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COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

Canada 

BC 

Proceedings of the Forest Ecosystem Dynamics Workshop

February 10–11, 1993

Compiled by
Valin Marshall, Ph.D.

prepared for
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C.
V8Z 1M5

December 1993

CANADA-BRITISH COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

Canada 

BC 

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TABLE OF CONTENTS

| | |
|--|----|
| Agenda | v |
| Foreword | ix |
| <i>T.J. Drew</i> | |
| Acknowledgements | x |
| <i>R.C. Dobbs</i> | |
| An Introduction to the Forest Ecosystem Dynamics Program | 1 |
| <i>D.W.F. Pollard</i> | |
| An Introduction to the Coastal Forest Chronosequences | 5 |
| <i>D.W.F. Pollard and J.A. Trofymow</i> | |
| Assessing Impacts of Environmental Changes on Biological Diversity of Forest Ecosystems | 8 |
| <i>V.G. Marshall</i> | |
| An Overview of the Stand Characteristics of the Intensively Studied Chronosequence Plots | 10 |
| <i>B.A. Blackwell and J.A. Trofymow</i> | |
| Changes in Plant Diversity in Douglas-fir Stands Following the Conversion of Old Growth to Second Growth | 16 |
| <i>M.W. Ryan and D.F. Fraser</i> | |
| Succession of Collembola in Stumps of Douglas-Fir Seres Representing Clearcuts to Old-growth Forest | 21 |
| <i>H. Setälä and V.G. Marshall</i> | |
| Variation in Carabid Community Structure Associated with Forest Successional Stages | 23 |
| <i>K. Craig</i> | |
| Differential Resource Use, Interspecific Interactions and the Effect of Logging on the Distribution and Abundance of Terrestrial Salamanders on Southern Vancouver Island | 26 |
| <i>T.M. Davis</i> | |
| Nematode Diversity and Distribution in Different Forest Soil Habitats | 28 |
| <i>T.S. Panesar and V.G. Marshall</i> | |
| Relationships Between Soil Fauna and Soil Pollutants | 31 |
| <i>J.P. Battigelli and V.G. Marshall</i> | |
| Terrestrial Molluscs: Their Role in the Ecological Dynamics of Forest Floor Communities | 35 |
| <i>D.A. Boag</i> | |
| Diversity of Mycorrhizal Fungi in Old-growth and Mature Second-growth Stands of Douglas-fir on Vancouver Island | 37 |
| <i>D. Goodman</i> | |
| Utilization of Residual Patches of Old-growth Douglas-fir by Forest Birds | 39 |
| <i>R.L. Millikin</i> | |
| Assessing the Effects of Forestry Practices on Carbon and Nutrient Dynamics in Coastal Forests | 44 |
| <i>J.A. Trofymow and C.M. Preston</i> | |
| Effects of Converting Coastal Old-growth Forests to Managed Forests: Changes in Site Carbon and Nutrient Contents During Post-disturbance Succession | 47 |
| <i>J.A. Trofymow and B.A. Blackwell</i> | |
| The Carbon Budget Model | 52 |
| <i>H.H. Barclay</i> | |

| | |
|--|----|
| Investigations of Carbon and Nitrogen Chemistry in Forest Ecosystems | 54 |
| <i>C.M. Preston</i> | |
| Efficacy Of 15N-labelled Fertilizer and Soil N Dynamics in Old-growth Cutovers on Northern Vancouver Island | 56 |
| <i>X. Chang, C.M. Preston, and G. Weetman</i> | |
| Long-term Recovery and Availability of 15N-fertilizer Applied to Immature Douglas-fir | 58 |
| <i>T. Aarnio, C.M. Preston, and J.A. Trofymow</i> | |
| Soil Microbial Activity in Coastal Douglas-fir Forests | 60 |
| <i>J.A. Trofymow</i> | |
| Conserving Genetic Resources of Forests in the Pacific and Yukon Region | 63 |
| <i>D.G.W. Edwards and A.K. Mitchell</i> | |
| Ex situ Conservation of Forest Biodiversity in British Columbia | 65 |
| <i>D.G.W. Edwards and Y.A. El-Kassaby</i> | |
| Genetic Diversity in Mountain Hemlock (<i>Tsuga mertensiana</i> (Bong.) Carr.) | 68 |
| <i>D.G.W. Edwards, M.D. Meagher, and Y.A. El-Kassaby</i> | |
| Sustainable Development of Natural Sources of the Emerging Anti-cancer Agent, Taxol | 72 |
| <i>A.K. Mitchell</i> | |
| National Leadership and Regional Management of the Ecological Reserves Project | 74 |
| <i>D.F.W. Pollard</i> | |
| Research and Management Strategies to Address the Climate Change Issue for the Forest Sector in the Pacific and Yukon Region | 76 |
| <i>R.A. Benton</i> | |
| Impacts of Global Warming on the Forest Sector in the Mackenzie Drainage Basin: Case Studies in the Peace and Liard Drainage Basins | 77 |
| <i>R.A. Benton</i> | |
| A Preliminary Examination of White Pine Weevil Hazard Potential in the Mackenzie Basin Under Climate Change | 80 |
| <i>B.G. Sieben, D.L. Spittlehouse, J.A. McLean, and R.A. Benton</i> | |
| Dendroclimatological Analysis of Submerged Logs from Heal Lake Near Victoria, British Columbia | 83 |
| <i>R. Hebda</i> | |
| Climate Change Workshops for the Forest Sector in the Pacific and Yukon Region | 86 |
| <i>D.F.W. Pollard</i> | |
| The Canadian Intersite Decomposition Experiment (CIDET): Long-term Rates of Leaf Litter and Wood Decay | 87 |
| <i>J.A. Trofymow</i> | |
| Project Review: Forestry Canada–Pacific and Yukon Forest Ecosystem Dynamics Research: Reports | 91 |
| List of Participants in Forest Ecosystem Dynamics: (Program PC–71) Workshop | 93 |

AGENDA

FOREST ECOSYSTEM DYNAMICS WORKSHOP

Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
February 10-11, 1993

Wednesday, February 10

- 08:30-08:35 Welcome: T.J Drew, Regional Director General, Pacific and Yukon.
- 08:35-08:45 Opening remarks: R.C. Dobbs, Director, Environment and Growth.
- 08:45-09:00 An Introduction to the Forest Ecosystem Dynamics Program and coastal forest chronosequences: D.F.W. Pollard, Program Head.
- 09:00-09:10 Project 7130: Assessing Impacts of environmental changes on biological diversity of forest ecosystems: V.G. Marshall, Project Leader.
- 09:10-09:20 An overview of the stand characteristics of the intensively studied chronosequence plots: B.A.Blackwell and J.A. Trofymow.
- 09:20-09:40 Changes in plant diversity in Douglas-fir stands following conversion of old growth to second growth: D.F. Fraser and M.W. Ryan.
- 09:40-10:00 Succession of Collembola in stumps of Douglas-fir seres representing clear-cuts to old-growth forests: H. Setälä and V. G. Marshall.
- 10:00-10:20 *Coffee*
- 10:20-10:40 Variation in carabid community structure associated with forest successional stages: K. Craig.
- 10:40-11:00 Differential resource use, interspecific interactions and the effect of logging on the distribution and abundance of terrestrial salamanders on southern Vancouver Island: T.M. Davis.
- 11:00-11:20 Nematode diversity and distribution in different forest soil habitats: T. Panesar and V.G. Marshall.
- 11:20-11:40 Relationships between soil fauna and soil pollutants: J.P. Battigelli and V.G. Marshall.
- 11:40-12:00 Terrestrial molluscs: their role in the ecological dynamics of forest-floor communities: D. Boag.
- 12:00-13:00 *Lunch*
- 13:00-13:20 Diversity of mycorrhizal fungi in old-growth and second growth stands of Douglas-fir on Vancouver Island: D.Goodman.
- 13:20-13:40 Utilization of residual patches of old-growth timber by forest birds: R. Millikin.
- 13:40-13:50 Project 7120: Assessing the effects of forestry practices on carbon and nutrient dynamics in coastal forests: J.A. Trofymow and C. Preston, Project Leaders.
- 13:50-14:10 Effects of converting coastal old-growth forests to managed forests: changes in site carbon and nutrient contents during post-harvest succession: J. A. Trofymow and B. A. Blackwell.

- 14:10–14:30 Carbon budget model: H. Barclay.
- 14:30–14:50 Investigations of carbon and nitrogen chemistry in forest ecosystems: C.M. Preston.
- 14:50–15:10 Coffee
- 15:10–15:30 Efficacy of ¹⁵N-labelled fertilizer and soil N dynamics in old-growth cutovers on Northern Vancouver Island: X. Chang, C. Preston and G. Weetman.
- 15:30–15:50 Long-term recovery and availability of ¹⁵N-fertilizer applied to immature Douglas-fir: T. Aarnio, C. Preston and J. A. Trofymow.
- 15:50–16:00 Soil microbial activity in coastal Douglas-fir forest: J. A. Trofymow.
- 16:00–16:30 Peripheral studies, general questions, and discussion.

Thursday, February 11

- 08:30–08:35 Opening remarks: D.F.W. Pollard.
- 08:35–08:45 Project 7150: Conserving genetic resources of forests in the Pacific and Yukon Region: D. G. W. Edwards and A. K. Mitchell, Project Leaders.
- 08:45–09:00 Ex-situ conservation of forest biodiversity in British Columbia: D. G. W. Edwards and Y. A. El-Kassaby.
- 09:00–09:15 Genetic diversity in mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.): D. G. W. Edwards, M. D. Meagher and Y. A. El-Kassaby.
- 09:15–09:35 Sustainable development of natural sources of the emerging anti-cancer agent, taxol: A. K. Mitchell.
- 09:35–09:50 National leadership and regional management of the Ecological Reserves Project: D. F. W. Pollard.
- 09:50–10:10 Coffee
- 10:10–10:20 Project 7140: Research and management strategies to address the climate change issue for the forest sector in the Pacific and Yukon region: R. A. Benton, Project Leader.
- 10:20–10:40 Impact of global warming on the forest sector in the Mackenzie Drainage Basin: case studies in the Peace and Laird drainage basins: R. A. Benton.
- 10:40–11:00 A preliminary examination of white pine weevil hazard potential in the Mackenzie Basin under climate change: B. Sieben and D. L. Spittlehouse.
- 11:00–11:20 Dendroclimatological analysis of submerged logs from Heal Lake near Victoria, B.C.: R. Hebda.
- 11:20–11:30 Climate change workshops for the forest sector in the Pacific and Yukon region: D.F.W. Pollard.
- 11:30–11:40 The Canadian intersite decomposition experiment (CIDET). Long-term rates of leaf litter and wood decay: J. A. Trofymow.
- 11:40–11:55 Peripheral Studies, General Questions, and Discussion.
- 11:55–12:00 Closing Remarks: D.F.W. Pollard.
- 12:00–13:00 Lunch

End of Workshop

REVIEW OF PROJECTS IN THE FOREST ECOSYSTEM DYNAMICS PROGRAM

Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5

Afternoon of February 11, 1993

Concurrent Sessions: (1) Review Panel and (2) All speakers and authors at the workshop.

Review Panel (Main Board Room, 1st Floor)

13:00–14:30 Forest Ecosystem Dynamics Program Review: O. Hendrickson, Chairperson.

This review will be attended by:

Review Panel

Program Director

Program Head

PFC scientists, at request of the review panel

14:30–16.00 Review Panel prepares its recommendation.

Participating speakers and authors (Conference Room)

13:00–13:10 Opening Remarks: V. Marshall, convenor.

13:10–14:30 Open discussion of projects:

- ~ Concerns raised during the workshop.
- ~ Relationships of projects to each other.
- ~ Relationships to national strategic plan.
- ~ Relationships to clients.
- ~ Relationships with Universities.
- ~ Future funding prospects and needs.
- ~ Human resources.
- ~ Other.

14:30–16.00 Rapporteur prepares summary of discussion: D.G.W. Edwards.

FOREWORD

As we entered the 1990s, Forestry Canada, Pacific and Yukon Region, embarked on a series of changes that would better position us to address the new issues facing the forest sector. In this process, we surveyed a wide range of clients to identify the specific items of concern, and from their responses we fashioned a new look to our programs. Among the scientists affected were those associated with the Shawnigan Lake Experiment studying fertilization and thinning. The group comprised specialists in fundamental aspects of tree growth and forest ecosystems, and had evolved a team approach to their work. Their new task was to develop a research program that would tackle one of the most nebulous and intangible topics on forestry's corporate table today—the environment.

Within a short time the group had identified several key elements of the topic in this Region, including one in particular—the effects of converting old growth to second growth—which has pressing local as well as regional dimensions. The net result was that the team remained intact and quickly gained momentum to develop the Forest Ecosystem Dynamics Program. That new program corresponded closely to one of Forestry Canada's highest priorities: to develop an "increased capability to predict and prepare for the consequences of human activities and natural disturbances such as climate change on forest ecosystems."

One year after its initiation, the Program was informally reviewed, through presentations and a field trip to new research installations in the Greater Victoria Water District. We believed that sufficient progress was evident to warrant full-scale peer review of the Forest Ecosystem Dynamics Program. That review was scheduled for February 1993.

This document summarizes the work completed up to the time of the full-scale review, and presents the recommendations of the review panel. While the panel recommended a number of changes, it also provided solid assurance that the Program is proceeding in the right direction, on several fronts that are clearly of importance today.

We are especially indebted to the Review Panel, Glen Dunsworth (MacMillan Bloedel), Ken Lertzman (Simon Fraser University), Brian Titus (Forestry Canada, Newfoundland Region), and Ole Hendrickson, chairperson (Forestry Canada, Science and Sustainable Development) for the effort that went into making the review a constructive and valuable exercise.

The report and the results of the review are a credit to all involved. I look forward to continuing successes from the Forest Ecosystem Dynamics team, and to their next workshop and review!

T. John Drew
Director General
Forestry Canada, Pacific and Yukon Region

ACKNOWLEDGEMENTS

The success of a research program depends on many factors, both within and outside the organization responsible for it. Of course, the choice of topic for investigation, and the energy and competence with which it is pursued, will ultimately control success, but it is important to recognize that even the best of teams require support.

The emerging Forest Ecosystem Dynamics Program had picked its topics well, for it found itself positioned to take advantage of several new sources of funds. Particularly important among these have been the Canada/British Columbia Partnership Agreement on Forest Resource Development (FRDA II), and the Federal Government's Green Plan (Forestry Practices, National Forest Genetic Resources Centre, Climate Change, and Ecological Reserves initiatives). Several special Forestry Canada programs have been valuable, notably Energy-from-the-Forest (ENFOR), Science and Technology Opportunities Fund, and the Graduate Supplement Program. Outside the Department, the Natural Sciences and Engineering Research Council (NSERC) and several Memoranda of Understanding with the Province of British Columbia have been important. Without these supplementary funds the Program would have been a much more modest undertaking, and indeed could not have supported either the diversity or the depth of research recorded in this report.

On the human resources side, the Program has been ably assisted by Visiting Fellows, including Heikki Setälä and Tuula Aarnio, both of Finland, and Tochi Panesar of UBC, and also by some fine contractors in the Region. Excellent contributions have been made by several graduate students during their M.Sc. or Ph.D. studies; the Program has in turn assisted these people, by providing a wider context for their work and obtaining financial support. There has also been a steady stream of high calibre Co-op and COSEP students, primarily from the University of Victoria, who have provided valuable assistance in the laboratory and field.

We wish to acknowledge the kind cooperation of the Greater Victoria Water District, MacMillan Bloedel, and Fletcher Challenge Canada in providing land for experimental plots and access to information that was crucial to plot location. Western Forest Products Ltd. has also been a generous cooperator in the Salal-Cedar-Hemlock Integrated Research Project.

Finally, the Program Head, Doug Pollard, and his organizing committee (Valin Marshall, Caroline Preston, and Heikki Setälä) are to be commended on the conduct of the workshop in February 1993, and for the production of these proceedings.

R. (Bob) C. Dobbs
Program Director
Environment and Growth

An Introduction to the Forest Ecosystem Dynamics Program

Douglas F.W. Pollard

Program Head
Forestry Canada, Pacific Forestry Centre
Victoria, B.C.

British Columbia's forests contain 40% of Canada's wood volume and, in 1989, accounted for \$12.6 billion of Canada's shipments of forest products, the majority of which were exported. Some 70 000 people were employed in the process.

Long renowned for its forest industry, the Pacific and Yukon Region is gaining a new reputation. Travel and news media have brought its magnificent forests to world attention. Biodiversity is of particular interest. A remarkable array of mountain, coastal, arctic, and continental landscapes, spread over 21° of latitude, harbour some of the world's most valued genetic resources in woody species. South central British Columbia, for example, is Canada's "hotspot" for diversity of conifer species. The Region is rich in bird and mammal species, but there are numerous less conspicuous organisms, many not even named, that also support the assertion that the Pacific and Yukon Region is a treasure-house of biological diversity with global significance. Its value as a genetic resource has long been known to European foresters, of course. Also, it is argued, the forests of the Region are important elements of Canada's carbon pool, and hence may be important in how we address climate change.

The principles underlying such productive and prolific diversity remain relatively unexplored. Biodiversity and its potential as a genetic resource are vulnerable to the vagaries of exploitation and other disturbances. This vulnerability is now recognized both within and outside the Region, and has led to pressures on the forest sector to reduce or even curtail its activities. The rapid evolution of new values for forestry, expressed by an increasingly interested and vocal public, threatens the socio-economic dependency that characterizes many of the Region's communities.

In addition to concerns about sustainability under current conditions, there are serious uncertainties associated with the emerging issue of climate change. A change in climate would disrupt the harmony that has evolved between forest ecosystems and the ecoclimatic regions they occupy. At risk are the forest resources upon which much of the socio-economic fabric of the Region is based. Major ecological disruptions would likewise have severe impacts on the biodiversity of the Region, and call into question the value of current conservation strategies that assume climatic stability. The stability of live and detrital carbon pools would be strongly affected by a change in climate, especially warming, adding to existing concerns about forest carbon pools and their management.

In short, the forest sector of the Pacific and Yukon Region finds itself at a critical point. While retaining much of its traditional role as a generator of wealth and employment, it is seen to be in conflict with less tangible roles concerned with the well-being of planet Earth. As lofty as such concepts may seem, they are already taking root in critical markets of Canadian forest products. Europeans are grasping the nettle of sustainability, and are calling for more responsible forestry practices. Media and non-government agencies have turned the spotlight on the Region, and it is only a matter of time before our claim to sustainable development is put to the test. If we fail, it will be to the detriment of our forest industry, and a serious reflection on the sector as a whole.

Organizational Posture

As part of Forestry Canada, the Pacific Forestry Centre has a voice in national and international affairs. We are located in the vicinity of some of the most contentious resource and conservation issues in Canada. But we are also located close to three universities and other sources of expertise, and have established networks with provincial and non-government agencies. The Centre has a cadre of scientific and technical staff experienced in problems associated with ecosystem function, biodiversity, conservation, and climate change. In 1991, these people were assembled into a team under the program title of "Forest Ecosystem Dynamics."

Like most government agencies, Forestry Canada has had to adapt to a leaner economic environment, and to new ways of doing business. It is currently operating on a diminishing A-base, but several B-base sources offer new potential for funding. Some of these are suitably oriented to support work in forest ecosystem dynamics, reaffirming the topic as a source of priority issues. As will be seen, the program has been singularly successful in tapping these supplementary funds; this has reassured us in our program direction. However, B-base funds have their own problems, not the least of which is a lack of dependability.

Opportunity

Through the Forest Ecosystem Dynamics Program, Forestry Canada Pacific and Yukon Region can improve scientific and public understanding of the dynamic nature of forest ecosystems in the Region. In particular, the Program gives us the opportunity to investigate the role of biodiversity and essential ecological processes in self-perpetuating ecosystems, and to address two related conservation issues, maintenance of genetic resources and climate change.

The Pacific Forestry Centre is located close to threatened landscapes of the Coastal Western Hemlock zone (CWH) and the Coastal Douglas-fir zone (CDF). Scoping and planning activities, pursued in an atmosphere of distrust and confrontation, show conclusively that there is inadequate information for developing an effective conservation strategy for these landscapes.

There are many interested stakeholders in the forests of the Pacific and Yukon Region. Some of these, notably provincial agencies and universities, have policies and programs that address the issues described above. Given adequate networking through appropriate institutions, the program will help these stakeholders achieve their goals, while meeting the corporate needs of Forestry Canada.

Statement of Purpose

The purpose of the Forest Ecosystem Dynamics Program is to contribute to an acceptable, scientifically based framework for the sustainable development of forests—a framework that meets both utilization and conservation needs.

We believe that sustainability will be found to be flourishing in the vast majority of forest ecosystems, including those harvested. If this can be effectively communicated to interested stakeholders, their concerns may be sufficiently addressed to reverse current trends of antipathy towards Canada's forest sector. Likewise, a better understanding of the principles of sustainability should encourage modifications to forest practices where necessary, including those needed for adaptive response to climate change.

Objectives

The Program has four objectives, each identified as a distinct yet interrelated project:

- to assess impacts of environmental changes on biological diversity of forest ecosystems;
- to assess the effects of forestry practices on carbon and nutrient dynamics in coastal forests ;
- to conserve genetic resources of forests in the Pacific and Yukon Region; and
- to address the climate change issue for the forest sector in the Pacific and Yukon Region.

Our intention is to develop a clearer understanding of the way in which forests respond to human intervention, and to establish guidelines that ensure that these responses are consistent with ecosystem sustainability.

General Approach

As our objectives indicate, the Program engages a variety of issues, and does not confine itself to the Region's boundaries (see Figure 1). The observer may wonder why, during a difficult period of fiscal restraint and limited human resources, the Program has not limited itself to providing more concentrated input on a single problem.

Part of the answer lies in the mandate and corporate obligations of Forestry Canada, whose expertise is drawn from regional establishments such as the Pacific Forestry Centre, to provide scientific support for government policies and to contribute to specific programs. Several examples may be found in Forest Ecosystem Dynamics: Project PC-71-40 is largely committed to supporting a major interdepartmental study of the Mackenzie Basin, led by the Canadian Climate Centre, Environment Canada; the Program Head was requested to lead the Green Plan Ecological Reserves Project; and Project PC-71-20, on carbon and nutrient cycling, leads a national experiment on decomposition.

The needs of our partners have likewise established compelling contexts for our research. In particular, the Salal-Cedar-Hemlock Integrated Research Project (SCHIRP) has established a model research partnership of industry, university, and government to investigate a serious problem of productivity decline in the north end of Vancouver Island. It is in the very nature of science that researchers increase their knowledge and experience through networking. Some in this program have gained international recognition in the process, and this too entails commitments.

A balance must be found between our external obligations and the need to contribute effectively to the priorities at hand. The Program has resolved this problem by establishing a core network of its own, aimed at elucidating some of the issues concerning conversion of old growth to second-growth forests. A network of researchers, comprising Forestry Canada staff and collaborators, is focusing its attention on a series of successional stages, from regeneration to old growth, in one of the most seriously threatened landscapes in the Pacific and Yukon Region—the Very Dry Coastal Western Hemlock subzone.

The chronosequence network provides a common platform from which all four of our objectives may be addressed; the potential for synergism is particularly strong in the areas of biodiversity and ecological processes. The success of the network may be measured in a variety of ways, but it is most noticeable in the degree of support we have received from supplementary funding sources, and in the number of visiting scientists, graduate and co-op students, and volunteer collaborators attracted to the Program. Indeed, the rapid proliferation of the network inspired the Participants Workshop reported here, for there is an urgent need for all involved to be conversant with work in progress. Before presenting progress reports for the four projects, however, it is necessary first to describe the setting of the chronosequence network.

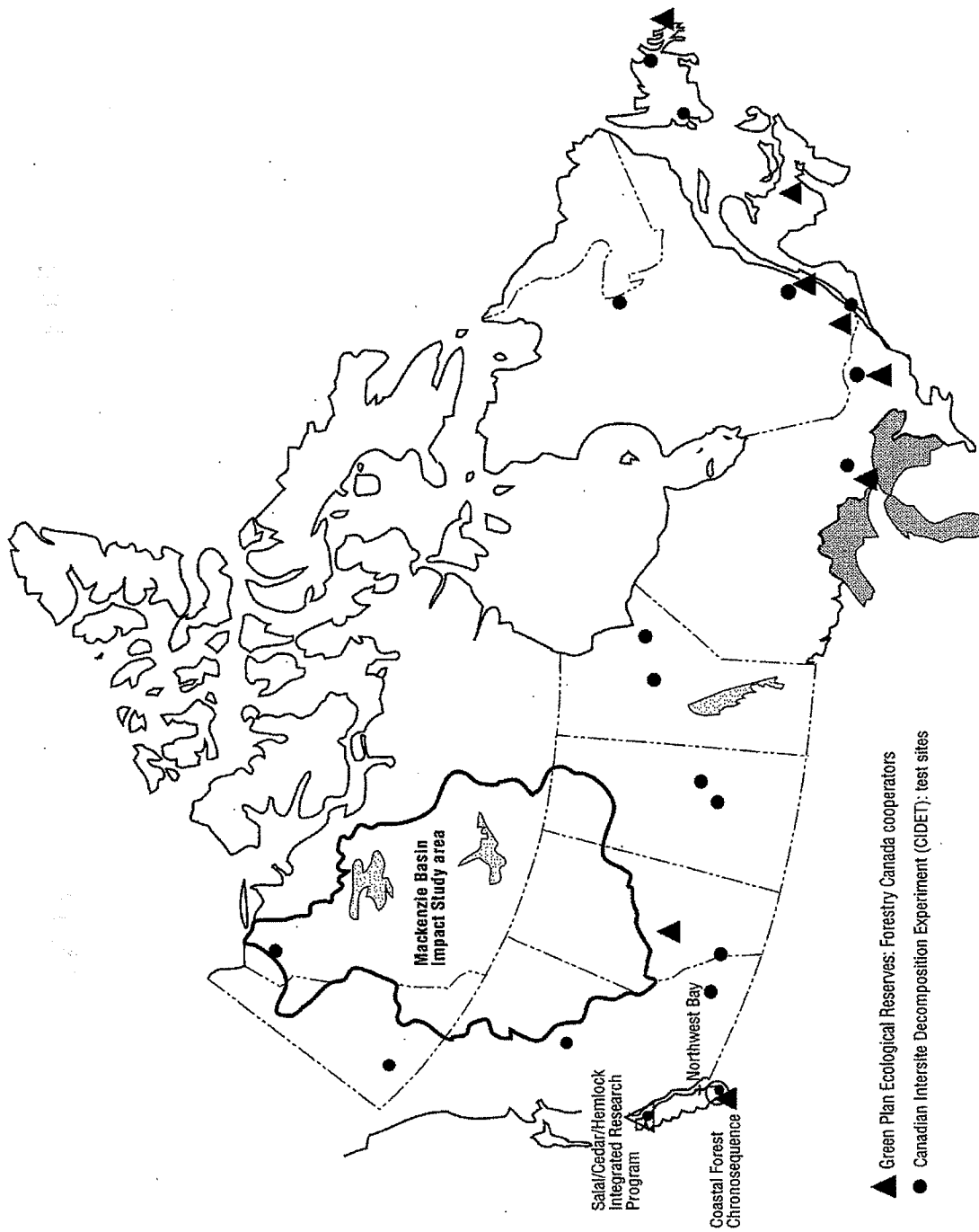


FIGURE 1. Research networks of the Forest Ecosystem Dynamics Program.

An Introduction to the Coastal Forest Chronosequences

Douglas W.F. Pollard and J.A. (Tony) Trofymow

Forestry Canada, Pacific Forestry Centre
Victoria, B.C.

Throughout the Program we adopt undisturbed forests as the standard by which human interventions are judged. Landscapes rich in these forests establish the baseline for biodiversity, by ecosystem and species diversity and by population structure and dynamics. Such forests are self-perpetuating, maintaining essential ecological processes that conserve energy, nutrients, and organic matter in both living and non-living forms.

In the Pacific and Yukon Region there is an added dimension: in coastal areas in particular, mild climates and infrequent or moderate fire favour longevity. The resulting old-growth forests are admired the world over for the magnificent landscapes they furnish. In essence, they epitomize harmony, stability, and diversity, although in fact they are highly dynamic and evolve continuously in response to natural global change. Perhaps their most singular characteristic is their propensity for organic matter accumulation, especially as coarse woody debris. This is the basis for carbon, nutrient, and water conservation, and sets in motion food chains that support rich biological diversity.

The changes caused by the conversion of old-growth temperate forest to second growth form a sharp focus for public concern. Important questions raised over the past decade include: What are the impacts on species diversity following conversion, and does the diversity recover in older second-growth forests? Does conversion lead to changes in the site carbon balance, resulting in net releases of carbon to the atmosphere (Harmon *et al.* 1990, Kurz *et al.* 1992)? Does conversion lead to a loss of nutrient capital on a site and hence threaten future productivity (Kimmins 1985, Kimmins *et al.* 1990)?

These questions are especially relevant in coastal British Columbia. Forestry Canada's biomass inventory has clearly identified this province as having a large amount of live biomass (and hence carbon). And while biomass concentrations rarely exceed 200 t/ha outside British Columbia, they can reach 1100 t/ha on the west coast (Bonnor 1985). Organic debris can exceed these quantities. When old growth is harvested, high rainfall and mild temperatures may lead to high losses of carbon and nutrients through accelerated decomposition and leaching (Kimmins 1985), and seriously diminish the essential nature of the ecosystem.

Harvesting over the last 100 years, and other disturbances, have created a mosaic of successional stages in British Columbia forests, often alongside unharvested old-growth areas. These sites present researchers with a special opportunity to study the changes occurring during forest succession and the extent to which old-growth conditions are restored as forests mature. The study of age sequences, with old-growth and successional stands in close proximity, can separate the effects associated with stand development from those resulting from between-site variability. Since conditions in old-growth stands change more slowly over time, compared to those in the first 90 years of secondary stand succession, these stands can serve as controls for between-site variability and represent conditions in the pre-harvest stand. The effects of climate on successional processes can also be inferred, through a comparison of age sequences from two biogeoclimatic zones.

The Establishment of Coastal Forest Chronosequences

In 1991, the Forest Ecosystem Dynamics Program initiated research into changes occurring as a result of conversion of old-growth to second-growth forests in the Coastal Western Hemlock (CWH) zone of southern Vancouver Island. Investigations will be conducted to characterize soil fauna, mycorrhizal fungi, small vertebrates and plant diversity, as well as changes in carbon and nutrient fluxes in seral stands representing four stages of development: regeneration, immature, mature, and old growth. A basic suite of four sites (a chronosequence) is delineated at each of a number of locations, representing specific forest types.

The network will conduct most of its research at three locations, readily accessible from the Pacific Forestry Centre, and all within the Very Dry variant of the zone (CWHxm). These core locations are referred to as Victoria Watershed South, Victoria Watershed North, and Koksilah. A summary mensurational survey

of these plots is included (Blackwell and Trofymow, in these proceedings). It should be noted that the CWHxm subzone is one of the most threatened forest landscapes in the Region. Furthermore, two of the core locations lie within the Greater Victoria Water District, the scene of intense current debate on logging and the fate of old growth. A more extensive sample of stands was considered necessary to quantify changes in carbon and nutrients with stand age, given the range of climates found within the CWH zone. Two additions were made to the three core locations in the CWHxm subzone. Another five are located on west Vancouver Island in the Very Wet Coastal Western Hemlock subzone (CWHvm1) (Figure 1). The specifications and locations chosen were as follows:

East side: Douglas-fir dominated stands (small components of hemlock or redcedar acceptable), midslope under 600 m elevation.

Locations: Greater Victoria Watershed South, Greater Victoria Watershed North, Koksilah, Nanaimo River, Loon Lake.

West side: Western hemlock dominated stands (secondary components of amabilis, redcedar or Douglas-fir acceptable), midslope under 600 m elevation.

Locations: Renfrew, Red/Granite Creek, Nitinat, Klanawa, Mt. Ozzard.

Each chronosequence lies within a 5 x 5 km or smaller area and contains stands of four ages (reference year 1990) on similar slope, elevation (within 200 m) and aspect:

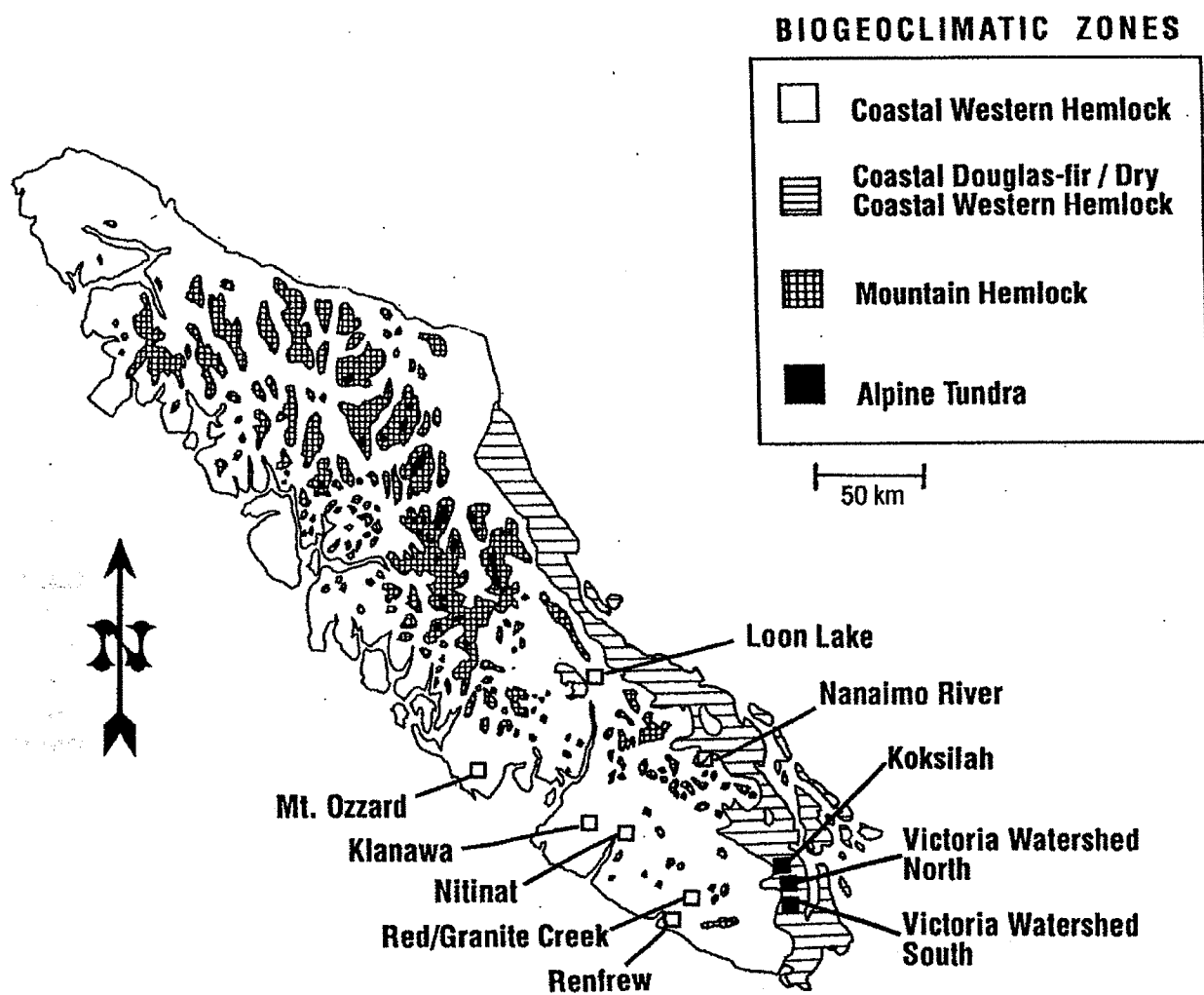
| Seral stage | Age in 1990 | Period of origin |
|--------------|-------------|------------------|
| Regeneration | 3-8 years | 1982-1987 |
| Immature | 25-45 years | 1945-1965 |
| Mature | 65-85 years | 1915-1925 |
| Old growth | >200 years | pre-1790 |

Although most second-growth stands were of harvest origin and burned, some of the mature stands were of wildfire or landslide origin. In those cases, stands with veterans were excluded. In some situations the second-growth stands within a chronosequence were sufficiently spread apart that it was necessary to include a second old-growth plot as a control for site variation.

Chronosequence location maps and plot descriptions for all 10 locations are detailed by Blackwell (1992). The report includes maps, road directions and distances to plots at each location, forest cover maps identifying individual plots, and basic site description data for each plot.

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* The western part of the Coastal Douglas-fir zone has recently been transferred to the Dry Coastal Western Hemlock zone (see Meidinger and Pojar 1991)

FIGURE 1. Locations of the 10 coastal forest chronosequences on Vancouver Island. Solid squares indicate locations of intensive study.

Assessing Impacts of Environmental Changes on Biological Diversity of Forest Ecosystems: An Introduction to Project PC-71-30

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The sustainability and use of forest resources depend on the continuation of essential ecological processes. These processes, affecting carbon, nutrient, and hydrologic cycles, are biological in nature and result from activities of the entire complement of forest organisms. Among the most important of these organisms are invertebrates and microorganisms inhabiting the soil and soil surface. The many thousands of named and unnamed species perform a vital role in decomposing litter, by transforming dead organic matter into a complex web of new substances and foodchains that characterize much of the edaphic environment. They are essential to the productivity, high level of biodiversity, and homeostasis of undisturbed forests (Marshall 1993). Little is known about these decomposer organisms or about the "non-crop" flora, how they interact, and how they influence the healthy functioning of forest ecosystems.

In addition to its value in contributing to ecosystem productivity and stability, Burton *et al.* (1992) listed four other reasons for promoting biodiversity: (1) to maintain non-timber values, notably the securing of furs, foods, and pharmaceutical products; (2) to enable the use of indicator species in monitoring and predicting ecological changes; (3) to retain alternative resources for future use as insurance against economic and climatic changes; and (4) to support aesthetic and ethical considerations. Foresters and other land managers should therefore recognize all these biological assets and learn how to manage them.

An essential prerequisite to proper forest management is an inventory of all biological components. This is currently difficult because of the large number of species expected to be present in forest ecosystems. Estimates for all living organisms in the world range from 5 to 80 million species. A rough estimate for British Columbia forests suggests over 55 000 species of living organisms (Table 1). The Very Dry Maritime portion of the Coastal Western Hemlock biogeoclimatic zone, where Douglas-fir predominates, likely includes tens of thousands of these species. Among mycorrhizal fungi alone, Trappe (1977) estimated that over 2000 species are potential associates of Douglas-fir. Since it is impossible to measure all biodiversity in an area, we have started with a catalogue of relevant and interesting groups whose taxonomy is well known or for which expertise is available. Table 1 also shows areas where our knowledge is deficient, for example, those of bacteria, fungi, and vertebrates. Future research could be concentrated on these groups.

In this project, we investigate how impacts from the conversion of old-growth to second-growth forests are manifest in organisms supporting the forest ecosystem. Our focus is on invertebrates and microorganisms inhabiting the soil. We shall expand the often limited taxonomic base, particularly among lesser known groups that are highly significant in self-perpetuating ecosystems. In addition, we shall extend our investigations to plant species, in particular bryophytes and other "non-economic" plants, that influence the microenvironments of the forest. We shall also investigate a number of vertebrate groups that are immediately linked to the invertebrate fauna by foodchains, notably salamanders and birds. It is at this last level, which features more conspicuous species, that public concerns over biodiversity are commonly expressed. However, the sustaining processes that affect carbon and nutrient pools (such as decomposition) occur at the more cryptic levels where much of this project is focused.

Our strategies include the following:

- to establish a taxonomic and ecological basis for evaluating effects of anthropogenic activities on soil biota in chronosequences in the Very Dry Maritime portion of the Coastal Western Hemlock (CWH) zone;
- to improve institutional and technical arrangements for incorporating biodiversity into management objectives; and
- to contribute to the training of young scientists in the area of biodiversity at both the undergraduate and graduate level.

TABLE 1. Major groups of organisms expected in forest ecosystems

| Category | Status ^a | Estimated species | |
|------------------|---------------------|---------------------------|--------------------|
| | | B.C. forests ^b | World ^c |
| Kingdom Monera | - | [2 100] | 30 000 |
| Kingdom Fungi | | 13 000 | 1 500 000 |
| Mycorrhizae | + | ? | ? |
| Kingdom Plantae | | | |
| Algae | - | [4 200] | 60 000 |
| Multicellular | + | 10 000 | 250 000* |
| Kingdom Animalia | | | |
| Protozoa | - | 250 | 100 000 |
| Rotifera | - | 50 | ? |
| Nematoda | + | 500 | 1 000 000 |
| Tardigrada | - | 80 | ? |
| Arthropoda | | | |
| Acar | + | 4 000 | 1 000 000 |
| Collembola | + | 200 | ? |
| Insecta | | 20 000 | 1 000 000 |
| Carabidae | + | ? | ? |
| Mollusca | | | 50 000* |
| Gastropoda | + | 100 | ? |
| Annelida | + | 125 | 12 000* |
| Chordata | | | |
| Amphibia | + | 20 | 4 200 |
| Aves | + | 450 | 9 100 |
| Total | | > 55 075 | |

^a + = Ongoing studies in Project PC-71-30; - = No studies.

^b [] = 0.7% ratio based on land area.

^c For world estimates, data modified from Wilson (1988) and Hawksworth and Mound (1991).

* = Already described species, total estimates not known.

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An Overview of the Stand Characteristics of the Intensively Studied Chronosequence Plots

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Introduction

In 1991, Forestry Canada Pacific and Yukon Region initiated a program of research to study the changes occurring as a result of conversion of coastal old-growth to second-growth forests. At 10 locations on Vancouver Island, plots were established in suites of seral stands. Five of these suites—chronosequences—are located on east Vancouver Island in the transition between the Coastal Douglas-fir (CDF) and the Very Dry Coastal Western Hemlock (CWHxm) biogeoclimatic zones, and the other five are located on west Vancouver Island in the Very Wet Maritime Coastal Western Hemlock zone (CWHvm) (Pollard and Trofymow, in these proceedings).

In addition to the carbon and nutrient survey being conducted on these chronosequences (Trofymow and Blackwell, in these proceedings), more intensive studies of small vertebrate, invertebrate, plant and mycorrhizal fungal diversity and microbial dynamics are being done on three of the chronosequences, Greater Victoria Watershed South, Greater Victoria Watershed North, and Koksilah. This paper summarizes the mensuration data for the intensive plots.

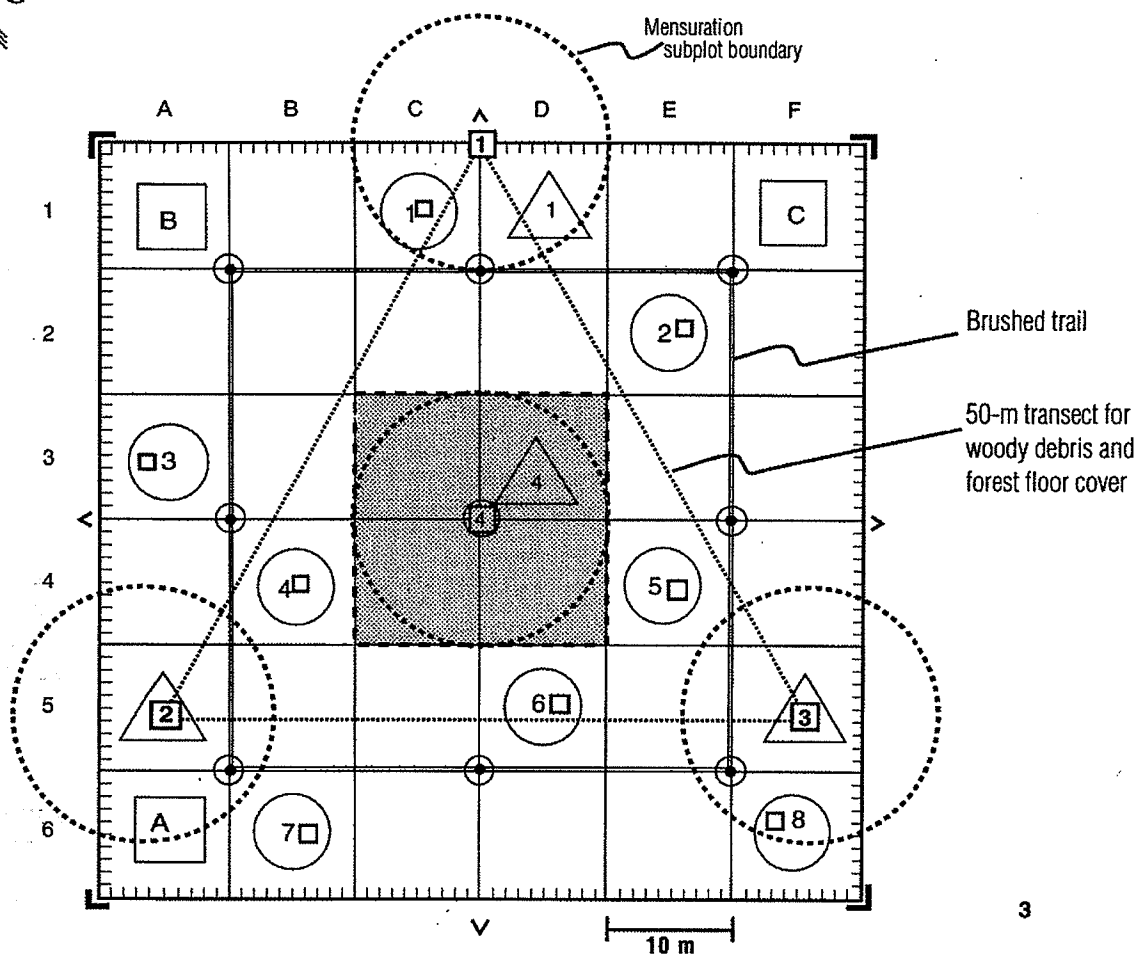
Methods

At all 10 chronosequences, triangular plots have been established for the survey of carbon and nutrient contents. From each benchmark, three 30 m radial lines were run to define three additional subplot centres 120° apart. Each of the four subplot centres is identified with a 1.5 m orange painted cedar stake that is flagged with a blue-, orange-, or lime-coloured ribbon. In addition, a 15-cm spike is inserted into the forest floor and flagged with the ribbon corresponding to the cedar stake. Subplot centres define the centre points of 5- or 10 m radius plots for standing biomass measurements. For the intensive chronosequences, the triangular plots are superimposed on 60 x 60 m square plots. These are further subdivided into 10 x 10 m square subplots that were used to facilitate the assignment of work areas for the different component studies (Figure 1).

Mensuration measurements of all dead and living overstory trees (DBH, height to live crown, and total height) by species and class (suppressed, intermediate, co-dominant, and dominant) were made to estimate plot biomass. Within each plot, three randomly chosen subplots were measured from the four subplots previously established. The size of tree inventory plots was either 78.5 m² or 314 m² (circular plots with a radius of 5 m or 10 m), depending on tree density. For the 10 m plot radius a minimum of 10 trees was required. In regeneration plots and in some other plots, trees less than 3 m made a significant contribution to total biomass. Total height and caliper at 5 cm from the base of each tree was measured. At each plot a minimum of five increment cores at breast height of dominant trees were collected to estimate stand age.

Results

Mensurational data for the three intensive chronosequence plots are summarized in Tables 1–3. In all 12 chronosequence plots the dominant overstory species was Douglas-fir. Western hemlock made a significant contribution to stand density in the immature and old-growth (02 and 06) plots in the Greater Victoria Watershed South (GVWS) chronosequence. Basal area attributable to hemlock was less notable (Table 1).



Plot markers

- 2 5 cm x 5 cm x 1.5 m cedar stakes with coloured flagging – defines subplot centres and triangle corners –1991/92
- L 2.5 cm x 2.5 cm angle aluminum – defines corners of 60 x 60 m plot –1991
- < 12 mm x 12 mm angle aluminum – defines midpoints of 60 x 60 m plot –1991
- 2.5 cm x 2.5 cm x 2 m cedar stakes painted yellow and white –1992
- 2.5 cm diameter x 2.0 m blue-tipped PVC pipe and brushed trail – defines inner 40 x 40 m plot – 1992

Subplot assignments



Forest floor, soil, woody litter sampling, decay and microbial activity studies (Trofymow, Preston)



Amphibia cover object (Davis)



Undisturbed core area



Subplot for soil zoology, microflora (Marshall, Trofymow, Panesar, Goodman, Craig)



Fine litterfall traps (to be placed –Pollard)

FIGURE 1. Forestry Canada coastal forest chronosequences. Example of intensive studies plot layout and subplot assignments.

Except in old-growth plots, stand density was high and in most plots exceeded 1000 stems per hectare. The highest stand density was recorded for the immature plot at Koksilah (plot 23) where more than 3300 stems per hectare were measured (Table 3). The number of dead standing trees, including stumps for the 12 plots, was quite variable, ranging from 40 to 1500 stems per hectare. The largest number of standing dead trees was measured in the immature plot at Koksilah (plot 23).

When plots of the same age were compared, basal area measurements were similar for living trees for all three old-growth plots (Tables 1–3). For the living trees in the immature and mature plots, basal area was more variable. Basal area in immature plots (02, 12, and 22) ranged between 30.4 and 48.6 m²/ha (Tables 1–3). The basal area measurements for the mature plots were more variable ranging from 63.0 to 87.3 m²/ha (Tables 1–3). This variation was attributed to site differences in tree diameter and stand density. The basal area in old-growth plots (06, 15, and 24) was uniform, ranging only from 83.1 to 87.7 m²/ha.

Diameter at breast height (DBH) measurements were largely a function of stand density (Tables 1–3). Mean DBH decreased with increasing stand density. The largest mean diameter trees were measured in the GVWS old-growth plot (06), where the mean of Douglas-fir trees was 76.8 cm (Table 1). In the GVWN, mean DBH values of 51.5 cm and 41.7 cm were measured for Douglas-fir trees and Koksilah chronosequences, respectively, (Table 2 and 3). Trends in mean height were similar to DBH measurements. Mean height of Douglas-fir was highest for the GVWS old-growth plot, where the mean height was 47.5 m. Mean Douglas-fir height in GVWN and Koksilah old-growth plots was 32.0 m and 21.4 m, respectively. The lower heights in Koksilah can be attributed to the large number of old-growth trees with broken tops. Aspect and topographic position made trees in this plot more susceptible to wind damage, compared to trees in the GVWS and GVWN plots.

Summary

From the mensuration data collected for the three intensive chronosequences, it can be concluded that plots equivalent in age are similar in tree species composition and stand density. Comparison of basal area measurements indicated that old-growth plots for the three chronosequences were very similar while other plots were more variable. This was attributed to variation in diameter and stand density between these sites. Future work on this project will involve the quantification of stand biomass and carbon and nutrient budgets.

References

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Table 1. Mensurational data (and standard error) from plots in the Greater Victoria Watershed South (GVWS) chronosequence - includes all living and dead trees greater than 3.0 m height only.

| Plot | Lifeform | Spp. | n | Mean Density #/ha | Basal Area m ² /ha | Mean DBH cm | Mean Height m | Maximum Height m | Mean Age years |
|---------------------|----------|---------|----|-------------------------|-------------------------------------|-------------------|---------------------|------------------------|----------------------|
| Living Trees | | | | | | | | | |
| 01 (1) | tree | all sp. | 34 | 1793 | 0.1 | 1.6 | 1.1 | 1.9 | 4 (1) |
| 02 (2) | tree | Hw | 28 | 1188 | 7.7 | 6.8 (1.1) | 7.7 | (0.8) | 18 (1) |
| | | Fd | 24 | 1019 | 22.7 (0.0) | 13.2 (2.2) | 11.9 | (1.1) | |
| | | | 52 | 2207 | 30.4 | | | | |
| 05 (3a) | tree | Hw | 1 | 11 | 0.0 | 22.5 | 20.5 | 20.5 | 89 (2) |
| | | Cw | 7 | 74 | 3.6 (0.0) | 23.1 (3.6) | 16.9 | (2.5) | |
| | | Fd | 40 | 647 | 82.1 (0.0) | 38.4 (3.1) | 33.5 | (1.6) | |
| | | Pw | 1 | 42 | 0.1 | 6.5 | 8.0 | | |
| | | Dr | 1 | 11 | 1.1 | 36.2 | 37.4 | | |
| | | | 50 | 785 | 87.3 | | | | |
| 06 (4) | tree | Hw | 32 | 340 | 5.7 (0.0) | 12.4 (1.4) | 10.4 | (1.3) | 235 (15) |
| | | Cw | 4 | 42 | 2.9 (0.0) | 26.9 (7.4) | 16.7 | (4.8) | |
| | | Fd | 14 | 149 | 73.6 (0.1) | 76.8 (5.6) | 47.5 | (2.0) | |
| | | Dr | 1 | 11 | 0.9 | 32.5 | 16.9 | | |
| | | | 51 | 542 | 83.1 | | | | |
| Standing Dead Trees | | | | | | | | | |
| 01 (1) | stump | Hw | 30 | 318 | 49.5 (0.0) | 38.1 (3.6) | 0.4 | (0.0) | |
| | | Fd | 3 | 32 | 13.2 (0.1) | 71.7 (9.0) | 0.6 | (0.3) | |
| | | | 33 | 350 | 62.7 | | | | |
| 02 (2) | stump | Fd | 3 | 127 | 67.1 (0.1) | 81.7 (4.4) | 0.7 | (0.1) | |
| | tree | Hw | 6 | 225 | 0.2 (0.0) | 3.0 (0.4) | 4.7 | (0.5) | |
| | | Fd | 12 | 509 | 0.3 (0.0) | 2.8 (0.2) | 4.2 | (0.3) | |
| | | | 21 | 861 | 67.6 | | | | |
| 05 (3a) | tree | Fd | 13 | 170 | 6.0 (0.0) | 19.3 (3.4) | 11.6 | (2.4) | |
| | | Dr | 4 | 42 | 2.9 (0.0) | 29.3 (1.5) | 15.5 | (6.7) | |
| | | | 17 | 212 | 8.9 | | | | |
| 06 (4) | tree | Hw | 22 | 223 | 2.1 (0.0) | 8.8 (1.6) | 5.1 | (0.6) | |
| | | Fd | 1 | 11 | 5.0 | 77.7 | 47.6 | | |
| | | Dr | 1 | 11 | 0.6 | 26.6 | 4.9 | | |
| | | | 24 | 267 | 7.7 | | | | |

Plot numbers in brackets indicate the original chronosequence plot number in the plot location and establishment report (Blackwell 1992).
Bold numbers indicate plot totals.

Table 2. Mensurational data (and standard error) from plots in the Greater Victoria Watershed North (GVWN) chronosequence - includes all living and dead trees greater than 3.0 m height only.

| Plot | Lifeform | Spp. | n | Mean Density #/ha | Basal Area m ² /ha | Mean DBH cm | Mean Height m | Maximum Height m | Mean Age years |
|----------------------------|------------|---------|-----------|----------------------|----------------------------------|----------------|------------------|---------------------|-------------------|
| Living Trees | | | | | | | | | |
| 11 (1) | tree | all sp. | 24 | 1018 | 0.3 | 2.7 | 1.5 | 2.3 | 6 (1) |
| 12 (2) | tree | Fd | 49 | 2080 | 48.6 | 16.4 | 18.2 | 23.5 | 32 (1) |
| 13 (3) | tree | Cw | 3 | 32 | 0.8 | 15.2 | 9.2 | 16.0 | 89 (2) |
| | | Fd | 60 | 1210 | 78.1 | 20.8 | 19.1 | 37.6 | |
| | | | 63 | 1242 | 78.9 | | | | |
| 15 (4) | tree | Hw | 16 | 170 | 3.1 | 10.9 | 7.7 | 29.0 | 306 (3) |
| | | Cw | 8 | 85 | 6.0 | 24.3 | 15.2 | 26.6 | |
| | | Fd | 34 | 361 | 77.7 | 51.5 | 32.0 | 47.4 | |
| | | | 58 | 616 | 86.8 | | | | |
| Standing Dead Trees | | | | | | | | | |
| 11 (1) | stump | Hw | 3 | 32 | 0.5 | 13.3 | 0.3 | 0.3 | |
| | | Cw | 5 | 53 | 15.1 | 53.2 | 0.4 | 0.7 | |
| | | Fd | 24 | 255 | 78.1 | 60.2 | 0.4 | 0.8 | |
| | | | 32 | 340 | 93.7 | | | | |
| 12 (2) | stump tree | Fd | 3 | 127 | 15.3 | 37.3 | 0.6 | 0.7 | |
| | | Fd | 12 | 509 | 2.1 | 6.5 | 8.8 | 15.2 | |
| | | | 15 | 636 | 17.4 | | | | |
| 13 (3) | stump tree | Fd | 1 | 42 | 14.1 | 65.0 | 0.5 | 0.5 | |
| | | Fd | 25 | 520 | 2.5 | 7.2 | 8.0 | 16.4 | |
| | | | 26 | 562 | 16.6 | | | | |
| 15 (4) | tree | Cw | 2 | 21 | 1.7 | 19.8 | 12.9 | 13.4 | |
| | | Fd | 4 | 42 | 1.0 | 26.8 | 8.6 | 18.8 | |
| | | | 6 | 63 | 2.7 | | | | |

Plot numbers in brackets indicate the original chronosequence plot number in the plot location and establishment report (Blackwell 1992).
Bold numbers indicate plot totals.

Table 3. Mensurational data (and standard error) from plots in the Koksilah chronosequence - includes all living and dead trees greater than 3.0 m height only.

| Plot | Lifeform | Spp. | n | Mean Density #/ha | Basal Area m ² /ha | Mean DBH cm | Mean Height m | Maximum Height m | Mean Age years | | | |
|---------------------|----------------|---------|----|-------------------------|-------------------------------------|-------------------|---------------------|------------------------|----------------------|------|----|-----|
| Living Trees | | | | | | | | | | | | |
| 21 (1) | tree | all sp. | 18 | 764 | 0.1 | 1.0 | 0.7 | 0.4 | 2-5 | | | |
| 22 (2) | tree | Hw | 1 | 42 | 0.0 | 3.8 | 3.5 | 3.5 | 33 | | | |
| | | Cw | 12 | 509 | (0.0) | 7.7 | 6.5 | (0.8) | 12.3 | | | |
| | | Fd | 49 | 2080 | (0.0) | 12.9 | 12.0 | (0.7) | 23.1 | | | |
| | | | 62 | 2631 | 39.2 | | | | | | | |
| 23 (3) | tree | Fd | 79 | 3353 | 63.0 | 13.7 | (0.8) | 12.8 | (0.6) | 27.3 | 76 | (2) |
| 24 (4) | tree | Hw | 1 | 11 | 0.5 | 24.5 | 15.4 | 15.4 | 278 | (14) | | |
| | | Fd | 44 | 467 | (0.0) | 41.7 | (3.8) | 21.4 | (1.7) | 35.9 | | |
| | | | 45 | 478 | 87.7 | | | | | | | |
| Standing Dead Trees | | | | | | | | | | | | |
| 21 (1) | stump stump | Cw | 2 | 21 | 7.4 | 65.0 | (15.0) | 0.5 | (0.0) | 0.5 | | |
| | | Fd | 28 | 297 | (0.0) | 61.7 | (5.3) | 0.4 | (0.0) | 0.6 | | |
| | | | 30 | 318 | 105.1 | | | | | | | |
| 22 (2) | tree | Fd | 1 | 42 | 0.1 | 6.3 | 6.2 | 6.2 | | | | |
| 23 (3) | tree | Fd | 35 | 1485 | 4.6 | 5.8 | (0.4) | 7.3 | (0.7) | 22.9 | | |
| 24 (4) | tree | Fd | 5 | 53 | 4.0 | 26.9 | (7.6) | 12.4 | (3.9) | 26.1 | | |

Plot numbers in brackets indicate the original chronosequence plot number in the plot location and establishment report (Blackwell 1992).
 Bold numbers indicate plot totals.

Changes in Plant Diversity in Douglas-fir Stands Following the Conversion of Old Growth to Second Growth

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Introduction

The goals of this investigation were:

1. to characterize the vegetation of old-growth Douglas-fir stands in the study area;
2. to assess the rate and degree of restoration of plant diversity (especially cryptogams and shrubs) at different stages of second growth;
3. to classify the vegetation on the study sites according to the biogeoclimatic system;
4. to investigate the diversity of cryptogams on a variety of substrates; and
5. to investigate the variability of the plots, to determine if they serve as good replicates of the type and age of stand they were chosen to represent.

Methods and Results

Information on cover and abundance of all vascular and non-vascular plants was gathered in each one-quarter of the plots using both visual surveys and sampling along transect lines. Information was also gathered on the type of substrate (rock, wood, decayed wood, humus or mineral soil) that cryptogams were growing on. Detrended correspondence analysis (DCA) (Hill and Gauch 1980) was used to assess the dissimilarity of the vegetation composition and cover values between the 12 plots using the CANOCO (Ter Braak 1988) and PC-ORD computer programs (McCune 1991).

The South, North and Koksilah plots were located in the CWHxm1, CWHxm2 and CWHmm2 variants, respectively, of the Coastal Western Hemlock zone of the Biogeoclimatic Ecosystem Classification system (see Harcombe and Oswald 1990a, b).

A total of 251 species were identified. The old-growth plots contained slightly fewer species (143) than did younger aged plots (161–169). North plots contained fewer species (143) than did the South (191) and Koksilah (193) plots. The number of species of trees, shrubs, herbs, and cryptogams varied depending on the age of the stand (Figure 1). Herb species richness increased with logging, but cryptogams richness decreased.

The vegetation on regeneration plots was composed of many invasive herbaceous species, in addition to residual forest species which appeared to have survived logging disturbances. Only forest cryptogams and some saprophytic vascular plants appeared to have been eliminated on regeneration sites. Herb cover was lower and cryptogam and shrub cover was higher on forest plots (Figure 2). In forest plots, cryptogam species richness was greatest on wood or rock (Figure 3), but cover was greatest on humus substrates. Large pleurocarpous mosses provided most of the cover.

The number of species restricted to a specific age class decreased with increasing age of the plot. Regeneration sites had a large number of species that were absent on forest plots; the old-growth forests lacked a few species that were present in younger plots (Table 1).

The vegetation structure on some plots was more diverse than that on other plots, but there appeared to be little relationship between the vegetation structure and either the species diversity or the location of the plot. Similarly, there were few discernible patterns in the structure of the vegetation with respect to the age of the plot. Immature stands appear to have a large number of small gaps in the tree and shrub layers, whereas mature and old-growth plots have a fewer number of small gaps and a greater number of large gaps.

Differences in the vegetation composition between plots are shown in the Detrended Correspondence Analysis (DCA) results. Initial results indicated that regeneration plots are substantially different from forested plots; so much so that all the forested plots are compacted to one side of the ordination. The data were

re-analyzed after the regeneration plots were removed (Figure 4). The forested plots are widely scattered in the ordination and there appears to be no relationship between the distribution of the plots and age class, but there is some pattern with respect to the location of the plots.

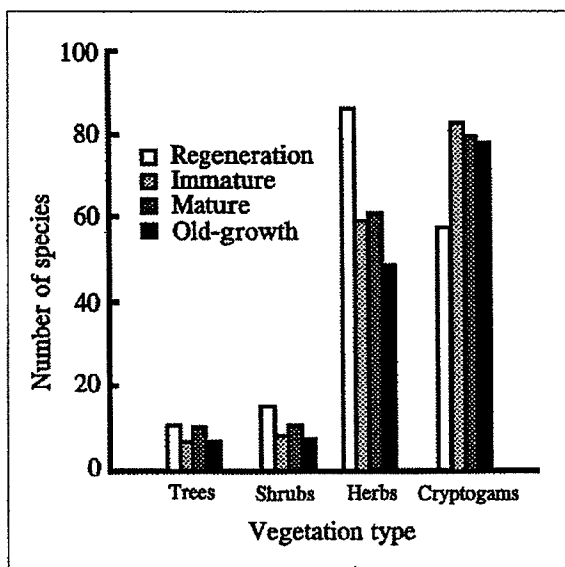


FIGURE 1. Number of species of trees, shrubs, herbs, and cryptogams found in each age class.

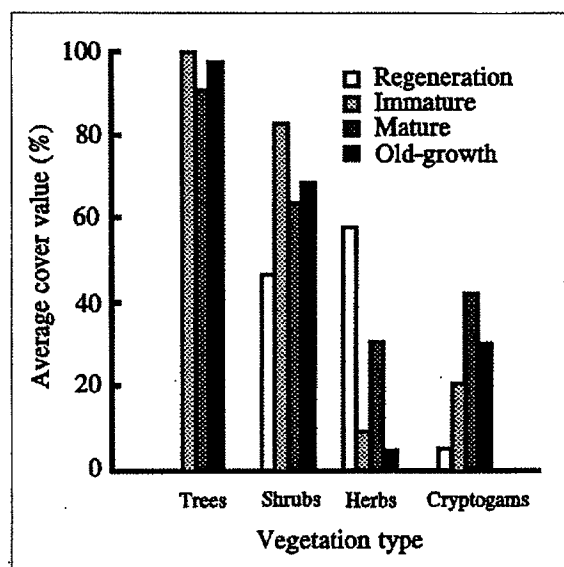


FIGURE 2. Average cover values of trees, shrubs, herbs, and cryptogams in each age class. Cover values for trees and shrubs are based on the sum of the cover values from their respective vegetation layers (e.g., dominant, main canopy, and A3 layers).

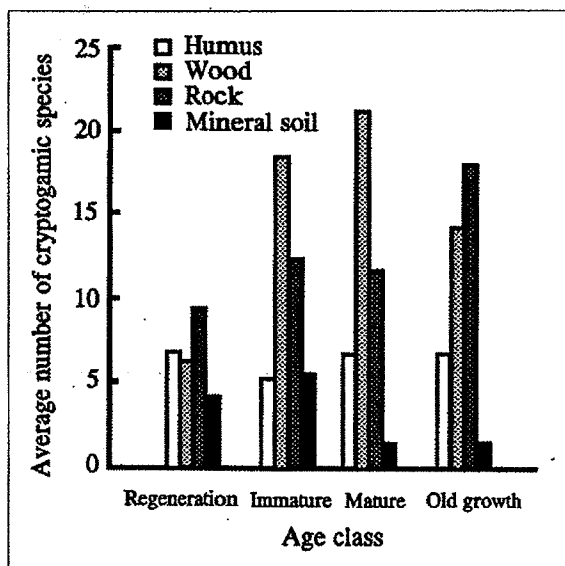


FIGURE 3. Average number of cryptogamic species on various substrates in each age class.

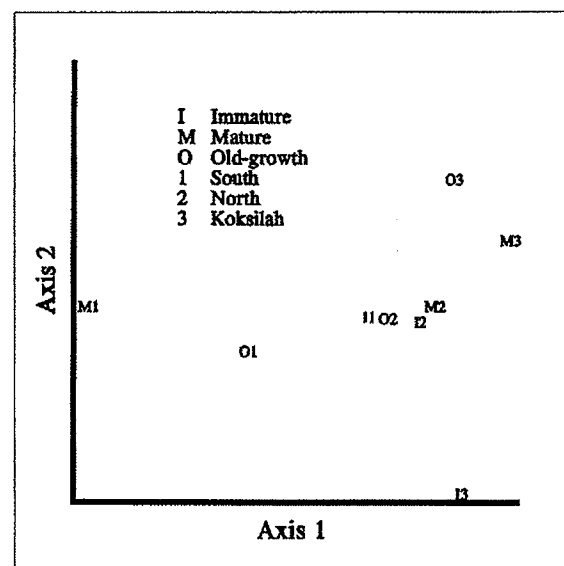


FIGURE 4. Ordination of all plots except regeneration plots. Each plot is represented by an alphanumeric code in which the letter and number represent the age class and location, respectively, of the plot.

TABLE 1. Species restricted to specific age classes. Those species followed by an asterisk are introduced species. Species are listed in alphabetical order, beginning with vascular plants followed by cryptogams.

Regeneration Sites

Agrostis exarata
*Anthoxanthum odoratum**
Aquilegia formosa
Arbutus menziesii
Carex lenticularis
Carex pachystachya
*Cirsium arvense**
*Cirsium vulgare**
*Crepis capillaris**
*Cytisus scoparius**
*Digitalis purpurea**
Epilobium minutum
Epilobium paniculatum
Gnaphalium
 microcephalum
Gnaphalium purpureum
*Holcus lanatus**
Juncus effusus
Lathyrus nevadensis
Lilium columbianum
Mimulus moschatus
Prunella vulgaris
Prunus emarginata
*Ranunculus repens**
*Rubus lancinatus**
Rubus leucodermis
*Rumex acetosella**
Salix sitchensis
*Sonchus asper**
Stellaria calycantha
*Veronica officinalis**
Vicia americana
Barbula species
Cephaloziella turneri
Cladonia species

Immature Sites

Allium cernuum
Athyrium filix-fermina
Carex species
Equisetum arvense
Festuca subulata
Lycopodium selago
Orobancha species
Pterospora andromedea
Trisetum cernuum

Immature Sites (cont.)

Anthoceros punctatus
Brachythecium frigidum
Cladonia cenotea
Cladonia gracilis
Cladonia pyxidata
Dichodontium pellucidum
Didymodon vinealis
Diplophyllum albicans
Lophozia ventricosa
Marsupella emarginata
Philonotis fontana
Scapania umbrosa
Scleropodium obtusifolium
Tortula ruralis

Regeneration & Immature Sites

*Aira caryophyllea**
Arctostaphylos columbiana
Cerastium vulgatum
Chrysanthemum
 *leucanthemum**
Danthonia spicata
Deschampsia elongata
Epilobium watsonii
Lonicera ciliosa
Madia exigua
Pinus contorta
Ribes lobbii
Trisetum canescens
Viola adunca
Funaria hygrometrica

Mature Sites

Blechnum spicant
*Epipactis helleborine**
*Ilex aquifolium**
Paxistima myrsinites
Symphoricarpos albus
Trillium ovatum
Cladonia verruculosa
Homalothecium fulgens
Peltigera pacifica
Porotrichum bigelovii

Old-Growth Sites

Collinsia parviflora
Listera caurina
Barbilophozia barbarta
Encalypta affinis
Heterocladium macounii
Metaneckera menziesii
Porella cordeana

Mature & Old-Growth Sites

Allotropa virgata
Calypso bulbosa
Hemitomes congestum
Hypopitys monotropa
Madia sativa
Monotropa uniflora
Taxus brevifolia
Frullania tamarisci
Isothecium cristatum
Lophizia incisa
Neckera douglasii
Plagiochila asplenoides
Plagiomnium venustum
Psoroma hypnorum
Timmia austriaca

The vegetation on a given plot tends to be more similar to that found in other plots occurring in the same location (but of a different age class) than with plots belonging to the same age class but occurring in different locations.

Discussion

In a previous study of the changes in western hemlock and Douglas-fir forests in the Nanaimo River valley, Mueller-Dombois (1965) reported similar results to those found in this study. Regeneration sites had the largest number of species because of the resilience of the understory vegetation, which resprouted after logging, and the occurrence of a large number of invasive herbs (of which many species were the same as those found in this study). Cryptogams and saprophytic species were also largely eliminated from sites that had been logged. Likewise, in Washington and Oregon, Schoonaker and McKee (1988) reported that species diversity was greatest on logged Douglas-fir sites as a result of an influx of weedy species and the occurrence of residual forest species. Once canopy closure was achieved on immature sites, diversity reached its lowest values. Alternatively, in the old-growth forests where the canopy was more structurally heterogeneous, intermediate levels of diversity were recorded although the number of plant species remained low, similar to that found in 30- to 40-year-old immature stands.

Distinct differences were observed in the total number of species found in the study areas. The lower total number of species and lower number of restricted species in the North plots may reflect the lack of microsite variability observed at these sites. In comparison, the perennially moist areas in the South plots and the rock outcrops in the Koksilah and South plots supported additional species not seen elsewhere.

The lack of specificity of cryptogams to a given age class (except for regeneration plots) contrasts with the results found by Lesica *et al.* (1991) who compared the cryptogams in stands of grand fir in Montana. In their study, 64 species were found on the forest floor, 29 were found in only one age class and 23 of these were found only in old-growth forests. The authors concluded that as old-growth forests are converted to younger aged forests many of these species will become less common. This contrasts with our results. Out of a total of 109 species of cryptogams, only 5 of the 28 species restricted to a specific age class were found in old-growth stands and these species appeared to be chance occurrences of uncommon species.

Cover values of cryptogams increased dramatically with age class, peaking in mature forests and then declining in old-growth forests. Similar results have also been noted by Alaback (1982) who studied the dynamics of understory species in Sitka spruce-western hemlock forests in southeast Alaska. He reported that moss biomass peaks in 140- to 160-year-old forest stands and declines with a corresponding increase in herbs and shrub cover. Similarly, in a comparison of bryophyte cover on old landslides (80+ years) and adjacent old growth forests on the Queen Charlotte Islands, Smith *et al.* (1986) found bryophyte cover was greater on landslides. Visual observations suggested that the amount of litter produced in old-growth forests was higher than that on landslides, so that the bryophyte cover was reduced because of increased mortality from smothering by litter.

Successional trends at the three locations are likely to be similar in that regeneration sites will have the greatest number of species because of (1) the invasion of these sites by a large number of weedy herbaceous species and (2) the re-emergence of almost all forest vascular species soon after logging. Once canopy closure occurs, many of the herbs will be eliminated and the shrub layer (dominated by salal) and cryptogam layer will increase in cover. As the stand matures, several saprophytic herbs will appear for the first time. Eventually, cryptogam cover will decline and the structure of the canopy will become more heterogeneous as individual Douglas-fir trees die and are replaced by western hemlock or western redcedar regeneration in the understory.

Current methods used to describe vegetation diversity are inadequate. Measurements of diversity or species richness use only quantitative values (number of species and cover values) as a measure of diversity, and fail to account for qualitative differences. Hence, a plot with a low number of species but supporting several rare or endangered species will have a lower index value than a plot with numerous widely-distributed weedy or introduced species. This problem is of particular concern when the preservation or conservation of rare or endangered species and ecosystems is being considered.

An important next step in the study of these systems will be to investigate the habitat requirements of rarer plant species and indicate how they are affected by conversion of old-growth to second-growth forests.

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Succession of Collembola in Stumps of Douglas-Fir Seres Representing Clearcuts to Old-growth Forest

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Introduction

The importance of coarse woody debris (CWD) as an essential component of terrestrial ecosystems has been recognized only recently (Harmon *et al.* 1986). Most of the CWD input in North American coastal forests is as logs, but in continuously harvested areas stumps may form the major part of CWD in the forest floor. Although CWD is reported to provide an array of important ecological functions, little information on the importance of stumps in forest ecology exists.

The aims of this study were to provide information on the succession of soil fauna during the decomposition of stumps in old-growth and managed Douglas-fir ecosystems, and to predict the outcome of forestry practices on the biodiversity of this fauna. Data on Collembola distribution and diversity are presented in this paper.

Material and Methods

The study was carried out in the chronosequence study areas established for the Forest Ecosystem Dynamics Program. Soil animals were sampled from Douglas-fir stumps of three different decay classes (from relatively intact to well-decayed wood). The sampling was repeated three times (in late summer, winter, and spring) in each of the four successional forest seres (regeneration, immature, mature, and old-growth) at three locations.

Results and Discussion

Stumps as a habitat

Decaying stumps of Douglas-fir proved to harbour a species-rich and abundant community of soil-inhabiting collembolans. A total of 72 species was detected during the study, covering the three locations with each successional sere and decay class of the stumps. On a volume basis, the population density in well-decayed stumps was equal or even exceeded that of the organic layers of surrounding soil. Moreover, as compared to other similar studies, the stumps seemed to be richer in soil microarthropods than were logs. These findings indicate that Douglas-fir stumps provide an important habitat for Collembola, and are, contrary to a general view (Lloyd 1963; Seastedt *et al.* 1989), not exploited by the fauna as a marginal habitat only.

Distribution of Collembola in the successional seres

The four successional seres of forests can be divided into two distinct groups with respect to the organization of the collembolan populations in the stumps: the three forested stands are distinctly separated from the clearcut stand. The number of specimens was significantly less in the regeneration site than in the forested sites. Also, the average number of species found in the regeneration site was slightly smaller compared to that number found in the forests.

The forested seres showed a collembolan fauna of similar composition. However, ordination analysis (DCA) indicates a weak clustering of the fauna into "seral communities." Of the total of 72 species encountered, none was restricted to any particular successional sere. However, two species of *Collembola* showed a marked preference for stumps in the regeneration site.

Conclusions

The collembolan fauna in the stumps of the earliest successional stage after disturbance (clearcutting) differed both qualitatively and quantitatively from the fauna typical of old-growth forest. This is probably due to the acute physical disturbance (reduced moisture, increased irradiation) caused by clearcutting and to the subsequent slashburning. This kind of perturbation is severe enough to decrease the collembolan diversity for at least some decades following the felling of old growth. Because the functional importance of *Collembola* in decomposition and nutrient mobilization of the wood is unknown, it is difficult to predict the ecological consequences of the reduction of the *Collembola* due to clearcutting.

Further analysis will include other faunal groups and an attempt to relate the findings to whole-tree logging and destumping practices.

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Variation in Carabid Community Structure Associated with Forest Successional Stages

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Introduction

The project that is currently under way is designed to assess how forestry practices affect carabid community structure. Specifically, the objectives are to gather and quantify data on carabid community structure in each of four successional stages, and to assess changes in species composition and diversity associated with changes in forest age. Carabid beetles (Coleoptera: Carabidae) have been selected for this study for a number of reasons: they have been well worked out taxonomically; they are relatively abundant and diverse; they are easy to trap; and they are highly sensitive to habitat changes (see Niemelä *et al.* [1993]). In addition, as predators near the top of the invertebrate food chain, they are an important component of any ecosystem (Coddington *et al.* 1991).

Study Areas, Materials and Methods

Data are being collected in two study areas located in the southeastern region of Vancouver Island, referred to as Koksilah and Greater Victoria Watershed South. Both areas are dominated by stands of coastal Douglas-fir and were selected because each contains timber stands of four different ages (i.e., a complete chronosequence) within a 5 x 5 km area. The different aged successional stages are referred to as: 1) regeneration (3–8 years old); 2) immature (25–45 years old); 3) mature (65–85 years old); 4) old growth (>200 years old).

Carabids are being collected by means of pitfall traps. These traps consist of two 450-ml plastic drinking cups, one nested within the other. The inner cup is filled approximately halfway with 35% propylene-glycol, which kills and preserves any insects that fall into the trap. The cups are placed in the ground so that the rim of the nested cup is flush with, or slightly below, ground level.

Twenty-four traps have been set in each successional stage, making a total of 96 traps in each study area. Trap placement is random within the confines of the subplots allotted for this study by project coordinators at Forestry Canada.

Traps are emptied on a monthly basis. Carabids are sorted from the rest of the traps' contents and then identified to species.

Results

Although there are much data yet to be collected and processed, the preliminary results suggest several trends. First of all, regardless of whether the data are looked at on a month-to-month basis, Koksilah independently of Greater Victoria Watershed, or all collected to date, the regeneration sites are the most diverse followed (in order) by the old growth, mature, and immature stages (Table 1). With equivalent successional stages and collection periods compared, the Koksilah site is more diverse than the Greater Victoria Watershed according to the Shannon and Simpson diversity indices (Ludwig and Reynolds 1988).

TABLE 1. Diversity of successional stages compared

| | Regeneration | Immature | Mature | Old Growth |
|----------------------------|--------------|----------|--------|------------|
| Shannon's Index: H' | 2.10 | 1.35 | 1.77 | 1.99 |
| Simpson's Index: λ | 0.133 | 0.310 | 0.205 | 0.155 |
| N2: 1/ λ | 7.53 | 3.22 | 4.87 | 6.44 |

It is clear that different species of carabids respond differently to changes in forest cover. Some species, as exemplified by *Pterostichus herculeaneus* Mannerheim, show a decrease in their populations after clearcutting (Figure 1). Within 25–45 years post-cutting, the population has reached or is near its old-growth density.

Species such as *Scaphinotus angusticollis* Mannerheim (and other species of this genus) are completely eliminated by clearcutting. Members of this genus are morphologically adapted to prey on snails (Lindroth 1961). Reduction in vegetation probably affects snail numbers. Population recovery appears to take place once the canopy is re-established (Figure 2).

A third type of response is seen with the species *Pterostichus algidus* LeConte, which appears to survive the clearcutting with just a reduction in number. However, it appears to suffer a continued decline such that none were found in the immature sites (Figure 3).

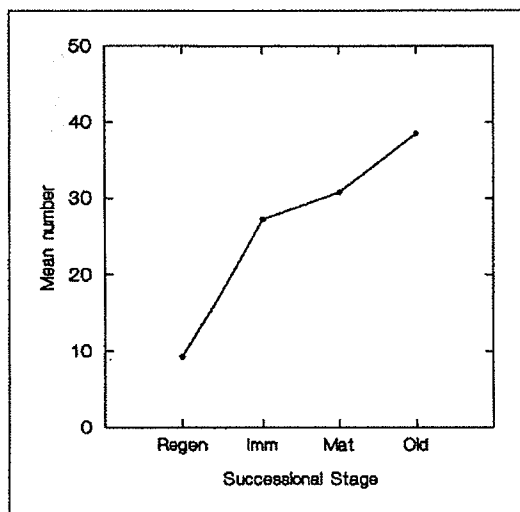


FIGURE 1. Mean number of *P. herculeaneus* trapped per stage per month during spring and early summer.

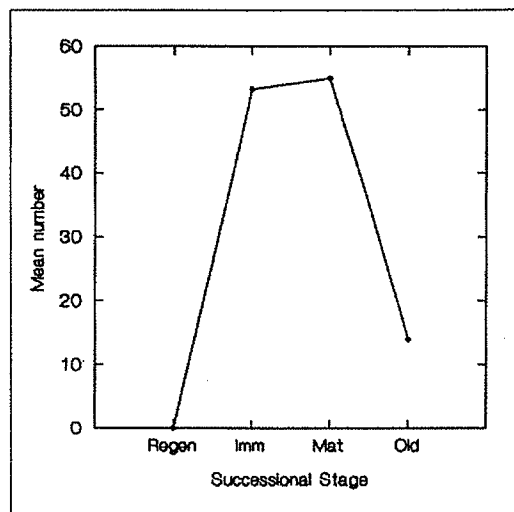


FIGURE 2. Mean number of *S. angusticollis* trapped per stage per month during spring and early summer.

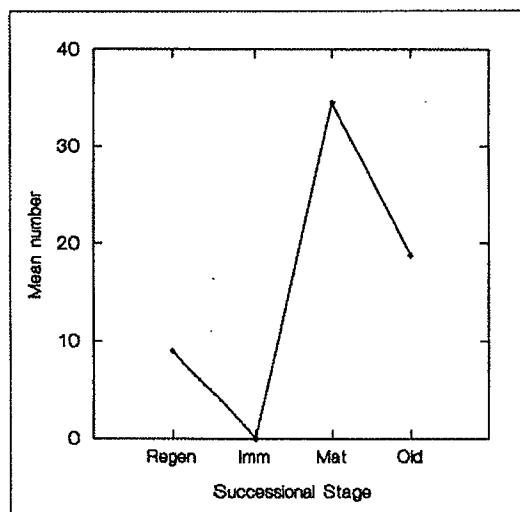


FIGURE 3. Mean number of *P. algidus* trapped per stage per month during spring and early summer.

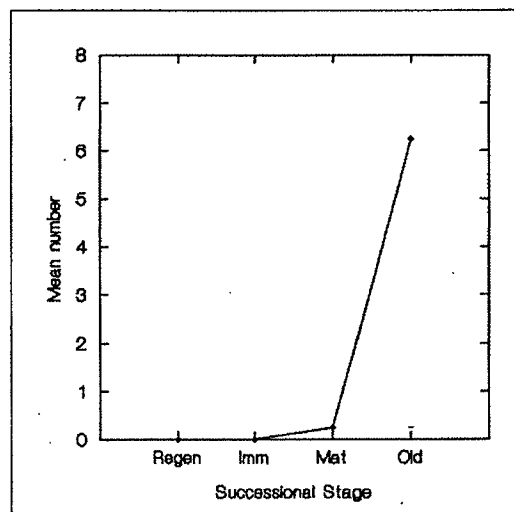


FIGURE 4. Mean number of *Z. matthewsii* trapped per stage per month during spring and early summer.

Finally, there is the true old-growth specialist, *Zacotus matthewsii* LeConte. This species is not found in the regeneration, immature, or even 65- to 85-year-old mature sites (Figure 4). As more old-growth forest is eliminated, such old-growth specialists will become endangered.

It is believed that the trends shown here will become reinforced as more data are processed.

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Differential Resource Use, Interspecific Interactions and the Effect of Logging on the Distribution and Abundance of Terrestrial Salamanders on Southern Vancouver Island

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Introduction

Concern that the fragmentation or loss of temperate old-growth forests might reduce amphibian diversity and abundance (Szaro *et al.* 1988; Hansen *et al.* 1991), of which terrestrial salamanders make up a significant fraction, has led to interest in developing systematic methods of monitoring salamander abundance and establishing which microhabitat characteristics are important for each species (Szaro *et al.* 1988; Corn and Bury 1990; Heyer *et al.*, in press).

In the terrestrial stages of the six sympatric species of salamanders on Vancouver Island, there is considerable overlap in the ranges of body sizes and resource requirements. However, little is known of the details of microhabitat use, prey types, or the degree to which these resources are partitioned; and nothing is known of role of interspecific interactions among them. It is not known why some species are relatively abundant at some locations, while other species are more abundant at other locations.

The objectives of this project are: 1) to determine the long-term effect of logging on the distribution and abundance of several coexisting species of terrestrial salamanders on southern Vancouver Island; 2) to assess various standard methods of estimating abundance by comparison with the actual density of terrestrial salamanders determined by total census; and 3) to establish the nature and extent of differential resource use and to evaluate the importance of interspecific interactions among these species.

Methods

Four study sites were selected in the Greater Victoria Watershed (GVW): old growth (> 150 years), clearcut (10–20 years), immature (40–60 years), and mature (80–100 years). Two additional sites were chosen, one in Goldstream Provincial Park and the other at Lake Cowichan, to document the extent of variation in abundance, and to investigate interspecific interactions.

Artificial cover objects (ACO; Heyer *et al.* in press) were used to monitor salamander abundance. Six ACO were arranged within 10 m diameter plots. Initially, six plots (36 ACO) were established in each of the four GVW sites and at Lake Cowichan. Another 12 ACO were placed in Goldstream Park. Late in 1993, additional sites with 12 ACO were established on Thetis Island and near Rosewall Creek Park, but data have not yet been collected. The 216 ACO were checked once every 2 weeks. Amount of coarse woody debris, number of sword fern bases, and other relevant data were recorded for each plot. Also, a series of time-constrained searches (TCS; Corn and Bury 1990), were completed at the GVW and Lake Cowichan sites. Microhabitat features and standard measurements were recorded for each individual capture.

To calibrate the ACO with respect to absolute abundance by a total census, three plots at Lake Cowichan with ACO, and three control plots were fenced. Within and outside these plots, salamanders were individually marked by toe-clipping and then released. Removal of salamanders will begin in 1993.

Results and Discussion

Combined searches in 1992 yielded 1289 captures of 1070 individual salamanders. Of these, 494 individuals were found on searches of ACO, the rest were found on TCS. Patterns of abundance under ACO were similar to what was found on TCS. The number of each species of salamander found under ACO varied among sites, although *Plethodon* was dominant at all sites (Table 1). Although few *Taricha* were found, the data suggest that they are not as common in the clearcut as in the other GVW sites. For *Plethodon*, there

was a significant difference in the number of salamanders captured among the four GVW sites ($0.001 < P[\chi^2 = 13.6, df=3] < 0.005$), but no difference among the three forested GVW sites ($0.25 < P[\chi^2 = 1.99, df=2] < 0.5$). Thus, abundance of *Plethodon* are reduced under clearcut conditions. Among forested sites, there was considerable variation in abundance. For example, there were about 4 times as many *Plethodon* and nearly 9 times as many *Taricha* at Lake Cowichan as were found at the forested sites in the GVW. At Goldstream Park, there were no *Taricha*, but there were over 5 times as many *Plethodon* as were found at Lake Cowichan and over 20 times as many as were found at the forested GVW sites.

TABLE 1. Number of salamanders (recaptures not included) found under ACOs in 1992. Each site had 36 ACOs and was searched 21 times, except Goldstream which had 12 ACOs and was searched 20 times.

| Site | Aneides | Ensatina | Plethodon | Taricha |
|----------------|---------|----------|-----------|---------|
| GVW clearcut | 0 | 0 | 9 | 0 |
| GVW immature | 2 | 3 | 29 | 5 |
| GVW mature | 1 | 3 | 32 | 3 |
| GVW old growth | 0 | 3 | 29 | 7 |
| Lake Cowichan | 0 | 0 | 113 | 43 |
| Goldstream | 0 | 0 | 212 | 0 |

Although there may be subtle differences among these sites, there are no obvious reasons for these differences in salamander abundance. It is known from previous work (Davis 1991) that the Rosewall Creek site is dominated by *Aneides*, although *Plethodon*, *Ensatina*, and *Taricha* are present as well. This suggests that there may be a geographical component to patterns of abundance of these species, but too few sites have been sampled to test this idea. Interspecific territoriality, historical constraints, or differences in physical conditions or resource availability may explain such patterns. At Lake Cowichan, there were significant differences in microhabitat use between *Taricha* and *Plethodon*. A positive relationship exists between the abundance of *Plethodon* and amount of cover ($r^2 = 0.77$), but no such relationship exists for *Taricha* ($r^2 = 0.01$).

These interesting patterns will be investigated further in 1993. Additional ACO will be placed at the Rosewall Creek site and in an adjacent clearcut. To investigate the possibility of a geographical component to patterns of distribution and abundance, a series of 20 mature forest sites will be searched that approximately represent a transect extending from Goldstream Park to Rosewall Creek. Other sites will be searched to elucidate the long-term effect of logging on these species. Interspecific interactions and behaviour with respect to physical conditions will be investigated in the field and laboratory.

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Nematode Diversity and Distribution in Different Forest Soil Habitats

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Introduction

Forestry activities in British Columbia in the past have included one or more of the following: clearcutting of old-growth forests, burning of residues, replanting with single species trees, fertilization, use of herbicides, and periodic thinning. In recent years, concern over impoverishment of biological diversity resulting from these practices has grown. At the same time, there is increasing awareness and consensus that the long-term sustainability of forest resources will depend largely on conserving overall biodiversity in these ecosystems (Boyle 1992). Recent research in coastal northwest forests has pointed to differences in plant and vertebrate species diversity between old-growth and managed and natural second-growth forests (e.g., Hansen *et al.* 1991). Parallel information on invertebrate diversity in forest ecosystems of these regions is essentially lacking.

Among the diverse groups of invertebrates that inhabit forest soils, nematodes are the most abundant. A forest soil may contain over 100 nematode species, and several million individuals per surface square metre. Their trophic and other interactions with cohabiting soil bacteria, protozoa, fungi, and microarthropods have important influences on essential soil processes and plant growth. Relationships of nematode taxa in forest soils to tree species or soil characteristics are indicated. Sensitivities of nematode taxa to soil conditions make them useful biological indicators, of, for example, site stability, the restoration capacity of soil ecosystems following anthropogenic or natural disturbances, and the presence of certain pedological conditions. Nematodes in at least two families have emerged as important biological control agents of soil-inhabiting insects. All these aspects of nematodes were reviewed in a previous report by Panesar and Marshall (1992).

In managing for conservation of soil fauna diversity, the first logical step is to produce good inventories of the species present. While our aim is to compare nematode diversity and distribution in a full suite of seral stages of forest development in each of three chronosequence sites, we present here results of our preliminary investigations at the old-growth seres at two sites (Table 1).

Methods

Soil is defined here in its broader sense, that is, the substrate in which vegetation takes root, including the dead organic material in and upon the mineral structure. Therefore, soil refers here to the "soil-rhizosphere" complex for species of trees, understory vegetation, and moss (Table 1). Five replicate samples were obtained for each complex by means of a 5 cm diameter metal corer. Each sample was divided into its organic and inorganic horizon, and each horizon was considered as a "habitat." The five samples for each habitat were bulked to eliminate nematode aggregative effect. For tree species, coring was done at "bare spots" under the canopy to minimize rhizosphere influence of understory vegetation. For understory plants, coring was done after the above-ground parts were clipped. In the case of moss on logs, the moss mat covering decayed logs and the substrate (i.e., the decayed log complex) were considered as two separate organic horizon habitats. Baermann funnels were used to extract nematodes from a single subsample, of known weight and volume,

from the bulked sample for each habitat. Nematodes in three aliquots were counted to obtain a mean count that was used to express nematode abundance per gram of oven dry weight (ODW) of the habitat. Nematodes were fixed in FA 4:1 fixative, and processed and mounted in glycerine.

TABLE 1. Nematode abundance and moisture content for organic and inorganic horizon (OH, IH) habitats of the rhizospheres of species of trees, understory vegetation, and moss, at two old-growth forest sites (GVWS, MBCK^a). Abundance = number of nematodes per gram of ODW of a habitat sample (s, w = summer, winter sampling).

| | No. of nematodes | | | | % Moisture content | | | |
|---------------------|------------------|----|----|----|--------------------|----|----|----|
| | OH | | IH | | OH | | IH | |
| | s | w | s | w | s | w | s | w |
| GVWS: | | | | | | | | |
| Douglas-fir | 29 | 46 | 6 | 5 | 29 | 57 | 19 | 16 |
| Cedar | 46 | 82 | 3 | 6 | 37 | 54 | 8 | 20 |
| Hemlock | 27 | 68 | 3 | 4 | 32 | 62 | 12 | 22 |
| Alder | 29 | 42 | 2 | 6 | 50 | 61 | 8 | 24 |
| Bracken fern | 16 | 13 | 4 | 7 | 42 | 57 | 15 | 54 |
| Sword fern | 23 | 41 | 2 | 4 | 39 | 58 | 17 | 23 |
| Oregon grape | 44 | 47 | 3 | 8 | 32 | 48 | 16 | 21 |
| Salal | 22 | 26 | 1 | 3 | 37 | 59 | 19 | 19 |
| Step moss on ground | 23 | 72 | 10 | 9 | 38 | 65 | 24 | 22 |
| Step moss on log | 49 | 50 | 25 | 39 | 45 | 61 | 74 | 69 |
| MBCK: | | | | | | | | |
| Douglas-fir | 26 | 64 | 6 | 3 | 29 | 64 | 13 | 23 |
| Cedar | 60 | 26 | 13 | 23 | 61 | 43 | 54 | 27 |
| Hemlock | 51 | 91 | 6 | 17 | 42 | 69 | 11 | 34 |
| Alder | 37 | 53 | 3 | 5 | 58 | 70 | 12 | 35 |
| Bracken fern | 18 | 5 | 9 | 11 | 44 | 44 | 13 | 23 |
| Sword fern | 12 | 65 | 6 | 7 | 16 | 71 | 31 | 23 |
| Oregon grape | 19 | 54 | 2 | 9 | 50 | 53 | 15 | 24 |
| Salal | 12 | 31 | 1 | 2 | 41 | 53 | 15 | 23 |
| Step moss on ground | 38 | 84 | 9 | 23 | 48 | 75 | 12 | 44 |
| Step moss on log: | | | | | | | | |
| moss mat | 23 | 34 | — | — | 59 | 67 | — | — |
| decayed log | 23 | 6 | — | — | 58 | 57 | — | — |

^a GVWS: Greater Victoria Watershed South, near Shawnigan Lake.

MBCK: MacMillan Bloedel's Cowichan-Koksilah holding, near Duncan.

Results and Discussion

Nematode abundance and % moisture content for the various forest soil "habitats" are shown in Table 1. Since the replicate samples for each habitat were bulked before subsampling, for reasons given above, the following comparisons are not based on statistical analysis. Moreover, the main objective of the preliminary work was to test field and lab methods, and produce a provisional list of nematode taxa. Even so, certain trends are evident:

1. Nematode abundance was in general higher in winter than in summer.
2. At least one factor for this variation appears to be the consistently higher "habitat" moisture levels in winter.
3. Nematode abundance was generally much higher in organic than in inorganic horizons of most habitats.
4. Rhizospheres of particular species of trees or understory vegetation constitute more favourable habitats for nematodes than do the rhizospheres of others.
5. Moss cover on ground and on logs is consistently a rich source of nematodes.

A composite list of 25 nematode genera identified to date from representative habitats consists of: *Achromadora*, *Acrobeles*, *Acrobeloides*, *Aphelenchoides*, *Aphelenchus*, *Aporceliamellus*, *Cephalobus*, *Cephalenchus*, *Chronogaster*, *Clarkus*, *Cryptonchus*, *Dorylaimus*, *Eudorylaimus*, *Iotonchus*, *Labronema*, *Miconchus*, *Mononchus*, *Monhystera*, *Paraphelenchus*, *Plectus*, *Prionchulus*, *Prismatolaimus*, *Pungentus*, *Teratocephalus*, and *Tylencholaimellus*. Many other families are represented in the collection. The number of genera is expected to increase several-fold as identification work progresses. Specific identification of the old-growth forest soil nematodes is currently the most important aspect of this study. This baseline information will allow diversity analyses and comparisons to be made with other successional stages of forest development.

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Relationships Between Soil Fauna and Soil Pollutants

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Introduction

Soil faunal activity is essential for the functioning of all terrestrial ecosystems. Soil fauna are important in the physical and chemical transformation of litter, the maintenance of soil fertility, and sustained productivity. By-products of human activities (e.g., air pollutants) affect the proper functioning of the soil fauna with a concomitant decrease in long term soil productivity. In Europe, changes in soil acidity (pH) induced by air pollution have been reflected in alteration of the soil fauna (Hågvar 1987). The fauna could therefore be used as early indicators of changes brought about in soil properties by pollutants (see Paoletti *et al.* 1991). In Canada, studies of this nature are lacking and even baseline data against which changes could be measured are not yet available. Our Acid Rain National Early Warning Systems (ARNEWS) plots, designed to detect early signs of damage in forests, provide an opportunity to observe possible changes in the soil fauna. Collembola were selected for initial study because of other information on collembolan diversity in immature Douglas-fir stands, especially stump data which have already been collected.

Objectives

(1) To study changes in soil fauna, specifically Collembola, at the Shawnigan Lake site between 1973 and 1992; and (2) to develop hypotheses (related to deposition, soil type, and selected indicator species) that could be tested under controlled laboratory conditions.

Methods

Soil samples were collected during October 1973 and October 1992 at the Shawnigan ARNEWS site. For both sampling occasions, sampling grids (3 m x 3 m) were located on the north, east, and west side in the buffer zone of control plot # 2-72. Each grid was subdivided into 1 m² microplots. One microplot was selected at random from each grid. Three soil cores were taken from each microplot using a 5 cm diameter soil corer. Samples from two of the cores contained L-H horizons and 0-3 cm mineral layer. The third core contained L-H, 0-3, 3-6, and 6-9 cm soil depths for a total of 24 samples.

Collembola were extracted from organic layers (L-H) using a high gradient apparatus. Mineral layers were extracted by Murphy split-funnel. Collembolan specimens were counted under a dissecting microscope. Mounting and identification of specimens followed Christiansen and Bellinger (1980-81), but some of their subgenera designations were considered as genera, agreeing with many other authorities.

Results and Discussion

Thirty-three species were identified from the 1973 samples and 53 species from the 1992 samples (Table 1 and Appendix 1 and 2). Only 12 species were common for both sampling times. These results are difficult to compare for two main reasons. First, the time lapse of 19 years would have permitted the build-up of organic matter and provided increased living space for more species. Second, there is a lack of information on species distribution of Collembola in British Columbia to permit speculation of possible occurrences of various species during early stages of development of Douglas-fir forests. It is likely that the additional species

occurring in 1992 were also present in the site in 1973, but in such low numbers as to evade detection. Only 24 samples were collected from each sample time and, considering the patchy distribution of many soil fauna species, a large number of samples might be required for a more realistic comparison.

TABLE 1. Number of collembolan species identified from 1973 and 1992

| | 1973 | | 1992 |
|----------------------------------|------|---|------|
| Total no. spp. | 33 | | 53 |
| No. common spp. | | 2 | |
| No. spp. common from stump study | 11 | | 17 |

Stumps seem to be a more stable habitat for Collembola, with little change in the faunal composition during forest succession (Setälä and Marshall, in these proceedings). Species composition of stumps also seems very different. A comparison of stumps and soil showed that only 11 and 17 species were common in stumps and soil for 1973 and 1992, respectively (Appendix 1 and 2). At least one dominant species in stumps (*Folsomia* n. sp.) has not yet been found in soil at this site. Another dominant stump species, *Anurophorus septentrionalis*, is rare in soil at the site.

The Anurididae were conspicuously absent from the 1992 samples. A few species in other families found in 1972 were also missing from the 1992 samples. Conversely, many species found in 1992 were not collected in 1973. It is therefore unlikely that the fauna are being adversely affected by pollutants as observed elsewhere (Rusek [1993]). Subtle alterations in oviposition, fecundity, and longevity of Collembola effected by changes in pH (Hågvar and Abrahamsen 1980) require much more detailed life-history studies. Further research should be directed at establishing a more exhaustive species list for the site from other material collected in the 1970s, and at doing additional sampling. A complete species list and detailed life cycle information could help to determine indicator species. Hypotheses on impacts of pollutants on Collembola could then be tested under controlled laboratory conditions.

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APPENDIX 1 1973 Species List

Total species: 33

Anurididae

Friesea wilkeyi, *Morulodes serrata**

Brachystomellidae

Odontella biloba, *Odontella cornifer**, *Odontella rossi*

Dicrytomidae

*Ptenothrix maculosa**

Entomobryidae

Entomobrya assuta, *Entomobrya menentotoma*, *Sinella* (S.) *curviseta*

Hypogastruridae

*Mitchellania virga**, *Mitchellania vulgaris**, *Xenylla affiniformis*

Isotomidae

Folsomia candida, *Folsomia fimetaria*, *Folsomia nivalis**, *Proisotoma* (P.) *mackenziana*

Neanuridae

Micranurida sp., *Neanura* (*Deutonura*) *frigida*, *Neanura setosa*, *Pseudachorutes curtus*,
Pseudachorutes subcrassoides

Neelidae

*Megalothorax minimus**

Onychiuridae

Archaphorura absoloni, *Onychiurus dentatus*, *Onychiurus eous*, *Onychiurus flavescens**,
Onychiurus millsii, *Onychiurus ramosus*, *Onychiurus reluctus*, *Mesaphorura pacifica**,
*Mesaphorura yosii**, *Protaphorura uenoi*

Tomoceridae

*Tomocerus flavescens**

* Indicates species also found in stump study (Setälä and Marshall, in these proceedings): 11

Species in bold face: common species between 1973 and 1992: 12

APPENDIX 2 1992 Species List

Total species: 53

Brachystomellidae

Odontella sp., *Xenyllodes* sp.? *armatus*

Dicrytomidae

Ptenothrix maculosa*

Entomobryidae

Entomobrya sp., ***Sinella (Sinella) curviseta***, *Sinella* sp. (no eyes), *Sinella* sp.

Hypogastruridae

Ceratophysella krafti, *Mitchellania horrida*, ***Mitchellania virga****, ***Mitchellania vulgaris****,
Mitchellania wallmoi, *Willemia biseta*, *Willemia denisi**, *Willemia intermedia*

Isotomidae

Cryptopygus sp.? *exilis*, ***Folsomia candida***, ***Folsomia fimetaria***, *Folsomia stella**,
Isotoma (Desoria) agrelli, *Isotoma (Desoria) ekmani**, *Isotoma (D.) multisetis*, *Isotoma (D.) tariva*,
Isotoma (D.) trispinata, *Isotoma (D.) uniens**, *Anurophorus (Pseudanurophorus) sp. ? arcticus*

Neanuridae

Christobella ornata, *Christobella* sp.? (4 eyes), *Micranurida pygmaea*, *Neanura persimilis*,
*Paranura colorata**, *Paranura* sp.1, *Pseudachorutes* sp., *Pseudachorutes* sp. (PAO-10)

Neelidae

Megalothorax minimus*

Onychiuridae

*Lophognathella choreutes**, *Mesaphorura macrocheata**, ***Mesaphorura yosiii****, *Multivesicula punctata*,
*Protaphorura cockle**, ***Onychiurus (Onychiurus) flavescens****, ***Onychiurus (O.) millsii***,
Onychiurus (O.) ramosus, *Sensiphorura marshalli*, *Tullbergia ruseki*

Sminthuridae

Arrhopalites clarus, *Arrhopalites* sp., *Sminthurides (Denisiella) sexpinnatus*,
Sminthurides (Stenadicia) sp.

Tomoceridae

*Tomocerus brevimucronatus**, *Tomocerus curtus*, *Tomocerus dubius*, ***Tomocerus flavescens****,
Tomocerus lamelliferus

* indicates species also found in stump study (Setälä and Marshall, in these proceedings): 17

Species in bold face: common species between 1973 and 1992: 12

Terrestrial Molluscs: Their Role in the Ecological Dynamics of Forest Floor Communities

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Introduction

Terrestrial molluscs form part of the cryptozoa of virtually all litter communities, ranging from arid grasslands to tropical rain forests. Apart from a few "pest" species associated with cultivated crops, the ecological position in the trophic structure of such communities remains, for these molluscs, poorly understood.

Most species are assumed to be generalist feeders, living largely on detritus of plant origin; they are reported to possess the enzyme cellulase and consequently can digest cellulose (Kerney and Cameron 1979). However, some species, including most slugs, feed on living plant tissue, whereas others are carnivorous, attacking other members of the cryptozoa such as earthworms and the eggs and young of arthropods and other molluscs. The molluscs are themselves the prey of a variety of vertebrate predators, as well as invertebrates such as carabid beetles (Digweed 1991) and certain dipterous flies (Kerney and Cameron 1979). They also serve as obligate intermediate hosts for a series of vertebrate parasites (protstrongylid nematodes and trematodes; Boag 1983). Thus, it would seem wise to include these invertebrates in any study of the dynamics of forest-floor communities, particularly as they are influenced by various timber extraction procedures.

Procedure Proposed

To address this subject, I think it necessary to consider initially a number of questions, including the following:

1. What is the nature of molluscan fauna associated with each forest-floor community?
2. Does this fauna change species composition and abundance as the various seral stages of post-logging forest regeneration change the nature of the overstory?
3. What are the life history characteristics of each species in each molluscan community?
4. What is the nature of the ecological space used by each species?

Out of these questions arise a series of secondary questions, the answers to which will hopefully extend our understanding of the dynamics of the forest-floor community under varying forest extraction procedures. These secondary questions include the following:

1. What trophic positions are represented among the molluscan species encountered in each community?
2. How efficient are these molluscs in detrital overturn?
3. What relationships are exhibited with other faunal components in each community?

To answer these questions, I propose to use a combination of field and experimentally controlled procedures. The former will involve the use of a series of sampling plots set out in the two most disparate seral stages of the forest under study (early regeneration and old-growth forest). Two sites will be chosen within each seral stage to measure within-habitat variation. The plots will consist of squares (0.25 m to a side) of corrugated fiberglass (darkened on one side), placed in groups of 16 with an interplot distance of 4 m (encompassing an area of 0.0144 ha). Molluscs found adhering to the underside of these artificial shelters (Boag 1990), recorded during regular inspections over the course of 1 year, will provide evidence of species composition at each site. By marking the snails associated with each plot (a specific number or colour), we can estimate abundance and use of space.

In the experimental approach, molluscs will be placed in artificial enclosures (cages or a maze) to measure with greater precision a series of population attributes difficult to measure in the field. These will include the life history characteristics (growth, survival, reproductive output) of given species living in enclosures under conditions that mimic those in the field. These enclosures will also be used to consider potential interactions among molluscs and other invertebrates. The maze will be used to test a given species' food preferences and trophic efficiency.

Results

The results of this investigation will not only extend our knowledge of this important group within the cryptozoa of forest-floor communities, but also help us to understand the dynamics of this community and the impact of industrial forestry on it. The questions addressed here will also have a bearing on conservation problems (viable population size, habitat preferences, dispersal corridors, etc.), landscape ecology (juxtaposition of forest stages, size of clearcut, species composition of regenerated forests, etc.), and plant husbandry (vulnerability of plant seedlings, role of detritivores in nutrient release, etc.).

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Diversity of Mycorrhizal Fungi in Old-growth and Mature Second-growth Stands of Douglas-fir on Vancouver Island

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Introduction

A large number and variety of fungi, including most forest mushrooms, penetrate and sheathe feeder roots of Douglas-fir (and other conifers), forming ectomycorrhizas. Symbiosis with mycorrhizal fungi is essential for the nutrition of conifers. Ectomycorrhizal fungi also benefit their hosts by acting as a barrier to pathogenic fungi, and by increasing the environmental tolerances of roots. Perry (1985) and Schoenberger and Perry (1982) have suggested that diversity of ectomycorrhizas is important for the stability of Douglas-fir ecosystems, but little is known of the roles of different ectomycorrhizal fungi in forests. The diversity of fungi forming ectomycorrhizas increases and the species of ectomycorrhizal fungi change as forests age (Chuchou and Grace 1990; Danielson and Pruden 1990). There is some evidence that some hypogeous fungi (those that produce no above-ground structures) may be specific to old-growth Douglas-fir (Luoma *et al.* 1991), but few studies have compared the mycorrhizal fungi of old-growth and younger stands. Objectives of this project are: 1) to compare old-growth and mature (80-year-old) stands of Douglas-fir with respect to diversity of mycorrhizal fungi; and 2) to relate the distribution of ectomycorrhizas to soil environment.

Methods

Core samples of soil were taken from the Koksilah site in both the spring and fall of 1992, and a site in the Greater Victoria Water District (GVWD) will be sampled in spring and fall of 1993. Stumps, logs, soil on rocky areas, soil adjacent to the boles of dominant trees, and soil not in these categories were sampled independently to see if these habitats differ in their mycorrhizal fungi. All ectomycorrhizas were extracted, counted, described, photographed, and separated into types on the basis of numerous morphological and anatomical characters. Where possible, types were identified to genus and/or species on the basis of previous descriptions. Organic and mineral soil were analyzed separately. Moisture content, bulk density, pH, total carbon, total nitrogen, mineralizable nitrogen, and extractable phosphorous content are being determined for each component.

Results and Discussion

To date, 39 types of Ectomycorrhizas have been described from 36 soil cores collected at the Koksilah site. The three dominant types, *Cenococcum geophilum*, *Hysterangium* sp., and *Rhizopogon vinicolor* were found in both age-classes and all habitats. *Piloderma* was found in four cores, all from logs or stumps. Thirty-five minor types were represented in one or two cores each. More extensive sampling is needed to determine if there is any specialization for habitat among the minor types. Twenty-four types were found in old growth, 26 in the mature (80-year-old) stand, and 7 in both. A detailed analysis of data for the Koksilah site will be done when all soil cores collected in the fall of 1992 have been examined. Soil nutrient determinations will soon be completed for all cores taken from the Koksilah site.

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Utilization of Residual Patches of Old-growth Douglas-fir by Forest Birds

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Introduction

Fragmentation of previously extensive forest into smaller, isolated patches has resulted in a loss of habitat for many bird species, particularly neotropical migrants (e.g., Whitcomb *et al.* 1981; Askins and Philbrick 1987). Species richness in isolated patches is strongly correlated with area of habitat (e.g., Blake and Karr 1987). Yet minimum habitat needs may include several patches of different habitat types (Haila *et al.* 1989). Explanations for reduced diversity in smaller patches include: increased parasitism and nest predation near forest edges (e.g., Yahner and Scott 1988); competition with edge species (Askins and Philbrick 1987); lower reproductive output and narrow tolerance ranges of neotropical migrants (Terborgh 1989); and additional stresses due to destruction of overwintering habitat.

Objective

The objective was to monitor bird populations in residual patches of old-growth Douglas-fir to determine the minimum size needed to retain viable populations of old-growth dependent bird species.

Methods of Investigation

The study area was situated in the Nimpkish watershed, Port McNeill Forest District on Vancouver Island. Eleven residual patches (a fairly homogeneous stand of old-growth Douglas-fir surrounded by early seral forest), ranging in size from 2 to 500 ha, were examined. Forest bird monitoring plots (10 ha) were established as far inside each patch as possible (Table 1). For patches less than 10 ha, the plot was extended beyond the patch edge into the surrounding habitat. Censuses were later differentiated by habitat (interior, edge, and surrounding vegetation). Analyses do not include surrounding vegetation.

TABLE 1. Description of study patches

| Patch | Size (ha) | Elevation (m) | Water* | Harvest |
|-------|-----------|---------------|----------|------------|
| 6x | 3.2 | 600 | 4 s | - |
| 2x | 4.2 | 1300 | 1 s | - |
| 2r | 2.0 | 1000 | 1 l | - |
| 2 | 10.0 | 1000 | 1 s | 1991 |
| 7 | 7.0 | 1300 | 3 s | - |
| 10 | 9.4 | 600 | 1 r | - |
| 1 | 25.0 | 1000 | 2 s | - |
| 8 | 48.0 | 1000 | 2 s, 1 l | 1993 |
| 5 | 56.0 | 600 | 1 s | 1993 |
| 6 | 72.0 | 700 | 1 r | 42 ha 1992 |
| 3 | 500.0 | 1000 | 1 s | - |
| 4 | 500.0 | 800 | 2 s | - |

* within or adjacent to the patch; s= stream, l= lake, r= river

Each patch was site typed and extensive vegetation measurements taken to relate habitat features within territories of selected bird species with habitat available throughout the patch (Noon 1981). Principal components analysis will be used to relate species counts to habitat variables.

Densities of birds were estimated using the spot-mapping method and territories were mapped for all species (Svensson 1970). Additional censuses were conducted during early evenings in May and June to verify breeding of those species that could not be adequately surveyed with the mapping technique. Each patch was also surveyed for owls, with the use of tape recorded territorial songs.

Species were coded by habitat use (incidental, foraging, nesting), then categorized by migratory status (resident, migrant) and preferred breeding habitat (interior, edge). Abundance and diversity (Shannon-Weiner index) data for these categories were regressed against the log of patch size.

To quantify the presence of predators in relation to patch size and the amount of edge, we put artificial nests in patches of 2, 3, 9, 48, and 500 ha, along transects at stations 0, 10, 75, 300, 450, and 600 m from the edge (178 nests). Each station had a ground and arboreal nest. Predation rate was calculated as number of nests lost per nests placed. Nests were checked 3 times over 19 days. Differences in predation rate were tested using a 2-way ANOVA.

Reproductive success was measured using mist nets and nest checks. We developed a system of aerial nets, but still too few birds were captured to compare between patches.

Results and Discussion

Contrary to studies in eastern North America, there were no apparent trends for increased species diversity or richness with patch size, for either all species or individual groups (old-growth or disturbance-related; tree, ground, or cavity nesters) (Figure 1). Furthermore, there was a significant decrease in abundance (individuals per hectare) with increased patch size for all species and individual groups except old-growth related species (Figure 2). Although not significant, there was also an increase in number of species and abundance of old-growth related species around 10 ha, notably Hammond's flycatcher, the varied thrush, and the golden-crowned kinglet.

Species present in the larger patches were resident interior forest birds (the pileated woodpecker, red-breasted sapsucker, gray jay, red-breasted nuthatch), except for the marbled murrelet. Species preferring the smaller patches were the western screech-owl, yellow-rumped warbler, and orange-crowned warbler. Raptors generally were more common in smaller patches, a finding that is consistent with that of other authors (e.g., Small and Hunter 1988).

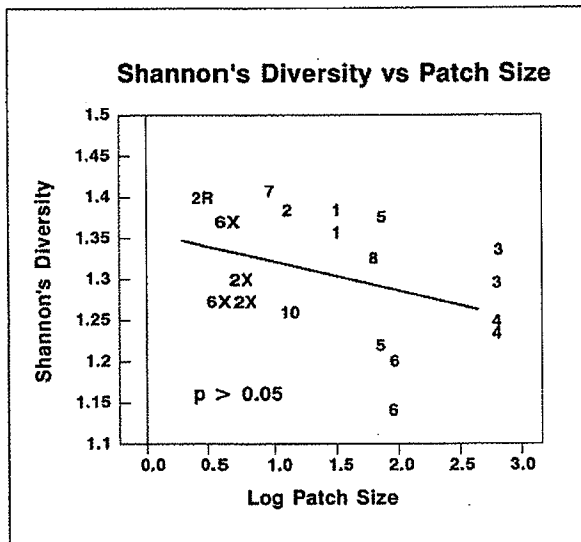


FIGURE 1. Relationship between bird species diversity and log of patch size.

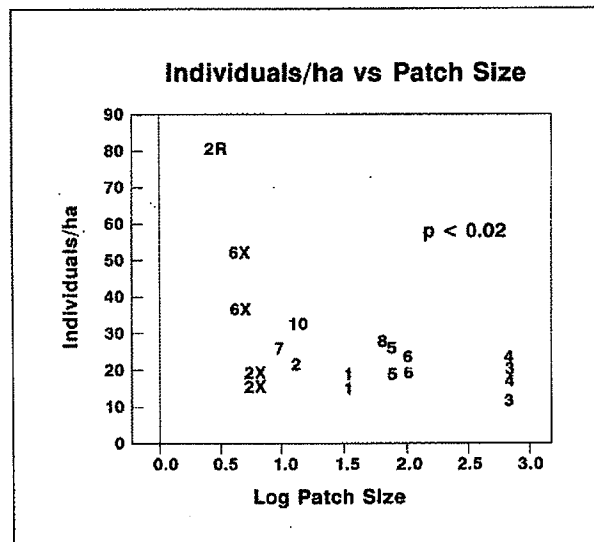


FIGURE 2. Relationship between bird density and log of patch size.

Species apparently not related to patch size were the hairy and downy woodpeckers, pine siskin, red crossbill, and western flycatcher. Although other authors have reported a minimum patch size of 15 and 40 ha for the downy and hairy woodpeckers, respectively (see Stauffer 1980), Robbins (1979) estimated the minimum forest area for the hairy woodpecker to be 4 ha. Our smallest patches may have been just large enough to support these species and others apparently unrelated to patch size. With the exception of the solitary vireo and cedar waxwing, long-distant migrants had distributions independent of patch size. This is contrary to the literature in which species with relatively low dispersal rates, narrow tolerance ranges, and low reproductive potential are considered to be most vulnerable to a rapid change in the forest landscape.

Factors associated with bird abundance in other studies have been tree species composition, tree size and height, canopy closure, canopy volume, and vertical layering (e.g., Rice *et al.* 1983). The patches in this study were selected to be homogeneous, and therefore may not have differed enough to indicate any influence of these factors. Main canopy cover characteristics are similar between the patches, although the proportion of forest interior habitat to disturbance-related habitat on the census plot decreased with patch size. Factors seemingly important in this study were the presence of water and vegetation structure.

Predation rate was significantly higher near forest edges and in smaller patches (Figure 3) (ANOVA, $p < .001$; Table 2, Sheffe's multiple comparison test, $p < .05$). Patch 8 was eliminated from the analyses because a predator followed the observers and destroyed 95% of the nests during the first sampling period. Distances 75 m and greater were combined for analyses to increase statistical power.

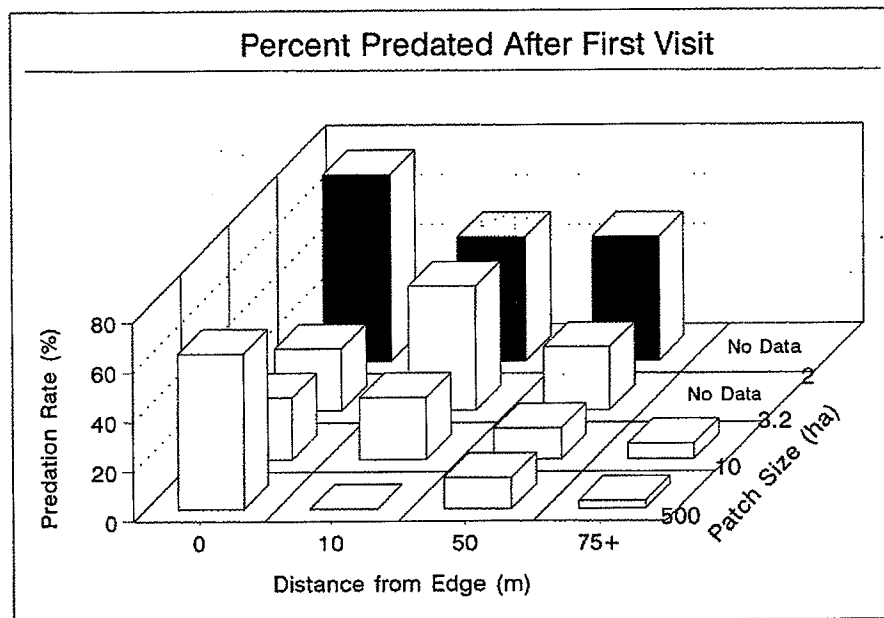


FIGURE 3. Relationship between predation rate, log of patch size, and log of distance from the edge.

TABLE 2. Sheffe's multiple comparison test

| | | | | |
|---------------------|------|------|------|------|
| Patch size | 2.0 | 3.2 | 10 | 500 |
| Mean predation rate | 58.3 | 33.5 | 15.0 | 12.5 |
| <hr/> | | | | |
| Distance from edge | 0 | 10 | 50 | 75+ |
| Mean predation rate | 46.9 | 31.3 | 25.0 | 4.2 |

Conclusion

Although, as predicted from other studies, predation was significantly higher near forest edges and in smaller patches and abundance of edge species was higher in smaller patches, we found no relationship between area of patch and species diversity or richness for all species or individual groups. Possible reasons are: 1) absence of cowbirds, so parasitism is not a problem; 2) lower prominence of neotropical migrants in this bird community; 3) delayed effects due to site tenacity or comparatively short time since isolation; and 4) other factors such as water, riparian vegetation or disturbances including mainly logging, roads, and windfall. Galli *et al.* (1976) found the minimum size for forest interior species to be 0.8 ha. Our patches were larger. Furthermore, as Haila *et al.* (1989) stated, minimum habitat needs may include several patches of different habitat types.

Future Work

Because there may be a time delay in the impact of fragmentation, it is important that population trends be measured over the long term and that more sensitive measures of population sustainability be used, such as reproductive output and energetic costs related to patch size.

So that forest structure can more accurately be related to distribution of birds and territory size, further vegetation analysis should be conducted in territories of forest interior species. Characteristics of foraging sites, including prey densities related to bark condition, tree size and species, and snag condition, should be compared at different bird densities as an indirect measure of habitat requirements. In this way, overwintering habitat needs of residents and non-breeders can also be measured. Bird territories need to be mapped over several years and the frequency of use of habitat types within the territory collated, to indicate minimum combinations of habitat needed by various bird species (see Haila *et al.* 1989). For a more accurate indication of minimal habitat needs, this study should be replicated in other watersheds. A larger commitment of funds is needed earlier in the breeding season.

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Assessing the Effects of Forestry Practices on Carbon and Nutrient Dynamics in Coastal Forests: An Introduction to Project PC-71-20

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The diverse and highly productive forests of the Pacific and Yukon Region are increasingly being perceived as significant elements of the global biosphere. The forests of British Columbia alone contain 40% of Canada's wood volume (Bonnor 1985). The living carbon reservoir in British Columbia forests is 5 billion tonnes, and could be a major element of Canada's carbon budget (Kurz *et al.* 1992). The use and management of these forests are viewed by some as indicators of national responsibility in the context of the global atmospheric environment.

An understanding of the biological roles of forests and of how they are affected by forestry practices has become a necessity for rational land use decision-making. This is especially evident for coastal forests, where productivity and biomass accumulations are high. Unfortunately, the principles underlying the biological roles of coastal forests are poorly understood. Harvesting, silviculture, and post-harvesting practices strongly influence succession, growth, formation of detritus, and decomposition. These processes determine the organic structure of the forest and are strongly associated with nutrient conservation, the hydrologic cycle, and provision of habitat for a multitude of organisms. It is generally assumed that the productive capacity and biological diversity of a forest diminish with harvest. Less readily acknowledged is the restoration of these values as trees become reestablished, as productivity becomes diffused among more elements of the ecosystem, and as habitat for organisms becomes more diversified. We do know, however, that some sites—especially those with low nutrient capital—are sensitive to disturbance. This has made their capacity to sustain repeated harvest the subject of some concern (Kimmins 1985).

Objective

The overall objective of the project is to establish how attributes of sustainable forestry, specifically nutrient dynamics and carbon retention, are affected by harvesting and other practices; and to identify opportunities for enhancing these attributes through forest management.

Effects of Conversion on Carbon and Nutrient Cycling

Research will proceed through comparative analyses of developmental phases of important coastal forest types, from regeneration to old growth. Much of the initial work is focused on determining the changes in quantity and characteristics of the carbon and nutrient pools. This is being done by measuring and sampling these different pools in sets of chronosequence in the CWHxm and CWHvm biogeoclimatic zones (Pollard and Trofymow, in these proceedings). In each phase investigated, the principal pathways and agents of carbon flux and the magnitude and form of important carbon pools will be determined; initial emphasis will be placed on biological, chemical, and physical factors affecting carbon and nutrient transfers at soil and forest floor levels, and on the changes in stand structure during post-harvest succession. Qualitative and quantitative analyses of variables will define the organic structure of the forest, including habitats and substrates for organisms active in essential ecological processes.

From this information, practical guides will be derived on the changing quantity and form of detrital carbon (including coarse woody debris), carbon retention, changing nutrient availability with forest succession, and other subjects critical to sustainable use of forest resources. Results of the survey of C and N distributions in successional stands will also be used to initialize a dynamic stand carbon and nitrogen cycling model which is being developed to prepare more refined estimates of carbon emissions resulting from the harvest of

old-growth forests. Funding for this work is from several sources including ENFOR under its sustainable forests initiative, the FRDA integrated resource management program, and the B.C. Ministry of Forests sustainable environment fund.

Nutrient Cycling in Low-productivity Sites

Much of the project is focused on the effects of conversion of old-growth to second-growth forests. However, the needs of our clients and the expertise we have developed in nutrient cycling, especially of nitrogen, have led us to develop links with other studies concerned with the effects of harvest on the long-term productivity of sensitive, nutrient-poor sites. In coastal forests these sensitive sites are found especially in dry rocky areas in the very dry Coastal Western Hemlock zone (CWHxm) and in the wet, nutrient-poor sites in the very wet hypermaritime Coastal Western Hemlock (CWHvh) zone. Young and immature forests in both these areas have been the subject of several fertilizer research experiments, the results of which have been used to justify and plan operational treatments. Most of the experiments have been empirical growth and yield trials or single tree fertilization trials. Much less is known about the long-term fate of the nitrogen in these systems.

We use N-15 tracer techniques to develop an understanding of the factors that limit N availability in low-productivity sites, including natural nitrogen cycling, the contribution of nitrogen-fixing plants, and the long-term fate and efficacy of nitrogen fertilization. Sampling now in progress of a 10-year study on a young coastal Douglas-fir site at Northwest Bay (Aarnio *et al.*, in these proceedings) will complement studies being completed on the distribution and transformations of N-15 at Shawnigan Lake, the location of the immature plot in the Greater Victoria Watershed North chronosequence. Results of these studies will be applicable to immature Douglas-fir stands in the CWHxm zone. Another study in the CWHvh zone on northern Vancouver Island (Chang, in these proceedings) will examine the effects of nitrogen fertilization and salal competition in old-growth cedar-hemlock cutovers. Funding for these studies has come from FRDA I, FRDA II, WFP and NSERC. Other collaborators include Lincoln University (New Zealand), UBC, and Agriculture Canada.

Methodology Development in Forest Soil Ecosystem Research

While chronosequence studies permit the study of long-term temporal trends of natural successional processes in a relatively short time period, they do have limitations (Cole and van Miegroet 1989). These limitations include differences in site conditions between plots and in initial harvest or disturbance history. A way to compensate for these limitations is to conduct studies of the short-term dynamics of a particular process. Thus, while traditional soil survey techniques are adequate to describe the conditions in the chronosequence plots and the information used to infer how soils change during secondary succession, they are of limited value in describing how soil dynamics change with succession.

Techniques for measuring changes in the dynamics and types of soil carbon and nitrogen pools require continued development. At the Pacific Forestry Centre, our focus has been on developing methods to characterize organic carbon, quantify nitrogen dynamics, and quantify soil microbial activity. Over the past 20 years, development in Nuclear Magnetic Resonance (NMR) spectroscopy has made possible its routine application to a wide array of problems. In particular, C-13 NMR of samples in the solid state offers a simple and powerful approach to characterizing the complex materials encountered in forest ecosystems (Preston and Rusk 1990). Similar advances in the use of N-15 tracer have improved our understanding of soil nitrogen pools and their dynamics. At the Pacific Forestry Centre, N-15 tracers have been carried out for many years and we now have two independent techniques for N-15 analysis: mass spectrometry and optical emission spectrometry. As methods for measuring the microbial biomass of forest soils have improved, so has our understanding of how forests soils function (Parkinson 1991). Two methods that have been successfully adapted to forest soils, and that we now use, are substrate-induced respiration measured with a multichannel IRGA and C14 labelling to differentiate substrate from bulk soil respiration.

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Effects of Converting Coastal Old-growth Forests to Managed Forests: Changes in Site Carbon and Nutrient Contents During Post-disturbance Succession

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Over the past decade, two important questions have been raised concerning the harvest and conversion of old-growth temperate forests to second-growth, managed forests: 1) Does conversion lead to changes in the site carbon balance, resulting in net releases of carbon to the atmosphere (Harmon *et al.* 1990; Kurz *et al.* 1992)? 2) Does conversion lead to a loss of site nutrient capital and thus threaten future productivity (Kimmins 1985; Kimmins *et al.* 1990)?

While good information on changes during secondary succession in timber biomass and to some extent nutrient contents can be obtained from yield tables, much fewer data are available on the amounts of carbon and nutrients in coarse woody debris (Trofymow and Beese 1990) and soil organic matter; on how the amounts change during post-harvest succession; and on whether in mature second-growth forests the amounts recover to those in climax forests (Kimmins *et al.* 1985). These carbon and nutrient pools are substantial: in older forests, coarse woody debris can represent up to 45% of the aboveground carbon and 21% of the aboveground nitrogen and phosphorus (Harmon *et al.* 1986).

In 1991, Forestry Canada, Pacific and Yukon Region, initiated a program of research to study the changes occurring as a result of conversion of coastal old-growth to second-growth forests (Pollard and Trofymow, in these proceedings). This ENFOR study complements many of the other studies in that program by providing a broader measure of several relatively static ecosystem variables. Other studies in the program focus on more dynamic variables or measures of biological diversity. To expand and regionalize the field study results, additional ecosystem site and soil classifications are being done with funding from FRDA and the B.C. Ministry of Forests. Results from the field study are also to be used to calibrate a carbon emissions model being developed with FRDA and B.C. Ministry of Forests funding (Barclay, in these proceedings). Samples material from the survey are also to be made available to an ENFOR-funded study by C. Preston (see Preston, in these proceedings), for characterization of organic matter.

This report summarizes information on plot establishment and layout and methods used in the carbon and nutrient survey. Data analysis and results are scheduled for completion by March 1994.

Objectives

The overall study objective is to establish how the amounts and distribution of carbon and nutrients on a site change during post-harvest succession, and how closely they recover to pre-harvest levels. This will be done by studying chronosequences in two coastal forest types in the CWHxm and CWHvm. The study has three phases. In the first year, potential chronosequences were located, final selections made and plots established. In the second year, the field sampling phase was further divided into three parts: in the first, measurements were made to determine the mass of trees, understory, coarse woody debris, forest floor materials, and soils in each plot; in the second, representative samples of the different material types from each plot were taken for determination of carbon and nutrient concentrations; and in the third, ecosystem classification descriptions were completed for each plot. In the final phase, a data base and summary of the distribution of nutrients among the various components is to be prepared and data analyzed for differences in site carbon and nutrient contents.

Methods

Plot establishment

In the initial phase of the study, 31 potential locations were identified and examined (Trofymow 1991) before the final selection of the 10 chronosequences on southern Vancouver Island was made (Pollard and Trofymow, in these proceedings). A plot location and establishment report for all 10 locations used in the survey (Blackwell 1992) includes written and sketch maps describing the road directions and distances to plots at each location, forest cover maps identifying individual plots and basic site description data for each plot.

At all 10 chronosequences, triangular plots were established for the survey. From each benchmark, three 30 m radial lines were run to define three subplot centres 120° apart. These subplot and plot centres were marked with 1.5-m flagged and painted cedar stakes and with 15-cm spikes inserted into the soil. At most locations the orientations of the subplots were random, although at the three intensive locations subplots were arranged 0°, 120°, and 240° from the centre benchmark. The subplot centres define the corners of an equilateral triangle, 51 m on the side, used for coarse woody debris and forest floor measurements, standing biomass measurements and understory vegetation, fine woody debris, forest floor and soil measurements and sampling (Figure 1). Because of the detailed sampling on the intensive plots, 60 x 60 m plots were established, superimposed upon the triangular plots and sharing a common centre benchmark (Blackwell and Trofymow, Figure 1, in these proceedings).

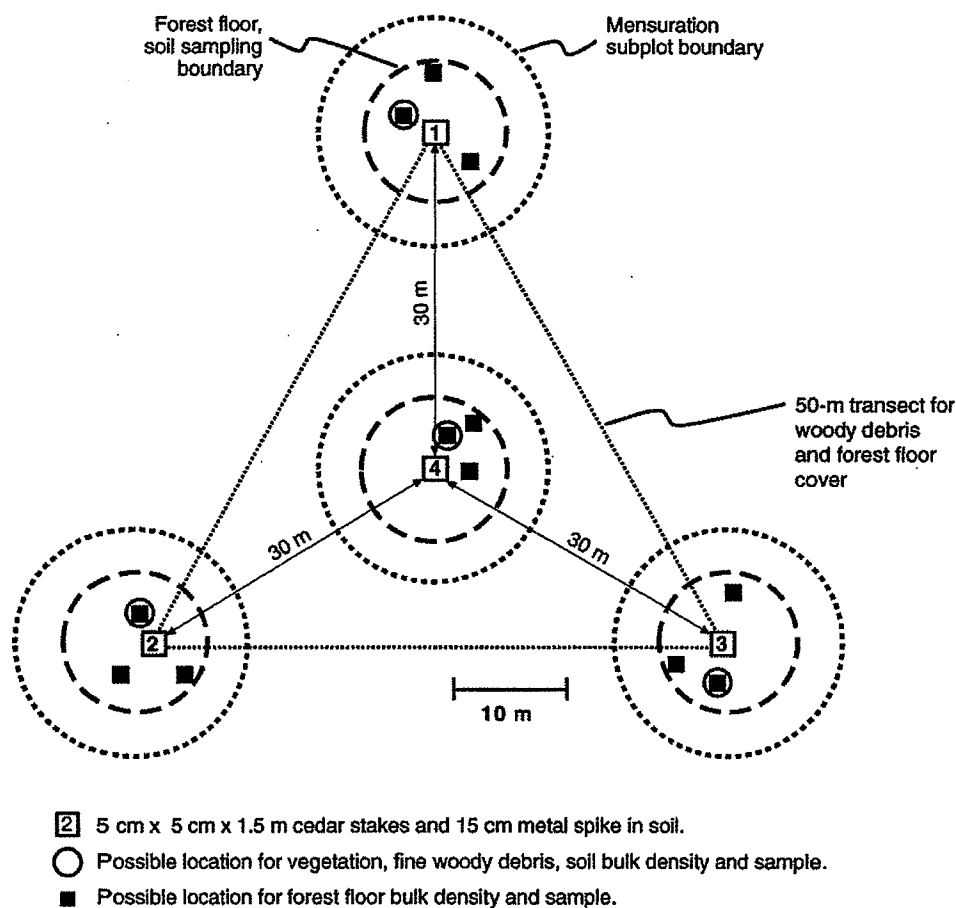


FIGURE 1. Forestry Canada coastal forest chronosequences. Carbon and nutrients measurements and sampling.

Plot measurements and sampling

Field work occurred between May and October 1992. Initially all 10 chronosequences were to have been surveyed, but following a review of time requirements and funding in May 1992, work was reduced to 8 chronosequences, four east island locations (Greater Victoria Watershed South, Victoria Greater Watershed North, Koksilah, Nanaimo River) and four west island locations (Renfrew, Red/Granite Creek, Nitinat, Klanawa). To facilitate sample identification and sample processing, all plots were given unique plot numbers. Table 1 shows the correspondence in plot numbering between the initial plot establishment report (Blackwell 1992) and the survey.

Mensurational measurements of overstory trees (DBH, height to live crown, and total height) by species and class were made according to methods described by Luttmerding *et al.* (1990, Chapter 5). Stumps and standing dead trees >7.0 cm diameter were also measured. Three of the four previously established subplots were measured. Tree inventory plots were circular with a 5 or 10 m radius depending upon tree density (Blackwell and Trofymow, in these proceedings). In some regeneration plots, trees <3 m height were a significant component of the biomass and thus total height and caliper measurements were also made. Tree biomass, carbon, and nutrient loadings will be calculated using appropriate biomass regression equations and nutrient concentration data from other studies on coastal tree species.

TABLE 1. Plot coding table for the Forestry Canada coastal forest chronosequences plots described in the plot establishment report (Blackwell 1992). Specific chronosequences can be referred to by the full name, a two- or three-letter designation (bolded letters), or number (Chr. No.). Plot numbers used in the establishment report (Plot Est. No.) are shown along with a unique plot number (Plot No.). Unique plot numbers are not consecutive to allow for the addition of other plots at a chronosequence. Plots sampled in 1992 are underlined.

| Chronosequence name | Chr. No. | Plot Est. No. | Plot No. | Chronosequence name | Chr. No. | Plot Est. No. | Plot No. |
|--------------------------|----------|---------------|-----------|---------------------|----------|---------------|-----------|
| Victoria Watershed South | 1 | 1 | <u>1</u> | Renfrew | 6 | 1 | <u>51</u> |
| | | 2 | <u>2</u> | | | 2 | <u>52</u> |
| | | 2a | 3 | | | 3 | <u>53</u> |
| | | 3 | 4 | | | 4 | <u>54</u> |
| | | 3a | <u>5</u> | | | | |
| | | 4 | 6 | Red/Granite Creek | 7 | 1 | <u>61</u> |
| | | 5 | 7 | | | 2 | <u>62</u> |
| | | | | | | 3 | <u>63</u> |
| Victoria Watershed North | 2 | 1 | <u>11</u> | | | 5 | <u>64</u> |
| | | 2 | <u>12</u> | | | | |
| | | 3 | <u>13</u> | Nitinat | 8 | 1 | <u>71</u> |
| | | 3a | 14 | | | 2 | <u>72</u> |
| | | 4 | <u>15</u> | | | 3 | <u>73</u> |
| | | | | | | 4 | <u>74</u> |
| Koksilah | 3 | 1 | <u>21</u> | | | | |
| | | 2 | <u>22</u> | Klanawa | 9 | 1 | <u>81</u> |
| | | 3 | <u>23</u> | | | 2 | <u>82</u> |
| | | 4 | <u>24</u> | | | 3 | <u>83</u> |
| | | 5 | 25 | | | 4 | <u>84</u> |
| | | | | | | 5 | <u>85</u> |
| Nanaimo River | 4 | 1 | <u>31</u> | | | | |
| | | 2 | <u>32</u> | Mt. Ozzard | 10 | 1 | 91 |
| | | 3 | <u>33</u> | | | 2 | 92 |
| | | 4 | <u>34</u> | | | 2a | 93 |
| | | — | <u>35</u> | | | 3 | 94 |
| | | | | | | 4 | 95 |
| Loon Lake | 5 | 1 | 41 | | | | |
| | | 2 | 42 | | | | |
| | | 3 | 43 | | | | |
| | | 4 | 44 | | | | |

Living understory biomass and fine woody debris (FWD), <1 cm in diameter, were determined by destructive sampling of four 1.0 m² plots, one at each subplot. Vegetation was separated into three categories: mosses and lichens, grasses and herbs, and shrubs. Individually labelled bags were returned to the Pacific Forestry Centre for drying at 70°C and weighing. Large volume samples were chipped and subsampled before being ground through a 2 mm mesh Wiley mill. Chemical analyses include total carbon, nitrogen, phosphorus and sulfur. Understory and FWD mass will be calculated using the overall subplot average and carbon and nutrient loading calculated from concentration data.

Forest floor load was estimated by removing and bagging all forest floor down to mineral soil in 12 samples, 20x20 cm in area, three samples from within 5 m of each of the four subplot centres. Decayed wood encountered during excavation was collected and bagged separately. Samples were screened through a 4-mm sieve and live roots >4 mm were separated and samples dried at 50°C. Following weighing, the three samples per subplot were combined and 1-L subsamples were taken and ground through a 2-mm mesh Wiley mill. Chemical analyses include total C, N, P, S, 1.0 M CaCl₂ pH, CEC, and exchangeable cations. Forest floor mass will be calculated by applying the overall subplot average to the percentage area occupied by forest floor, calculated from the forest floor transect measurements. Carbon and nutrient loadings will be calculated using average forest floor mass and concentration data.

Samples of mineral soil were collected at each subplot from 0-10 cm and 10-30 cm for determinations of bulk density and chemical analysis. Bulk density, determined by the volume of sand/silica chips needed to fill a plastic lined hole, and coarse fragment determination (rocks >2.5 cm) were made in the field for all soil pits for the layers 0-10 cm and 10-30 cm. Samples at 30-50 cm were taken for chemical analysis from all four subplots and for bulk density at one subplot. Lower soil depths could not be sampled in all plots because of the presence of bedrock. Samples were sieved through a 4-mm sieve to separate most of the gravels, then through a 2 mm sieve, and the fractions dried, and weighed. Medium roots and organic matter were separated from the >2mm fraction by water flotation, dried, weighed, and ground through a 2 mm mesh Wiley Mill for chemical analysis. The <2-mm fraction was analyzed for colour, texture, total C, N, P, S, 1.0 M CaCl₂ pH, dithionate extractable Fe and Al, CEC, and exchangeable cations. Mineral soil carbon and nutrient loadings will be calculated using bulk density and concentration data for the 0-10, 10-30, and 30-50 cm depths.

Forest floor depth and substrate type were measured at 75 points at 2-m intervals along each of three 50-m transects located on the sides of the triangle joining the three subplot centres. Substrate types included decayed wood, undisturbed forest floor over decayed wood, coarse woody debris, exposed bedrock, exposed mineral soil, surface water, and organic matter other than forest floor. Forest floor depths and percentage cover data are used in calculation of forest floor load.

Amounts of coarse woody debris, >1 cm diameter, were determined by the line intercept method using three 50-m transects connecting the three subplot centres and following methods as described by Trowbridge *et al.* (1989) and modified by Blackwell *et al.* (1992). Where possible, materials >7.0 cm were identified as to species and decay class (I, II, III, IV, V) (Sollins 1982) and two 3- to 5-cm discs of the 7.1-12.0 cm and >12.0 cm of each class of wood identified were collected for relative density determinations and chemical analysis. Highly decayed material was excavated and volumes estimated in the field. Three 15-cm length samples of each of the three smaller size classes, 1.1-3.0, 3.1-5.0, 5.1-7.0 cm (nine samples) were randomly collected for relative density measurements and chemical analysis. Sample volumes were determined in the laboratory by measuring their specific gravity relative to water. Samples were dried at 70°C and weighed, and then a subsample was sawn, chipped, ground through a 2-mm mesh in a Wiley mill, and analyzed for total C, N, P, and S.

Ecosystem site, soil description, and classification information was collected for each plot following the procedures in Luttmerding *et al.* (1990, Chapter 2). These included photographs, measurements, and descriptions of slope, aspect, soils, humus form, geology, biogeoclimatic zone variant, and indicator and overstory species cover. A single soil pit, dug to parent material in each plot, was used to describe soil horizons and depths. Increment cores of six dominant or co-dominant trees were taken in each plot to determine stand age.

Results

Two reports are to be completed by February 1993, compiling field data sheets for the plot measurements and sampling and the site and soil descriptions. Chemical analyses are to be completed by April 1993. Data base preparation and summaries are to be complete by August 1993.

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The Carbon Budget Model

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Background

The carbon budget (Trofymow and Blackwell, in these proceedings) project is attempting to compare the carbon budgets of old-growth forests with those in forests of younger seral stages. Sites have been located on the western and eastern sides of southern Vancouver Island. In each site there are plots representing the four age classes in the chronosequence. The sampling of carbon from trees and coarse woody debris in soils and the forest floor will provide data for comparing the different age classes and assessing their rates of carbon storage. A model was wanted to allow us to quantify the processes occurring in the turnover of carbon and to investigate various management interventions on carbon cycling.

Purpose

The model will be used in two related contexts: 1) to compare the carbon cycling dynamics among the four age classes in the chronosequence and to assess the characteristics of old-growth forests which may be unique and desirable; and 2) to assess the effects of management interventions on the ability of the forest to sequester carbon from the atmosphere and retain it.

Type of Model Required

Forest models generally can be divided into two types: mensurational (predictive) and mechanistic (process-oriented) models. Mensurational models rely heavily on growth data and assume that conditions do not change over the period of prediction. They are usually good predictors of growth and future volume but give little or no insight into forest processes. Mechanistic models are generally poor predictors of volume, since the final outputs are the result of a chain of processes, each of which is modelled with some degree of error. The strength of mechanistic models lies in their flexibility and responsiveness to changing conditions, and thus they are ideally suited to investigating scientific hypotheses and the effects of management interventions. For these reasons we have chosen to develop a process-oriented model to address the characteristics of different aged stands that go beyond the strictly mensurational aspects. This flexibility is expected to facilitate investigation of some of the effects of climate change.

Model Development

We have chosen to use the Shawnigan model (SHAWN) as the basis of the new carbon budget model. Not only is SHAWN a process model, but it was specifically meant to model the Shawnigan experimental trees, with all their variations in treatment. This site forms one of the seres in the chronosequence. The model is also in a sufficiently advanced state that much of the work for the carbon budget model has already been done using SHAWN as its basis.

SHAWN started its life as a site model (Barclay and Hall 1986), with trees not being explicitly identified. Eventually information on the trees from 25 plots at the Shawnigan experimental site were incorporated into the model, including their known diameters, heights, heights to the live crown, and positions. The processes that operated on the total amounts of wood, foliage, etc., now operate on each tree individually. Competition among trees was modelled by Arney's Competitive Stress Index (CSI) (Arney 1973), using relationships derived subsequently from the Shawnigan data (Barclay and Layton 1990). Thus, SHAWN is now a distance-dependent individual tree model which has nitrogen as its driving force, modified by stand density, temperature, water availability, and soil processes.

In the carbon budget model, we have taken SHAWN and incorporated a more complete carbon tallying facility. The next step is to complete and incorporate an updated water balance and temperature submodel based on information from Campbell (1985). After that we will construct and incorporate a more realistic soil decomposition submodel similar to that used in the Canada forest sector carbon budget model (Kurz *et al.* 1992). Finally, a user-friendly interface will be installed to allow its use as a gaming model to investigate a variety of possible management interventions.

Use of the Model

A parameter sensitivity analysis will eventually be done on the model similar to, but more extensive than, that presented by Barclay and Hall (1986). This analysis will indicate parameters that need careful measurement, processes and attributes that are particularly sensitive to management intervention, and the general behaviour of the model. It will also identify conditions which may adversely affect certain seral stages of the forest. In addition, it will be used as a gaming tool to assess the efficacy of various interventions on the ability of the forest to store and sequester carbon. Ultimately, we plan to publish a set of guidelines to facilitate carbon storage.

Validation

1. The output of each of the major submodels will be examined independently of the other submodels. In this way we can assess the behaviour of each component.
2. The output of the model will be compared with data obtained from the chronosequences in a manner similar to the comparisons of the Shawnigan model with data from the Shawnigan experiment (Barclay and Hall 1986). The initial data from the chronosequences will provide an estimate of carbon distribution at one time. Subsequent measurements of a restricted number of features will provide estimates of fluxes of carbon. These will be used for comparison with model output.
3. The sensitivity analysis, in addition to providing information about the real system, also allows assessment of the behaviour of the model as a whole.

Deliverables

1. A gaming model to allow investigation of the actions of management interventions on carbon retention.
2. A sensitivity analysis to assess the effects of system parameters on the variables of interest.
3. A set of guidelines for managers to provide information on carbon retention resulting from various management scenarios.

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Investigations of Carbon and Nitrogen Chemistry in Forest Ecosystems

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Understanding how soil carbon and nitrogen dynamics change with secondary succession and how they function in low-productivity sites requires knowledge of the chemical identity of the material in the various pools and their transformations. Thus, our chemistry investigations aim to characterize the C and N in the various pools identified in the ecological studies, and to understand the factors controlling the rate constants and fluxes that characterize the ecosystem. We focus on two areas: characterizing the nature of organic C, and using N-15 tracers to elucidate the movement and transformations of N.

Nuclear magnetic resonance (NMR) spectroscopy is the primary technique used to characterize organic C (Preston and Rusk 1990). The NMR facility at the Pacific Forestry Centre—still a first for forest ecology research—is equipped with a Bruker WM 250 MHz NMR spectrometer with multinuclear capability. It is a medium field instrument for solutions only, and spectra of solid-state samples are obtained through a network of collaborators and contractors. Our NMR studies of organic matter have included litterfall, woody debris, forest floor, organic horizons, and humified and poorly decomposed organic residues in mineral soil horizons. Work on the dissolved organic carbon pool should begin in 1993. Phosphorous-31 NMR is also used to determine the forms of extractable P; much of this P is in organic form, and thus closely tied to the organic C pool.

Large-diameter decaying fallen logs are a prominent feature of the forest floor in the Coastal Western Hemlock biogeoclimatic zone. The information available on changes in the major organic components, however, is still very limited, the traditional analytical procedures ("proximate analysis") are laborious, and the interpretation of the operationally defined chemical types often unclear, especially for highly decomposed samples. However, major organic components can be determined from a solid-state C-13 CPMAS NMR spectrum (i.e., NMR with cross-polarization and magic-angle spinning), which is obtained non-destructively in a few hours on about 300 mg of dry, powdered sample.

A study of heartwood in fallen logs of three species decomposing for up to 200 years in old-growth forests (Preston *et al.* 1990) showed that the main progress of decay was loss of carbohydrate C, with accumulation of a dark red, crumbly or pasty residue of virtually unaltered guaiacyl lignin. Signals from alkyl and carbonyl C were weak, but tended to increase slightly with decomposition, most likely due to the selective preservation of waxes and resins (alkyl C), and to oxidation of lignin. Accumulation of chitin was not observed, and there was little evidence for lignin decomposition or for formation of humic polymers. The pattern was consistent with attack by brown-rot fungi and very slow chemical hydrolysis, especially in the later stages.

We are now examining decomposition of small-diameter thinnings (<25 cm) after up to 20 years residence time in a second-growth Douglas-fir forest (the Shawnigan Lake site) which forms one of the immature plots of the chronosequence. In addition to solid-state C-13 NMR, chemical analysis of hydrolysable monosaccharides is being used to look at relative losses of cellulose and hemicellulose. Preliminary results (Preston 1993) show that with a drier site and smaller diameters, decomposition appears to proceed in a non-selective manner, characteristic of white-rot fungi. Despite a huge loss of mass and C, there is little change in overall composition up to 11 years after felling, but at 19 years, the relative proportion of lignin has started to increase. By this time, approximately the end of the first stage of decay in the old-growth study, these small diameter logs have lost structural integrity and are collapsing into the forest floor. These studies will be extended to selected samples from other sites of the chronosequences, to develop an overall model of decomposition of large woody debris.

We are also using NMR to characterize litterfall and the changes due to decomposition in the forest floor. We characterized deep organic horizons (Folisoils) in the CWH zone of northern Vancouver Island. These develop due to limited decomposition and lack of disturbance, and are a factor in poor growth of young plantations (deMontigny *et al.* 1993). The studies of litterfall and organic horizons demonstrated the presence

of tannins (Preston and Sayer 1992), a component which is often missed or poorly quantified in ecological studies. Tannins sometimes indicate plant stress, discourage herbivory, and inhibit decomposition and N availability. From their detection via solid-state spectra, we have developed appropriate protocols to extract, purify, and quantify tannins in ecological investigations. Again, while these investigations have been carried out on a limited number of sites, they do represent both zones of the chronosequence and appear to have general validity. They will be extended to selected suites of samples from the chronosequences.

While levels of C are lower in the mineral horizons (typically <3%), they can also be characterized by NMR, by using a combination of physical and chemical fractionation. In addition to conventional humic fractions, two important pools appear to be "particulate organic C" (POC), a light fraction floatable in water and dissolved organic C (DOC). For example, using NMR, the effects of fertilization at Shawnigan Lake were reflected in a greater degree of decomposition in both the POC and humin fractions (Preston 1993). We now plan a more general investigation of successional changes in the quality of soil organic matter, using selected suites of samples from the chronosequences.

The focus has been on C-13 NMR, but some preliminary studies are under way to characterize forms of extractable P (orthophosphate, monoesters and diesters, pyrophosphate, polyphosphate, and phosphonate) in selected sites and chronosequences (Preston, in press). It is also possible to use N-15 NMR of enriched samples, and we hope to develop this area in future, to complement our conventional and tracer N techniques.

Soil N analysis and the use of N-15 tracers have been carried out at the Pacific Forest Centre for many years. We have two independent techniques for N-15 analysis: mass spectrometry and optical emission (Preston 1992). This allows analysis of samples down to a few µg of total N, and over the whole range of abundances, including investigations using variations in natural abundance. Conventional techniques include Kjeldahl digestion and distillation, specific-ion electrodes, and combustion analysis for total N. Thus, it is possible to tailor analytical protocols for the widest possible range of sample types. Two studies in progress are discussed elsewhere (Chang *et al.*, in these proceedings; Aarnio *et al.*, in these proceedings).

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Efficacy Of ^{15}N -labelled Fertilizer and Soil N Dynamics in Old-growth Cutovers on Northern Vancouver Island

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In the wetter Coastal Western Hemlock biogeoclimatic zone of coastal British Columbia, large areas of trees planted on cutovers from old-growth western redcedar and western hemlock ("CH" sites) experience growth checks a few years after planting when salal (*Gaultheria shallon* Pursh), a ericaceous evergreen shrub, invades the sites (Weetman *et al.* 1989). This has attracted the attention of both the forest industry and academia. The SCHIRP (Salal-Cedar-Hemlock-Integrated-Research Project) has been studying this regeneration problem for about 10 years. Nutritional (mainly N) stress is generally regarded as one of the factors leading to the regeneration failures. Since controls on N cycling and availability in forest soils remain poorly understood and site specific, full interpretation has often been difficult. Detailed information on the fate of applied N fertilizers, the effect of salal competition on fertilizer N recovery, and the role of the soil microbiota are lacking. We are using three interrelated approaches to study these questions.

Effect of Salal Competition on the Distribution and Recovery of N-15 Fertilizer

A field study was established in 1991 on Tree Farm Licence 25 near Port McNeill. It is a completely randomized factorial design with three tree species (western redcedar, western hemlock, and Sitka spruce), two treatments (understory left [designated "control"] and understory removed ["treatment"]) and four replicates. The 24 microplots (1 m radius) were fertilized with N-15 labeled $(\text{NH}_4)_2\text{SO}_4$ in spring 1991 at 200 kg N ha^{-1} . Current-year needles were taken in June, August, and November of 1991 and July and October of 1992. In October 1992, 12 microplots (2 replicates) were destructively sampled. Work is in progress to analyze the recovery and distribution of N and N-15 in plant biomass and soil. Soil will be extracted to determine inorganic, organic, and microbial biomass N and N-15.

Preliminary results of foliar sampling in the first growing season (1991) confirmed the presence of N-15 in trees and understory. Salal removal did not significantly affect first-year tree foliage N concentration in June, August, and November. The N-15 enrichment in tree foliage appeared to be greater in control than in treated plots, which was obviously a dilution effect. The N-15 content in biomass will be greater in treated plots than in untreated plots. Results from the destructive sampling in October 1992 showed that salal removal did not have significant effect on tree height growth both in 1991 and 1992, but caused greater foliar and branch (stem) biomass growth in both growing seasons. Control plots produced much more litter biomass. Root biomass was greatly reduced by salal competition in the control plots.

Microbial Nitrogen Dynamics in a Clearcut Chronosequence and its Implications for Tree Nutrition

Little research has been reported on forest soil microbial biomass N and its function in N cycling (Schimel and Firestone 1989). Messier (1991) reported that conifer seedlings planted on CH sites 8 years after clear-cutting and burning grew less than seedlings planted on 2-year-old CH sites with and without the presence of competing vegetation. This was explained by the short-term flush of nutrients on CH sites. We have undertaken studies to clarify the role of microbes in this short-term flush phenomenon.

Three stands (with similar stand conditions), each of old-growth CH and 3- and 10-year-old cedar plantations on CH cutovers, were selected. On May 23, July 16, August 26, and October 18, 1992, one composite sample was taken from each stand in the following form: woody partly decomposed material (FW), non-woody partly decomposed material (FNW), woody humus material (HW), non-woody humus material (HNW), and soil (S). At each sampling date, salal foliage and current year western redcedar foliage samples were collected. Microbial biomass N was analysed using the fumigation-extraction method. Samples from one of the sampling dates will be incubated for 40 weeks aerobically and periodically leached to study the mineralization potentials of the clearcut chronosequence.

Extractable N (in non-fumigated samples), which contains mineral N and some small-molecular organic N, is an index of plant available N in the humus material. The sequence for extractable N in FNW was: old-growth (91.6 $\mu\text{g/g}$) > 3-year old (60.7 $\mu\text{g/g}$) > 10-year-old plantation (49.0 $\mu\text{g/g}$). Outstandingly higher extractable C in the non-fumigated FNW samples from the old-growth forest may be a result of the accumulation from continuous organic matter decomposition. The accumulation slowed down after clearcutting and burning of the old-growth forest. Microbial N and C in the FNW material were much higher in the old-growth forest (805 and 10280 $\mu\text{g/g}$, respectively) than in the 3-year-old (434 and 5073 $\mu\text{g/g}$, respectively) and 10-year-old (443 and 6178 $\mu\text{g/g}$, respectively) plantations. Microbial C/N ratios give us a good indication of the availability of microbial N for mineralization and for tree uptake thereafter. Interestingly, microbial C/N ratios in FNW were in the order of 10-year-old (14.4) > old-growth (12.9) > 3-year-old (11.9) plantations. This means that the 3-year-old plantation has a higher N supplying power through microbial biomass decomposition. An examination of microbial C/N ratios revealed that the same trend holds for HW, HNW, and soil materials, with the exception of the FW material. Less competition for mineral N from the microbial population and more easily decomposable microbial biomass in the 3-year-old than in the 10-year old plantation are probably part of the reason that younger plantations do not suffer N deficiency on CH clearcut sites.

Future Work—Incorporation of N-15 into a Forest Soil in an Application Chronosequence

Fertilizer N applied to forest ecosystems is known to be immobilized easily by forest floor material and soil organic matter (Preston *et al.* 1990), with subsequent low availability to plants. This process leads to accumulation of N in the upper horizons of the soil profile, with up to 76% of applied N found in the soil (Nõmmik and Larsson 1989). The objectives of this study are: 1) to provide information about the chemical forms and potential availability of immobilized N; 2) to explore the relationships between residence time and N incorporation into soil; and 3) to compare chemical extraction results with a bioassay.

A chronosequence of N application will be obtained from N-15 applied in the spring of 1988, 1991, and 1993. Mineral, microbial and non-microbial organic N and N-15 will be determined on field moist samples. Exchangeable ammonium, non-exchangeable ammonium, organic N fractionation and aerobic N mineralization, and their N-15 enrichment will be analyzed using available methods. Soil samples from each horizon will be used in a pot experiment planted to western hemlock seedlings in the fall of 1993 as a bioassay of N-15 availability. Results from this study are expected to provide useful information about residual fertilizer N forms and their availability.

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Long-term Recovery and Availability of ¹⁵N-fertilizer Applied to Immature Douglas-fir

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Introduction and Background

In forest ecosystems, high amounts of nitrogen (N) are stored but only about 1% of it is available in inorganic form. Growth is therefore often nitrogen limited. Fertilization is used to increase the amount of available N for stand growth. Urea is commonly used mainly because of its high N content and low cost. However, the efficiency of fertilization is quite poor; uptake by crop trees in one growing season can be as low as 5-15% of added N and most of it seems to occur during the first growing season (Hulm and Killham 1990; Preston *et al.* 1990). If conditions are favourable for volatilization, leaching, or denitrification, there can be a loss of added N from the ecosystem. A high proportion of the added N often remains in soil in immobilized or fixed forms, but it has been shown to be more easily remineralized than native soil N (Popovic 1977). More detailed studies are needed on the long-term fate of applied N and on the nature of processes involved, so that we can determine what forest management practices could be used for optimizing tree uptake and minimizing losses of N from the ecosystem. The use of N-15 labelled fertilizers makes it possible to study nitrogen redistribution quantitatively in the ecosystem.

Previous Results

A long-term field study on ¹⁵N uptake and growth response of added N by 11 year old lodgepole pine in interior British Columbia (Spillimacheen) was recently completed at the Pacific Forestry Centre. Small (2 m radius) single tree plots were destructively sampled, 1 and 8 years after fertilization, and recovery of N-15 in trees, understory, and soil was determined. After eight growing seasons, trees increased 34% in stem volume in fertilized plots compared to controls. However, only a small proportion of the applied N (5.8%) was taken up by plot trees, while larger proportion of it remained in the soil. Most uptake occurred during the first growing season after application and only a small additional uptake in the next 7 years (Preston 1992). It was also found that up to 50% of the soil N-15 was lost during this 7-year period, which suggests continuing mineralization of the immobilized N-15. Although insignificant amounts of residual fertilizer N-15 were taken up by trees in the field, these amounts were taken up by lodgepole pine seedlings at twice the rate of native soil N in a greenhouse study. Further research is needed to determine what factors are limiting the uptake of available N by trees.

Nitrogen Dynamics in Immature Coastal Douglas-fir Stand

A further opportunity has arisen to study the long-term fate of N fertilizer applied at an operational level to a stand type that would be a candidate for commercial fertilization. This coastal Douglas-fir stand of intermediate productivity and 40 years old at the time of application is situated on east-central Vancouver Island at Northwest Bay, near Nanaimo, and is similar to the immature stands of Douglas-fir in the chronosequence experiment. Nitrogen-15 urea (200 kg N/ha; worth \$250,000) was applied in spring and fall

1982 on six (11 x 11 m²) plots. There is good background information available on the fate of N in the first 3 years after fertilization (Nason 1989). The results agreed with previous observations that increased plant uptake of N occurs soon after application and that urea N is rapidly immobilized, with high amounts retained in soil in organic forms.

Objectives of the present study are to get better insight of mechanisms of N transformation, transport, and loss over 10 years, and to combine results with the results obtained from previous studies at Shawnigan Lake to enhance understanding of the effects and efficiency of fertilization in second-growth Douglas-fir. This is done by determining the amounts, form, and distribution of N-15 urea fertilizer in trees, understory, litter, and soil. The distribution of N-15 in various functional groups of soil fauna and the proportion in microbial biomass in different layers of forest floor are also under study. The availability of residual soil N-15, as well as native N, to trees is to be estimated by a pot trial. A second pot trial has also been established using N-15 labelled soil to examine the role of soil fauna and the importance of functional diversity of fauna on the N dynamics of these Douglas-fir forest ecosystems.

Besides urea, another common fertilizer, ammonium nitrate, was also used in the study in Spillimacheen. Once immobilized in soil in an organic form, the residual soil N behaved similarly regardless of its original form (Preston 1992). In contrast, results from a long-term forest fertilization trial in Finland, which used a slow-release form of N (urea formaldehyde), as well as urea and ammonium nitrate in a Scots pine stand, showed that the greatest amounts of N were available in urea formaldehyde-treated plots (Martikainen *et al.* 1989). Laboratory incubations using soil from the Northwest Bay site are in progress to study the initial transformations of added N-15 (urea and urea formaldehyde) and the behaviour of different kinds of organic N compounds. The results will be compared to those obtained from the field and pot trial studies.

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Soil Microbial Activity in Coastal Douglas-fir Forests

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During forest development, carbon fixed by trees accumulates not only in the trees but also as organic matter in detrital pools such as coarse woody debris, the forest floor, and the soil. The amount of carbon in these detrital pools can often exceed that in the living tree biomass (Harmon *et al.* 1986). In the Canadian forest sector carbon budget model, assumptions about the size and dynamics of these pools greatly affects the overall carbon balance (Kurz *et al.* 1992). As well, this detritus contains a significant fraction of the forest's nitrogen, and as stands age a greater fraction can accumulate in the detritus. In some forests where rates of organic matter turnover and nutrient mineralization are especially low, the decrease in nutrient availability has been suggested as the prime cause for the reduction in tree growth as stands mature (Williams 1972).

Other than losses from stand disturbances such as harvesting or fire, carbon is lost from the soil and detrital pools as CO₂, through the respiration of roots and soil organisms (the latter respiring carbon derived from the decomposition of plant detritus). The activity and respiration of roots and soil organisms is controlled primarily by soil temperature and moisture. It has been demonstrated that up to 85% of the variability in soil respiration rates for a specific soil can be accounted for by variations in soil temperature and moisture (Coleman and Sasson 1980). Obviously any large changes in the numbers of roots or soil organisms will also affect rates of soil respiration as well as changes in the amount and kind of detritus available for decomposition by soil organisms (Hendrickson *et al.* 1982).

Soil temperature and moisture are affected by the forest cover—soil temperature through shading, and soil moisture through interception and transpiration. Therefore, in order to relate soil abiotic conditions to climate, functions must be used that account for the effect of the forest cover. Several models for soil moisture and temperature have been developed which use Leaf Area Index (LAI) as the primary variable.

This study has two objectives: 1) to monitor the effects of seasonal weather and stand cover type on soil moisture, temperature, respiration, microbial biomass, and litter decomposition; and 2) to obtain data on soil temperature and moisture under different forest covers for use in fitting an appropriate soil temperature and moisture model. Work will be conducted within plots established in the intensive CWHxm chronosequences (Pollard and Trofymow, in these proceedings).

Site Weather and Stand Conditions

Although it would be ideal to measure weather and soil conditions in all four seres at all three intensive chronosequences (Greater Victoria Watershed South [GVWS], Greater Victoria Watershed North [GVWN], Koksilah) for the entire 3-year study, logistical constraints require an alternative plan. Soil temperature, moisture, and weather measurements using data loggers and electronic sensors will be made for a 3-year period in the regeneration stand at all three locations. Weather data to be collected include daily and monthly air temperature, humidity, precipitation and solar radiation. In successive years, air and soil temperatures and moistures will be measured in the three other seres in a different chronosequence each year. In this way, site differences in weather can be measured over all 3 years while within-year measurements can be used to account for between-sere effects. Initial stand condition information collected as part of the carbon and nutrient survey (Trofymow and Blackwell, in these proceedings) will be supplemented with overstory LAI measurements to be made with a LICOR LAI2000 light ceptometer.

Soil Temperature and Moisture

Monthly monitoring of the four seres will begin with GVWN during 1993/94, GVWS in 1994/95, and Koksilah in 1995/96. Thermistors, soil moisture blocks, and a CR21X data logger will be used to measure air and soil temperatures (two replicate subplots at two soil depths: LFH/soil interface and 50 cm) on a daily maximum, minimum and average basis. Although soil moisture blocks can be monitored continuously, their

calibration requires data from other methods. Thus, in the chronosequence under study the daily soil moisture measurements will be supplemented with monthly measurements of volumetric soil moisture by neutron probe at 10, 20, 40, and 50 cm. Four access tubes, one in each subplot, will be installed in each plot adjacent to areas where soil respiration, microbial biomass, and litter decomposition are being measured.

Soil Respiration and Microbial Biomass

To monitor soil biological activity, soil CO₂ evolution will be measured and related to changes in the seasonal soil moisture and temperature regimes and to stand development. Once a month, at four subplots in each of the four seres under study, CO₂ evolution over a 1-day period will be measured with NaOH base traps. As well, four times a year samples of the forest floor will be taken adjacent to the traps, and the amounts and activity of the heterotrophic populations monitored by substrate-induced respiration and basal respiration using a multichannel IRGA. This technique has recently been applied to forest soils and proved extremely useful in understanding how soils function (Parkinson 1991).

Litter Decomposition

To integrate the effects of stand and site conditions over the 3-year period, a litterbag experiment has been installed in all seres at all three intensive chronosequences. Such a study was also suggested as an important ancillary study during a proposal development workshop for the CIDET experiment (Trofymow, in these proceedings). Two major questions to be addressed by this litterbag study include:

1. What are the effects of stand development on rates of decay? Are the changes in soil temperature and moisture conditions with stand development sufficient to explain variation in rates of decay between stands of different age?
2. What are the effects of stand development on the types of organisms affecting litter decay? Does the abundance and types of decomposing microflora change with stand development? Does the activity and influence of the soil macrofauna change with stand development?

In October 1992, four strings of litterbags were installed in three subplots within each of 12 plots, 4 seres x 3 locations. Two types of litter (Douglas-fir needles and western hemlock wood) and mesh bags (fine mesh - 0.2 x 0.4 mm, coarse mesh - 3.0 x 3.0 mm) were used. Six treatments were included:

- 10-g needles in a fine mesh bag placed on the surface
- 50-g wood block in a fine mesh bag placed on the surface
- 50-g wood block in a coarse mesh bag placed on the surface
- 50-g wood block in a fine mesh bag buried at 10 cm
- 50-g wood block in a coarse mesh bag buried at 10 cm
- coarsely chipped 50g wood block in a fine mesh bag on the surface
- coarsely chipped 50-g wood block in a coarse mesh bag on the surface

Bags will be sampled at 12, 24, 36 and 48 months after placement and mass loss and nutrient content measured. As well estimates of microbial biomass and, if possible, species of colonizing bacteria, fungi, and microarthropods will also be made. In addition to testing for the effects of stand age and microclimate on rates of decay, several other comparisons can be made. The comparison of coarse and fine mesh bags tests for the effects of macrofauna on decomposition; comparison of chipped and unchipped wood tests for the effects of surface area exposure on rates of decay; and comparison of surface and buried wood tests for the effects of microenvironment on decay rates.

Acknowledgements

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Conserving Genetic Resources of Forests in the Pacific and Yukon Region: An Introduction to Project PC-71-50

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Forests of the Pacific and Yukon Region are highly diversified and harbour some of the world's most prized genetic resources in woody species. For example, with 16 species, south-central British Columbia features the highest concentration of conifers in Canada. The entire Region has long served as a major genetic resource for less-endowed parts of the world.

Many agencies—regional, national, and international—have commented on the Region's biological heritage, and have expressed concern over the possibility of irreversible losses resulting from a combination of lack of appreciation of their value, limited knowledge on the dimensions of genetic diversity in the Region, and a dearth of institutional and technical instruments for their conservation.

Two approaches may be taken to conserve genetic resources. In the first, locally evolved, adapted populations are maintained *in situ*, through a variety of measures ranging from seed stands to ecological areas with strong jurisdictional protection. However, effective strategies must be based on an adequate knowledge of such populations; while tree improvement programs have spurred research into important commercial species, some significant gaps remain in the Region's tree flora. A distinct problem lies in the incomplete representation of forest types in protected areas, and in the limited understanding of what is currently protected. The second approach to conservation is through *ex situ* measures, notably seed storage and plantations. Here, too, lie several problems, resulting from inadequate knowledge of the behaviour of genetic materials *ex situ*.

In 1991, the Forestry Minister announced the program, "Partners in Sustainable Development of Forests," as one of Forestry Canada's contributions to the Green Plan. The program commits Forestry Canada to two important conservation initiatives. In the first, a new National Forest Genetic Resource Centre is aimed at conserving plant and other forest resource materials. In the second, Ecological Reserves, Forestry Canada will help the forest sector in completing the representation of Canada's diversity of forests in the national network of protected areas.

The Forest Ecosystem Dynamics Program is contributing to the conservation of plant and other forest resource materials, the first initiative, with several studies aimed at addressing several *in situ* and *ex situ* issues. Specifically these deal with: population structure of mountain hemlock, a species that has gained prominence in high elevation forestry in coastal parts of the province; appropriate technology for preservation of gene resources of western forests; and the effects of long-term storage on the genetic integrity of stored seeds. One of the arguments for *in situ* conservation is that it maintains the most options for the future, because as yet unrealized resources are protected, as well as those with current utility. This project recognizes the special place of Native people's knowledge of natural products, in particular pharmaceuticals, and will pursue opportunities to safeguard this information. We are responding to the emergence of Pacific yew as the world's most important source of taxol, recently approved for the treatment of ovarian cancer. The quest for yew bark has raised questions regarding the security of the species and the ability of the Region to meet escalating demands for raw material. The taxol issue is extremely volatile, as pharmaceutical testing continues in light of intense public interest. Our initiative is designed to encourage the sustainable development of this new resource.

For the second initiative, Ecological Reserves, the Forest Ecosystem Dynamics Program has been asked to provide national leadership for the enhancement of Canada's network of forested ecological reserves. Cooperatively, by fostering partnerships at regional and national levels, Forestry Canada will help the forest sector in completing the representation of Canada's diversity of forests in a national network of protected areas.

The conservation of genetic resources is an important aspect of biodiversity, today a highly topical issue on scientific, public, and political agendas. The Forest Ecosystems Dynamics Program will maintain a flexible position to respond to emerging needs and opportunities in the Region, particularly where they coincide with priorities in the federal government's Green Plan.

These goals are pursued within the following strategies:

- Develop protocols for conserving genetic resources of forests in the Pacific and Yukon Region.
- Prepare guidelines for the sustainable use of Pacific yew for taxol.
- Evaluate diversity of minor crop species to foster their continued maintenance in the biodiversity of the Region.
- Provide national leadership and regional management of the Green Plan Ecological Reserves project.
- Improve institutional and technical arrangements for incorporating the conservation of genetic resources into management objectives.

***Ex situ* Conservation of Forest Biodiversity in British Columbia**

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Introduction

Biological diversity of our forests, which has become a preeminent concern of forest practitioners, users, and the public, has three major components: species diversity, ecosystem diversity, and genetic diversity. This project focuses on the conservation of genetic diversity because no similar studies were being conducted; work on species and ecosystem diversity is under way elsewhere. Since little information is available on the impact of *ex situ* conservation on the genetic diversity of tree seeds, this project was initiated.

Ex situ conservation in crop plants relies on frequent rejuvenation (i.e., production of new plants, conducting of controlled crosses, and harvesting of fresh seeds for further storage). *Ex situ* conservation in forestry, specifically conifers, cannot accommodate this rejuvenation component because of the well-known long duration required by seedlings to reach sexual maturity. Thus, the genetic integrity of stored seedlots has to be assumed to remain constant, unchanging over time. This project is designed to test the efficacy of this assumption through simulated (accelerated), long-term ageing.

Before any testing is begun, two fundamental questions must be addressed: 1) what genetic differences exist in germination parameters; and 2) what genetic differences exist in dormancy levels. These questions are essential for establishing benchmarks against which deterioration during simulated ageing can be evaluated, and for testing the hypothesis that genotype-specific differences in dormancy are related to rate of deterioration.

Germination/dormancy-breaking is a by-product of enzymatic activity. Most of the proteins involved in this are stored in the nutritive (megagametophyte) tissue. It is expected, therefore, that rate of deterioration in stored seeds will be associated with changes in the protein matrix. The protein matrix will be monitored through the simulated ageing process to determine the presence or absence of associated changes.

Objectives

The objectives of the project are:

- to determine if commonly used forest tree seed storage practices result in a reduction of genetic diversity;
- to relate any reductions to specific genotypes;
- to identify specific changes (gene markers) in the protein matrix with deterioration during storage; and
- to propose alternative approaches to current seed storage procedures to circumvent any changes in the genetic composition of stored seedlots.

Materials and Methods

The species to be studied will include all coniferous species under domestication programs (coastal: Douglas-fir, Sitka spruce, western hemlock, western redcedar; and interior: lodgepole pine, "interior" spruce), minor species (mountain hemlock), and a representative broadleaved species (red alder) (Table 1).

TABLE 1. *Ex situ* Conservation Work Plan 1992–1997

| Species | Genetic differences | Accelerated aging | Biochemical analysis |
|------------------|--|---|----------------------|
| Douglas-fir | Inheritance of germination - published 1992 Germination speed - publication 1992 Manipulation of dormancy - data analysis - publication 1993 | Completed - data analysis ongoing - reporting in progress | In progress |
| Sitka spruce | Inheritance and germination differences - completed - publication 1992 | Completed - publication 1993 (in press) | 1994/95 |
| western hemlock | Inheritance, germination differences and dormancy - in progress | 1993/94 | 1994/95 |
| western redcedar | Germination differences - completed Preliminary data presented | 1994/95 | 1994/95 |
| mountain hemlock | Germination differences - completed | 1993/94 | 1994/95 |
| lodgepole pine | Inheritance, germination differences and dormancy manipulation - in progress | 1993/94 | In progress |
| interior spruce | 1993/94 | 1994/95 | 1994/95 |
| red alder | 1993/94 | 1994/95 | 1994/95 |

The methods to be used include: 1) traditional seed pretreatments; 2) modified seed pretreatments; 3) simulated (accelerated) ageing techniques; and 4) biochemical analyses (2-D electrophoresis).

The standard method developed for simulating ageing in crop plants will be modified by means of pilot tests, to suit individual tree species. (Work already carried out on Douglas-fir, Sitka spruce, and mountain hemlock has indicated that custom-made ageing treatments are required for every species.) The modified method will then be used to determine whether differences in resilience to simulated long-term storage exist, and whether these differences are genotype specific.

Standard germination tests will be employed to establish benchmarks for germinability/dormancy and to establish the presence of genetic differences among genotypes.

Biochemical analyses (2-D electrophoresis) are being used to determine changes in the protein matrix and whether such changes (losses/additions) are genotype specific.

Results

1. Genetic differences in germination parameters and dormancy have been found in Douglas-fir (El-Kassaby *et al.* 1992), Sitka spruce (Chaisurisri *et al.* 1993b), and western redcedar (El-Kassaby *et al.* 1993). Evidence of strong genetic (maternal) control ($h_b^2 > 0.5$) has been found for Douglas-fir, Sitka spruce, western redcedar (El-Kassaby *et al.* 1993a) (Table 2), and mountain hemlock. The unique structure of coniferous seeds dictates this strong maternal effect (4:1 maternal:paternal) (El-Kassaby *et al.* 1992). A novel interpretation of germination parameters has also been reported (Thompson and El-Kassaby 1993).

2. Since strong genetic control over germinability/dormancy has been established, similar differences in rate of seed deterioration can be expected. Genotype-specific differences in rate of deterioration under simulated ageing have been documented for Sitka spruce (Chaisurisri *et al.* 1993a) and in Douglas-fir (in preparation); work has begun on western hemlock, mountain hemlock, and lodgepole pine. These results indicate that the genetic makeup of a seedlot will be different before and after simulated ageing.
3. Biochemical analyses are under way to establish the protein matrix for fresh, untreated seeds of Douglas-fir and lodgepole pine. Investigation of changes in the matrix caused by simulated ageing are under way.

TABLE 2. Estimates of variance components, significance level, and broad-sense heritabilities (h_b^2) for germination parameters of Douglas-fir, Sitka spruce, and western redcedar (Source: El-Kassaby *et al.*, 1993)

| Species | Source of variation | Degrees of freedom ^a | Germination parameters ^b | | |
|------------------------|---------------------|---------------------------------|-------------------------------------|---------|----------|
| | | | GC | PV | GV |
| Douglas-fir (Df) | Among trees | t-1 | 0.058** | 3.602** | 1.681** |
| | Residual | t(r-1) | 0.005 | 0.348 | 0.134 |
| | h_b^2 | | 0.92 | 0.91 | 0.93 |
| Sitka spruce (Ss) | Among clones | c-1 | 0.003** | 0.710** | 19.537** |
| | Residual | c(r-1) | 0.004 | 0.204 | 6.744 |
| | h_b^2 | | 0.42 | 0.78 | 0.74 |
| Western redcedar (Cwr) | Among clones | c-1 | 0.020** | 0.521** | 23.055** |
| | Residual | c(r-1) | 0.005 | 0.151 | 5.733 |
| | h_b^2 | | 0.79 | 0.78 | |

* = $P < 0.05$, ** = $P < 0.01$

^a t = no. of trees (Df, t = 19, t = 12),

c = no. of clones (Ss, c = 18, Cwr, c = 22),

r = no. of replications = 4.

^b GC = germination capacity; the percentage of seeds that had germinated at the end of the test (transformation = arcsin).

PV = peak value (Czabator 1962); a mathematical expression of the break of a sigmoid curve representing a typical course of germination (no transformation).

GV = germination value (Czabator 1962); a mathematical expression combining speed and completeness of germination into a single value (transformation = $\sqrt{X} + 0.5$ for Df).

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Genetic Diversity in Mountain Hemlock (*Tsuga mertensiana* (Bong.) Carr.)

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Introduction

In many locations where few other conifers survive, mountain hemlock is an important subalpine species as a protective cover for watersheds, as a wildlife habitat, and as a major component in the long-term maintenance of the subalpine environment. It occurs predominantly in coastal areas between 1000 and 1500 m in southern B.C. and Alaska, at lower elevations in extreme northern ranges, and at higher elevations (1200–2100 m) in southeastern BC, northern Idaho, northwestern Montana, and the Cascade mountains. It is subject to increasing harvesting pressures, and no gene-conservation plan or tree improvement program exists. Little is known about the variation within the species, which is widely spread in latitude and which is disjunct in the interior of the province and adjacent U.S.

With current timber harvesting extending further into the subalpine elevations, it is important to obtain and understand the traits and characteristics of high-montane species, their range, diversity, regeneration potential, and success. Since the Green Plan of the National Forest Genetic Resources Centre (NFGRC) initiative placed emphasis on investigations of minor species, this project was devised to assess major aspects of genetic diversity of mountain hemlock in British Columbia.

Objectives

The objectives of the project are to determine:

1. The mating system. This is the vehicle for moving variation from generation to generation, and which determines how variation is structured within and among populations.
2. Reproductive success and germination ecology. The extent of genetic control over dormancy and germination must be established if *ex-situ* conservation is to be evaluated and if regeneration efficiencies are to be maximized. Simulated (artificial) ageing of seeds will provide data to determine if there is any loss of genetic legacy during storage. Germination ecology will be investigated using a thermogradient system (courtesy of and in collaboration with Dr. C.L. Leadem, B.C. Ministry of Forests) that permits several temperatures and dormancy-breaking treatments to be studied simultaneously and synchronously on a variety of seed sources.
3. Adaptive and quantitative seedling attributes:
 - a) Quantitative variations in seedling attributes (height, diameter, shoot/root dry weight) will be analyzed for inter- and intra-population variation in morphology and field performance. A provenance trial has been proposed to study interpopulation differences. A common-garden trial will be planted in 1993 to study intrapopulation variation.
 - b) Frost-hardiness patterns/environmental-adaptation patterns will be established with a view to preparing seed transfer guidelines.

4. Genic variation, the variation among and within populations at the gene level, will be determined by means of isozymes. Together these data will provide information on qualitative, physiological, and genetic traits of the species.
5. Morphology of foliage, buds, cones, and seeds collected from designated range-wide locations in British Columbia will be analyzed.
6. Genetic relations to other species:
 - a) relationship with other conifer species. Reciprocal controlled pollinations will be conducted to assess hybridization with western hemlock (*Tsuga heterophylla* (Rafn.) Sarg.) (re *Tsuga* X *Jeffreyi*) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.); resulting seeds will be sown and studied for putative hybridity.
 - b) a surrogate for other organisms, such as insects and fungi.

Methods

Survey of existing knowledge

To assess the state of knowledge of mountain hemlock, an annotated bibliography, with emphasis on species diversity, reproductive biology, regeneration success, and genetics is being compiled (Table 1).

Generating new information

Generation of new information will be carried out on two levels: among trees within (intra) populations, and among (inter) populations. Sources of materials are:

- two stands represented by individual-tree seed collections (approx. 20 individual trees per stand) from southern Vancouver Island, contributed by Canadian Pacific Forest Products (CPFP), and
- 20 bulked, wild-stand seed collections, made by companies and the B.C. Ministry of Forests (MOF), selected to provide good representation of coastal mountain hemlock, plus one (available) interior representative.

Results

Existing knowledge

Approximately 60 published articles on mountain hemlock have been surveyed; most concern growth rates and tariff tables for estimating tree volumes; stand structure; ecology; fire outbreak, disease susceptibility, and regrowth patterns; biomass; seeding habits; container seedling growth; chemotaxonomy; and nutrient cycling. Scattered information on reproductive morphology and reproductive method, natural regeneration, hybridization, and genetic variation was found. The bibliography will be published in 1993.

New information

Seeds from CPFP's two individual-tree stand collections have been analyzed to determine:

- familial variation in germinative parameters (using standard germination tests). This has been completed; data analysis is under way.
- genotype specificity under simulated (accelerated) ageing. This has been completed; data analysis is under way.
- Seedlings have been grown in containers for a common-garden trial to analyze intrapopulation variation in seedling attributes. Height-growth measurements were made throughout the 1992 growing season; destructive sampling is under way for shoot/root dry weights.

Seeds from the MOF bulk lots are being analysed to determine:

- Reproductive success and germination ecology: Preliminary results show mountain hemlock germination to be highly temperature sensitive, being completed in less than 3 weeks at constant 20°C. However, stratification for 12 weeks produced no germination in 2 months at 15–10°C. Two seed sources were used to develop the appropriate protocol for accelerated-ageing tests; 100% RH at 37.5°C was found to give the clearest results. This treatment will be applied to the remainder of the bulk seed sources (MOF), and to the individual-tree lots (CPFP) to determine if differences in resistance to simulated long-term storage exist, and if these differences are genotype-specific. This is essential information when considering *ex-situ* conservation of genetic diversity.
- Adaptive and quantitative seedling traits. Seeds are being prepared for sowing in a nursery to produce seedlings for (a) studies of interpopulation variation in seedling attributes, and for a provenance trial if resources permit, and (b) for stock on which to test frost hardiness.
- Cone crops were poor in 1992 for mountain hemlock (and most other species) and only one additional seed source was found. Seeds are being extracted.
- Cone, bud, and foliar morphology studies, along with associated organisms (insects, fungi), were deferred to 1993.
- Reciprocal cross-pollinations of western to Sitka spruce were carried out, and cones have been collected and seeds are being extracted. Crosses to mountain hemlock are required.

TABLE 1. Mountain hemlock work plan 1992-1997

| Study/activity | 1992/93 | 1993/94 | 1994/95 | 1995/96 | 1996/97 |
|---|--|---|---|---|----------------------------------|
| 1. Literature review | - Basic listing. - Revisions. | - Revisions completed. - Publication. | | | |
| 2. Germination ecology and reproductive success | | | | | |
| a. Genetic control | - Data collection completed. | - Analysis in progress. | - Report, submit for publication. | - Publication. | |
| b. (i) Preliminary test for modelling ageing | - Data collection completed and analyzed. | - Conclusion. | | | |
| b. (ii) Accelerated ageing tests | - Test inter pops (MOF)/intra pops (CPFP). | - Continue tests. - Data analysis. | - Data analysis. - Report, submit for publication. | - Publication. | |
| c. Thermogradient system (MOF) | - Four seedlots tested. - Preliminary data analysis. - Four more lots on test. | - Test four more lots (total 12). - Data analysis. | - Report, submit for publication. | - Publication. | |
| 3. Intrapopulation variation | - Nurser (seedlings grown, two pops, CPFP). - As above. | - Analysis of seedling attributes (destructive sampling). - Establish common garden (1+0). | - Report? - Measure, analyze. | - Report, submit for publication. | - Publication. |
| | - Mating system (CPFP materials). | - Data collection. | - Data analysis. | - Report, submit for publication. | - Publication. |
| 4. Interpopulation variation | | | | | |
| a. Morphology and field performance | - Sow 20 bulked seedlots (MOF). | - Quantitative variation in seedling attributes. - Plantation reconnaissance? | - Complete measurements. Analyze. - Transplant? - Plant to field (provenance trial) or common garden? | - Replant mortality. - Measure. - Data analysis. - Report, submit for publication. | - Publication. |
| b. Adaptation/frost hardness | - As above. | - Establish protocols for frost-hard. testing (MOF). - Complete data collection. | - Complete frost-hard. testing (MOF). - Data analysis. | - Analyze. - Report (seed transfer). - Report, submit for publication. | - Publication. - Publication. |
| c. Genetic variation | - Isozymes (CPFP materials). | | | | |
| 5. Cone, bud, and foliar morphology | - Establish protocols—preliminary work. | - Additional sample (see 4a) collection. - Sample prep./measurement (UBC?). | - Complete measurements (UBC?). - Analyze. | - Complete analysis. - Report, submit for publication. | - Publication. |
| 6. Genetic relation to other | - Crosses made. - Cones collected. | - Extract seeds (92/93 crosses). - More crosses. - Collect cones. - Extract seeds. | - Sow seeds. - Nursery. - Measure seedlings. | - Analyze. - Report, submit for publication. | - Publication. |

Sustainable Development of Natural Sources of the Emerging Anti-cancer Agent, Taxol

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Introduction

Promising clinical trials of taxol, the anti-cancer agent isolated from the bark of Pacific yew (*Taxus brevifolia* Nutt.), have resulted in an increasing demand for the raw material and raised concerns about the unsustainable exploitation of natural stands in the Pacific Northwest. Massive research and development programs aimed at increasing taxol supply have been undertaken in the United States, Canada and France. These include studies of the full and partial chemical synthesis of taxol, and intensive culture of *Taxus* species and cultivars for taxol production. However, expectations are that it will take from 2 to 10 years before alternatives to taxol extracted from bark are certified for clinical use and production is scaled up to meet the demand.

The following investigations are being conducted to foster the sustainable utilization of Pacific yew for taxol: 1) tolerance of yew to environmental stresses associated with disturbance; 2) vegetative propagation of representative genotypes; 3) impacts of pathogens on propagated and wild trees; and 4) environmental effects on taxol production.

Methods

Tolerance of yew to environmental stresses associated with disturbance

Foliar physiology and morphology were studied in seedlings and excised shoots taken from trees growing in different light environments. Measurements of photosynthesis were made under different light intensities ($0-850 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD, photosynthetic photon flux density), 20°C , and 1.5 kPa VPD (vapour pressure difference), using an open gas exchange system. Branch and leaf structure of trees growing in sun and shade were characterized with respect to foliage age classes, specific leaf areas ($\text{cm}^2\cdot\text{g}$), and the distribution of stomata.

Vegetative propagation of representative genotypes

Pacific yew branches representative of different sites and tree ages and of male and female trees were collected and cuttings treated with 0.8% IBA were set in flats containing sand:peat:perlite under cool air and warm soil (20°C) conditions. Cuttings from English yew (*Taxus baccata* L.) were similarly treated. After 8 months, rooting percentages were determined.

Results and Discussion

Little is known about native North American yews. Of the over 300 articles surveyed (Mitchell 1992a), only 11 were on Pacific yew and 11 on Eastern yew (*Taxus canadensis* Marsh). The majority of references pertain to the English yew, its cultivars, and hybrids.

Tolerance of yew to environmental stresses associated with disturbance

Shade acclimation of Pacific yew was characterized by unusually large shifts in photosynthetic light responses (Mitchell 1992b). At low light intensity ($50 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD), photosynthetic rates were 30% of maximum (100%; $4.4 \mu\text{mol CO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) in sun grown leaves and 70% of maximum (100%; $3.1 \mu\text{mol CO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) in shade grown leaves. Photosynthetic rates remained within 10% of maximum over a broad range of light intensities ($250-450 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD) in both sun and shade grown leaves. At high light

intensity ($850 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD), rates declined to 40% of maximum in shade leaves and 85% of maximum in sun leaves. Within a single tree, a mosaic of sun and shade leaves were found, each acclimated to the light environment in which they grew.

Foliar morphology and branch structure of Pacific yew were also affected by exposure (Mitchell 1992b). Shade grown leaves had higher specific leaf areas ($\text{cm}^2\cdot\text{g}$) than sun grown leaves. On a single leaf basis, sun and shade grown leaves did not differ in the number of stomata. Branches from exposed trees tended to have fewer age classes of leaves (7) and more current shoots (69% of total) than branches from shade grown trees (11 age classes and 31% of total). Shade grown trees tended to invest in leaf maintenance, while exposed trees tended to invest in leaf production.

Vegetative propagation of representative genotypes

In general, cuttings from *T. baccata* rooted significantly faster and with a higher success rate (near 100%) than those from *T. brevifolia* (Mitchell 1992c). Cuttings from young *T. brevifolia* rooted better, 70.8%, than those from old trees, 48.2%, and variability was high among individuals, 14.5–87.5%. Collection site also appeared to affect rooting success, but variability among individuals from a given location masked significant differences. Of the seven locations sampled, the highest rooting percentage was 66, and the lowest was 25. Comparisons were also made between cuttings collected from sunny and shady sites, and rooting percentages were similar, 41.5% and 50.7%, respectively. There was no significant difference in rooting between male and female trees, 53 and 47.2% respectively.

Conclusions

- There are inter-specific differences between English and Pacific yew biology; not all information can be directly transferred.
- Male and female trees did not differ in foliar physiology or morphology, regardless of the light environment in which they grew.
- Sun and shade grown trees differ with respect to both carbon acquisition (photosynthetic light optima) and allocation (shoot maintenance or production).
- Propagation of high taxol-yielding individuals for intensive culture may be difficult if the parent trees are old.

Future Research Priorities

1. Drought tolerance of yew and its implications for harvesting and stand management.
2. Pests and diseases associated with yew and their implications for replanting and intensive cultivation.
3. Assessment of *in situ* and *ex situ* management practices for taxol yield.

Acknowledgement

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National Leadership and Regional Management of the Ecological Reserves Project

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Introduction

As a signatory to the 1992 Caracas Declaration on Parks, Protected Areas and the Human Future, Canada is required to contribute to a global network of protected areas, representative of the nation's diversity of ecosystems. In its Report to Parliament, Forestry Canada has undertaken to "ensure the preservation of representative areas of each forest ecosystem in Canada" (Forestry Canada 1993).

The Department's commitment is made primarily through the Green Plan project, Ecological Reserves. The project is national in scope, with activity in most establishments. Leadership is provided from the Pacific Forestry Centre, with Dr. T.J. Drew as Lead Regional Director General and D.F.W. Pollard as the designated Team Leader. The project is modestly funded (\$80 000–\$100 000 per annum, 1992–1996), and relies heavily on partnerships with provincial and other agencies with direct responsibility for protected areas. (The term "Ecological Reserves" has specific meanings in different agencies, and has led to some confusion about the aspirations of Forestry Canada. The more general term "protected areas" will be used in most cases.)

Problem or Opportunity

The project was initiated with a workshop in Toronto, April 1992, to which representatives of several government and non-government organizations were invited. The workshop was designed to allow participants to discuss obstacles to the completion of a national network of protected areas, and to develop an appropriate Strategic Plan for the project. The following priorities were identified.

- The National Conservation Area Data Base (NCADB), developed by State-of-the-Environment Reporting (SOE), Environment Canada, should eventually meet national needs for measuring and guiding progress in protected areas. However, it contains virtually no information on ecosystems, and cannot at present be used to assess how well the diversity of forest ecosystems is represented in protected areas.
- There is a shortage of knowledge, particularly among agencies maintaining protected areas, on the way forest ecosystems function; this shortage can compromise the objectives of a protected area.
- Progress in completing a network is hampered by a widespread lack of appreciation about the value of protected areas to society.

Objectives and Progress to Date

To ensure adequate representation of Canada's diversity of forest ecosystems

National and regional forestry data sets (e.g., Canadian Forest Resource Data System, provincial forest inventories) are being canvassed under contract by Ducks Unlimited, for input into the NCADB. Ecoregions and Ecodistricts have been adopted as a provisional framework for assessing progress in a protected areas network.

The project followed advice from our partners, notably CCEA and World Wildlife Fund Canada, and refrained from developing a National Register of Forested Ecological Reserves. However, the Minister and senior levels of management already need an assessment of the status of the envisaged network, at the best level of approximation. Priorities for 1993–94 thus include preparation of a provisional national list of protected areas, compiled according to criteria of representivity.

Improved planning and management of ecological reserves and adjacent lands

This problem will be addressed at selected sites in Model Forests. An analysis of existing protected areas in and close to Model Forests was conducted on the basis of the NCADB. Some 95 listed areas were located within the 10 Model Forests, and a further 88 occurred within 10 km of their boundaries. Results of the analysis and an outline of the project were presented at the second national meeting of Model Forest representatives at Hinton, November 1992.

Up to three well-conceived proposals, aimed at improving the effectiveness of protected areas in or near Model Forests, will be funded in 1993-94.

Advocacy and information in support of a continental network of protected areas

The completion of a continental network of protected areas will be promulgated as a vital part of global conservation strategy. Regional, national, and international efforts towards this goal will be advocated through senior level policy positions, articles in professional journals, appropriate representation at key conferences, and presentations to decision-makers (see references).

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Research and Management Strategies to Address the Climate Change Issue for the Forest Sector in the Pacific and Yukon Region: An Introduction to Project PC-71-40

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Global climatic patterns are continuously in flux. Ice ages of continental glaciation and fossilized evidence of tropical and subtropical life in Canada's arctic archipelago remind us of climatic extremes in our country's past. The issue is not whether the climate changes, but whether the rate of change will increase and whether the biosphere as we know it is capable of adaptation.

Anthropogenic climatic change has become one of the key issues of the nineties. The impacts of climate change, however, are not uniform across the planet. The output from various global circulation models (GCMs) all show a marked increase in the effects of global warming as one moves from the equatorial to the polar regions. As a result, the forests of the temperate and boreal regions are much more likely to be impacted by increases in temperature and variations in precipitation than those in equatorial regions.

Estimates from various GCMs predict annual temperature increases ranging from 2°C to 10°C across the range of forested lands of Canada. This entire range is expected to be experienced within the Pacific and Yukon Region alone. Precipitation patterns are also expected to alter significantly. The combination of the two will inevitably result in a change in the current pattern of vegetation cover, including our forests.

Knowledge of climates and forests, past and present, are essential to our understanding of the interrelationship of climate and the corresponding vegetation patterns. With this knowledge we can develop adaptation strategies to deal with the scenarios of future climates.

The first priority of this project is to provide an analysis of the potential impacts of climate change on the forest sector and its economy in the Peace River region of the Mackenzie Drainage Basin. Research is conducted in partnership with the Mackenzie Basin Global Warming Impacts Study of the Canadian Climate Centre. This work will entail development of methods and analytical tools for investigation of the impacts of global climate change, and will contribute to integrated resource analysis networks dealing with the climate change issue throughout Canada and North America.

The project is pursuing a unique opportunity to examine in detail post-glacial climates in the Pacific and Yukon Region, through dendroclimatological analysis of a long series of ancient logs from a drained lake bed. Related studies should reveal how forests responded to those changes in climate.

Also summarized in this section is the Canadian Intersite Decomposition Experiment. The experiment, conducted under Project PC-71-20, should provide insight into how the decomposition of litter may be affected if climate changes.

This project will undertake to:

- provide an analysis of the potential impacts of climate change on the forest sector in the Peace River region of the Mackenzie Drainage Basin;
- contribute to integrated resource analysis networks dealing with the climate change issue in Canada and North America;
- contribute to a better understanding of climate and forest interactions in the Pacific and Yukon Region; and
- develop microclimate monitoring networks for research applications in forest resource management.

Impacts of Global Warming on the Forest Sector in the Mackenzie Drainage Basin: Case Studies in the Peace and Liard Drainage Basins

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The Mackenzie Basin is the sixth-largest drainage basin in the world and the largest in Canada. The vegetation within the basin ranges from grassland through boreal forests to arctic tundra. Land uses in the area range from subsistence hunting and trapping through to agriculture, forestry, and mining.

The Socioeconomic Impacts of Global Warming on the Mackenzie Basin, sponsored by the Atmospheric Environment Service provides a platform for information and data exchange and the opportunity to look at the forest sector in relation to other sectors, particularly with regards to potential competition for land use and resource access.

The size of the study area and the complexity of the forest sector limits the ability for detailed analysis of the impacts of climate change on the forest industry in the Mackenzie Basin. To address this issue, the forest industry component will deal with a case study region within the Mackenzie Basin. The Peace-Liard drainage study area provides an opportunity to investigate the potential impacts on the forest sector in a variety of physioclimatic regimes and the potential to extrapolate results into similar physioclimatic areas throughout the Mackenzie study area.

The Peace-Liard study area is composed of five predominant physiographic regions. These are: the Liard plateau, the Rocky Mountain trench, the Rocky Mountains, the foothills region, and the Alberta plateau. This last region is the largest and most uniform of the regions. Its uniformity and continuance into the prairies provide the opportunity to extrapolate models and results into other areas of the Mackenzie Basin.

Study Components

Database

(R. Benton, Pacific Forestry Centre)

Much of the current year has been spent in the accumulation and aggregation of the database required for the various researchers to conduct their individual studies. The database is still under development and is expected to be completed by mid-1993.

When completed, the database will contain information on forest cover, species mix and age, soils, site quality, economic (census) data, pest data, climate, protected areas, topography, drainages, transportation, and other factors important to the understanding of the forest sector.

Growth and yield

(P. Marshall, University of British Columbia)

There is potential for marked increases in the forest growth due to a longer growing season and the possibility of carbon dioxide fertilization. This component of the study, in conjunction with the species dynamics segment, will ultimately drive the wood supply and economic analysis section. This study will provide estimates of the available timber supply based on estimates in changes to the potential growth response of the trees with the changing climatic conditions. Several growth and yield models exist which could be used for this purpose. One such model relates site quality for major species to climatic variables. Assuming that site quality does not rapidly decline, it is possible to compare model outputs using climate parameter values from current and future climate scenarios.

Stand dynamics

(P. Marshall, University of British Columbia)

There is an expectation that species will migrate as the climate changes with projected global warming. While many factors are involved with species habitation of a given location, it is possible to estimate the potential range of species movement given current knowledge of soil and species limitations and the estimated climate outputs from the GCMs.

The ability of a species to survive or expand will determine potential shifts in the availability of a given resource. It also has implications for the maintenance of biodiversity of a given region or potential ecological reserves and other protected areas.

The species dynamics component of the forest sector study has been initiated this year, looking at the relationships between major forest types and current climatic conditions. Present knowledge of species tolerances and site limitations is being used in conjunction with future climatic conditions to estimate large scale changes in forest cover.

Disturbances

Disturbance factors are largely driven by climatic parameters such as temperature, precipitation, and extreme events. This component of the study is intended to address some of the potential impacts on the forests, given current knowledge of the relationships between climatic variables and forest pest and fire occurrences.

Fire

(L. Kadonaga, University of Victoria)

Forest fire frequency and intensity is projected to increase in areas where the climate becomes warmer and drier. The fire component of the forest sector study deals primarily with the sensitivity of fire susceptibility size to climate changes.

Pests

(B. Sieben, University of British Columbia)

The study region suffers from four significant forest pests. Spruce weevil, spruce beetle, and spruce budworm are all present in the study area. Forest tent caterpillar is also a hazard to a more limited extent in the Alberta plateau region.

A study by a University of British Columbia graduate student, working in conjunction with researchers from the B.C. Ministry of Forests, is currently under way to investigate the sensitivity of spruce weevil attack to climatic conditions, particularly changes in heat sums during critical insect and vegetation development periods.

Further studies being conducted at the Pacific Forestry Centre may provide insights into the cyclical nature of other major forest pests in the study region using time series analysis methods. The results of this study may be used in conjunction with GCM outputs to investigate the potential changes given global warming.

Wood supply and economic analysis

(G. Armstrong, University of Alberta and B. White, Northern Forestry Centre)

Both hardwoods and softwoods are harvested in the region. The primary forest products from the region are pulp and pulpwood products, particularly from the Alberta plateau portion of the region. Saw logs are also produced but make up a smaller proportion of the overall forest utilization.

Global warming potentially means warmer winters, thus later freeze up and earlier spring breakup conditions. Harvest operations stand to be significantly impacted, as much of the harvesting is done in the winter months to allow access to areas that would otherwise be unavailable for use, and to limit the environmental impacts. While this issue will not be specifically addressed, an attempt will be made to incorporate estimates of freeze-up and breakup into estimates of available wood supply.

Outputs from the growth and yield and stand dynamics components of the study will be used to estimate future wood supply using currently existing models. Forest level wood supply models (such as MUSYC, TRIM, or ATLAS) will be used for the economic study component. Inferences as to economic impact can be derived based on comparisons between model outputs from runs using present day and future estimated wood supply/requirement data. These inferences may be limited, however, in that the impacts of climate change on the world's forests and their related economies may far outweigh subtle changes in smaller regional areas.

Protected areas

(D. Pollard and R. Benton, Pacific Forestry Centre)

An additional study undertaken with the forest sector component investigates protected areas within the study area. The intent of this component of the project is to examine the implications of global warming on protected areas (reserves) from the standpoint of resource conservation, and to stimulate interest in assessing the protected areas network of the Mackenzie Basin. To date, an inventory of the areas protected for ecological, wilderness, recreational, and other purposes has been conducted and summarized.

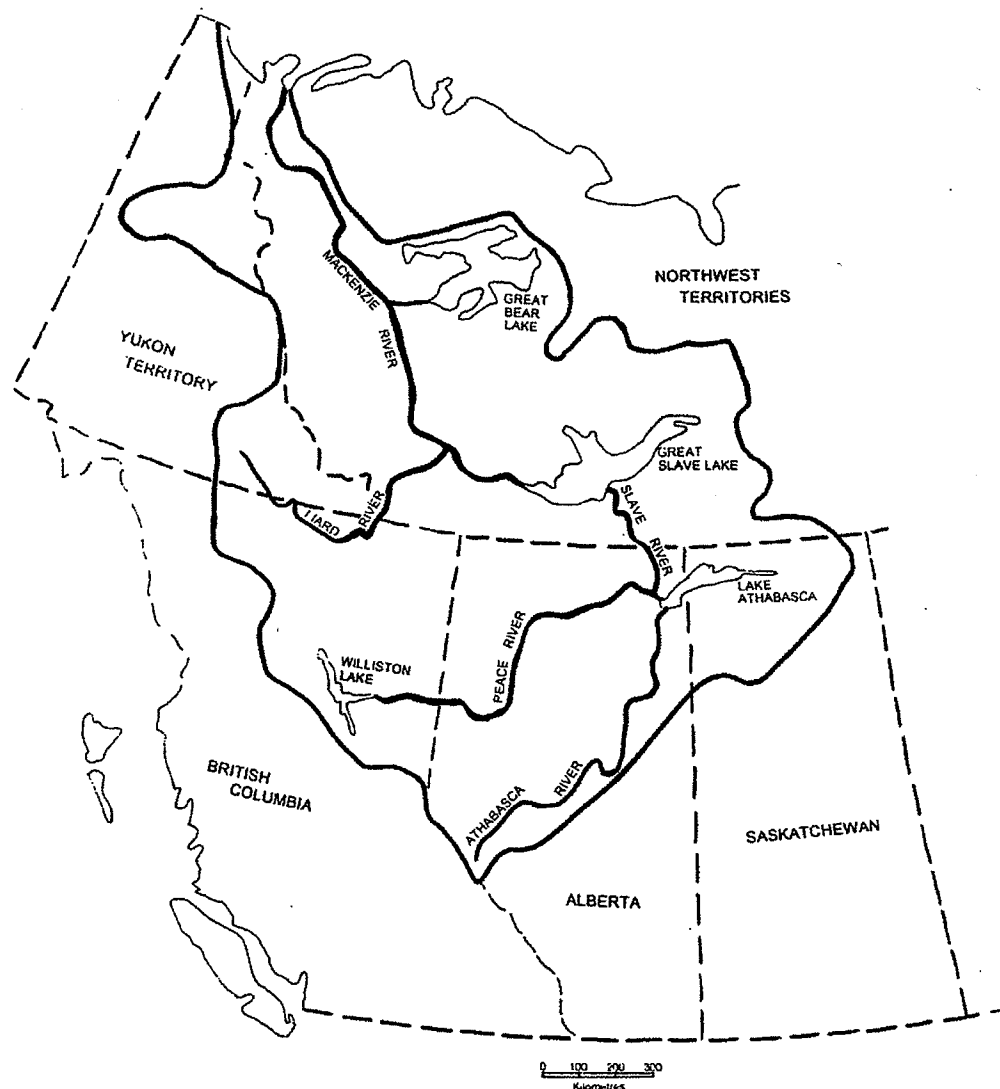


FIGURE 1. Location of the Mackenzie Basin study area.

Methods

Heat sums were calculated by interpolation using 1951–1980 Environment Canada monthly degree day normals (Atmospheric Environment Service, 1982). Heat sums for a 7.2° C base temperature were derived by interpolation between the 5 and 10° bases. This approach gives values that are about 3% higher than those calculated from daily data.

Monthly heat sum normals for the interpolated 7.2° C base were summed for May through September to calculate the total heat available. Three hazard classes were used to produce hazard rating maps: high (>800 degree days), medium (720–800 degree days), and low (<720 degree days).

A climate warming scenario of a 2.2° C increase in mean daily temperature was simulated by determining the hazard using the 5° C base degree day normals.

Degree day lapse rates depict the change in heat accumulation with elevation. Lapse rates were constructed from adjacent climate stations at different elevations. Lapse rates were used in conjunction with topographic maps to aid in the determination of elevational boundaries for each hazard class.

Results

Under the present climate, most low elevation sites in the three western provinces are at risk, as are sites along the Mackenzie River as far north as Fort Good Hope. With a 2.2° C warming, most sites in the western provinces will have sufficient heat for weevil development, as well as a significant portion of the basin north of 60° north latitude including low elevation sites up to Fort McPherson. The climate change scenario resulted in the area of the high hazard class increasing from 24 to 51% (Table 1).

TABLE 1. Relative proportion of the Mackenzie Basin in each hazard class under present and climate change scenarios

| Hazard class | Present climate | Climate change |
|--------------|-----------------|----------------|
| Low | 55 | 28 |
| Medium | 21 | 21 |
| High | 24 | 51 |

Conclusions

The hazard rating system indicates where there is sufficient heat available for the white pine weevil to complete the summer component of its life cycle. The actual range of the weevil may be less than the potential range indicated by the hazard rating system because of factors including the insect's predators and parasites and the lack of a suitable host tree. The effect of overwinter conditions on adults is not assessed.

The hazard rating system indicates that a significant portion of the basin is at risk under present climate conditions. Although much of Alberta is warm enough for weevil development, there is currently little weevil damage. This could change when aspen now shading spruce is harvested, converting stands to pure spruce.

Leaders exposed to direct sunlight may be at an increased risk as these leaders have been found to be 2–3° C above air temperature, while shaded leaders remain close to air temperature. The climate warming scenario of 2.2° C represents approximately the same temperature increase associated with moving a leader from shade to full sunlight. Thus, the present and climate change scenarios depicted in this paper may also be viewed as a hazard rating system using shaded and unshaded leaders. The climate change scenario is equivalent to a hazard rating system for unshaded (warm) leaders, while the present climate scenario is equivalent to a hazard rating system for shaded (cool) leaders.

With climate change, the white pine weevil's range will expand upward in elevation and northward in latitude. If the assumed climate change occurs, almost all of the southern region will be susceptible to weevil attack, as well as a significant portion of the northern basin. Cohen (1991) states that with a 2 x CO₂ climate change scenario the average summer basin temperature will rise by 3.5° C. Thus, the weevil hazard may be even greater than depicted in this study.

Further studies will examine the difference between leader and air temperature, silvicultural control through shading, the time period for weevil development, and improved spatial distribution of temperature data.

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Dendroclimatological Analysis of Submerged Logs from Heal Lake Near Victoria, British Columbia

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Introduction

In the summer and fall of 1991, the Capital Regional District (CRD) drained a small natural lake, Heal Lake, to provide room for the expansion of regional landfill facilities. The sediments exposed in the bottom of the lake revealed excellent preservation of organic materials, especially large logs. Because of the need to remove lake bottom sediments before landfilling, an opportunity arose to obtain large volumes of stratigraphically controlled samples for paleoecological analysis. Notable was the large number of well-preserved logs on, and within the sediment, with the potential of yielding a long tree-ring chronology and climatic record.

Proposals were made to the CRD, Atmospheric Environment Service, and Forestry Canada (FRDA-II) by myself to carry out sampling and preliminary investigations. My goal was to obtain a detailed climatic record derived from conventional pollen and macrofossil studies of sediments and detailed analysis of tree rings. This report presents the preliminary results of field sampling, pollen analysis, and assessment of fossil log sections for detailed dendroclimatological study under Forestry Resource Development Agreement II (FRDA-II).

Field Work

Field activity extended to November 1992, at which time the last of the excavations in Heal Lake were completed by the CRD and the last of the logs were removed. At that time, with the assistance of a faller provided by the CRD, the remaining logs were subsampled. A 15–20 cm thick disc was removed from each log and a 3 m long section of each sufficiently long log was retained and shipped for storage at the Pacific Forestry Centre.

In the field each disc and log segment was numbered and described in a field notebook. In total, 706 discs and approximately 300 logs were recovered.

Also, Forestry Canada staff collected woody material at the site for analysis of insect remains.

During October and November, sediment samples were taken from the remaining sections. Sampling concentrated on strata near the base of the section made accessible by the last phases of excavation.

Laboratory Work

Lab work has concentrated on study of sediment samples, particularly from the base of the sequence. The objective is to define with some precision major climatic events through pollen and sediment analysis. The climatic framework thus generated is a critical adjunct to the analysis and interpretation of tree-ring data from the logs. Close-interval samples have been prepared according to standard techniques (Faegri and Iversen 1975). Conventional pollen analysis, following conventional techniques (Hebda 1983) of 30 samples from the base of the sequence has been completed.

With the use of the measuring system at Forestry Canada, tree-ring data has been extracted from 10 Heal Lake logs, with single radii from each and two radii from one of the logs. The radiocarbon age of these logs varies from 150+/-50 years Before Present (BP) to 4270 +/- 70 years BP.

Steps have also been taken to make data collected at Forestry Canada compatible with information available from other regional sites and with the master tree-ring chronology for bristle cone pine at the University of Arizona Tree-ring Laboratory. A fourth-year University of Victoria student has received a "Work Study" award to carry out the computer work to harmonize the various data sets so that Heal Lake data can be cross-matched and dated with known records elsewhere.

Results

Vegetation and climate

Preliminary pollen analysis of the lowermost part of the record ca. 13 000–10 000 BP has revealed the predominance of a forested, largely lodgepole pine landscape. However, the samples beneath the first organic deposits yielded the first-ever evidence for non-forest, late glacial plant communities on the coast. Shrubs, mostly willow, alder, and soapberry (*Shepherdia canadensis*) seem to characterize the vegetation. Immediately, though, lodgepole pine woodland replaces shrub communities and continues until just after 11 300 BP, when pine is suddenly replaced by alder.

The sudden alder rise occurs in association with a silty zone in the lake sediments, at the same time as the surrounding landscape undergoes major disturbance. A sand and gravel diamicton is deposited in shallow water at the edge of the basin.

Alder levels decline shortly thereafter, but remain significant for perhaps 500–800 years. As alder declines, pine recovers and eventually returns to levels like those before the alder event. All of this record occurs before the advent of Douglas-fir, recognized regionally to be about 10 500 years ago.

For the time being, this sequence of vegetation and landscape change is interpreted to represent a dramatic cooling in the late glacial period, but earlier than the well-documented "Younger Dryas" cooling of Europe and the North Atlantic. If so, this will be the first direct evidence of such cooling on the west coast of North America.

Tree rings

Ring widths have been measured along 11 radii of 10 logs. From this preliminary analysis, and a comparison of plots of the ring widths of logs HLL-9 (about 150 years old) and HLL-32 (more than 4 000 years old), it is clear that chronology characteristics have varied significantly through time at Heal Lake. Consequently the ring record in the logs recovered at Heal Lake contains significant growth and climatic information.

Computer cross-dating and regional chronology

The University of Victoria student has only begun to examine the requirements to match Heal Lake data to that of the bristle cone pine chronology. Living tree-ring index records for the Hesquiat Peninsula of west Vancouver Island and for Waterloo Mountain near Duncan have been acquired and entered into computer files for cross-dating.

To develop a broader initiative to establish a regional chronology, the first British Columbia tree-ring users group meeting was held at the University of Victoria in early December. The group decided to pursue the establishment of a regional living chronology in Douglas-fir and other species.

Plan to March 31, 1993

1. To complete analysis and then write up and submit for publication a paper demonstrating late glacial cooling at Heal Lake.
2. To measure ring widths of selected discs at the Pacific Forestry Centre. Measurements began in the first week of January, 1993, by James Clowater, a Forestry Canada trained biology co-op technician. Because of the large number of discs, measurement will concentrate on those of more recent age to connect them to a regional living chronology.

3. To obtain a sample of living discs and establish a recent regional chronology for the Heal Lake area. We will be assisted in this by Forestry Canada staff.
4. To harmonize the format of Heal Lake tree-ring measurements with data from other laboratories and bristlecone pine chronology. This will be carried out by University of Victoria students and University of Victoria computer staff.
5. To radiocarbon date 20–25 selected discs, with emphasis on spanning the log record, to establish absolute ages of the chronologies recorded in the discs. The objective will be to examine and describe the way chronology characteristics have varied through time at one site under different climatic regimes.

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Climate Change Workshops for the Forest Sector in the Pacific and Yukon Region

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Introduction

The implications of climate change for forest management in the Pacific Northwest formed the topic of an international symposium in Seattle, October 1991. The symposium was sponsored by Forestry Canada, B. C. Ministry of Forests (BCMF), Environment Canada, and several U.S. agencies. It was followed by the production of a comprehensive volume of proceedings (Wall 1992) that addresses issues of interest in the Pacific and Yukon Region.

The symposium increased awareness of the climate change issue, to the extent that forestry staff, especially in regional offices of the BCMF, were being asked by interested publics for information on the topic and for advice on how to deal with it.

A series of regional workshops were proposed to the Extension and Technology Transfer Program of the Canada/B.C. Forest Resources Development Agreement (FRDA). The proposal called for distillation of the salient features of the symposium proceedings to form the basis of presentations to regional staff of BCMF and to public audiences, again in each of the Ministry's six regions.

To date, little progress can be reported on this initiative because FRDA funds were withdrawn under the fiscal restraint before action could be taken. However, those responsible for the proposal welcome the opportunity for discussion of the topic, so that a decision may be taken about revitalizing the workshops in 1993-94.

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The Canadian Intersite Decomposition Experiment (CIDET): Long-term Rates of Leaf Litter and Wood Decay

Study Leader

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Introduction

Climate change has the potential to have large impacts upon the continued productivity and health of Canadian forests. Forestry practices can also affect site carbon balances, influencing the amounts of C exchanged with the atmosphere. Currently, several projects are under way to model quantitatively the current and potential changes in the C budgets of Canadian forests (e.g., Kurz *et al.* 1992). To develop the models, published results and expert advice were used to develop algorithms and provide input data. For many of the processes modelled, information was limited. In particular, data on soil processes such as decomposition rates were found lacking in extent and in length. Some forest types have been extensively studied while others have not. More significantly, long-term studies are rare, with most having been for 2–3 years. To overcome this deficiency, a group of researchers was assembled to conduct a long-term intersite decomposition experiment.

Objectives

The objectives of the experiment are five-fold: 1) to provide data on the long-term rates of litter decomposition and nutrient mineralization for a range of forested ecoclimatic regions in Canada; 2) to examine the role substrate quality and climate have on long-term decomposition rates; 3) to examine the relative importance of site factors and microclimate on decay rates; 4) to test the influence that site moisture regimes have on decay rates; and 5) to test specific hypotheses on the patterns of litter decay.

Experimental Design

Ecoclimatic region specific decay rates

To obtain data on long-term decay rates over the broad range of forested ecoclimatic regions, 18 upland and 3 wetland sites were chosen (Figure 1). Sites were selected to be representative of upland forest types for the ecoclimatic region they were within, as well as for proximity to a nearby climatic station and the availability of a site cooperator. At each site, four replicate plots are established with enough bags of 11 standard litter types (Table 1) placed to allow for annual collections for 10 years. The 20 x 20 cm bags are constructed from polypropylene mesh shade cloth with 0.2 x 0.4 mm openings and contain 10 g of litter or a 50 g wood block.

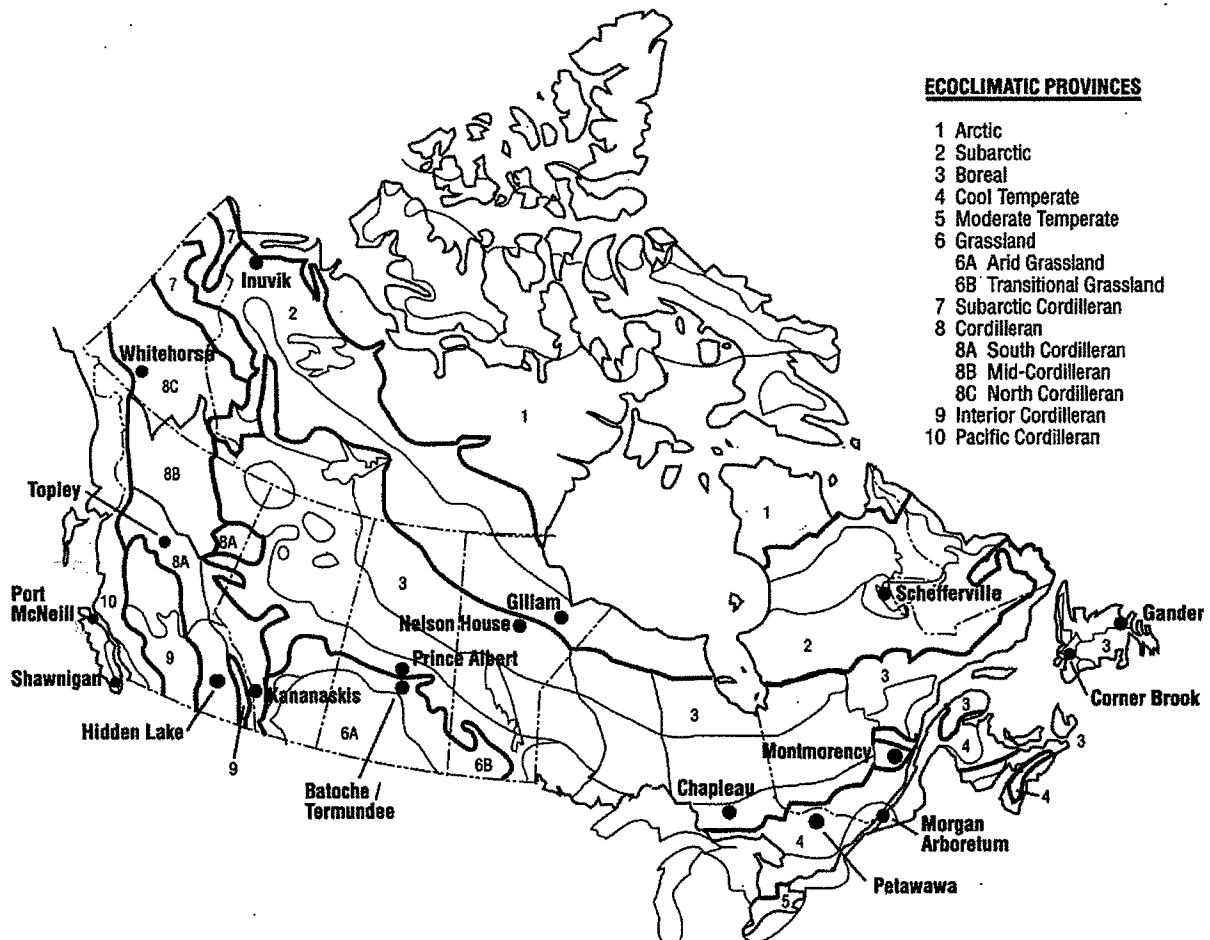


FIGURE 1. Distribution of experimental sites across the ecoclimatic regions of Canada (after Ecoregions Working Group 1989). Batoche/ Termundee, Nelson House and Gilliam have paired upland/ wetland sites.

TABLE 1. Litter type and species used in the decomposition experiment

| Common name | Binomial | Collector |
|------------------|------------------------------|-----------|
| Leaves | | |
| Aspen | <i>Populus tremuloides</i> | Visser |
| Beech | <i>Fagus grandifolia</i> | Fyles |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | Trofymow |
| Black spruce | <i>Picea mariana</i> | Titus |
| Tamarack | <i>Larix laricina</i> | Zoltai |
| Bracken fern | <i>Pteridium aquilinum</i> | Duchesne |
| Fescue | <i>Fescue occidentalis</i> | Monreal |
| Western redcedar | <i>Thuja plicata</i> | Prescott |
| Jack pine | <i>Pinus banksiana</i> | Weber |
| White birch | <i>Betula papyrifera</i> | Titus |
| Wood | | |
| Western hemlock | <i>Tsuga heterophylla</i> | Trofymow |

Substrate quality and climate

To extend the results to other regions, decay rates can be related to climate (Bunnell *et al.* 1977; Meentemeyer 1978) and substrate quality (Melillo *et al.* 1989). Previous studies often confounded the effects of climate and substrate quality because of limitations in the number of substrates or sites used. Regression models will be used to develop a response surface, with measures of substrate quality and climate as independent variables. Dependent variables will include mass remaining, nitrogen content, and the mass loss rate constant. Climatic independent variables include annual temperature, degree days, total precipitation, and actual evapotranspiration. Substrate quality independent variables include lignin/nitrogen ratio, C/N and C/P ratios, extractive content, and fractions of soluble, structural and phenolic C, determined by chemical analysis and ^{13}C NMR.

Microenvironment and site factors

General decomposition models using macroclimate and substrate quality alone can be criticized in that site specific factors may play as large a role in determining decay rates. Regression models will be developed using the dependent variables as above, along with site factor independent variables such as vegetative cover, slope, aspect and soil depth, nutrient contents and concentrations, and microclimate independent variables including soil temperature and moisture.

Site specific moisture regimes

As moisture regimes can greatly affect decay rates, we propose to test for effects of moisture by comparing decay rates at two spatial levels: at the macrosite level by comparing decay rates of all 11 litter types in 3 paired lowland/wetland boreal forest sites, and at the microsite level by comparing the effects of placement, above- or belowground, of wood blocks.

Patterns of litter decay

Results from this experiment can also be used to examine specific models of litter decay. Several groups (Paul and Voroney 1980; Parton *et al.* 1987; Harmon and Melillo 1990) have suggested that as a first approximation, long-term decomposition of fine litter can be described as the sum of exponential decay curves for each different chemical fraction (Soluble, Structural, Lignin), as in the following equation which will be used as a null model in the analysis of the data:

$$\text{Mass}(T) = \text{SolubleC} * e^{-K_f T} + \text{StructuralC} * e^{-K_s T} + \text{LigninC} * e^{-K_m T}$$

Temperature and moisture conditions are assumed to influence the rate constants (K_f , K_s , K_m). Based on this model, Harmon and Melillo (1990) suggest that the overall decay curve of fine litter can be divided into three phases, each corresponding to the loss of specific litter fractions. We hypothesize that with annual sampling, only two stages of litter decay will be observed, the first corresponding to a combination of phases 1 and 2, and a second corresponding to phase 3. We also hypothesize that exogenous N availability, microclimate, and initial substrate concentrations will affect specific rates of mass loss more in the first stage of decay than in the final stage. Finally, Melillo *et al.* (1989) have hypothesized that a specific ratio (lignin/ lignin+cellulose = 0.5) marks the transition from the first to last stage of litter decay.

Results

Plot establishment and litterbag installations were completed in October, 1992. Soil samples, site descriptions and site maps have been completed for about half the sites, with the remainder to be completed by June 1993. Macronutrient contents, characterization by NMR, and proximate analysis of the 11 litter types will be completed by March 1993.

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Project Review: Forestry Canada – Pacific and Yukon Forest Ecosystem Dynamics Research

Reports of Reviewers

The following sets of recommendations summarize the findings of two review procedures conducted on the Forest Ecosystems Dynamics Program of Forestry Canada, Pacific and Yukon Region. The first resulted from the formal peer review process, for which a Review Panel was convened and chaired by Ole Hendrickson, Forestry Canada, Science and Sustainable Development. The panel comprised Glen Dunsworth (MacMillan Bloedel), Ken Lertzman (Simon Fraser University), and Brian Titus (Forestry Canada, Newfoundland Region). The full text of the panel's report is available from the Director General, Forestry Canada, Pacific and Yukon Region.

A separate review, led by Valin Marshall, was held in an open forum of participants themselves, immediately after the Workshop, and concurrent with the deliberations of the review panel. Recommendations were drafted from the report of the rapporteur (George Edwards, Forest Ecosystems Dynamics Program). While it is not the purpose of this report to discuss the findings of either review process, the reader will observe several items common to each review that constitute compelling directions for the Program.

Recommendations of the Review Panel

It was recommended that:

- involvement of Program staff in reviewing goals and priorities for other organizations studying forest ecosystem dynamics be continued and strengthened; and that these organizations participate in reviews of Program activities.
- informal discussions be held with University of Victoria scientists to explore possibilities for collaboration in canopy arthropod studies.
- the proceedings from the Forest Ecosystem Dynamics Workshop be circulated widely to staff in provincial agencies and universities involved in forest ecosystem research.
- the possibility of using FRDA Technology Transfer funds to publish the proceedings of the 1991 biodiversity symposium sponsored by the Government of British Columbia be explored. **Note:** These have now been published as *Our Living Legacy, Proceedings of a Symposium on Biological Diversity*. M.A. Fenger, E.H. Miller, J.F. Johnson, and E.J.R. Williams (editors). 1993.
- interagency studies involving university, industry, and provincial cooperators (such as SCHIRP, the Salal Cedar Hemlock Integrated Research Project) be encouraged.
- an establishment report for the chronosequence sites be prepared as soon as possible, and contain (in addition to basic mensuration data) the logging history for each plot, its biogeoclimatic classification, the size distribution of woody debris, and (if possible) descriptive landscape indices.
- synthesis papers based on the chronosequence work be prepared as soon as possible, having the unifying theme of how old-growth forest conversion affects biodiversity; and that the possibility of preparing an account for general readers be explored.
- biodiversity studies focus on the Program's strengths in plants, soil invertebrates, and other soil dwelling organisms. The Program should not attempt to duplicate efforts of other organizations in areas such as bird and mammal studies. Studies that go beyond species identification to investigate functional roles of organisms as components of food webs and processors of organic substrates should receive priority.
- alternatives to using SHAWN as the basic framework for modeling carbon and nutrient dynamics be examined.

- geneticists with the B.C. Ministry of Forests and the forest industry be invited to a mountain hemlock workshop to discuss conservation strategies and the design of field studies of harvesting impacts on reproduction and population genetics.
- opportunities for cooperative research with industrial taxol producers be pursued. Physiological work on *Taxus brevifolia* should emphasize questions related to seedling regeneration and factors influencing taxol production, such as light stress in clearcuts.
- studies of tree rings as "proxy climate data" be encouraged, with the aim of testing the ability of global circulation models to correctly represent past climates.
- workshops based on the results of the 1991 Seattle symposium on "Implications of Climate Change for Pacific Northwest Forest Management" be held if funds are available.

Recommendations From the Open Forum Discussion

It was recommended that:

1. Chronosequence plots:
 - that long-term tenure of the plots be obtained to ensure their secure existence for many years to come; that they should receive some form of "protected area" status; and that they should be registered with the B.C. Ministry of Forests;
 - that a plot-establishment plan be drawn up, to contain a full description of the plots, their size, the size of patches in which they are found, and their history, and that they are fully mapped;
 - that a plot-maintenance program be established; and that a coordinator of the plots be appointed to assist collaborators in establishing and coordinating their work;
 - that searches be continued for an additional 2-3 chronosequences that would make the plots more valuable for other types of long-term research;
 - that new plots be in patches of at least 50 ha;
 - that the plots include lasting (non-timber) values.
2. Linkages of the projects:
 - that an overview of the Forest Ecosystem Dynamics Program be prepared to show how the biodiversity, carbon cycling, genetic conservation, and climate change projects are linked.
3. Funding for university student support:
 - that funding mechanisms be developed to support graduate students for more than 1 year at time; and that such funding take into account that students begin their work in the fall, 6 months into the federal fiscal year.
4. Human resources:
 - that means be found for using the Pacific and Yukon pool to hire assistants for more than 4 months at a time; and that the program not have a sole reliance on co-op students outside its in-house technical support.
5. Technology transfer:
 - that annual workshops be held to allow program participants to discuss progress, mutual problems, and new developments;
 - that information on the Forest Ecosystem Dynamics Program be prepared for public consumption, in the form of low-technical reports and workshops held at different sites around the Province.

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