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Long-term Productivity of Boreal Forest Ecosystems II. Expert Opinion on the Impact of Forestry Practices

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ABSTRACT

A federal–provincial working group is coordinating research and information exchange on the maintenance of boreal forest ecosystem productivity. Natural Resources Canada, Canadian Forest Service–Sault Ste. Marie, is focusing its research activities on jack pine (*Pinus banksiana* Lamb.) while the Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, is concentrating its research activities on black spruce (*Picea mariana* [Mill.] B.S.P.). The risk of losses in site productivity associated with harvesting will require extensive research over a period of years. In the interim, this report provides a synopsis, based on expert opinion, of current scientific views on the potential impact of full-tree and tree-length harvesting on site productivity in boreal jack pine and black spruce forests.

Expert opinion was solicited by questionnaire and at four workshops conducted in April 1993 on the nature of harvesting impacts on boreal forest productivity and on alternative strategies that would maintain site productivity. At the broadest level, the most important issues were: species shifts; changes in percent organic matter; and physical site disturbances, including altered hydrology and rutting. Individuals surveyed emphasized the need for future research and monitoring of these changes. Scientists, industry, and government field staff all indicated that loss of organic matter and nutrient removal were of concern on dry, jack pine sites. Altered hydrology and rutting were identified as key concerns on wet sites.

This report is one in a series that focuses on harvesting impacts on boreal forest productivity. Companion reports include an annotated bibliography of 379 references on boreal forest productivity (Taylor et al. 1995) and a report (in preparation) on recommended practices for shallow, coarse sandy and wet boreal sites.

RÉSUMÉ

Un groupe de travail fédéral-provincial coordonne la recherche et l'échange d'information sur le maintien de la productivité de l'écosystème forestier boréal. Ressources naturelles Canada (Service canadien des forêts, Sault Ste. Marie) concentre ses activités de recherche sur le pin gris (*Pinus banksiana* Lamb.), tandis que le ministère des Ressources naturelles de l'Ontario (Centre for Northern Forest Ecosystem Research) concentre les siennes sur l'épinette noire (*Picea mariana* [Mill.] B.S.P.). Des recherches approfondies durant quelques années seront nécessaires pour déterminer le risque de diminution de la productivité après la récolte. Ce rapport résume les opinions scientifiques actuelles concernant l'impact potentiel des méthodes d'exploitation par arbres entiers et par fûts entiers sur la productivité des sites dans les forêts boréales de pins gris et d'épinettes noires.

L'opinion des spécialistes à ce sujet a été obtenue par le biais d'un questionnaire et lors de 4 ateliers organisés en avril1993 sur les répercussions de la récolte sur la productivité de la forêt boréale et les stratégies qui permettraient de préserver la productivité des sites. Au niveau le plus large, les préoccupations les plus importantes sont : les changements d'espèces, la diminution de la teneur en matière organique et les perturbations du terrain (y compris l'altération des conditions hydrologiques et l'orniérage). Les personnes questionnées ont souligné la nécessité d'étudier et de surveiller tous ces changements. Les scientifiques, l'industrie et le personnel de terrain des gouvernements ont tous indiqué, pour les sites secs où pousse le pin gris, que la perte de matière organique et d'éléments nutritifs était une préoccupation. Dans le cas des sites humides, ils ont considéré l'altération des conditions hydrologiques et l'orniérage comme plus inquiétants.

Ce rapport fait partie d'une série consacrée aux répercussions de la récolte sur la productivité de la forêt boréale. Une bibliographie annotée contenant 379 mentions de publications sur la productivité forestière dans la zone boréale (Taylor *et al.*, 1995) a déjà été publiée, et un rapport sur les pratiques recommandées pour les sites boréaux humides, sablonneux et à sol mince est en préparation.

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INTRODUCTION

Scientific studies have been established by Natural Resources Canada, Canadian Forest Service (CFS)–Sault Ste. Marie and the Ontario Ministry of Natural Resources (OMNR) to study the effects of full-tree and tree-length harvesting on site productivity in northeastern and northwestern Ontario. Concurrently, a number of studies have been initiated to summarize available information on the effects of harvesting jack pine and black spruce in the boreal forest so as to provide interim management information for decision makers, and to determine information gaps. The first product was an annotated bibliography on long-term forest productivity in the boreal forest (Taylor et al. 1995). This second report summarizes the results of an opinion survey on the impacts of full-tree and tree-length harvesting on site productivity in the boreal forest. The participants included both Canadian and American scientists who are active researchers in the field of boreal forest productivity, government field staff who manage Crown forests, and company foresters who manage private lands and portions of Crown lands for the sustainable production of wood products. A third report summarizes best practices for maintaining site productivity following forestry activities on shallow, nutrient-poor, and organic sites.[1]

Much of Canada's fiber production is harvested from the boreal forest, and many of the products derived from this region are sold on the international market. Forest practices in areas producing wood products for export are coming under increased national and international review. There are concerns that harvest-related activities (e.g., extensive aboveground biomass removal from boreal sites) are causing long-term effects. These concerns have increased as full-tree harvesting methods become more common.

Concerns with full-tree logging, expressed at class environmental assessment hearings over the past several years; decline in the extent of Ontario's conifer forests, documented in the recent provincial forest audit (Hearnden 1992); and recent changes in forest technology and forest management practices have led to the establishment of a joint federal–provincial Technical Working Group on Sustainable Productivity of Boreal Forest Ecosystems. The objective of this working group is to coordinate research and information exchange on boreal forest productivity. Federal research scientists are studying jack pine (*Pinus banksiana* Lamb.) forest communities; provincial scientists are studying various aspects of black spruce (*Picea mariana* [Mill.] B.S.P.) ecology. The working group was established in December 1991 to coordinate research and information exchange so as to satisfy information needs identified under the Ontario Sustainable Forestry Initiative (Ontario Ministry of Natural Resources 1991), the Ontario Environmental Assessment Process (Environmental Assessment Board 1994), and the Forestry Canada Ontario Region Strategic Plan (Forestry Canada 1990). It's mandate includes establishing multiyear studies to quantify harvesting impacts on site productivity, ensuring common research methodologies, and developing guidelines for harvesting. It has also been assigned the task of presenting interim guidelines on best practices to maintain site productivity based on research results and expert opinion.

The working group is comprised of research scientists from Natural Resources Canada, Canadian Forest Service–Sault Ste. Marie; the Ontario Forest Research Institute (OFRI), Ontario Ministry of Natural Resources; and the Centre for Northern Forest Ecosystem Research Institute (CNFER). Working group members are listed in Table 1. A list of commonly used acronyms can be found in Appendix A.

Both agencies are examining boreal site productivity within the following research areas:

i) ecosystem classification and dynamics;
ii) development of interim guidelines and indicators;
iii) nutrient cycling modeling;
iv) biomass removal experiments; and
v) seedling ecophysiology assessment.

The current focus of activity deals with anthropogenic impacts that may affect sustainability. The project's principal studies will quantify the disruption and restoration of ecosystem function, particularly with respect to harvesting and other operational treatments, such as site preparation, prescribed burning, etc., in order to predict the effects of these operations on the long-term productivity of boreal ecosystems. The locations of existing CFS and OMNR research sites are displayed in Figure 1.

[1] Kershaw, H.M.; Jeglum, J.K.; Morris, D.M. Best practices for maintaining site productivity in boreal jack pine and black spruce forests. Nat. Resour. Can., Canadian Forest Service–Sault Ste. Marie, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. (In prep.)

Figure 1. Location of jack pine and black spruce research sites in Ontario.

A definitive scientific understanding of the risk to sites of a loss in productivity related to harvesting activities, however, will require extensive research over a period of years. Until the results from such long-term studies are available, this report provides an interim synthesis of expert opinion on the nature and extent of potential forest productivity changes associated with full-tree and tree-length harvesting regimes in jack pine and black spruce forests. Members of the working group agree that nutrient-poor and sensitive areas (e.g., shallow, coarse-textured soils, and organic sites) represent the greatest concern for sustainable forestry in the North. These systems were the subject of detailed discussion at a series of workshops conducted in 1993 and 1994, and were addressed via a number of specific questions on the questionnaires.

Expert opinion was solicited and information exchange promoted through the distribution of a series of questionnaires dealing with harvesting effects on site productivity, and at four workshops attended by researchers

Table 1. Sustainable productivity of boreal forest ecosystems technical working group.

	Natural Resources Canada, Canadian Forest Service	Ontario Ministry of Natural Resources
Cochairs	Dr. J.K. Jeglum/H.M. Kershaw Dr. N.W. Foster Dr. I.K. Morrison	Mr. D.M. Morris Dr. A.G. Gordon Dr. N. Balakrishnan

and practitioners who work with eastern North American boreal ecosystems. Results from these surveys are presented in this report. They provide an indication of those site conditions considered to be most sensitive to current forestry practices, and highlight gaps in the current understanding of processes associated with harvesting activities on site productivity.

Overview of Forest Productivity

Forest productivity is limited by the capability of the land base to support growth and development (Carmean 1975, Kramer and Kozlowski 1979). It varies with species composition, genetics, local climate, soil texture, drainage, soil depth, and site history (Wilde 1952, Barbour et al. 1987). Forest humus, ground cover, and microclimatic conditions have a strong influence on nutrient cycling and associated tree growth (Coile 1952, Foster and Morrison 1983). Site productivity can be measured in a variety of ways. Site index, which identifies the height of dominant, free-growing trees of a particular species at a specific age (Plonski 1974, Carmean 1975, Clutter et al. 1983), is often used as an index of site productivity. Total biomass or standing crop measures the dry weight of organic matter per unit area in a particular component of the ecosystem at a particular instant in time. It is a second measure of site productivity and can be related to site production using a standard formula (Clutter et al. 1983, Moore and Chapman 1986). In more detailed studies, net primary production or the amount of organic matter incorporated by a plant on an area basis (gross primary production minus the loss due to respiration) over a given period of time provides a more dynamic index of the capability of the site to support plant production (Moore and Chapman 1986). These measures account for the rate of accumulation and decomposition of biomass on a given site, and this relates to the rate at which resources are made available for plant growth (carrying capacity).

There are indications in the literature that harvesting methods in boreal forest communities may significantly influence biological productivity and nutrient status through such physical site impacts as soil compaction, rutting, erosion (particularly on shallow soils and on steep topography), mixing of nutrient-rich soil surface horizons with nutrient-poor lower horizons (during site preparation activities), destruction and/or loss of surface organic matter, and removal of nutrient-rich vegetation such as twigs and leaves during harvesting or site preparation (Gordon 1981, Gordon[2], Groot 1987, Maliondro 1988, Foster and Morrison 1989). Harvesting methods can also influence soil microflora and fauna, which in turn can influence long-term site productivity (Switzer and Nelson 1972, Gosz et al. 1976, Hendrickson et al. 1985).

Timber harvesting and management activities can also influence species composition and forest structure. In turn, this may modify ecosystem function. This function includes the rate of biological energy flow, the rate of nutrient and material cycling, and the ecological regulation of not only these two fluxes but of organisms within the system that are dependent upon them (Odum 1962). Net primary production represents the captured energy (carbon dioxide fixation and conversion to chemical energy) available for all other trophic levels within the food chain for the ecosystem. Although the focus of this study is limited to net primary productivity, the study team recognized the linkages to wildlife productivity. For example, forestry operations influence the availability of nest sites for forest birds and the provision of browse (Telfer 1974, Welsh and Fillman 1980). They can also modify riparian communities and increase or decrease beaver *(Castor canadenis)* populations. Forestry practices can remove or enhance suitable habitat for small but important components of boreal ecosystems. For example, it has been reported that small mammal populations, important in the distribution of seeds, fungal spores, and mycorrhizae, change in composition and numbers following clear-cutting in boreal black spruce forests (Martell and Radvanyi 1977, Martell 1979, Martell and Macaulay 1981).

In turn, changes in wildlife productivity can have a direct influence on site productivity for tree communities. One of the workshop themes was harvesting–wildlife linkages. It was determined at this workshop that the scope of a single study would be too broad to include all aspects of

[2]Gordon, A.G. 1982. The consequences of full-tree logging and biomass harvesting relative to maintaining forest ecosystem stability. Paper presented at the 1982 Annual Meeting of the Ontario Professional Foresters Association. 29 January 1982, Sault Ste. Marie, Ontario.

site productivity, and that the focus should remain on the site's ability to maintain levels of net primary production. Ultimately, these drive energy and productivity values at all other trophic levels within forest ecosystems.

Taylor et al. (1995), in their collection of literature on long-term productivity, indicate that the following were commonly cited as harvesting impacts on site productivity:

i) removal of nutrients contained in biomass;
ii) physical changes to the soil associated with the effects of heavy equipment on mineral and organic soils, including compaction, soil mixing, and drainage pattern disruption;
iii) effects of road building on erosion and stream water quality;
iv) loss of biodiversity associated with changes in species composition and forest structure;
v) changes in patch size and age distributions for various ecosystem components; and
vi) loss of old-growth forests and other critical habitats.

A concern expressed during the class environmental assessment (EA) hearings in Ontario was the impact of full-tree harvesting on site productivity (Environmental Assessment Board 1994). This practice concentrates nutrients at the roadside into slash piles, thereby resulting in increased nutrient depletion on the harvested sites compared to nutrients left on-site when harvested trees are delimbed at the stump. Intensive site preparation, such as blading, also concentrates the remaining superficial forest floor materials into windrows, leaving wide strips of exposed mineral soil and further decreasing surface organic matter.

The potential impact of forest industrial activities on site productivity is a complex subject, as outlined in past literature reviews (Leaf 1979, Kimmins et al. 1985, Standish et al. 1988), and will require intensive research. In the interim, there is a need to identify those systems that are most sensitive to changes and to identify known concerns. The authors believe that the following results accurately reflect the best informed judgments of the forestry community on the extent and likelihood of the impact of full-tree harvesting on site productivity.

QUESTIONNAIRE SURVEY OF EXPERT OPINION

Survey Technique

Scientists and other government and company staff involved in either boreal forest ecology or silviculture programs were contacted by mail to solicit their expert judgement on the potential impacts of full-tree harvesting on forest productivity. The Delphi Technique (U.S. General Accounting Office 1969, Fraser et al. 1985), a set of carefully designed sequential questionnaires, interspersed with summarized information and feedback of opinions from earlier responses, was adapted for this study. This technique was designed to facilitate judgemental decision making through the pooling of knowledge.

The first questionnaire in this study asked individuals to respond to broad, general questions designed to facilitate open-ended responses and to identify specific issues. Many of the participants were contacted by telephone to discuss the project, to remind them to respond to the questionnaire, and to exchange information on studies in boreal forest productivity and forestry impacts. The specific concerns and issues that were identified from the initial response were used to formulate a more structured second questionnaire that asked participants to rank specific attributes on a relative scale of importance from one to five. In this way, general responses about the types of impacts of full-tree and tree-length harvesting on long-term productivity led to the development of a series of scenarios with respect to the impact of these forestry practices on productivity factors, stratified by broad site conditions.

Results from the second survey were used to reorder the questionnaire categories from the greatest to the lowest concern. This revised questionnaire was returned to the participants with concerns listed in order of assigned importance (Appendix B). They were then asked to confirm or modify mean rankings. In addition to the mailing, many of the participants were invited to a related workshop where the results were summarized and presented. This allowed for information exchange prior to the completion of the third questionnaire. The survey process is outlined in Figure 2.

Participant Selection

One hundred and nineteen questionnaires were mailed to preselected individuals who worked with boreal forest ecology. This list was submitted to the working group for review and approval. Individuals were selected from a diverse background and geographic range. The survey was forwarded to research scientists at the federal and provincial levels of government; university research scientists from Ontario, New Brunswick, Alberta, and the Lake States; forest company staff; the forester for the North Shore Tribal Council; and representative Ontario government forestry and wildlife staff referred to as "government field staff". Only one individual responded negatively to the request to participate in the survey, citing extreme discomfort with the degree of speculation required and concern that the survey outcome would have negative effects on permitted forestry practices in the absence of scientific evidence.

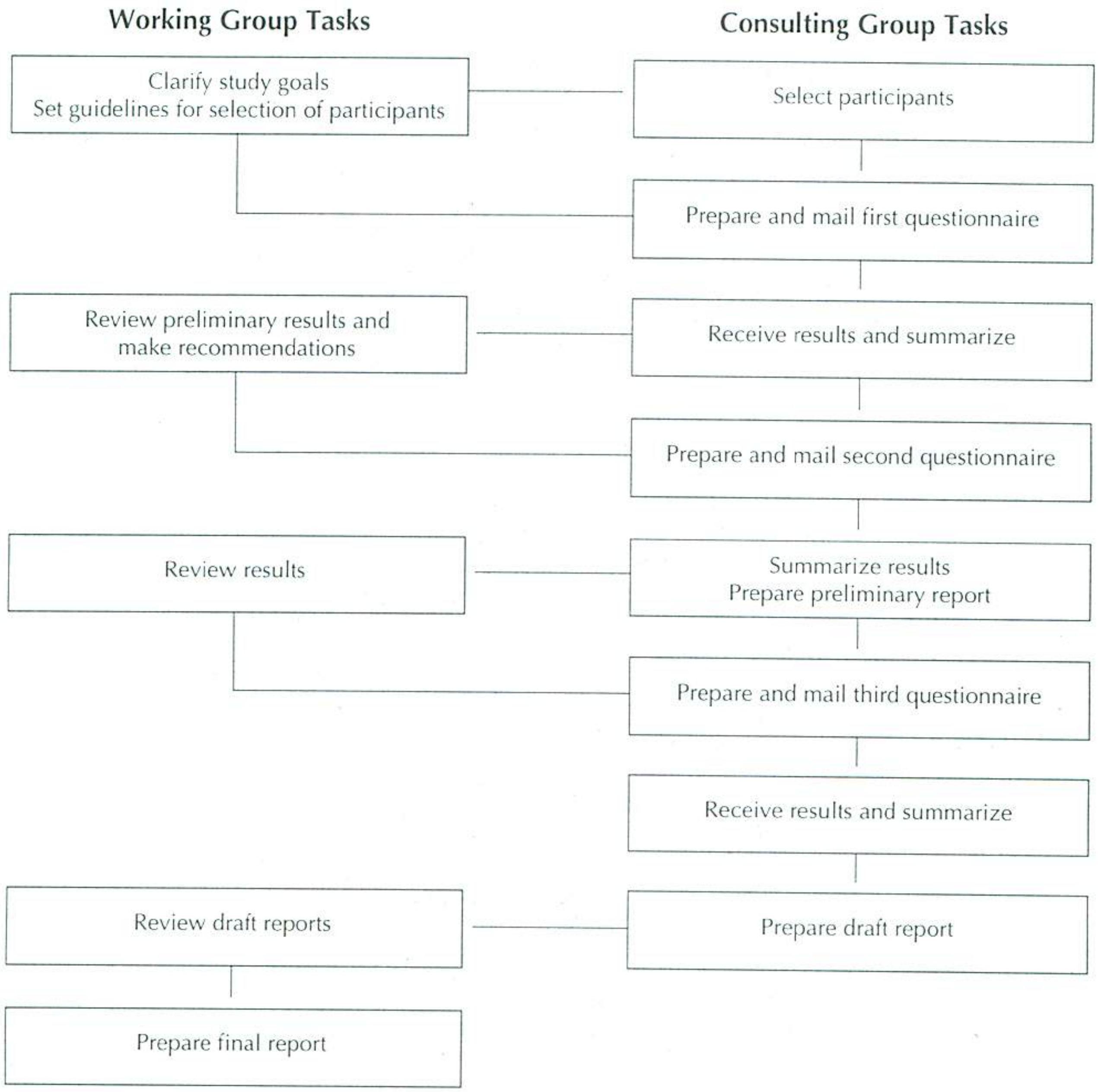

Figure 2. Project flow chart.

Individuals were specialists in forest ecology (vegetation and wildlife), silviculture, and ecophysiology. The results were tabulated to show the distribution of concerns among the research and field communities.

Results of Questionnaire Survey

Response to the questionnaires is summarized in the following section. The return of a preliminary test questionnaire was low (12), with individuals citing time constraints, concerns with the "open" nature of the questions, and uncertainty with how the information would be used. This approach was abandoned and a more structured questionnaire was developed based on responses from the initial contact. This structured questionnaire was then mailed to participants. Most participants were also contacted by telephone to provide an opportunity for information exchange.

The results from this survey were considered interim and were used to develop a final questionnaire. The response to both structured questionnaires was 40 percent (48 questionnaires). Return rates as low as 20 percent are considered acceptable from mail surveys. It is the results from this third questionnaire, where respondents had an opportunity to evaluate and revise their initial responses, that are presented. A mean ranking for each factor was calculated based on the responses. No modifications were adopted where a respondent failed to assign a rank to an individual factor. For Questions 2, 3, and 4, the response from the scientific community was compared to the response from forest industry and government field staff. Responses from two individuals that did not fall into these three categories were included only in the overall mean ranking. Any wide variation in response to a question was identified. These were viewed as areas requiring future research.

Respondent characteristics

The first three questions were designed to identify the field of expertise, employment category, and geographic expertise of the participant population. The majority of the participants were government employees. This reflects the heavy government involvement in boreal forest research and silviculture in Ontario. This section is organized by question as they appeared on the questionnaire sent to the participants.

Question 1a. Please describe your area of expertise with respect to boreal ecology.

The majority of respondents were Ontario provincial government employees, specializing in forest ecology and the silviculture of jack pine and black spruce (Table 2). Of those who responded to the initial survey, 65 percent specialized in forest ecology, 59 percent specialized in silviculture, and 12 percent specialized in soil science. Very few individuals specialized in other areas of research. As some individuals specialized in more than one area, totals can exceed 100 percent. Similarly, the response to the second survey was primarily from those who specialized in forest ecology (50 percent) and silviculture (50 percent). Of those who specialized in forest ecology, 50 percent focused on nutrient cycling; 72 percent indicated that they studied vegetation–soil relationships. Only 10 percent of those who responded to the final questionnaire defined themselves as experts in soil science; 4 percent indicated that they specialized in microclimatology and ecophysiology. Very few to no respondents specialized in landscape ecology, zoology, entomology, pathology, aquatic biology, or hydrology. Future workshops and surveys should target researchers in these fields so as to include their input.

Question 1b. What is your employer category?

Collectively, government represented 61 percent of the second questionnaire response and 66 percent of the final questionnaire response. Federal and provincial research scientists provided the greatest response to all of the questionnaires, representing 32 percent and 7 percent, respectively. Provincial employees directly involved in harvesting and silvicultural planning and operations represented an additional 22 percent and 27 percent of the response to the second and final questionnaires, respectively. The response from these two groups was fairly consistent throughout the survey. In contrast, participation by university staff fell from an initially high response of 21 percent to 12 percent. Time constraints were cited as the reason for the reduced return rate. Response from the private sector (forest industries) rose from 14 percent in the initial survey to 22 percent in the final survey (Table 3). One response was received from the North Shore Tribal Council.

Question 1c. What is your geographic expertise?

Most of the respondents (initial survey, 80 percent; final survey, 90 percent) indicated that they worked in Ontario (Table 4). Response from those who worked outside Ontario (Quebec, Alberta, New Brunswick, and the Lake States) was low, reflecting the limited targeting of researchers in these geographic areas. Again, percentages may exceed 100 percent because some respondents indicated that they worked in more than one geographic area.

Delineation of critical issues and concerns

As expected, there was a general consensus that full-tree harvesting would have an impact on site productivity under certain site conditions and silvicultural treatments. For example, on shallower sites the primary concern was nutrient removal. On deeper, fresh to moist sites, consensus pointed to plant community changes (e.g., stand structure, species shifts).

Table 2. Field of study of those who responded to the survey.

Field of study	Second questionnaire (percent of respondents)	Final questionnaire (percent of respondents)
Forest ecology	65	50
Soil science	12	10
Microclimate and ecophysiology	4	4
Silviculture	59	50
Other	8	4

Total number of respondents: 48 (second questionnaire); 48 (final questionnaire).

Table 3. Employment sector of survey respondents.

Employment sector	Second questionnaire (percent of respondents)	Final questionnaire (percent of respondents)
Government	61	66
University	21	12
Private sector	14	22
Other (First Nations)	04	00

Total number of respondents: 48 (second questionnaire); 48 (final questionnaire).

Table 4. Mean rank, by employment category, of harvesting impacts on site productivity indicators for black spruce communities in the boreal forest region.

Site productivity indicators	Scientists	Industry	Field staff	All respondents
Shallow uplands				
Loss of organic matter	1.1	2.1	2.1	1.7
Nutrient removal	**1.9**	2.5	1.5	2.0
Decomposition processes	2.6	3.3	2.7	2.4
Erosion	2.5	2.9	3.2	2.7
Altered hydrology	3.6	3.3	3.7	3.3
Rutting	4.6	3.4	4.7	4.0
Compaction	3.9	3.6	3.1	3.4
Forest structure changes	3.1	3.5	3.8	2.8
Species shifts	3.7	4.2	3.1	3.1
Dry deep sites				
Loss of organic matter	2.5	3.4	**2.1**	2.1
Nutrient removal	2.3	4.3	**1.7**	2.1
Decomposition processes	2.5	4.0	2.9	2.4
Erosion	3.5	3.3	3.5	3.1
Altered hydrology	3.5	4.3	4.0	3.3
Rutting	4.0	4.4	4.5	3.6
Compaction	3.8	3.1	3.8	3.5
Forest structure changes	3.1	3.8	2.8	2.4
Species shifts	3.5	3.9	3.1	3.4
Fresh to moist				
Loss of organic matter	2.6	3.3	2.9	2.5
Nutrient removal	**2.4**	**2.9**	3.3	2.6
Decomposition processes	**2.1**	3.8	3.0	**2.4**
Erosion	3.2	3.6	3.5	3.4
Altered hydrology	3.1	3.5	**2.4**	2.8
Rutting	2.5	3.6	3.8	2.9
Compaction	2.5	3.3	2.6	2.5
Forest structure changes	**1.9**	3.5	**2.4**	**2.1**
Species shifts	**2.2**	**2.6**	**2.4**	**2.2**

Average rank values were calculated from questionnaire responses. These are ranked from 1 (most important) to 5 (least important); **bold** figures indicate the highest ranked factors.

Question 2. What are the major harvesting impacts on site productivity?

Individuals were asked to separately identify potential harvest impacts on site productivity for jack pine forests growing on dry shallow soils, dry deep soils, and fresh to moist soils (Table 4). Similarly, they were asked to identify potential harvest impacts on site productivity for black spruce forests growing on upland shallow soils, deep mineral soils, wet mineral soils, and wet organic soils (Table 5). They were further asked to assign a rank, from 1 (very important) to 5 (least important), to each impact. A low value, therefore, represents a high concern. Values in bold represent those factors that were identified as being of greater concern (less than or equal to a rank of 2.5), based on survey response.

Jack pine: With respect to harvesting jack pine on shallow sites, nutrient loss (**2.0**), loss of organic matter (**1.7**) through biomass removal in industrial wood, and loss of soil through accelerated surface soil erosion (**2.7**) had the lowest mean ranks (reflecting greatest concerns) (Table 4). Species shifts were given intermediate ranks. Forest structure changes, rutting, and compaction were given high rankings (low concern). Nutrient removals (**2.1**), loss of organic matter (**2.1**), and stand structure changes (**2.4**) were identified as areas of greater concern on dry deep sites. Stand structure changes (**2.1**) and species shifts (**2.2**) were given the lowest ranks (factors of greater importance) on fresh to moist sites following harvest. The importance of these changes are not well understood and the matter requires further investigation.

Scientists, industry staff, and government field staff all indicated that they were concerned with nutrient removal. Of concern also was the loss of organic matter on shallow dry sites (Table 4). Many respondents indicated that this should be the focus of further research to define where and when problems occur, and to determine the magnitude of changes. Scientists (**1.9**) and field staff (**1.5**) assigned a lower rating (indicating greater importance) than did industry (**2.5**). Operational concerns on these dry, shallow sites (for example the effects of logging on compaction, rutting and altered hydrology) were given greater weight by industry representatives than by scientists. This is reflected in the literature, where very few scientific studies address harvesting effects on physical site changes on shallow sites. A few respondents provided two ranks, one for level terrain and one for steeply sloped terrain. They also indicated that clear-cut size, season of harvest, and other compounding factors (such as forest age and composition, weather conditions at time of harvest) affect the importance of site impacts. The rankings assigned, therefore, represent only average conditions.

Scientists ranked loss of organic matter (**2.5**), nutrient removal (**2.3**), and decomposition processes (**2.5**) as factors of intermediate concern on deep dry sites (Table 4). Industry assigned higher ranks (**>3.0**), indicating less concern, for all harvesting impacts on these sites than did the scientists and provincial field staff. Government field staff indicated greatest concern with nutrient removals (**1.7**) and loss of organic matter (**2.1**) on these sites.

On fresh to moist sites, mean rankings indicate that stand structure changes (**2.1**) and species shifts (**2.2**) are, on average, the factors of greatest concern (Table 4). Scientists also indicated concern with decomposition processes (**2.1**) and nutrient removals (**2.4**) on these sites. Loss of organic matter, nutrient removal, and decomposition processes are all associated with nutrient availability. Differences in ranking of importance for these three processes may reflect varying interpretations of these terms. This highlights the need to select terms that are commonly used by each group, or to fully define terms, in any survey of expert opinion.

Overall, loss of organic matter (**1.7**, **2.1**) and nutrient removal (**2.0**, **2.1**) were rated as the greatest concern on shallow uplands and dry, nutrient-poor jack pine sites, respectively. Changes in stand age structure (**2.1**) and species shifts (**2.2**) were identified as key concerns on fresh to moist sites. Species shifts largely reflect concern with a reduction of the spruce and pine component in boreal forests, and a lack of good information on the effects of changing understory plant species composition.

Black spruce: Mean rankings for shallow upland black spruce sites (Table 5) were similar to those listed for dry jack pine forests: namely, loss of organic matter (**1.5**) and nutrient removal (**1.9**). These factors were not highlighted as critical concerns for black spruce on other site conditions. On the deep mineral sites, species shifts (**1.9**) and stand structure changes (**2.0**) were assigned the lowest ranks (greatest concern). Altered hydrology (**1.6**, **1.4**) and rutting (**1.7**, **1.6**) were considered to be the major impacts on wet mineral and wet organic sites.

When viewed by participant group, scientists and government field staff ranked nutrient removal (**1.9**, **1.6**) and loss of organic matter (**1.1**, **1.7**), respectively, as factors of greatest concern on upland black spruce sites (Table 5). Industry also placed greatest concern on the loss of organic matter (**2.1**). Such response indicated a need for further research on harvesting impacts and nutrient cycling on shallow upland sites.

In general, all groups ranked stand structure changes (**2.0**) and species shifts (**1.9**) as factors of greatest concern on these deep mineral sites (Table 5). Government field staff

Table 5. Mean rank of harvest impacts on black spruce sites.

	Scientists	Industry	Government field staff	Mean
Shallow uplands				
Loss of organic matter	1.1	**2.1**	1.7	1.5
Nutrient removal	**1.9**	3.0	1.6	1.9
Erosion	2.5	3.0	2.3	2.4
Altered hydrology	4.4	3.6	3.57	3.2
Rutting	4.1	4.6	4.1	3.9
Compaction	3.2	3.2	3.2	3.5
Loss of advanced growth	2.7	**2.7**	2.2	2.8
Loss of seedbed	2.7	3.7	2.4	2.7
Stand structure changes	2.5	3.2	2.2	2.5
Species shift	3.5	3.1	2.2	2.9
Wet mineral soils				
Loss of organic matter	3.8	4.0	3.0	3.3
Nutrient removal	2.5	3.9	3.0	3.0
Erosion	3.8	3.2	3.6	3.5
Altered hydrology	**1.8**	2.2	1.9	1.6
Rutting	1.8	2.0	1.9	1.7
Compaction	2.6	2.1	1.8	2.1
Loss of advanced growth	2.7	2.8	2.6	2.6
Loss of seedbed	2.5	3.8	2.1	2.9
Stand structure changes	2.6	4.4	2.6	2.7
Species shift	2.6	3.1	2.9	2.7
Deep mineral soils				
Loss of organic matter	2.7	4.3	3.6	3.1
Nutrient removal	2.5	4.0	3.2	3.1
Erosion	3.2	3.7	3.1	3.4
Altered hydrology	2.9	2.9	2.5	3.0
Rutting	2.9	3.2	3.5	3.2
Compaction	2.4	2.8	2.8	2.6
Loss of advanced growth	2.4	2.9	2.2	2.7
Loss of seedbed	2.8	3.4	2.3	3.0
Stand structure changes	2.0	2.7	2.2	2.0
Species shift	2.4	2.1	2.1	1.9
Wet organic sites				
Loss of organic matter	3.3	1.8	4.2	4.1
Nutrient removal	2.7	1.5	3.3	3.2
Erosion	3.6	3.5	4.7	4.4
Altered hydrology	1.2	3.3	1.2	1.4
Rutting	2.0	3.5	1.3	1.6
Compaction	2.8	3.2	3.0	3.3
Loss of advanced growth	2.2	2.0	3.1	2.7
Loss of seedbed	2.3	4.0	2.5	2.8
Stand structure changes	2.4	3.2	2.4	2.9
Species shift	2.8	2.7	2.8	3.1

Average rank values were calculated from questionnaire responses. These are ranked from 1 (most important) to 5 (least important); **bold** figures indicate the highest ranked factors.

also indicated that the loss of advanced growth (**2.2**) and the loss of seedbed (**2.3**) were of concern. Scientists ranked loss of advanced growth as a factor of some concern (**2.4**) on these sites.

Overall, altered hydrology (1.4) and rutting (1.6) received ranks of greatest concern on wet organic sites. Scientists and field staff, respectively, emphasized these concerns, but assigned very low ranks to altered hydrology (1.2, 1.2) and rutting (2.0, 1.3). Industry assigned low ranks to loss of organic matter (1.8) and nutrient removal (1.5) on these sites to emphasize the need for information on the effects on future productivity of biomass removal (organic matter and nutrients) from wet sites. Loss of advanced growth (2.0) was also ranked low by industry, thereby reflecting their concern with practices that fail to retain advanced regeneration.

Question 3. What are the key ecosystem processes altered in nutrient poor boreal sites?

Overall changes in the nitrogen (**2.2**), phosphorus (**2.4**), and calcium (**2.4**) cycles, as well as carbon allocations (**2.5**), were ranked highest as key ecosystem processes altered by full-tree harvesting on nutrient-poor sites (Table 6). In addition to nutrient cycling impacts, biomass production, decomposition processes, leaching, the hydrological cycle, and species shifts or changes in successional pathways were rated of high concern with mean ranks between **2.7** and **2.8**. Seedbed quality/quantity (**2.4**) changes received the lowest rank (highest concern) with respect to tree-length harvesting impacts. Changes in the nitrogen cycle, phosphorus cycle, decomposition processes, and species shifts also had mean rankings less than **3.0**.

A number of other effects were listed in the comments section of the survey form. These included: "changes in patch dynamics, stand structure, species/age diversity, mineralization and leaching, renewal, and reestablishment processes", and "a decline in the ratio of photosynthesis to respiration".

When the data were summarized by employment category, scientists ranked the nitrogen (**1.7**) and calcium (**2.3**) cycles, carbon flow (**2.4**), and leaching (**2.4**) as the highest impacts from full-tree harvesting (Table 6). Government field staff ranked leaching (**1.5**) as the impact of greatest concern. Industry placed changes in fuel loads (**2.5**), the nitrogen cycle (**2.5**), and the calcium cycle (**2.6**) as the three factors of greatest concern. Several respondents wrote that fuel was often insufficient to carry prescribed fire on these sites, thereby reducing the opportunity for this site preparation option. Changes in seedbed quantity/quality (**2.1**, **2.0**, **2.4**) was ranked highest by scientists, government field staff, and overall, respectively, as the primary impact of tree-length harvesting (Table 6).

Question 4. What forestry practices could be adopted to minimize harvesting impacts?

Strategies that were suggested for minimizing the potential impacts of full-tree and tree-length harvesting are ranked in Table 7. The most important options for shallow sites under full-tree harvesting systems were: avoidance (**1.9**), spreading slash (**2.0**), careful logging (**2.1**), and processing at the stump (**2.1**). These recommendations reflect concerns with nutrient removal from sites associated with biomass removal, mass displacement through soil erosion, and altered site microclimate following harvesting. For areas harvested using tree-length systems, processing at the stump (**2.0**), spreading slash (**2.3**), careful logging (**2.2**), avoiding shallow sites (**2.2**), and the general application of conservation methods (**2.3**) were the preferred options.

With few exceptions, scientists gave greater weight to each suggested approach for minimizing impacts of harvesting on long-term productivity than did industry and government field staff (Table 7). This may reflect the focus of many scientists in understanding ecosystems and how activities will affect ecosystem processes. Within the forest industry, the focus is on determining the most efficient methods for regenerating the forest following harvesting rather than on longer-term, more theoretical issues of site productivity over multiple rotations. Scientists assigned the greatest weight (mean ranks less than **2.0**) to applying conservation methods, such as avoiding shallow sites, adopting careful logging practices, processing wood at the stump, and retaining/spreading slash back on harvested sites. Fertilization was not identified by any of the groups as a practical measure for minimizing harvest-related nutrient losses on these sites. Lengthening rotations, adopting tree crop rotations, and using prescribed fire to minimize impacts were also ranked low in priority as practical mitigating measures.

Question 5. What are the key nutrient and site factors that should be monitored?

Individuals surveyed identified site disturbance (**2.1**, **2.0**), change in percentage organic matter (**2.1**, **2.2**), and species shifts (**2.1**, **1.9**) as the key factors to monitor following full-tree or tree-length harvesting (Table 8). There was a consensus that monitoring complete or partial nutrient cycles is appropriate only as a research tool. Respondents indicated a need to develop practical field monitoring methods to assess impacts. There were also comments concerning the lack of information on threshold levels of organic matter removal without future growth reduction. Some respondents noted the short-term benefits to pine regeneration of reductions in surface organic matter.

Table 6. Mean rank of key ecosystem functions altered in nutrient poor boreal sites.

	Scientist	Industry	Government field staff	Mean
Full-tree harvesting				
Biomass production	2.7	2.9	2.7	2.7
Decomposition	2.7	3.3	2.6	2.7
Carbon cycle	2.4	3.3	2.4	2.5
Nitrogen cycle	**1.7**	**2.5**	2.9	2.2
Phosphorus cycle	2.6	2.9	2.1	2.4
Potassium cycle	2.6	2.9	3.0	3.1
Calcium cycle	**2.3**	**2.6**	2.9	2.4
Magnesium cycle	3.3	3.3	2.9	3.0
Hydrologic cycle	2.7	2.9	3.1	2.7
Leaching	2.4	3.7	**1.5**	2.8
Soil structure	2.9	4.8	3.7	3.3
Fuel load	3.6	**2.5**	**2.1**	3.4
Seedbed quality/quantity	2.8	3.1	3.3	3.0
Species shifts/succession	2.5	3.8	2.6	2.7
Tree-length harvesting				
Biomass production	3.1	3.8	3.4	3.5
Decomposition	2.8	3.4	2.6	2.9
Carbon cycle	2.9	3.3	3.1	3.3
Nitrogen cycle	2.7	2.9	2.9	2.8
Phosphorus cycle	3.0	3.6	2.7	2.9
Potassium cycle	3.6	3.1	3.0	3.2
Calcium cycle	3.1	3.4	3.0	3.1
Magnesium cycle	3.7	3.5	2.9	3.3
Hydrologic cycle	2.9	3.9	3.6	3.0
Soil structure	3.0	4.4	3.6	3.1
Fuel load	3.2	4.0	2.8	3.0
Seedbed quality/quantity	**2.1**	3.6	**2.0**	**2.4**
Species shifts/succession	2.7	3.4	2.6	2.9

Average rank values were calculated from questionnaire responses. These are ranked from 1 (most important) to 5 (least important); **bold** figures indicate the highest ranked factors.

Measuring the length of the growing season; the availability of nutrients; changes in soil pH; changes and recovery of bulk density; forest floor disturbances, including the survival of advanced growth and the extent of 'deep' rutting; assessing slash loading; and recording a suite of indicator species were suggested as factors for monitoring in the second survey. The response from the final survey provided mean ranks for these and other parameters identified as concerns in earlier questions. Differences in ranking assigned by industry, field, and research communities were not identified for this question. Many individuals within each group declined responding to this question, or responded only partially, citing a lack of information as to what measures would be practical, efficient, and effective. This further emphasized the need to develop a concise but effective monitoring system.

Questions 6 to 9. Other information

One of the early objectives of this survey was to catalogue information available as internal file notes, research in progress, and published information. Of the respondents, 37 percent forwarded a list of publications. These were included in the annotated bibliography (Taylor et al. 1995). Journals, books, and file reports were the most frequently cited publications. An overwhelming majority of respondents requested that the annotated bibliography be forwarded to them upon completion, thereby confirming their interest in this subject.

Table 7. Mean rank of alternate methods for minimizing impacts on nutrient poor sites.

	Scientist	Industry	Government field staff	Mean
FULL-TREE HARVESTING				
Conventional systems				
Avoid sensitive/shallow sites	**1.6**	2.6	**2.0**	**2.0**
Careful logging	**1.7**	**2.3**	3.1	**2.2**
Process at stump	**1.9**	2.6	2.4	**2.2**
Use high-flotation tires	2.6	2.8	**2.2**	2.8
Restrict season	3.0	2.7	2.6	2.9
Prescribed burning	3.6	3.3	3.0	3.8
Other systems				
Apply conservation methods	**1.9**	3.6	2.6	2.4
Design forest	2.5	3.2	2.8	2.9
Modify harvest patterns	**2.1**	3.2	2.7	2.7
Eliminate full-tree harvesting	2.3	3.9	3.7	3.2
Lengthen rotation	4.1	3.4	2.8	3.5
Tree crop rotation	3.4	4.1	3.1	3.6
Spread slash	**1.5**	2.9	**2.3**	**2.0**
Fertilize	3.7	4.8	4.4	4.4
Minimum understorey disturbance	n.a.	**2.3**	**2.2**	2.5
TREE-LENGTH HARVESTING				
Conventional systems				
Avoid sensitive/shallow sites	**2.0**	2.9	**2.3**	2.5
Careful logging	**1.8**	**2.3**	3.4	**2.3**
Process at stump	**1.5**	2.8	2.6	**2.2**
Use high-flotation tires	2.3	2.9	3.3	2.8
Restrict season	3.0	4.0	3.0	3.2
Prescribed burning	2.9	2.8	2.4	3.1
Other systems				
Apply conservation methods	**1.9**	3.7	3.4	2.6
Design forest	2.6	3.3	3.4	2.8
Modify harvest patterns	**1.9**	3.4	2.8	2.6
Lengthen rotation	3.5	4.2	3.6	3.9
Tree crop rotation	3.2	4.6	3.4	3.9
Spread slash	**1.8**	3.3	**2.1**	**2.4**
Fertilize	3.9	4.8	4.4	4.5
Minimum floor disturbance	2.5	**2.2**	3.3	2.8

Average rank values were calculated from questionnaire responses These are ranked from 1 (most important) to 5 (least important); **bold** figures indicate the highest ranked factors.

To minimize the possibility of overlooking a key research scientist, respondents were also asked to identify colleagues who worked in the field of boreal ecology. Interest in attending an information session on boreal forest ecosystem productivity was also solicited through the questionnaire. Of the respondents, 78 percent indicated an interest in attending these sessions. Specific areas of interest included harvesting and silvicultural practices related to site productivity (48 percent), modeling impacts of alternate silvicultural practices (33 percent), seedling ecophysiology and growth response (33 percent), and wildlife linkages (26 percent). These workshops were held in April 1993, and are summarized in the following section.

Table 8. What key nutrient elements, physical site factors or other parameters should be consistently monitored and measured?

Impacts	Average rank (1–5)	
	Full-tree harvesting	Tree-length harvesting
Physical parameters		
Soil depth	3.4	3.3
Soil texture	3.6	3.4
Soil compaction (bulk density)	2.5	2.7
Site disturbance	**2.1**	**2.1**
Depth and amount of rutting	2.4	2.7
Percent on-site slash	2.4	2.5
Chemical parameters		
Change in percent organic matter	**2.1**	**2.2**
Carbon cycle	3.1	3.4
Nitrogen cycle	2.3	2.4
Phosphorus cycle	2.9	2.8
Potassium cycle	3.1	3.2
Calcium cycle	3.1	3.0
Magnesium cycle	3.3	3.5
Soil pH	3.1	3.0
Soil moisture	2.7	2.8
Hydrologic cycle	3.0	2.8
Biological parameters		
Length of growing season	3.8	3.7
Biomass production	2.5	2.6
Decomposition rate	2.9	3.1
Species shift/succession	**2.1**	**1.9**
Percent of advance growth	2.4	2.4
Habitat/landscape structure change	2.4	2.3
Key wildlife species	2.7	2.4

Average rank values were calculated from questionnaire responses. These are ranked from 1 (most important) to 5 (least important), **bold** figures indicate highest ranks.

WORKSHOP SURVEY OF EXPERT OPINION

Survey Technique

Four workshops were conducted in Ontario in April 1993 to bring together people involved in boreal forestry. Held in four locations in northern Ontario, these were designed to introduce interested people to the Sustainable Productivity of Forest Ecosystems Program being developed by the CFS and the OMNR. Workshops were designed to discuss predicted impacts on site productivity of full-tree harvesting compared to other harvesting systems. The emphasis was on jack pine and black spruce forests.

These workshops were to supplement information gathered through a comprehensive literature search, a broadly distributed questionnaire survey, and long-term field studies. Secondary objectives were to introduce the Technical Working Group on Sustainable Productivity of Boreal Forest Ecosystems to the forest science community, and to provide a forum for information exchange among those involved in boreal forest ecology.

Each of the workshops consisted of a morning session of presentations followed by a less structured afternoon session for information exchange and discussion on four themes. A scientist from the technical working group, plus one or more coordinators, organized each workshop. The location, themes, and workshop coordinators are listed in Table 9.

A scientist from the working group provided a presentation on the overall program at each location. Presentations were given by Dr. A.G. Gordon in Toronto; Dr. N.W. Foster in Timmins; Mr. D.M. Morris in Thunder Bay; and Dr. J.K. Jeglum and Ms. H.M. Kershaw in Sault Ste. Marie. The overview included a summary of events leading up to the establishment of the working group, the objectives of the working group, and an outline of the field sampling procedures.

Workshop Technique

Participants from the research community and forest industry, as well as provincial resource managers, were invited to attend four regional workshops that focused on wildlife linkages, silviculture, modeling, and ecophysiology. One member of the Technical Working Group on Sustainable Productivity of Boreal Forest Ecosystems provided an overview of their mandate. A facilitator then led discussions on the themes. Critical concerns were summarized through discussion and debates.

SUMMARY OF EXPERT OPINION

Summary of Questionnaire Survey

The potential impact of industrial forest activities on long-term productivity is a complex subject—one that will require extensive research. The results from this survey serve as only one of several interim reports that indicate those factors that are most likely to be negatively impacted by the removal of tree biomass through full-tree and tree-length harvesting systems. The current understanding of forest ecologists and silvicultural scientists and practitioners is that impacts are site specific. Differences of opinion, based on employment category, were most evident when evaluating organic and deep mineral black spruce sites. Greater uniformity of response in rating the key impacts of forest practices on drier sites represents greater consensus on key issues.

Nutrient removal is identified as the most critical concern on dry, jack pine sites; forest species shifts and structure changes are considered to be the two most critical changes on fresh to moist jack pine sites. For black spruce communities, greatest importance was placed on nutrient removals for shallow, upland sites. On deeper mineral sites, species shifts were identified as important factors. Altered hydrology, rutting, and compaction were ranked of greatest concern on wet mineral and organic sites.

The ranking of key ecosystem processes altered on nutrient-poor sites varied with the harvesting system. The survey results indicated that full-tree harvesting may modify the nitrogen, phosphorus, and calcium cycles along with carbon flow. Under the tree-length harvesting system, however, seedbed quality and quantity and species shifts were identified as the key structural aspects being altered. Planning measures that restrict full-tree harvesting on shallow sites and encourage the spreading of slash, careful logging, and processing at the stump were the most frequently cited mitigation measures for minimizing potential losses in site productivity.

It must be clarified that the results from this survey do not represent definitive answers to harvesting impacts, nor do they represent definitive evidence that the impacts occur. These findings, together with information from the published literature, represent the current state of knowledge in this subject area. It is hoped that they will contribute to future research design and hypothesis development.

Summary of Workshops

Toronto workshop—wildlife linkages

Dr. A.G. Gordon provided a program overview, and presented research results on site productivity and nutrient cycling within spruce communities. Projections from his research indicate that potassium may be a limiting element on sandy outwash sites and organic sites under repeated harvesting. Although his research indicates that nitrogen is usually limiting, it is generally the element least vulnerable to harvesting impacts. He emphasized that biomass removal impacts on site productivity vary with site conditions and treatments. Significant differences between the effect of logging and wildfires were also identified. These included different microclimatic conditions associated with standing dead timber as compared to total removal of standing trees, different nutrient pools, and different vegetation response. These differences need to be quantified to better understand how clear-cut harvesting methods affect site productivity, as compared to wildfire. Dr. Gordon was particularly concerned with the degree of nutrient leaching and loss of organic matter following full-tree harvesting plus prescribed burning. In practice, however, this is very uncommon in northern Ontario. Finally, Dr. Gordon raised the issue of the impact of growing genetically improved trees on nutrient supply; these trees may require more nutrients than natural populations. Industry representatives suggested that this concern would apply to a limited area as approximately 70 percent of cutovers are regenerated through natural regeneration or seeding.

There was a consensus that future research should examine the following:

i) the effect of perturbation on ecosystem structure and function; and
ii) the impact of full-tree harvesting followed by prescribed burning on the gene pool and site productivity.

Table 9. Workshops on the long-term productivity effects of harvesting.

Location	Date	Theme	Scientist and coordinator
Toronto (TO)	April 20	Wildlife	Dr. A.G.Gordon, OMNR Dr. M.E. Taylor, Geomatics Int. H.M. Kershaw, Devlin Consulting Services
Timmins (TI)	April 22	Silviculture	Mr. P.K. Bidwell, OMNR Dr. N.W. Foster, CFS H.M. Kershaw, Devlin Consulting Services
Thunder Bay (TB)	April 27	Modeling	Mr. D.M. Morris, OMNR H.M. Kershaw, Devlin Consulting Services
Sault Ste. Marie (SSM)	April 29	Ecophysiology	Dr. J.K. Jeglum, CFS H.M. Kershaw, Devlin Consulting Services

Dr. M. Taylor led the afternoon session on wildlife concerns. He raised a number of questions for the participants to address. These included:

i) What level of protection is required to maintain long-term site productivity?

ii) What, if any, wildlife species serve as effective bioindicators of changes in long-term site productivity?

iii) How should one address the "scale of site impacts" with respect to harvesting effects on long-term site productivity?

iv) Should a nested hierarchy be adopted in research designs?

A synopsis of the discussion in these areas is presented below.

i) Level of Protection for Forest Ecosystem Maintenance

This issue was not resolved. There were differences in opinion ranging from a need for very little disturbance in large areas to the need to study and mimic landscape level successional changes. Most participants agreed that disturbances in any one area within any rotation period should be restricted in size. There was also agreement that disturbance did not cease to exist when trees reach the "free to grow" or 3-m height level. Wildlife biologists emphasized the role of large, contiguous, undisturbed areas for certain species and the value of mature, large-diameter trees for nesting sites, cover, and food.

ii) Wildlife Species as Indicators of Change

Participants provided an overview of their own work. Dr. R. James studies songbird populations in jack pine. He emphasized that critical species and species groups used for monitoring vary from place to place. Generally, pileated woodpeckers (*Dryocopus pileatus*) leave an area when the large-diameter trees are removed. Northern goshawk (*Accipiter gentilis*) use small patches of large jack pine and hunt in 20-year-old jack pine. Although the literature indicates that extensive tracts of old growth are required for their survival, Dr. James did not observe this requirement in his study area. His review of the literature indicates that cavity nesters, in contrast to other bird species, are most affected by full-tree harvesting. Similar reductions would be associated with any clear-cut harvesting system.

Dr. J. Bendell discussed his work in the area of the Hwy. 144 and Hwy. 560 junction near Gogama, Ontario. He is examining those factors that determine the abundance and distribution of ruffed grouse (*Bonasa umbellus*) and spruce grouse (*Conachites canadensis*). Currently the focus of his work is on the effect of *Bacillus thuringiensis*, which is used to control eastern spruce budworm (*Choristoneura fumiferana* [Clem.]), on other animal populations.

Participants indicated that the capital or stock of wildlife species, in terms of species and distribution at all trophic levels within a given ecosystem on the site, are critical. Specific groups of species should be followed at different scales of observation. Dr. Bendell provided examples of linkages of research results at different scales, and indicated that the ability of black spruce to resist snowshoe hare (*Lepus americanus*) browsing has been attributed to a fungus. Changes in fungi and bacteria populations were cited as critical for studying site productivity at the forest floor level.

The need to establish adequate controls to follow the response of wildlife populations to alternate harvesting and treatment programs was highlighted. Dr. Bendell emphasized the need to consider harvest and treatment size, shape, and setting when examining the changes in the environment associated with logging. Participants collectively indicated that the impact of harvesting on areas adjacent to the cut has not been adequately addressed. They further indicated a need to study the rate of repopulation by species guilds or groups of organisms at different scales.

Concern was also expressed that there is insufficient information on environments and associated species in burned areas as compared to logged areas. Dr. Gordon discussed the various impacts from logging and fire, and emphasized differences in the amount of woody material left on site, the lack of standing material to provide shade and moderate microclimate on logged areas, and differences in patterns of disturbance.

iii) How to Address the Scale of Impact?

All participants confirmed the need to consider the scale of impact. Dr. James emphasized that maintaining an environment for the long-term production of moose (*Alces alces*) would not necessarily protect the environment for all species. He provided as an example, the pileated woodpecker, which does not utilize early successional forests commonly used by moose for browse. He suggested that managers should consider protecting an area sufficiently large enough to support top carnivores, such as the wolf (*Canis lupus*). He further suggested that if these species are protected, by default, the system itself may be protected for many other species. This is not to imply that full-tree clear-cut areas are not used by wolves. It does suggest that the pattern of clear-cutting in forests of other ages needs to be defined with respect to supporting large carnivores. Dr. Rempel suggested that impacts should be examined at the mesoscale, macroscale, and microscale.

Dr. Rempel also emphasized the need to define the functional ecosystem that is to be maintained. For example, moose may be used as an indicator for the maintenance of early successional ecosystems or pileated woodpecker as an indicator of "climax" communities. He also indicated a need to consider the pattern of forest communities in terms of species, age, structure, and biodiversity across the landscape, and the maintenance of this texture.

iv) The Need to Link Research Science with Industry

The group rephrased the question: "Should a nested hierarchy be adopted in research designs?" to emphasize the need to "link research science with industry". There is a need to minimize duplication of research, to ensure consistency in design and interpretation of data, and to ensure that study results are answering present and future issues as they apply to current and planned technology. By working together, research results will also be available to industry in a timely fashion. Forest managers can therefore use the most up-to-date information in their planning and operations.

The loss 5 years ago of provincial funding for forest management agreement area roads was also discussed. The recent expansion of road networks into forested areas and its impact on forest ecosystems was seen to be one of the most critical issues with respect to wildlife. The group summarized their views on the need for future research as follows:

i) How severe is the impact of road construction on long-term site productivity?

ii) What are the impacts on the forest if the forest industry manages only the "best" sites in the future and does not operate on suboptimal sites?

iii) What are the impacts on the forest if the forest industry uses extensive management techniques on both productive and suboptimal sites?

iv) Prescriptions should be developed by site type to reflect the nutrient pools and related cycling of these nutrients within given ecosystems. Rotation lengths or harvesting cycles should be delayed or extended if nutrient depletions are a concern.

v) What is the impact of current and projected forest practices on the nutrient supply of growing "genetically improved" trees? Such improved stock may require higher levels of nutrients than do the natural populations currently being studied.

vi) How important are caterpillar cycles (e.g., spruce budworm) in the abundance and distribution of small mammals and game birds?

vii) How can one control pest species to minimize the impact on site productivity?

viii) Are predators, biological controls, or chemical controls the most effective measures with the least negative impacts on boreal ecosystem productivity?

Timmins workshop—silviculture

The workshop in Timmins was attended by forest company and provincial government staff. The program overview was presented by Dr. N. Foster. He also provided results from past studies on site productivity and nutrient cycling in jack pine communities, and presented comparable research results from sandy sites in New Zealand and Scandinavia. These showed a decline in forest productivity under full-tree harvesting systems, and indicated that compaction and slash removal are of major concern.

Dr. Foster divided the research approach to the study of harvesting impacts on site productivity into three tasks:

i) measurement of the impact of current practices (biomass, nutrient content);

ii) development of a theoretical model of harvesting impacts; and

iii) understanding recovery processes under alternate scenarios.

Discussions from this workshop have been organized under the following headings: nutrient cycling and nutrient pools, linkages between nutrient cycling and silvicultural systems, research design, an overview of participant research, and a summary of participant recommendations.

Nutrient Cycling and Nutrient Pools

Dr. Foster indicated that soil nutrient supply is difficult to assess through time. Approaches to studying nutrient cycling and nutrient budgets were summarized, and results from fertilizer studies on till and sandy soils in northern Ontario were presented. Foliar nitrogen content among commercial tree species was also presented. This demonstrated a higher nitrogen content within spruce crowns than within aspen crowns. Implications of variation in nitrogen accumulation associated with tree age were also discussed. Sufficient nitrogen must remain on a site to support early growth and the strong demand for nitrogen by younger age classes. This led to a discussion of nitrogen losses associated with blading and prescribed burning.

Linkages Between Nutrient Cycling and Silvicultural Systems

Workshop discussions were generally proactive; therefore, suggestions for minimizing harvesting impacts through modified harvesting systems were highlighted. These included shortwood systems, scattering chips and slash, use of high-flotation tires, and horse logging. The group suggested that future studies address ecosystem management, careful logging, the maintenance of landscape diversity, and modified harvesting systems.

Research Design

Participants provided feedback on the research design. They indicated that future studies be designed to test the effects of plot size, ingress from adjacent treatments, and regional climate on harvesting impacts on site productivity. Of particular concern was future comparison of research results from northwestern Ontario spruce plots to the more moderate, moister, clay-based spruce communities in the Clay Belt of northeastern Ontario. There is also a need to better understand whether nutrients are locked up in undecomposed humus under shade, and to study the rate of decomposition of slash under variable moisture and light conditions. Future studies should also examine the implications of stocking on long-term site productivity.

Overview of Participant Research

An overview of forest management activities under the Abitibi Model Forest Program, with an emphasis on protection of advanced growth regeneration, was provided. Activities in areas under operation by Superior Forest Products, where feller-bunchers and careful logging systems are used, were also summarized. Decreased site disturbances associated with clam bunk skidders, as opposed to traditional cut and skid systems, and reduced damage to advanced regeneration from saw heads were emphasized. Harvesting practices that were modified to minimize visual impacts and to accommodate remote tourism values in the Hornepayne area were also discussed.

Summary of Recommendations

In addition to expressing individual concerns, participants at the workshop indicated a need for further information or synthesis, including:

i) importance of micronutrients, including boron, on boreal site productivity;

ii) turnover of nitrogen and the role of microorganisms in site productivity;

iii) determining the impact of prescribed burning on boreal site productivity; and

iv) defining the rate of weathering of tills and outwash materials in northern Ontario.

Many participants expressed a strong interest in clearly defining the benefits and limitations of using prescribed burning with respect to long-term productivity. They further indicated that the best practice "guidelines" should indicate where, if anywhere, prescribed fire should be discouraged. One participant suggested that prescribed burn plots in the Geraldton area be examined to determine the impact of this practice.

Thunder Bay workshop—modeling

Workshop discussions are summarized under the following headings: research design, management guidelines, and modeling.

Research Design

One participant indicated a need to link sampling protocols with the measurement protocols utilized by the provincial growth and yield program. Mr. Morris emphasized the need to adopt a predictive, long-term productivity model to provide short-term analysis of harvesting impacts. The group also emphasized the need to define the base against which harvesting effects would be measured. This will require an assessment of natural disturbance processes involving fire, spruce budworm, and blowdown events.

Mr. Morris indicated that plot selection for the black spruce component extended over two field seasons. This was necessary to provide homogeneous stands within a range of site types and productivity classes.

Management Guidelines

Forest industry representatives were concerned with the proposed development of management guidelines for nutrient poor sites, based on the literature review and expert opinion. Some participants suggested that the use of common harvesting equipment not be restricted by any proposed modifications, due to high investment costs. Other participants acknowledged the possibility of diversifying equipment, provided a phase-in period was included. Some participants were concerned that the proposed treatments might not mimic the 'normal' operational practices. Mr. Morris indicated that a decision on season of harvest had not yet been determined, but scheduling would attempt to coincide with normal operations.

Some participants emphasized a need to measure the amount of slash remaining on site following logging. This may be an important variable and could explain some of the observed differences in regeneration following harvesting. As such, it may be directly related to changes in site productivity. One participant indicated that there is a provincewide database on slash loadings related to original stand conditions and treatment. This database is kept by the Fire Management Staff of the OMNR and the Fire Research Group of CFS. Mr. Morris indicated that they will be conducting both pre- and postharvest assessments of slash on experimental sites.

Site preparation and resulting compaction is thought by some scientists to be more critical than is the harvesting method. Typical spruce sites do not retain a high percentage of their nutrients in the duff layer, and therefore site preparation may not be as critical as in pine sites (Gordon 1981). Participants concurred that the issue of full-tree versus tree-length harvesting was perceived to be a critical question posed at public environmental assessment hearings.

Modeling

In the afternoon an overview of the FORCAST model of H. Kimmins was provided by Mr. D. Duckert and Mr. Morris. There was agreement that there is a need for interim short-term decisions with respect to modified practices on 'sensitive' sites while waiting for results from multiyear studies. The effectiveness of using models to address site productivity was discussed. The parameters used in the FORCAST model were clarified through a 'hands-on' exercise where the participants were able to select a number of alternate silvicultural scenarios using the FORCAST model.

Thunder Bay workshop participants were interested in future procedures for linking research results with practical applications within the economic realities of forest companies. In addition, they identified a need to standardize sampling protocols with the provincial growth and yield program so that productivity data could be linked to the broad provincial database. They also expressed a need to define, as a companion study, the natural disturbance cycles in the areas adjacent to intensive study areas. With respect to model development and applications, practitioners indicated that many of the input parameters for the current models are unavailable for Ontario.

Sault Ste. Marie workshop—ecophysiology

Dr. Jeglum indicated that the Sustainable Productivity of Boreal Forest Ecosystems Program focus is on issues that relate to biomass removal, both in terms of harvesting systems and site preparation tools and applications. During his presentation, Dr. Jeglum reviewed alternate approaches for measuring mineral nutrient regimes. These ranged from the soil/parent material/humus based system, to the indirect floristic approach, to analyses of foliar nutrient contents and visual deficiency symptoms, to the traditional fertilizer response approach of agriculturalists. Dr. Jeglum indicated that the derivation of nutrient indices was an ongoing problem for researchers in this field. The working group decided to adopt the traditional applied forestry approach of using site index to stratify sites by productivity classes. Results will be tied to the Forest Ecosystem Classification system for the region.

Discussion is summarized under the following headings: new forestry practices, modeling, and seedling bioassays.

New Forestry Practices

Dr. Jeglum supplemented his overview by showing slides that demonstrated visual impacts of harvesting in northeastern Ontario. The positive and negative consequences of drainage disruption, piling slash at roadside, careful logging, alternate harvesting patterns, and the use of alternative harvesting and site preparation equipment on regeneration and site productivity were briefly discussed. He also raised several questions for the group's consideration.

i) Is exposed mineral soil a requirement for successful jack pine regeneration and survival?

ii) Is it better to completely remove the organic layer for jack pine regeneration? If not, what is the optimal degree of disturbance?

iii) How do different harvesting systems influence microclimate and long-term productivity?

iv) Are concerns more critical on highly productive sites that will be intensively managed or on less productive sites that will be extensively managed?

Results of soil analysis from a variable-aged vegetated Australian dune system were summarized to indicate that some sand-based soil systems aggrade over time and then degrade. Dr. Jeglum suggested that some of the deepest, coarse outwash sandy systems may lose nutrients due to deep leaching. Dr. R. Fleming presented a proposed research plan to examine seedling response to microclimate and local site conditions created through different harvesting systems and alternative site preparation methods. Microclimate may be the limiting factor influencing relative plant response during stand establishment and early growth.

It should be pointed out that in some areas the industry is moving away from heavier mechanical site preparation methods. Jack pine is now successfully seeded or planted directly onto sites that have not been mechanically site prepared to remove the surface organic mat or where only very light site preparation methods have been applied.

Modeling

The group realized the need for short-term answers and indicated that modeling was a practical approach to examining the potential impacts of different forestry practices on site productivity. For example, variable slash loadings following harvesting will add considerable 'noise' to the analysis; it also influences observed regeneration following harvesting. Provincial stand/slash loading information is available. Dr. Morrison provided an overview of nutrient cycling and presented some results from his work in boreal jack pine communities. His productivity indices could be used in forest modeling. Several participants indicated that one must understand the natural conditions created following wildfire and prescribed burning and that these must be included in any predictive model.

Seedling Bioassays

Stock quality, stock selection, and planting quality were the issues of primary concern. The group emphasized the need to assess the initial condition of the planted stock and the planting sites. A recommendation was brought forward that stock handling and planting be closely supervised by a dedicated staff member and not left to a contractor. Dr. Colombo indicated that he would assist in assessing the initial quality of the stock as his group has designed standardized procedures for assessing stock health.

Further work is needed to reflect the current trend of relying on natural regeneration and seeding for postharvest forest establishment.

Summary of Expert Opinion

The survey results show that concerns with full-tree harvesting on long-term site productivity are common among those working in the boreal forest. Field staff, industrial forestry staff, and scientists emphasized that concerns vary with site conditions and harvesting systems. They also indicated that much of the specific research to quantify these effects has not been done. Nutrient removal, often associated with loss of organic matter, was the primary concern on dry and shallow sites; altered hydrology and species shifts were the dominant concerns on mesic (fresh) and wet sites.

This study represents the views of many individuals who work and study in the boreal forest. Only one individual strongly indicated that long-term productivity cannot be assessed. He was concerned that an opinion survey would lend strength to the philosophy of forest preservationists. Alternative views endorsing the value of summarizing our current understanding of site productivity related to harvesting practices were expressed by other participants.

A subsequent study is in progress to define the 'sites at risk' for productivity losses under specific harvesting activities so as to discourage global restrictions. A set of interim 'best practices' will be developed for these sensitive sites.

These studies are designed to begin to answer the following questions: What are the effects of full-tree harvesting on boreal conifer ecosystems? Are the changes to the ecosystem associated with full-tree harvesting similar to the effects of natural disturbances? Are boreal conifer ecosystems resilient to these changes? Field studies that will begin to quantify some of the effects of harvesting and site preparation activities on site productivity are now in progress in northern Ontario. Results from these will begin to address some of the unanswered questions.

Although it must be emphasized that the present state of knowledge is uncertain, it may be inappropriate to await conclusive evidence before taking measures to limit the extent of biomass removal from sites where resident soil organic matter is low. The effects of full-tree harvesting on forests will vary with the silvicultural prescription, soil type, forest cover, microclimate, and a multitude of other interacting factors. The second value of this survey is the identification of areas where opinions vary widely and where there is a consensus. Such identification can aid in setting priorities for future research.

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APPENDIX A. ACRONYMS APPEARING IN THE REPORT.

BSD – Bird Species Diversity

CFS – Canadian Forest Service

CNFER – Centre for Northern Forest Ecosystem Research

COFRDA – Canada-Ontario Forest Resource Development Agreement

COJFRC – Canada-Ontario Joint Forestry Research Committee

FEC – Forest Ecosystem Classification

FERIC – Forest Engineering Research Institute of Canada

FRDA – Canada-British Columbia Forest Resource Development Agreement

FORCYTE – FORest Nutrient CYcling Trend Evaluator

GIS – Geographic Information System

IRM – Integrated Resource Management

IUFRO – International Union of Forest Research Organizations

JABOWA – an individual tree growth model developed by JAnak, BOtkin and WAllace

NEST – Northeastern Region Science and Technology Development Unit

NODA – Northern Ontario Development Agreement

NWOFTDU – Northwestern Ontario Forest Technology Development Unit

OFRI – Ontario Forest Research Institute

OMNR – Ontario Ministry of Natural Resources

SIP – Site Preparation

TWINSPAN – TWo-way INdicator SPecies ANalysis

USDA – United States Department of Agriculture

WTH – Whole Tree Harvest (entire tree removed, including stump and roots)

APPENDIX B. LONG-TERM PRODUCTIVITY OF BOREAL FOREST ECOSYSTEMS.

Final Questionnaire (1994)

Name ______________________________ Date ______________________________

Address ______________________________ Phone/Fax ______________________________

Affiliation ______________________________

1. Please describe your own area of expertise with respect to boreal ecology. (mark appropriate space with an "X")

   ___ Forest Ecology ___ Silviculture

   ___ Soil Science ___ Microclimate and Ecophysiology

   ___ Other (specify) ______________________________

   What is your employer category?

   ___ Government ___ University ___ Private Sector

   What is your Geographic expertise?

   ___ Ontario ___ Prairies ___ Quebec ___ Maritimes ___ U.S.A.

Note: In the following questions, the factors have been ranked according to the results of the first questionnaire.

Please rank all factors in the space provided using the following scale:

Most Important 1 2 3 4 5 Least Important

Abbreviations used in questionnaire:

NR no responses to these factors in the first questionnaire

* these factors were added for this questionnaire (from "other" category)

2. Based on your observations, the major impacts of harvesting on site productivity in the boreal ecosystem are?

JACK PINE

Former Rank(1-x)	**Dry, Shallow Sites**	New Rank
1	Loss of organic matter	___
2	Erosion	___
3	Altered hydrology	___
4	*Nutrient removal	___
5	No impact	___
5	Rutting	___
5	*Decomposition processes	___
5	*Forest structure changes	___
NR	Compaction	___
NR	Species shift	___

Former Rank(1-x)	**Fresh to Moist Sites**	New Rank
1	Loss of organic matter	___
2	No impact	___
3	Species shift	___
4	*Nutrient removal	___
4	Altered hydrology	___
4	Erosion	___
NR	*Decomposition processes	___
NR	*Forest structure changes	___
NR	Compaction	___
NR	Rutting	___

Former Rank(1-x)	Dry, Deep Sites	New Rank
1	No impact	___
2	Loss of organic matter	___
3	Species shift	___
4	Erosion	___
4	*Nutrient removal	___
5	Altered hydrology	___
NR	Rutting	___
NR	Compaction	___
NR	*Decomposition processes	___
NR	*Forest structure changes	___

BLACK SPRUCE

Former Rank(1-x)	Shallow Upland Sites	New Rank
1	Loss of organic matter	___
1	Erosion	___
2	Species shift	___
3	No impact	___
4	Altered hydrology	___
5	Rutting	___
5	*Nutrient removal	___
NR	Compaction	___
NR	*Stand structure changes	___
NR	*Loss of seedbed	___
NR	*Loss of advanced growth	___

Former Rank(1-x)	Wet Mineral Sites	New Rank
1	Rutting	___
2	Compaction	___
2	Altered hydrology	___
2	Species shift	___
3	Loss of advanced growth	___
4	No impact	___
NR	Erosion	___
NR	Loss of organic matter	___
NR	Nutrient removal	___
NR	Stand structure changes	___
NR	Loss of seedbed	___

Former Rank(1-x)	Deep Mineral Sites	New Rank
1	Species shift	___
2	No impact	___
3	Loss of organic matter	___
NR	Erosion	___
NR	Compaction	___
NR	Altered hydrology	___
NR	*Nutrient removal	___
NR	*Stand structure changes	___
NR	*Loss of seedbed	___
NR	*Loss of advanced growth	___
NR	Rutting	___

Former Rank(1-x)	**Wet Organic Sites**	New Rank
1	Altered hydrology	___
2	Rutting	___
3	Species shift	___
4	Compaction	___
5	Loss of organic matter	___
5	Nutrient removal	___
5	Stand structure changes	___
5	Loss of seedbed	___
5	Loss of advanced growth	___
NR	No impact	___
NR	Erosion	___

3. Key ecosystem functions altered in nutrient poor sites are:

Former Rank(1-x)	**Full tree Harvesting**	New Rank
1	Carbon cycle	___
2	Phosphorus cycle	___
3	Hydrologic cycle	___
4	Magnesium cycle	___
5	Potassium cycle	___
5	Biomass production	___
5	*Calcium cycle	___
6	Nitrogen cycle	___
7	*Seedbed quality/quantity	___
7	*Fuel load	___
7	*Decomposition process	___
7	*Leaching	___
7	*Soil structure	___
NR	Species shift/succession	___

Former Rank(1-x)	**Tree-length Harvesting**	New Rank
1	Hydrologic cycle	___
2	Carbon cycle	___
3	Phosphorus cycle	___
3	*Seedbed quality/quantity	___
4	Nitrogen cycle	___
4	Magnesium cycle	___
4	Potassium cycle	___
4	Species shift/succession	___
4	Biomass production	___
NR	Fuel load	___
NR	Calcium cycle	___
NR	Decomposition process	___
NR	Leaching	___
NR	Soil structure	___

4. Suggestions for minimizing impacts

Former Rank(1-x)	**Full tree Harvesting**	New Rank
1	Spread slash	___
2	Tree crop rotation	___
2	*Minimize forest floor disturbance	___
2	*Modify harvest patterns	___

2	*Avoid sensitive/shallow sites	___
2	*Careful logging	___
2	*Apply conservation methods	___
2	*Design forest to minimize impacts	___
2	*Prescribed burning	___
3	Restrict season	___
3	Process at stump	___
4	Lengthen rotation	___
5	High flotation tires	___
6	*Eliminate full-tree harvesting	___
7	Fertilize	___

Former Rank(1-x)	**Tree-length Harvesting**	New Rank
1	Spread slash	___
2	Process at stump	___
3	*Minimize forest floor disturbance	___
3	*Modify harvest patterns	___
3	*Avoid sensitive/shallow sites	___
3	*Careful logging	___
3	*Apply conservation methods	___
3	*Design forest to minimize impacts	___
3	*Prescribed burning	___
3	Restrict season	___
4	Lengthen rotation	___
4	High flotation tires	___
NR	Fertilize	___
NR	Tree crop rotation	___

5. **What key nutrient elements, physical site factors or other parameters should be consistently monitored and measured?** (Please mark all factors)

Former Rank(1-x)	**Full tree Harvesting**	New Rank
1	Nitrogen cycle	___
2	Phosphorus cycle	___
3	Potassium cycle	___
4	Species shift/succession	___
5	Magnesium cycle	___
5	Biomass production	___
6	*Soil texture	___
6	*Soil compaction [bulk density]	___
6	*Soil depth	___
6	*Soil pH	___
6	*Soil moisture	___
6	*Change in % organic matter	___
6	*Decomposition rate	___
6	*Site disturbance	___
6	* % on site slash	___
6	*Depth and amount of rutting	___
6	* % of advance growth	___
6	*Length of growing season	___
6	*Calcium cycle	___
6	*Key wildlife species	___
6	*Habitat and landscape structure changes	___
7	Hydrologic cycle	___
7	Carbon cycle	___

Former Rank(1-x)	Tree-length Harvesting	New Rank
1	*Soil texture	
1	*Soil compaction [bulk density]	
1	*Soil depth	
1	*Soil pH	
1	*Soil moisture	
1	*Change in % organic matter	
1	*Decomposition rate	
1	*Site disturbance	
1	* % on site slash	
1	*Depth and amount of rutting	
1	* % of advance growth	
1	*Length of growing season	
1	*Calcium cycle	
1	*Key wildlife species	
1	*Habitat and landscape structure change	
2	Phosphorus cycle	
3	Nitrogen cycle	
4	Potassium cycle	
5	Species shift/composition	
6	Carbon cycle	
7	Hydrologic cycle	
7	Magnesium cycle	
7	Biomass production	