worker, 2001
>
> *"When you got back in the hills, I don't know, we never paid attention."* Forest Worker, 2001

Additionally, changes in methods for collecting forest inventory data over time account for some variation between modern and historical inventories (Axelsson and Östlund 2001). For example, historical inventories did not include deciduous species or trees under 12 inches DBH where modern inventories do include deciduous species and all tree sizes. Also, it is difficult to compare information collected by different agencies or organizations, as different organizations have different requirements and specifications for the information the collect. The two forms of historical written records used in this study - the cruise report[12] and the logging plan[3] - were compiled by different organizations. The cruise report[12] contained inventory data for three merchantable strata, and was used to advertise the available timber to licensees. The logging plan[3] was a more comprehensive inventory used to support harvesting operations for the duration of the sale, and includes more detailed inventory data for 23 strata. The original purpose for collecting the information is reflected in the detail and quality of the historical data.

The use of colloquial names presents another challenge when using historical information. Colloquial names are often used for plants and animals, and these names are different from contemporary common and scientific names. The lack of scientific nomenclature creates challenges when identifying organisms from historic ecosystems (Edmonds 2001). For example, the logging plan identified "Swamp Spruce" as a major stratum and describes the location where this stratum is found as "very swampy in all cases"[3]. Conventional nomenclature leads us to believe the species is black spruce a small, shrubby tree, characteristic of cold, poorly drained, nutrient-poor soils in bogs and swamps and upland sites near wetlands (MacKinnon et al. 1992). As interior spruce can grow on wet sites and attain a large size, using a DBH threshold (e.g. if < "X" than black spruce, or if > "X" interior spruce) is one approach that may be useful for distinguishing between species such as interior spruce and black spruce described in written records. However, without a more detailed description of the species and stratum an accurate identification cannot be guaranteed.

Implications for Forest Management

This paper introduces a method for defining reference conditions in sub-boreal British Columbia using multiple lines of culturally-derived evidence, combined with data from contemporary reference sites. This method can be both practical and resource efficient and supports sustainable forest management in British Columbia. Reference conditions described using this method may be used as a point of reference to evaluate contemporary forest conditions and management strategies for sub-boreal British Columbia forests. Additionally, these reference conditions may be used to set goals or objectives for ecological restoration. Industrial land use activities (i.e. timber harvesting and road construction) that began in the early 1940s changed the landscape structure on the JPRF, but ecological restoration may not be a desirable overall management objective for the JPRF. A management approach based on ecological restoration may, however, be appropriate in some areas like the northern portion of the JPRF in TSX65876. In this instance, results obtained in this study will provide relevant reference conditions for ecological restoration and assist in establishing a framework for ecological restoration activities.

- Chapter 6

Overall Summary and Conclusions

This research was designed to demonstrate an approach for developing reference conditions for ecological restoration in sub-boreal British Columbia, Canada. In this region, changes in forest conditions have resulted from more than 60 years of timber harvesting and other management activities. With the increasing emphasis placed on sustainable forest management as a management paradigm, it is important to understand how the forests of today differ from those present before the commencement of large-scale industrial forest management. Understanding the anthropogenic (human-caused) processes that have altered the condition of these forests is an important element of reconstructing the state of natural forests prior to industrial development, and critical to defining reference conditions for ecological restoration projects. The John Prince Research Forest (JPRF) was used as a case study for this research because it is representative of the ecological, historical and traditional values of the region. The forest showcases examples of Douglas-fir at the northern extent of its range; a 60-year history of commercial logging; and issues in the Tl'azt'en traditional territory. The approach developed here may be adapted for use in other regions of sub-boreal British Columbia with similar natural and anthropogenic disturbance histories.

Oral history sources were used to develop a general land use history, and to guide research toward other available data sources that support ecological restoration on the JPRF. Although oral histories were limited in their direct ecological value, they did provide the broad context which was especially useful for interpreting other sources of information. Also, oral histories helped researchers to understand the limitations that existed within other forms of information. For example, interviewees were frank about the possibility of locating reference sites that were representative of the historical forest. Understanding that reference sites are sometimes not representative of the historical forests, it was possible to interpret data from reference sites accordingly.

Quantitative analysis of historical aerial photographs and current inventory data provided the basis for setting quantitative management targets at the landscape level through the use of modern technology. It is important to note that this approach is dramatically limited by the data available to the user. To accurately define targets for ecological restoration, the range of natural variation that exists within an ecosystem must be accounted for. It is not possible to describe the natural range of variation using only one source. However, it is uncommon to locate more than one set of aerial photographs that depicts pre-industrial management forest conditions. This limitation can be addressed, in part, by comparing site-specific data with general guidelines outlined by the Biodiversity Guidebook (British Columbia Ministry of Forests and British Columbia Environment 1995), or by other authors (e.g. Delong 1998).

Written records (i.e. manuscripts and government records) were valuable with respect to the quality and quantity of data provided. It was extremely useful to have multiple sources of written documents dealing with the same area, as some documents were able to compensate for the limitations of others. Using both the cruise report[12] and the logging plan[3] in combination offered information that was more substantive than either of the records independently. For example, although the logging plan contained more detail with respect to qualitative and quantitative data, the cruise report included a map that displayed cover types spatially on the landscape. Integrating these two sources assisted in filling in the gaps present in both records.

Stand level data from reference sites is potentially the most useful source of information to support silvicultural planning with respect to ecological restoration. This source provides the most detailed characterization of strata and stands, allowing researchers flexibility when collecting data. Reference sites are limited in availability, as these sites are relatively inaccessible and difficult to locate. Also, caution must be exercised when interpreting data from reference sites, as these sites may not adequately represent the natural range of variation within historical forests. The results presented in this study demonstrate the potential of this data source; however, additional research that further examines the potential of these sources may be employed.

Through a multi-disciplinary approach to ecological restoration in sub-boreal British Columbia, this research has identified candidate areas for ecological restoration on the JPRF. Specifically, Timber Sale (TS) X65876, was heavily impacted by diameter-limit harvesting systems, and was identified as a candidate area for ecological restoration. Using a range of sources, this research has characterized potential landscape and stand level reference conditions for ecological restoration. Additional work is needed to more comprehensively define the natural range of variation that typifies this ecosystem, and to further explore the use of stand level data for defining reference conditions within TSX65876.

Management Recommendations

There are three broad management recommendations that come out of this work. First, it will be critical for managers to prioritize the importance of ecological restoration as a management objective on the JPRF. Incorporating ecological restoration as a management objective on the JPRF should include a consideration of the social importance of ecological restoration and consideration of Aboriginal and/or community values with respect to ecological restoration. By defining the priority of ecological restoration on the JPRF, managers will set the stage for research that focuses on developing the most appropriate reference conditions for ecological restoration, and research that establishes appropriate mechanisms for involving the community in ecological restoration initiatives. As a research forest, the JPRF has a unique opportunity to showcase "good" ecological restoration (i.e. management of forests in the context of natural disturbance processes, while also incorporating historical social, cultural, political, aesthetic and moral aspects of ecological restoration) as an alternative management option for the central interior of British Columbia.

Second, it is well established that changes in climate influence vegetation at multiple levels in forests, in addition to historical disturbance regimes (natural and cultural). Thus, managers on the JPRF will need to evaluate reference conditions for desired species composition for ecological restoration in the context of climate change. Management based on the assumption that climate is a stable entity will lead to an inaccurate interpretation of the natural variation on the JPRF. The establishment of management targets based on reference conditions for ecological restoration may be misguided without some consideration of the effects of changes in climate in this region. Incorporating knowledge of changes in climate with historical records of vegetation will increase our understanding of the potential natural range of variability within the JPRF.

Finally, it will be necessary for managers to consider the JPRF in a regional context, and identify the specific ecological conditions to be restored here. Although the JPRF is managed as a distinct unit, from an ecological and social perspective it is important to realize that the JPRF remains physically and biologically linked with the surrounding region. Also, in relation to the size of the Sub-Boreal Spruce Biogeoclimatic Zone the JPRF is a relatively small geographic unit when viewed at the landscape level. Given this consideration of scale, ecological restoration on the JPRF may not be relevant or practical from an ecological context. However, by using the JPRF to demonstrate "good" ecological restoration that is ecologically, socially and economically sustainable, it may be possible to influence current land use practices throughout sub-boreal British Columbia.

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