FRDA REPORT 025

EVALUATION OF SOIL DEGRADATION AS A FACTOR AFFECTING FOREST PRODUCTIVITY IN BRITISH COLUMBIA
A PROBLEM ANALYSIS PHASE I

BY
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ABSTRACT

PRE AMBLE

Soil degradation is a term used to describe the loss of productivity caused by soil disturbance resulting from forestry practices employed during tree harvest, site preparation or stand tending. The issue is three-fold. First, areas being reforested today (including backlog NSR) may be influenced by soil disturbance from harvesting activities and require special rehabilitative measures. Second, treatment of these previously harvested sites by means of mechanical, chemical and prescribed fire techniques may impart degrading effects on the soil. Third, forestry practices currently being employed to harvest the stand and prepare the site for regeneration, may be adding to the area of sites already influenced by soil degradation.

OBJECTIVES

The overall objectives of this study are to outline the areas of greatest impact, to demonstrate the necessity for research and survey expenditures, and to provide a basis for prioritization of such expenditures. This report is Phase I of the overall project. It identifies the causes, nature and extent of soil degradation on forest land in B.C. and provides an estimate of the potential loss of productivity. Phases II and III of the project will be completed in 1987/88.

METHODOLOGY

Data and information were gathered by four principal methods:

1. Literature review.
2. Questionnaire sent to industry and government personnel.
3. Interview and discussions with individuals involved in soil degradation research.
4. Summary data provided by the Ministry of Forests and Lands.

Only information and summary data for the time period 1976 to 1985/86 were collected and analyzed.

CONCLUSIONS AND RECOMMENDATIONS

The study has shown that of all forest harvesting techniques, ground skidding has the greatest potential to impart soil degradation. Of all site preparation techniques, windrowing and blade scarification are considered the most significant in regard to soil degradation. This study estimates that approximately 400,000 ha of degraded forested soils have been created by forestry practices in the Province between 1976 and 1985/86. It is estimated that over 20% of the area harvested during that period has been degraded.

The potential reduction of productivity resulting from soil degradation created by forestry practices over the ten year period (1976-1985/86) is conservatively estimated at approximately 400,000 cubic metres annually. This translates to an annual loss to the provincial economy of approximately 80 million dollars (assuming $200/m³). A liberal interpretation of available data suggests that the present annual loss to the provincial economy as a result of forestry practices between 1976 and 1985/86 is approximately 126 million dollars. The annual productivity loss resulting from soil degradation is estimated to be increasing by 50,000 cubic metres or 10 million dollars per year. If present forestry practices continue, the annual loss may double in less than ten years.

Costs for rehabilitating productivity on degraded forest land are estimated to be in the range of $500 to $5,000 per hectare. However, rehabilitation seldom fully recovers the original site productivity. Costs for prevention or reduction of soil degrada-
tion are estimated at between $250 and $1,800 per hectare through the use of alternative harvesting systems and between $0 and $200 per hectare for the improvement of pre-harvest planning. Significant reduction of harvesting degradation can be accomplished with no increase in costs.

Depending upon the economic models used, rehabilitating degraded soil may or may not be cost justifiable. Some alterations of harvesting systems appear to be cost justifiable for avoiding or reducing soil degradation. All research results appear to corroborate that the prevention of soil degradation is more effective and far less costly than rehabilitation. Improved planning is viewed as a cost-effective means of reducing future soil degradation.
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1.0 INTRODUCTION AND STUDY OBJECTIVES

This report has been prepared in response to a request from the Canadian Forestry Service, through the auspices of the Canada-B.C. Forest Resources Development Agreement (FRDA), to evaluate soil degradation as a factor affecting "Not Satisfactorily Restocked" (NSR) backlog forest lands in British Columbia.

The specific objectives of this study are to identify the nature and extent of soil degradation on forest land in B.C. and evaluate its effects on regeneration/plantation performance, and to recommend procedures needed to improve soil management and forest regeneration procedures. Where information is lacking, recommendations will be made for specific research projects to fill those gaps.

The overall study encompasses these two specific objectives by subdividing the tasks into three phases. These three phases and their sub-objectives are briefly outlined as follows:

PHASE I

a. Outline the causes, nature and extent of existing soil degradation in B.C. resulting from forestry operations.

b. Evaluate the relationship between soil degradation from forestry operations and existing NSR land.

c. Express the potential loss of conifer productivity from soil disturbance on existing NSR land in terms of land area impact, volume loss, and dollar loss on a regional and provincial basis and evaluate the implications of such losses in terms of the provincial AAC and the economic health of the province.

d. Assess the feasibility of, and probable costs associated with rehabilitating productivity and/or regenerating productive coniferous stands on severely disturbed forest land.
PHASE II

Outline appropriate research needs and strategies to develop and assess:

a. Effective site rehabilitation measures;

b. Appropriate soil management techniques;

c. Efficient monitoring systems and programs; and

d. Appropriate harvesting and site preparation technology.

PHASE III

a. Evaluate the effectiveness of current site degradation and rehabilitation regulations, legislations and policy, and the implementation thereof.

b. Evaluate the adequacy of government and private sector staffing levels to deal with site/soil degradation problems.

c. Evaluate government and private sector training needs.

Only Phase I is the subject of this report. The results of this report and subsequent discussions with the review agencies (Ministry of Forests and Lands, and Canadian Forestry Service) will be used to help formulate more succinct terms of reference for Phases II and III of the problem analysis. It is currently understood that Phases II and III will be undertaken and completed in fiscal year 1987/88 as part of the overall contract.

It is necessary for the reader to be fully aware of the intent of this report. The purpose of this report is to examine existing information and knowledge to provide insight into the nature and extent of the soil degradation/forest productivity issues. The results of the study are intended to guide and direct future work on the subject in such a manner as to focus attention on the most significant issues.
While the subject of soil degradation as a factor affecting NSR backlog forms a significant part of this study, it does not constitute the overall scope of the work. Rather, the subject has been considered as it relates to all of the forest land base in B.C., not just that land designated as NSR. This broad scope facilitates a comprehensive analysis and discussion of the topic.

Two other aspects related to the scope of this project need to be understood. First, the term 'soil degradation' by definition connotes negativity. Consequently, much of the discussion in the following report may seem at first glance to be overly pessimistic and negative. However, this is not the authors' intent. We believe that the subject is, in actuality, a positive one in that by understanding and resolving issues of soil degradation the productivity of the forest land base can be maintained for the overall benefit of society. We have strived for objectivity in order to provide a body of information which is of value to government and industry, and hence society as a whole. We have not entered into any detailed discussion or recommendations regarding how the costs (and benefits) of soil degradation should be shared. Rather, we have presented our findings and results on a generic basis in order for them to be used in a cooperative fashion between industry and government. Second, we have ascertained that the current understanding of the full scope of the soil degradation/productivity issue is in a deplorable state throughout the Province. This statement may appear at odds with the number of research papers and reports presented in the bibliography on the subject. While each of these studies has great value in its own right related to specific soil degradation and soil disturbance issues there is a very significant lack of understanding regarding how to apply the results in a meaningful and comprehensive (province-wide) fashion. This is particularly acute regarding the relationship of soil degradation effects on productivity.
Specifically, there is a very real and, we believe, a potentially damaging lack of coordinated effort to minimize soil degradation, to rehabilitate degraded soils and to research and adequately address the problem. We believe that there is real need to facilitate a common approach to solving the problems of soil degradation by industry and the two levels of government so that the results can be used in a positive environmental, economic and social framework.

The study was conducted under the guidance of Dr. Richard Smith and Mr. John Senyk (CFS) and Mr. Gerry Still (MoFL). Mr. Greg Utzig and Mr. Mark Walmsley prepared specific sections of the report. Many others contributed their ideas and information, and suggestions regarding the content of the report. While their valuable assistance is greatly appreciated, there simply are too many to list here. Any errors or omissions are the responsibility of the authors.
2.0 METHODS OF STUDY

2.1 INTRODUCTION

The primary objective of the problem analysis is to identify the nature and extent of soil degradation on forest land in B.C. and evaluate its effect on regeneration/plantation performance. In order to achieve this objective, it was necessary to gather and analyze existing information on the broad, or general, aspects of the problem and then focus the investigation on specific issues (many of these specific issues, however, will be dealt with in Phases II and III of the overall project). One of the most valuable aspects of the data and information gathering process was the direct consultation component of the work with individuals directly involved with soil degradation research and forestry managers/staff in industry and government who have some knowledge and experience related to the issues.

A literature review was undertaken and accomplished by several means. A computer search was made to identify pertinent scientific articles. Through the use of a questionnaire, key individuals throughout the Province were canvassed for reports and articles they either had in their possession, or could direct us to. As part of the questionnaire process, respondents listed scientific papers and research reports which they deemed valuable to the study. By means of this process, a comprehensive collection of reports/papers was assembled and reviewed. The bibliography (Chapter 12) contains a listing of those articles which were utilized during the study.

The questionnaire used to ascertain the nature and extent of concerns, data sources and professional judgement from a variety of forest research scientists and forest land managers in both government and industry is contained in Appendix I. Response to the questionnaire, which was circulated province-wide, was positive
in that the majority of questionnaires were returned. The purpose of the questionnaire was not that of an 'opinion poll' but rather that of information and idea gathering. The questionnaire responses helped focus the study by identifying specific issues and knowledgeable individuals. Several respondents questioned the value of the questionnaire, stating that erroneous or incorrect interpretations of the information provided could result. We recognized this concern and have not used the information provided in any conclusive or statistical fashion unless it was corroborated by other research findings.

Our work in obtaining data on forest harvesting practices and silvicultural treatments on a provincial basis required contact with a number of Branches of the Ministry of Forests and Lands (most notably: Engineering, Research, Silviculture, Planning and Inventory, Valuation and Protection). Contacts were made in Victoria, and more specifically in Regional and District centres throughout the Province. The data gathered in this fashion were, for the most part, summary information for entire Forest Regions or the Province as a whole. Since we have no means of checking these data, we have relied on its accuracy relative to the overview purpose to which we have applied it.

In addition to the very significant research results provided by research scientists and foresters in the U.S. Pacific Northwest, two other sources of data and information proved valuable to our work. First, data and results from industrial and government research foresters and managers related to studies that have been conducted in the Province. Second, a number of the papers presented at the Tenth B.C. Soil Science Workshop (February 21, 1986) proved most instructive. While these papers are still unpublished and in draft form they were made available to us by Dr. Dan Lousier (Ministry of Forests and Lands, Research Branch). For the most part, they constitute the state-of-the-art in B.C. regarding the subject of site disturbance and soil degradation.
We have relied on data provided to us from the Ministry of Forests and Lands and utilized it extensively in our analysis. In this regard it is important to point out that there is a serious lack of long-term data and information regarding forestry activity in the Province. We have therefore been forced to piece together bits of data from various sources which, in some cases, do not always corroborate each other. However, it is our opinion that the results of the data analysis reported in subsequent chapters of this report are meaningful in the context of evaluating general trends and averages.

2.2 CALCULATIONS OF AREA DEGRADED AND PRODUCTIVITY LOSSES

The primary data source for the estimates of the area of forest soils degraded and the resulting productivity losses was the Ministry of Forests and Lands annual reports (MoFLAR). Data from the MoFLAR's was broken into treatment and slope classes by combining it with data from Valuation Branch harvesting studies and the Silviculture Branch site history records.

Relevant literature was reviewed to establish which forestry practices contribute to soil degradation and what percent of the areas treated by those practices was likely to be degraded. Based on this review, the authors established percentages for each practice to calculate the total area degraded by forestry practices between 1976 and 1985/86.

Based on further review of the literature, percentage growth losses were estimated for degraded soils associated with each type of disturbance. These percentage reductions were then applied to the mean annual increments (MAI) for the various Forest Regions and multiplied by the areas of degraded soils calculated previously. These numbers were then multiplied by an estimated economic value to arrive at the cost to the provincial economy.
The general lack of data and the scale of a provincial calculation has created the need for various assumptions on the authors' part. The calculations presented in Chapter 5 and 6 reflect conservative assumptions which are explained in those chapters. Appendix II presents the results of using more liberal assumptions.
3.0 SOIL DEGRADATION: DEFINITION OF TERMS AND CONCEPTS

3.1 INTRODUCTION

Soil is one component of the environment which is essential for human survival and provides economic opportunities for growth and development (other factors being water and climate). Hudson (1981) discussed this issue from an historical perspective by outlining evidence that soil quality often played a key role in the growth and decline of early civilization. The context of this evidence is important since British Columbia's wealth is based upon the vast forests nature endowed it with. In this historical context, it is perhaps instructive to note that while soil degradation has been a topic of concern and research in the U.S. since the 1940's, similar recognition in B.C. did not occur until the 1970's.

While soil depletion and degradation are of concern to a variety of economic activities (agriculture, fisheries, wildlife) this study focuses specifically on the forest resource and does not discuss other resource values. We are investigating the actual site effects of soil degradation on commercial forest regeneration and plantation performance (productivity) and not the effects of processes such as siltation on fish bearing streams, loss of recreational values or nutrient/chemical effects on water quality. The issue of soil degradation/forest productivity has been addressed on a provincial basis using summaries for the various Forest Regions or the Province. While site specific or local data and concerns may become masked by using provincial means or averages, significant trends can be established which will aid in directing more detailed analysis.

3.2 DEFINITION OF TERMS

It is critical to note the distinction between site and soil. A site is a naturally functioning ecosystem which is uniform in
climate, parent material, physiography, soils, vegetation and animals. One site is distinguished from another site by dis-similarities in biogeochemical cycling and energy exchange among the above noted components. Soil is one component of a site that provides a storehouse of water and essential nutrients for tree growth as well as the physical means of supporting the tree.

Further, it is important to distinguish between degradation and disturbance. Soil disturbance generally refers to visible physical changes in a soil from its natural state (e.g. exposed or mixed mineral soil horizons). Severe soil disturbance is often equated with soil degradation (e.g. very deep gouging). Degradation is any change in physical, chemical or biological properties which reduces productivity. Disturbance may be an indicator or a means of measuring degradation but not always. Some types of soil disturbance can in fact produce positive effects on productivity (e.g. shallow mixing). Degradation results from abrupt changes caused by both natural processes (erosion, flooding) as well as human activities (road construction, prescribed burning). Erosion related soil degradation can also lead to off-site damages such as stream sedimentation or road washouts. Off-site damages are not considered in this study. The scope of this report encompasses only the examination of soil degradation as it relates to forestry operations including both harvesting and silvicultural treatments. Further, the term degraded soil is not to be confused with the use of the same term in a pedological sense, where degraded refers to soil weathering and leaching.

The following list provides definitions for factors affecting soil degradation as used in this report.

**Soil Compaction and Puddling**

Soil compaction is an increase in bulk density, a decrease in total pore space and non-capillary pore space, an increase/decrease in
capillary pore space and depending upon compaction force, a decrease in infiltration rate, permeability and effective pore diameter. Puddling is a change in soil structure from granular to massive. Subsequent changes to soil thermal properties may also result.

Soil Erosion

The removal of soil material by means of water, wind or gravity. Includes both mass wasting and waterborne surface erosion.

Soil Displacement

The mechanical movement of soil by man's influence from one area to another. For example, the excavation required to construct a skidroad on sloping ground. Other examples include windrowing and stumping (stump extraction) which can drastically disrupt soil horizons. The term 'scalping' is often used in this context and includes the loss of surface organic horizons.

Soil Water Availability

Change in available water storage brought about by changes in bulk density and subsequent modifications to pore space and permeability. Subsequent changes to soil thermal properties may also result. Soil water availability can also be reduced by disruption of subsurface water movement (seepage interception).

Loss of Organic Matter and Soil Nutrients

The removal or displacement of surface organic layers from the soil by mechanical (scalping), fire or chemical means and the subsequent loss of soil nutrients. The effects of nutrient loss caused by mineral soil leaching and mineral soil displacement are also considered in this category. Net reductions in vegetation product-
ion, litter fall or changes in decomposition rates can also reduce organic matter contents of the soil.

**Changes in Soil Acidity**

Increase or decrease in soil pH and the subsequent influence on nutrient availability and losses of nutrients due to leaching. An example would be the exposure or mixing of calcareous soil horizons with near neutral surface horizons.

**Changes in Soil Biology**

Decrease in mycorrhizal formation and changes in species and/or populations of soil bacteria, fungi and actinomycetes and the concomitant impact on decomposition, and nutrient cycling and availability.

### 3.3 RELATIONSHIP OF FOREST SOIL AND AGRICULTURAL SOIL DEGRADATION

The major impetus for undertaking this study is the need to quantify forest soil degradation effects on productivity on a regional scale, such as has been done for agricultural soil degradation. The Select Standing Senate Committee on Agriculture, Fisheries and Forestry (1984) stated the following:

"The Standing Senate Committee on Agriculture, Fisheries and Forestry has travelled extensively in Canada examining the issue of 'soil degradation', a problem which is already costing Canadian farmers more than $1 billion per year in farm income. It has determined that we are clearly in danger of squandering the very soil resource on which our agriculture industry depends."

This recent report on agricultural soils, coupled with current research information on forest soils, indicates that soil degradation precipitated by some forest management practices may be resulting in significant adverse effects on site productivity.
However, there are a number of things which differentiate forestry from agriculture in the context of soil degradation and productivity. Forestry operations generally require only two or three entries onto the land per rotation thereby reducing chances of soil degradation. However, this also reduces the opportunities for measuring crop performance and rectifying identified problems. In contrast to agricultural crops, which are usually harvested annually, the harvest interval for forest crops is much longer (50 to 150 years). This has often lead us to believe that nature and time will heal the soil degradation 'wounds' caused by forestry operations. While this may be the result in some cases, it is not generally true.

Productivity losses from degradation will become even more crucial as the Province moves to second growth stand management. For example, a portion of a plantation suffering reduced growth due to soil degradation, may result in trees on the degraded area being of non-commercial size at the culmination age for the plantation. In this case, there is not simply a percent productivity reduction relative to the area degraded, but in effect a total yield loss for the degraded area. The alternative of uneven-aged forest management may cause additional soil degradation by increasing soil disturbance and compaction. Multiple entries with machinery during the growth cycle is certainly a factor which is recognized in agricultural soil degradation.

Two other aspects related to forestry in B.C. should be recognized. First, B.C. is unique in Canada since it has the most diverse and complex landform and climate patterns. The Select Standing Senate Committee (1984) described B.C. as follows:

"The physiography of the province, coupled with the variations in the climate, bestow upon British Columbia virtually all of the soil degradation problems found in the rest of the country and a few more besides."
In contrast to agriculture, forestry occurs on a great number of these diverse landscapes resulting in the fact that forest management must accommodate great biogeoclimatic diversity. Further to this, more forest harvesting in the province is occurring on potentially sensitive sites. That is to say, with the completion of the first cut on more easily accessible, valley bottom lands, forestry operations have progressively moved onto higher elevation, more steeply sloping lands which are more vulnerable to degradation. This trend tends to increase the emphasis on the issue of soil degradation and maintenance of productivity.

3.4 SOIL DEGRADATION/FOREST PRODUCTIVITY INTERRELATIONSHIPS

It is not safe to simply assume that site degradation is a result of soil degradation alone and therefore by controlling soil degradation one can maintain site productivity. The fact is that numerous variables may simultaneously affect the biological processes of the forest and hence have an influence on productivity. As discussed by Ballard (1986), McNabb (1986) and McNabb and Campbell (1985) utilizing measurements of productivity to determine the degree of soil degradation ignores the influence of other site variables and their interrelationships (e.g. plant competition). When we measure productivity, we are measuring the net effect of all variables. To measure soil degradation by means of growth and yield models we must hold all other variables constant. Unfortunately, this is extremely difficult to do. This concept is important to note in the context of research results which have shown increased growth on some sites which have been disturbed (Smith and Wass 1979, Ballard 1985). In these cases, harvesting or site preparation may have negatively influenced soil fertility but the net result has been improved performance when comparing disturbed and undisturbed sites. Improvement of other site factors affecting seedling growth may have compensated or masked the soil-related influences. In these cases, the negative influence of soil degradation is often ignored. However, if
seedling performance appears better on disturbed vs undisturbed sites, perhaps the increase could be greater were we to understand the relationships inherent in the biological environment of the tree.

An additional consideration is that the only true measure of forest productivity is one that is based on data from a full rotation. Short-term measurements of seedling survival and growth are insufficient to obtain a true indication of the impacts of soil degradation on productivity.

When considering the relationship of soil disturbance to soil degradation, it is important to appreciate that the same degree of soil disturbance on two different sites may have quite different results in terms of soil degradation. For example, given the same degree of disturbance, a fine textured soil will exhibit greater bulk density increases than a coarse textured soil. Therefore, the fine textured soil has a greater likelihood of suffering some degree of soil degradation. This is a simplistic example of a complex situation which has both short-term as well as long-term implications. Soil degradation, in some circumstances, may not exhibit a linear relationship with time throughout the full rotation age of the stand due to ameliorating effects.

Such complexities point to the fact that site specific data and information is valuable when examining soil degradation/productivity relationships. In fact, this aspect is one which has been of most concern to the authors of this report. As a result of the paucity of research data on the topic, we have been forced to apply the results of a few research findings (some, in fact, imported from the U.S. where soil conditions may be quite different in comparison to B.C.) to entire forest regions and the Province as a whole. One can perhaps argue that by broadening or generalizing the results on this basis it is possible to overcome the influence