Forest Yield Predictions:
Risk Modeling and Simulation

Final Report

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1990

This is a joint publication of Forestry Canada
and the Alberta Forest Service pursuant to the
Canada-Alberta Forest Resource Development Agreement

Forestry Canada
Northern Forestry Centre,
Edmonton, Alberta

Project # 1444-90

DISCLAIMER

The study on which this report is based was funded in part under the Canada/Alberta Forest Resource Development Agreement.

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FOREST YIELD PREDICTIONS:

RISK MODELLING AND SIMULATION

PROJECT DESCRIPTION

This Federal-Provincial joint program is aimed at
developing risk analysis and improved modelling techniques
for making realistic projections of future timber supplies
from the boreal forest under various risks.

STUDY OBJECTIVES

1. To model the risk of fire at the stand and forest level to aid
    management decisions on the effect of such occurrences on annual
    allowable cut (AAC) and future timber supplies.

2. To determine the frequency of large-scale insect and disease
    occurrences, and derive a model to assess their impact on the
    present and future forest yields.

3. To test, review, and modify the fire, insect and disease, and
    other risk factor models for application over boreal forest
    ecoregions in western Canada.

NEED FOR STUDY

Boreal forest is a major forest region of Canada occupying approximately
82% of the forest land in the country and contributes significantly to
the national economy. In Alberta, the boreal tree species are of vital
importance in the production of sawlogs and pulpwood. Improved
techniques are essential for making realistic projections of future
forest supplies and to sustain present rates of development in the
province.

Prevailing climatic conditions of long, cold winters and short growing
season are responsible for slow growth rates typical of the boreal tree
species. Fires which frequently result in destruction of large areas
comprising the future growing stock are a common occurrence. During the
past two decades the forest area lost in Alberta due to fires averaged
0.5 % annually, which is considerable because of the long rotations
under which the boreal forests are managed. During a rotation of 100
years, for example, about a half of Alberta's forest area can be
expected to suffer fire losses if all stands were equally prone to fire

hazards. In addition, there is mortality due to insect and disease infestations.

All these risk factors can cause considerable errors in prediction and realization of AAC. These problems have not so far been objectively handled in resource allocation and management in the boreal forest. There is at present a general lack of available tools to make reliable predictions.

Long-term planning of forest management should be based mainly on expectation of return on investment and management efforts. Fire, insect, and disease risk losses must be included in projected expectations, as these are predictable for large areas within a given time frame. An objective assessment of risk factors is a necessity for rational formulation of management and timber harvesting strategies in the boreal forest of western Canada.

Five stages were estimated to complete the study. These are:

1. **Initial stage:** a review of risk and uncertainty factors in growth and yield due to fire and insect and disease occurrences; collation and evaluation of data relating to such factors.

2. **Preliminary development stage:** preliminary attempts at development of a conceptual model dealing with risk factors relating to growth and yield.

3. **Intermediary stage:** implementation of model concepts and strategies to achieve parameter estimation, calibration, and AAC prediction.

4. **Refinement stage:** improvement and refinement of risk factor model and parameter estimates to enhance model capabilities, and a validation test on independently collected and most recent data in a different geographical location.

5. **Final stage:** finalizing risk factor model and its components for the boreal forest, and recommendations for its extension to disjunct outliers and ecoregions, including preparation of a manual for operational use and guidelines to prescribe management and timber harvesting strategies.

    The study provides needed opportunities for cooperation with provincial agencies and forest industry to meet their requirements for realistic determination of future supplies when subjected to the above-mentioned risk factors and uncertainties.

RESEARCH CONTRACTS:

The following risk-related research contracts were initiated and developed, and guidance provided for completing the scientific work involved:

a) W.R. Dempster & Associates Ltd. 1987. Risk management in forest planning. DSS Contract (Scientific Authority: T. Singh).

b) Van Kooten, G.C. and E.E. Wheaton. 1987. Risk and uncertainty in forest management: implications for decision making (Research Proposal). (Scientific Authority: T. Singh).

c) Petty, J. 1988. Insect and diseases infestations on forest lands: implications for forestry risk management in Alberta. DSS Contract (Scientific Authority: T. Singh).

d) Monenco Consultants Ltd. 1988. Selection, modification, and testing of insect and disease risk model for forest yield prediction in the boreal forest of Alberta. DSS Contract (Scientific Authority: T. Singh).

e) Van Kooten, G.C. and E.E. Wheaton. 1988. Modelling approach to forest management under risk and uncertainty constraints. DSS Contract (Scientific Authority: T. Singh).

f) Van Kooten, G.C. and E.E. Wheaton. 1988. Risk and uncertainty in forest management: the case of the boreal growth (Research Proposal). (Scientific Authority: T. Singh)

g) Monenco Consultants Ltd. 1989. Risk and uncertainty in forest management. DSS Contract (Scientific Authority: T. Singh).

h) Van Kooten, G.C. and E.E. Wheaton. 1989. Modelling approach to forest management under risk and uncertainty constraints. DSS Contract (Scientific Authority: T. Singh).

ACCOMPLISHMENTS

The three modelling methodologies used were: 1) probabilistic, 2) deterministic, and 3) dynamic modelling. This would enable a comparative assessment of the merits of the three approaches adopted in the study.

Probabilistic Modelling

W.R. Dempster & Associates Ltd. 1987. Risk management in forest planning. DSS Contract. Scientific Authority: T. Singh

A preliminary version of the FOrestry RIsk Model (FORIM) based

on Hinton leasehold and East Slopes fire risk data has been
developed.

Because of the availability of most data bases needed for
modelling, McLeod working circle in the leasehold of Champion
Forest Products Ltd. was selected as a logical unit for the
formulation and development of the risk model.

Preliminary work was done for computing the probabilities
of fire occurrence and analyzing their effects on short- and
long-term timber losses. Cumulative probabilities of obtaining the

expected timber volumes were determined for McLeod Working Circle
under different scenarios of fire risk levels and rotations.

Conclusions and Recommendations:

1.   In the forests of Alberta, destruction of timber through
        fire and biotic damage significantly affects the long-term
        timber supplies.

2.   Rational allocation and management of timber resources in
        Alberta forests are affected by the risk of destruction.

3.   Sequence in which stands are harvested can influence the
        expected volume losses.

4.   Expected volume losses are affected by rotation length.
        Rotations based on culmination of mean annual increment
        should be reduced if risk and uncertainty conditions
        prevail.

5.   Risks in the East Slopes are related to stand and location
        parameters, including species composition and elevation.

6.   Harvesting at "safe" sustainable levels will result in
        large and immediate reductions in allowable cut, and in the
        accumulation and ultimate loss of growing stock.

7.   Annual allowable cuts should not be reduced in response to
        risk. The cost of ensuring an even-flow of timber harvests
        is likely to be very high in the boreal forests because of
        risks.

8.   Optimistic assumptions regarding the future yields from
        regenerated stands has little rational basis in the boreal
        forests. Current planning should not rely heavily on
        "distant" projections which contain a high degree of
        uncertainty.

9.   Pragmatic scheduling of existing stands over a reasonable
        conversion period, with frequent replanning, is a preferred

approach to timber supply forecasting.

10.   Efforts to reduce risks must be coordinated with other
management activities. Considerable potential exists for
reducing the probability of fire and other catastrophic
losses at little extra cost in industrial forest management
areas.

11.   An improved basis is required for risk-adjusted harvest
sequencing at the management unit level. This can be
achieved through the development, and incorporation, of
hazard changes in the operational harvest-scheduling models.

12.   The concept of expected value should be emphasized in boreal
forestry. This is particularly important in investment
decisions regarding facility development and discretionary
silvicultural inputs in areas subject to significant risks.

13.   Quantification of risk is needed for rational risk
management investment decisions. Collation of available
risk data on ecoregional basis is a useful start.

14.   Quantitative studies of biotic damage and risk to
regenerated stands started by the Northern Forestry Centre
should be continued, and rigorously analyzed. Measurements
should also include the collection of mensurational data
needed for growth modelling.

15. Need for additional software and hardware was identified
for risk analysis tasks related to the boreal forest of
Alberta.

Deterministic Modelling

Petty, J. 1988. Insect and diseases infestations
on forest lands: implications for forestry risk management
in Alberta. DSS Contract. Scientific Authority: T. Singh

Monenco Consultants Ltd. 1988. Selection, modification,
and testing of insect and disease risk model for
forest yield prediction in the boreal forest of Alberta.
DSS Contract. Scientific Authority: T. Singh

Monenco Consultants Ltd. 1989. Risk and uncertainty in
forest management. DSS Contract. Scientific Authority:
T. Singh

The existing data on risk factors and growth and yield were
located and examined through necessary data screening, computer

programming, and preliminary modelling procedures under the guidance of the Study Leader. Permanent sample plot data were also accessed.

FORMAN model was selected, modified, and tested for impacts on AAC in the Footner Lake and the Peace River volume sampling regions in northern Alberta. The effects of tent caterpillar, spruce budworm, and spruce bark beetle on a FMU (P6) in the Peace River Forest were simulated under low, medium, and high levels of disturbance severity to show volume losses under each infestation.

Phase I (Footner Lake and Peace River Forests)

The objectives for this phase in the study were to identify insect infestation data and a suitable model for studying the impacts of such occurrences on forest yield, to modify and test the selected model, to present guidelines for its use, and to make recommendations for future modifications.

The search for the model included a review of literature, and discussions with Dr. G. Baskerville, Forestry Department, University of New Brunswick.

The use of a sequential forest projectional model (FORMAN) was recommended. Fully stocked yield curves and forest age class distributions for Footner Lake and Peace River forests were obtained from Alberta Forest Service. These were modified to account for low, moderate, and severe levels of defoliation by forest tent caterpillar and spruce budworm. The modifications were based on a review of literature.

Projections of the residual forest volume mortality and age class distribution over a 90 year period were made for a specified level of harvest each year. The model was used to predict the anticipated losses of residual forest volume or AAC due to insect and disease occurrences.

Conclusions and Recommendations

1. Forest tent caterpillar defoliation, with the exception of severe levels, generally had a negligible effect on future residual volumes at the end of a 90 year period. Spruce budworm defoliation had a more significant effect on residual forest volumes.

2. A number of modifications are needed in the FORMAN to make more precise forest yield predictions. Adjustments are also indicated in the simulation procedures. These include:

   a) Determining the periodicity and extent of various past outbreaks.

b)   Selecting a smaller area (e.g. a forest management unit),
     and inputting more detailed stand or compartment
information.

c)   Devising a set of yield equations which will predict growth
     relationships for various stand types and densities. In
     view of the scarcity of quantitative growth estimates,
     consideration should be given to linking FORMAN model with
     a stand development model.

d)   Assigning a harvest schedule to the study area so that
     harvesting is more realistic.

e)   Allocating silvicultural costs for scarification and
     replanting, and assigning the anticipated stand type
     that would develop in the second rotation.

Phase II (Forest Management Unit: P6)

This phase consisted of modelling the effects of tent caterpillar,
spruce budworm, and spruce bark beetle on a Forest Management Unit
(P6), occupying an area of 1923 km^2 in the Peace River Forest.

Yield curves for the FMU were derived from data supplied by
Alberta Forest Service. These were used to provide a projection
for the future 45 years under present AAC and low level of
infestations.

Yield curves were subsequently developed for volume estimates
under higher levels of infestation severity, and used for
simulating the future forest yields. The effects of insect
infestation risks were calculated under different levels of
disturbance severity.

A preliminary examination of the effects of fire as a risk was
also completed. Moderate and severe fire levels were used for the
simulation.

Conclusions and Recommendations

1.   Insect outbreaks posed significant volume losses, and
     threatened the ability to sustain harvesting at the current
     AAC levels.

2.   Some problems were encountered due to limited data and model
     limitations. These may be reduced or eliminated by
     deriving yield curves based on inventory data for an area
     larger than FMU, such as an entire forest or a combination
     of 3 to 6 FMUs.

3.   There is need for investigating methodologies to improve

objective approaches for aggregating stand types and similar
yield curves.

4.   Modify FORMAN model to allow stand vulnerability cal-
culations for harvested stands undergoing silvicultural
treatments resulting in new yield curves.

5.   Modify the model so that the long output file is split
into several smaller files to contain specific information.

6.   Investigate the logistics and methodology for linking
the FORMAN model to a GIS, initially on a portion (300 - 500
km^2) of a FMU.

7.   Examine additional methodologies for assessing fire as a
risk factor, such as modifying the model to simulate t h e
burning of a portion of FMU, randomly.

7.   Need to access adjoining boreal ecoregions to extend
the general scope and validity of the model.

The suggested modifications would: a) decrease the yield curve
analytical difficulties, b) improve the stand vulnerability
assessments, c) allow flexibility in forest management options,
and d) take the risk methodology a step closer to its use at the
forest or district level.

Dynamic Programming

Van Kooten, G.C. and E.E. Wheaton. 1988. Modelling
approach to forest management under risk and uncertainty
constraints. DSS Contract (Scientific Authority: T. Singh).

Van Kooten, G.C. and E.E. Wheaton. 1989. Modelling
approach to forest management under risk and uncertainty
constraints. DSS Contract (Scientific Authority: T. Singh).

A. Choosing a Method

The review of literature on risks in managing renewable resources
showed the importance of taking risk and uncertainty into account
in forest management decisions. Powerful theoretical tools needed
for analysis of inherently dynamic management decisions were
examined.

Risk was defined as the risk attitude (usually risk averseness) of the decision maker. Uncertainty was defined as the occurrence of uncertain stochastic events which affect forest growth, such as insect infestations, diseases, and forest fires. The focus in the study was on the uncertainty regarding forest growth from one period to the next.

Conclusions and Recommendations

The study recommended that stochastic dynamic programming (DP) be used to examine the issues of uncertainty in forest management. The usefulness of this approach was demonstrated with a simple example. Modifications to the stochastic DP model are needed to make it more realistic.

The likely occurrence of forest fires could possibly be handled through introduction of another state variable such as forest debris. An increase in debris accumulation will increase the probability and magnitude of fire.

The model can be extended in several other directions. It is possible to introduce planting strategies after clearcutting the areas to be managed. Other strategies such as thinning and chemical spraying may also be included provided sufficient information is available on the expenditures involved. While any such extensions are possible, the additional state variables are likely to increase the matrix size, thereby making the solution more difficult to handle..

It was recommended that the first step should involve construction of a stochastic DP model based on actual field data from a particular forest or stand. Correct input from forest managers was needed to fine tune the model components.

B. Application to Peace River & Footner Lake Forests

In this study, optimal forest management strategies for the Peace River and Footner Lake forests in northwestern Alberta were examined. A Markov decision support model was employed; the model is dynamic as it links time periods.

Site indexes for the two forests and growth equations for white spruce were derived from permanent sampling plot data provided by Alberta Forest Service. Uncertainty was introduced into the model via the estimated growth equations.

The stochastic growth equations constituted the dynamic constraints or probability transition matrix in the model. The objective function maximized in the stochastic DP model was the discounted net returns from commercial forest operations.

Profits at any time were determined by the commercial wood volume available in the stand and the decision taken by the manager regarding the strategy to be used. Five choices were assumed in the decision-making process: 1) no management, 2) spraying to reduce insect growth, 3) fertilizing, 4) spraying and fertilizing combined, or 5) clearcutting the stand.

Conclusions and Recommendations

1. The optimal strategy varied according to the decision criteria such as discount rate, the cost of each choice, and the level of the state variable (wood volume).

2. If the uncertainties in tree growth are taken into account, the forest should be cut earlier than otherwise.

3. The savings to society and private companies as a result of applying this methodology are not inconsequential: $30 per ha for timber producing land in northwestern Alberta. These could be higher in regions with less severe climate.

4. For uncertainty in growth, decisions relating to forest management should not be based on age only, but also on available timber volume, insect infestation levels, and other risks.

5. The idea of a fixed rotation age should be modified to favour a more flexible regime.

6. Other state variables, such as insect and disease infestation levels and change in climate, may be used as state variable. However, any such extensions in decision making will necessitate substantial cooperation between foresters, economists, climatologists, and entomologists.

7. An integrated approach to forestry could yield substantial dividends in terms of improving forest management practices.

Comparison of Models

The three risk models tested in the study showed merits in context of the situations in which applied. They also indicated the direction in which the next FRDA project should proceed. The first two modelling approaches (Probabilistic and Deterministic) will be combined in the future work recommended for the FORMAN model. This combination will provide the ease and facility for using the model at operational level, where foresters could continue working with the familiar but improved yield curves to deal with risks.

Dynamic Modelling has merit in providing a more sophisticated methodology that needs to be developed further for decision making based on optimal strategies for forest management. The stochastic **DP Model** will be taken through the refinement and final stages to achieve this goal.

A more valid comparison between FORMAN and DP Model will be made when these tasks are completed and the models finalized under the next phase of FRDA.

Other Activities under Risk Modelling

1. A **Forestry Risk Advisory Group** consisting of provincial, federal, and university persons met in March 1987 to review and recommend research needs relevant to the project.

2. A forestry seminar entitled **"Decision support models for forest management under risk and uncertainty"** was organized and held at NoFC during December, 1989.

3. The project received cooperation from other project and study leaders at NoFC because of its multi-disciplinary nature. Inputs from growth and yield, fire, insect and disease, and forest resource groups was an essential part of the study plan to provide a unifying link.

PRESENT STATUS AND FUTURE DIRECTION

Present Status

The project has gone through the Initial, Preliminary, and Intermediate stages (stages 1, 2 and 3). **The next two stages are important for the project:**

> **Refinement stage:** improvement and refinement of risk factor model and parameter estimates to enhance model capabilities, and a validation test on independently collected and most recent data in a different geographical location.

> **Final stage:** finalizing risk factor model and its components for the boreal forest, and recommendations for its extension to disjunct outliers and ecoregions, including preparation of a manual for operational use and guidelines to prescribe management and timber harvesting strategies.

Future Direction

1. Proposals have been made to undertake the next two stages needed to complete the project under FRDA.

2. Field collection/collation of the most recent data would be useful a) to fill information gaps and b) to validate, re-fine, and finalize the model and its parameters (Stage 4 and 5).

3. A handbook or users' manual should be prepared for the Alberta Forest Service to show the application of the risk models for selecting optimal management strategies.

4. Risk modelling and simulation should be extended to ecoregions other than the boreal forest.

5. Global warming imposes a serious risk to the boreal forest and its commercial and non-commercial resources. Management strategies need to be developed to adjust for the adverse effects of climatic change on AAC.

PROJECT PUBLICATIONS

1987:

Dempster, W.R., and N.A. Stevens. 1987. Risk management in forest planning. Joint publication, Canada-Alberta Forest Resource Development Agreement.

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Van Kooten, G.C. 1988. Risk and uncertainty in forest management:
        Choosing a method of analysis. SRC Tech. Rep. No. 219.
        Saskatchewan Research Council, Saskatoon, Sask.

<u>1989</u>:

Brown, G. and G.C.Van Kooten. 1989. Forest management under
        uncertainty: An application to the boreal forest of
        northwestern Alberta. SRC Pub. E-2330-2-E-89.
        Saskatchewan Research Council, Saskatoon, Sask.

Monenco Consultants Ltd. 1988. Selection, modification, and
        testing of an insect and disease model for forest yield
        prediction in the boreal forest of Alberta. Calgary,
        Alberta.