Can we meet increasing demands for forest growth and yield information under increased scope, changing inventory technologies, and uncertain climate and disturbance regimes?

Valerie LeMay, PhD, RPF (BC)

Growth and Yield Innovations Conference 2023

Co-sponsored by the Western Mensurationists and the Forest Growth Organization of Western Canada, Canmore, Alberta, June 18 to 21, 2023

How do we address this question?

- First, why is growth and yield information important?
- What GY models do we have now? How did these develop and change to current times?
- What are the changes in scope, forest inventories, and climate/ disturbance regimes? How does this impact GY models?

Why is growth and yield information important?

Forecasts of forest ecosystems are critical for managing these ecosystems under natural and human disturbances, as well as for satisfying human curiosity.

The Condor 110(3):563–568

DO CROSS-SCALE CORRELATIONS CONFOUND ANALYSIS OF NEST SITE SELECTION FOR CHESTNUT-BACKED CHICKADEES?

ELSEVIER

LANDSCAPE

Challenges
vegeta

Depart

Energy for Sustainable Development 18 (2014) 58–66

Contents lists available at ScienceDirect

Energy for Sustainable Development

ELSEVIER

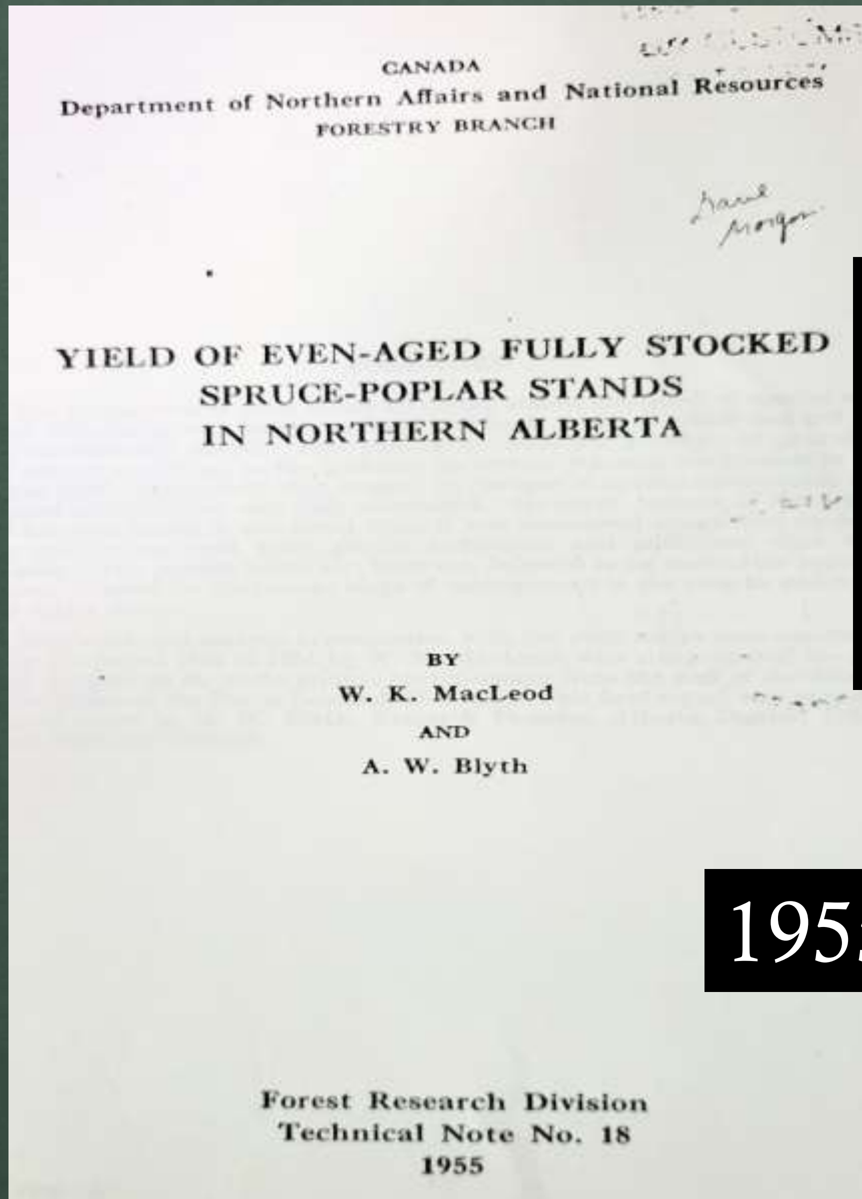
The use of fuelwood market segmentation and product differentiation to assess opportunities and value: A Nicaraguan case study

CrossMark

K. Baker *, G.Q. Bull, V.M. LeMay

What are the current GY models? How did they develop?

Growth and yield (GY) models have been developed for more than 100 years, and yield records of harvests from plantations and other forest areas have been passed down to foresters and managers for centuries.


CANADA
Department of Northern Affairs and National Resources
FORESTRY BRANCH

YIELD OF EVEN-AGED FULLY STOCKED SPRUCE-POPLAR STANDS IN NORTHERN ALBERTA

BY
W. K. MacLeod
AND
A. W. Blyth

Forest Research Division
Technical Note No. 18
1955

Even-Aged Spruce-Poplar in NE Alberta

1955

FOREWORD

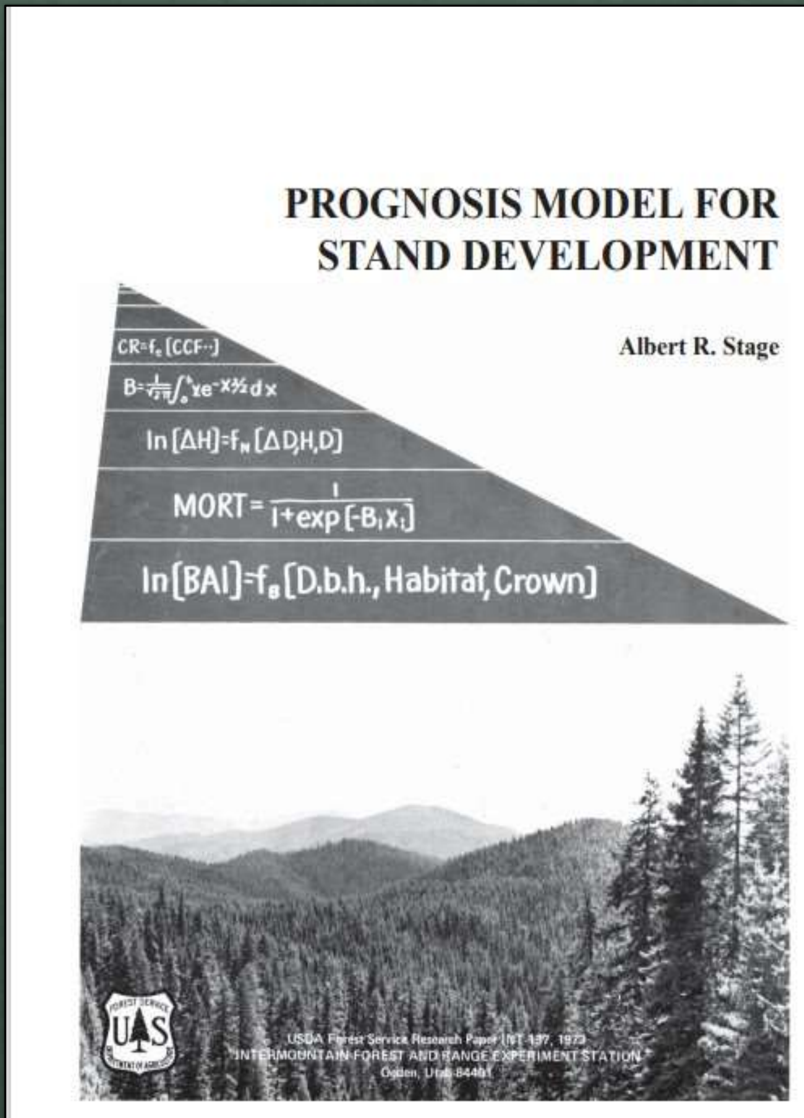
"The preparation of yield tables for mixed stands composed of species with widely differing growth habits presents a difficult problem, which has not yet been satisfactorily solved. This publication does not attempt to provide a fully adequate solution to the problem… particularly with respect to changes in species composition and extended extrapolation."

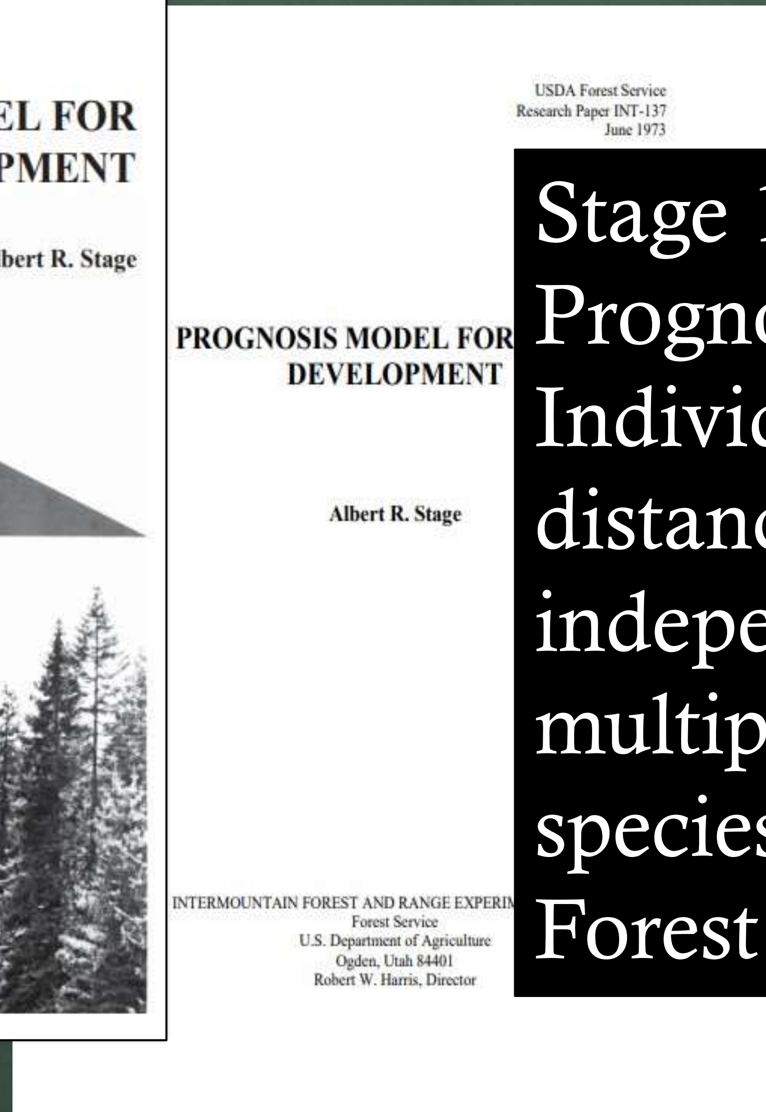
Simple Computer Technologies

Using the fairly simple computer technologies of the 1970s and 80s coupled with remeasured permanent sample plots, complex GY models were developed in research facilities and universities.

Matrix, Cohort, DBH distributions

Bruner, H. D. and J. W. Moser, Jr. 1973. A Markov chain approach to the prediction of diameter distributions in uneven-aged forest stands. Cananadian Journal of Forest Research. 3:409-417.




USDA Forest Service
Research Paper INT-137
June 1973

PROGNOSIS MODEL FOR
DEVELOPMENT

Albert R. Stage

INTERMOUNTAIN FOREST AND RANGE EXPERIM
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Robert W. Harris, Director

Stage 1973 Prognosis: Individual- tree distance independent, multiple species USDA Forest Service

ABSTRACT

This paper describes a set of computer programs for combining quantitative silvicultural knowledge with past growth data from a sampled stand to make a prognosis of the course of development that the forest stand is expected to follow under alternative management prescriptions. An important design criterion of this procedure is that the prognosis model should apply to stands containing any mixture of species or age and size classes that grow as a community. The model simulates the deviation-amplifying aspect of the growth process by a unique procedure for introducing the stochastic elements in a deterministic computing algorithm. The growth rates predicted by the built-in models for diameter change are compared to the actual past growth of the sample trees to calibrate these models for the particular stand for which the prognosis is to be computed. Selection of trees to be cut at any period can utilize a variety of tree characters to emulate a wide range of silvicultural prescriptions.

An application of these programs to develop prognoses for lodgepole pine stands in the presence of an infestation of mountain pine beetles is described.

Dynamics and simulated yield of Douglas-fir / by Kenneth J. Mitchell.

Title: Dynamics and simulated yield of Douglas-fir / by Kenneth J. Mitchell.

Related Title: Forest science. Vol. 21, no. 4 (Suppleme

Author/Creator: Mitchell, Kenneth J.

Published/Created: Washington, D.C. : Society of American F

Permalink: http://resolve.library.ubc.ca/cgi-bin/catsea

Mitchell 1975
Individual- tree
distance
dependent,
Douglas-fir
Yale

https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-inventory/growth-and-yield-modelling/tree-and-stand-simulator-tass Accessed May 25, 2023

VT52

DEC VT52 terminal

Developer	Digital Equipment Corporation
Type	Video terminal
Release date	1974/1975
Successor	VT100

https://en.wikipedia.org/wiki/VT52 Accessed May 25, 2023

IBM System/3, Model 15

The Model 15 instruction cycle time was 1.52 microseconds and supported 48K-512K of semiconductor memory. It could be ordered with hard disc or magnetic tape mass storage. In contrast, some modern day cell phones have 8 internal processors, each with a clock speed of 1.80 GHz (55 nanoseconds), and supports 128GB-1000GB of memory.

https://en.wikipedia.org/wiki/IBM_System/3 and https://www.computerhistory.org/collections/catalog/102667928 Accessed May 25, 2023

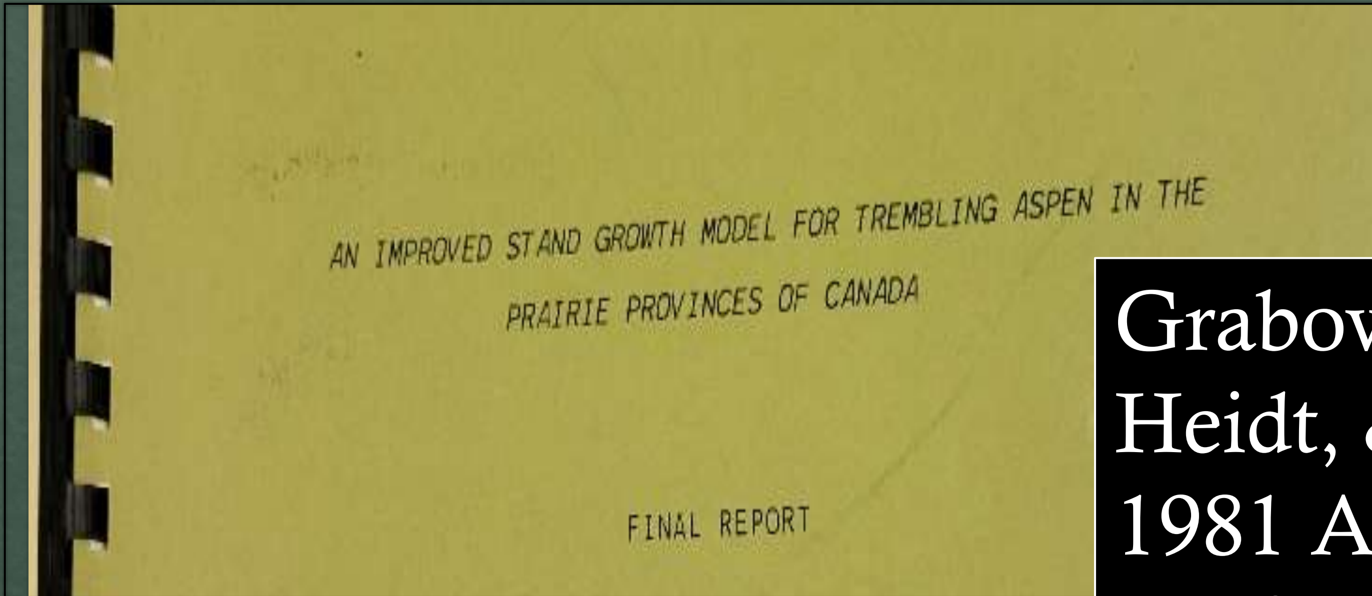
Apple I Desktop, 1976

Rare Apple I Sells For $471K in Auction

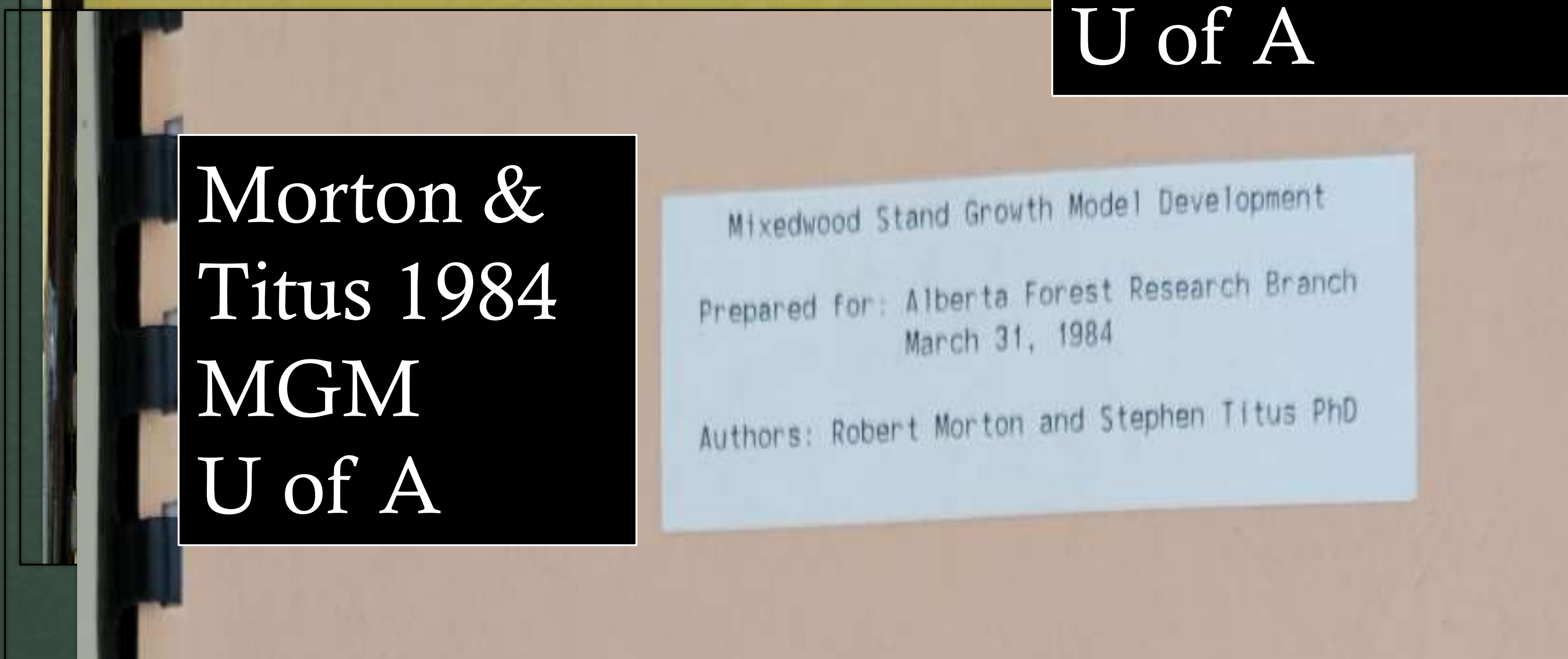
By **Haider Ali Khan** — May 27, 2019 2:03 pm UTC

A fully-functioning Apple I machine was placed on the auction block at Christie's in London and sold for £371,000 or approximately $471,000.

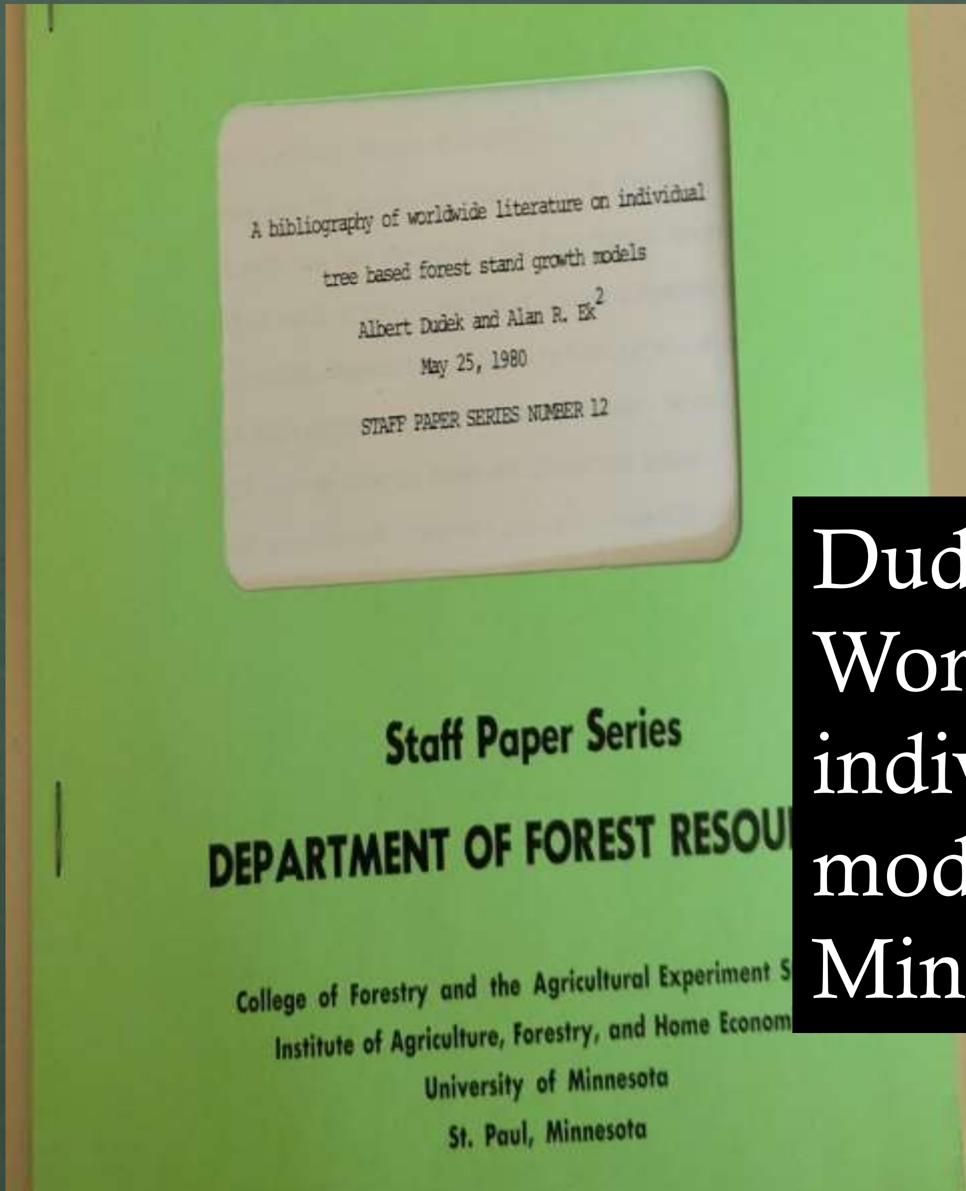
https://www.ilounge.com/news/rare-apple-i-sells-for-471k-in-auction Accessed May 23, 2023



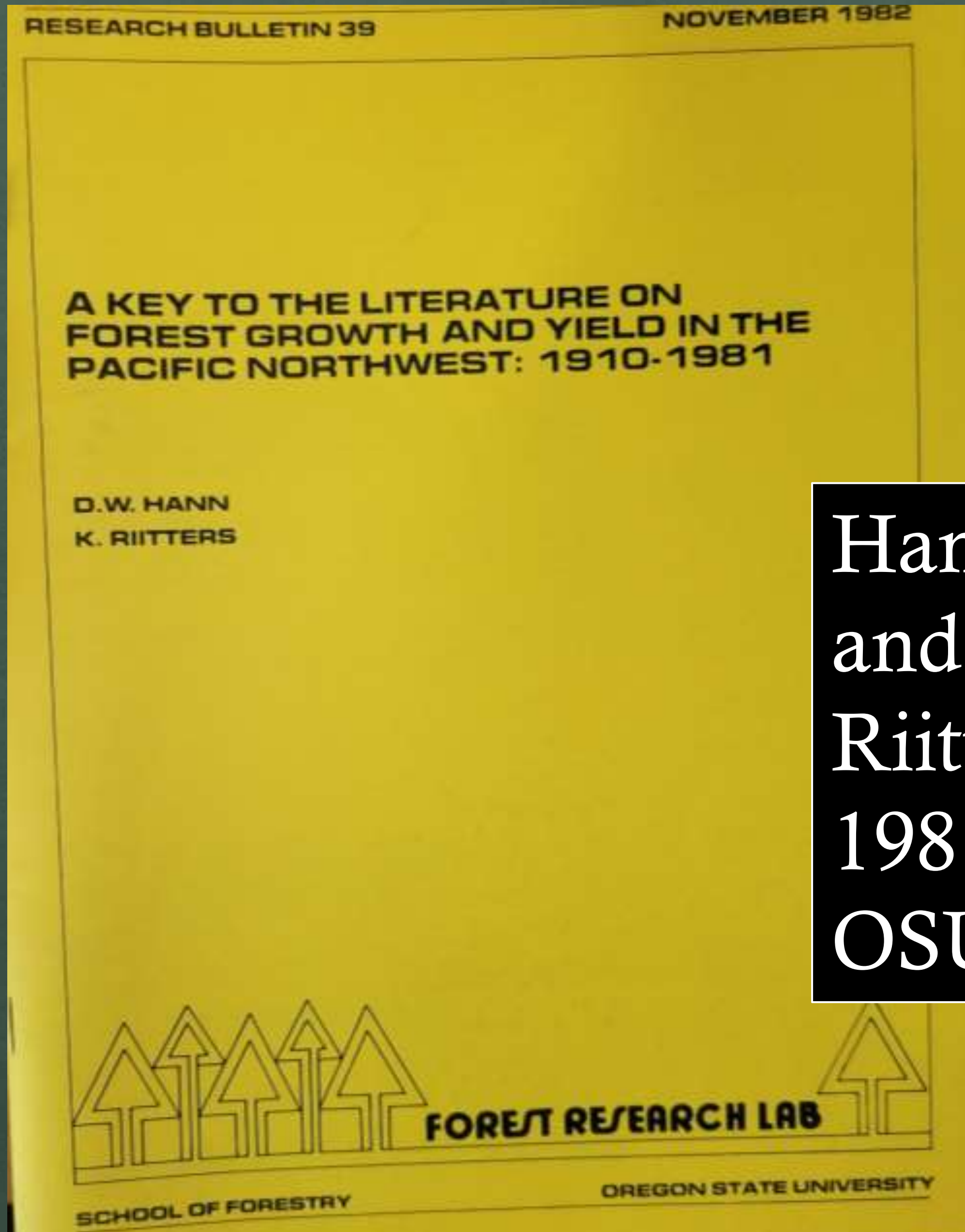
Grabowski, Heidt, & Titus 1981 Aspen GY U of A



Morton & Titus 1984 MGM U of A



Dudek and Ek. 1980. Worldwide literature on individual tree growth models. University of Minnesota



Hann
and
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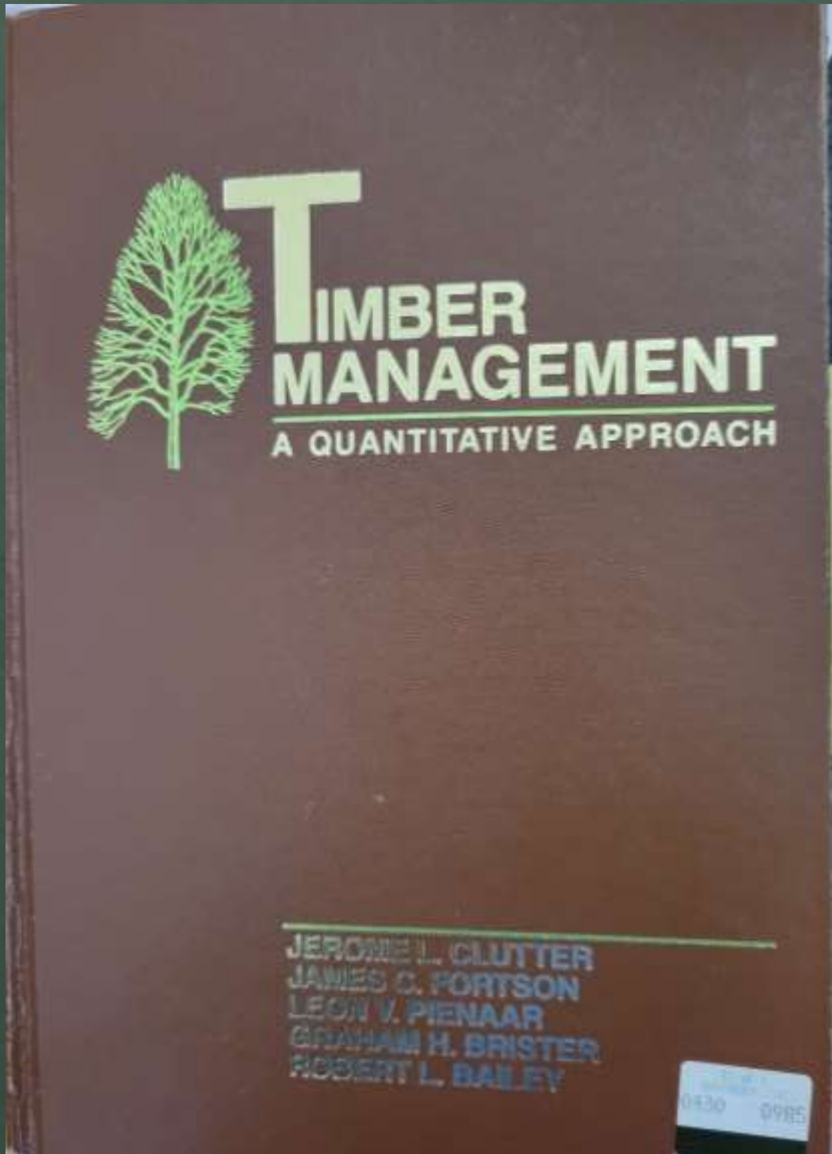
1981
OSU



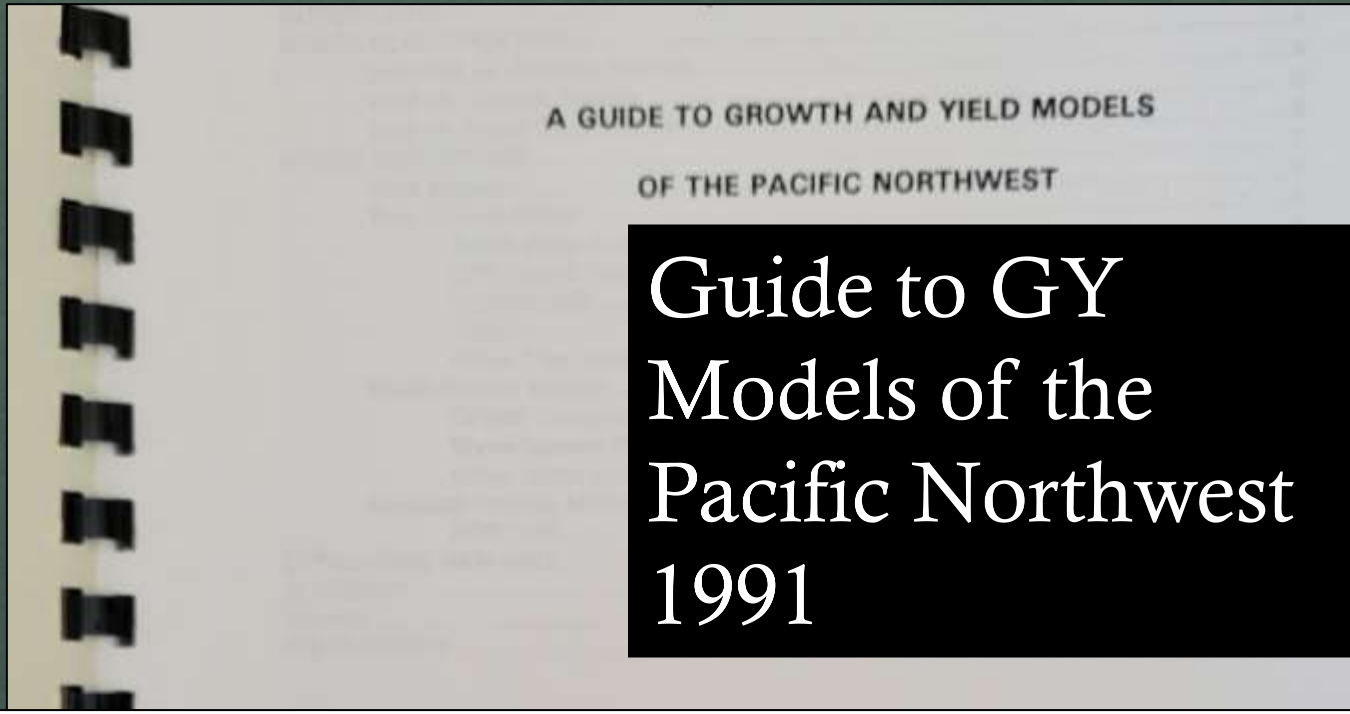
Clutter et al. 1983. Problems of using Temporary Sample Plots (TSPs) rather than Permanent Sample Plots (PSPs) for yield tables.

YIELD TABLES FOR ALBERTA FOREST COVER TYPES

W. R. Dempster and Associates Ltd.

November, 1983

Dempster and Associates. 1983. Yield tables using PSPs for Alberta.

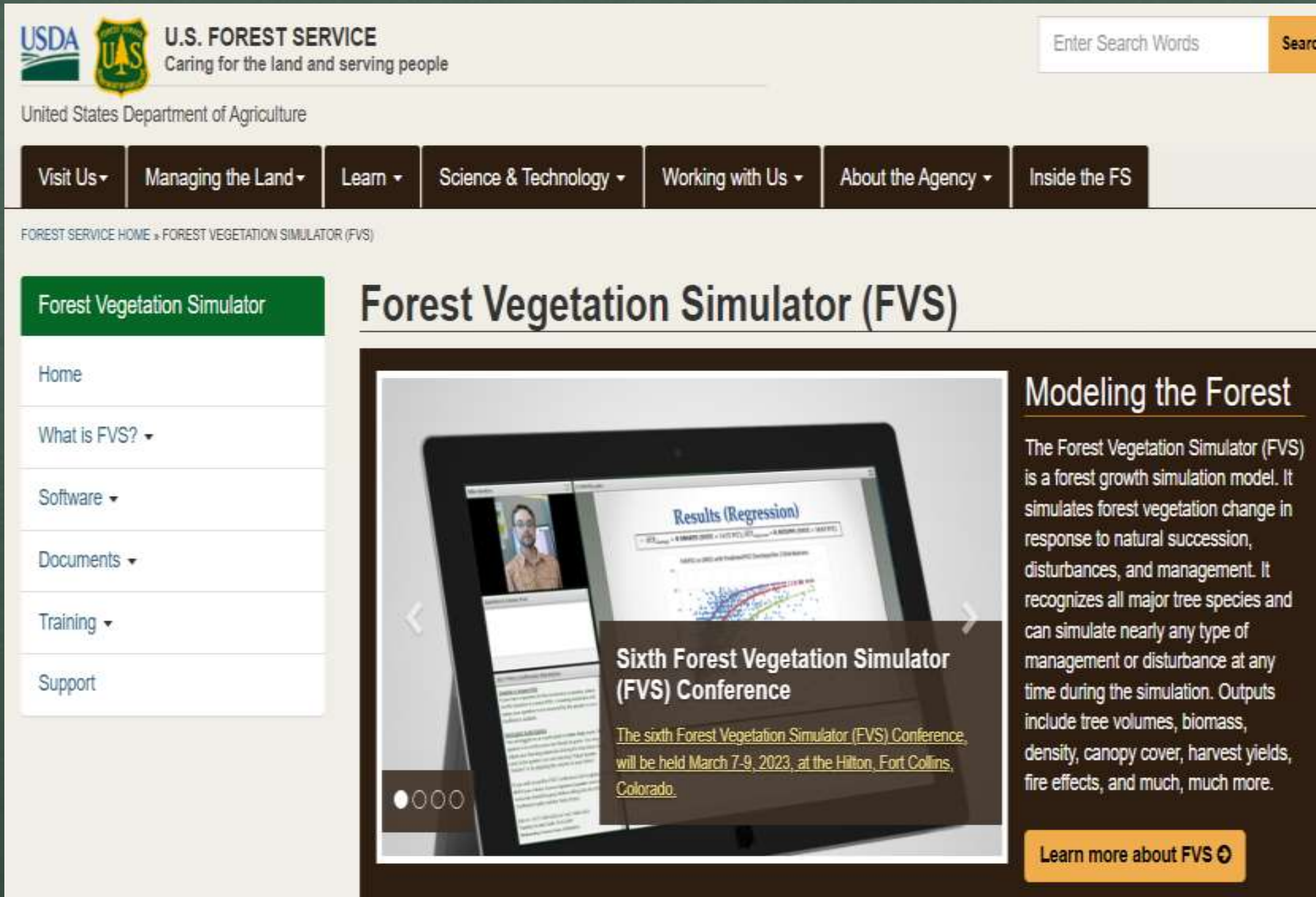

A GUIDE TO GROWTH AND YIELD MODELS
OF THE PACIFIC NORTHWEST

Guide to GY Models of the Pacific Northwest 1991

Status of growth and yield research: 1991 joint technical session of forest measurements, tree improvement and silviculture, and forest management working groups

by Valerie M. LeMay[1], Richard Greenwood[2], Peter L. Marshall[1], Margaret Penner[3], and Doug Walker[4]

Current GY Models



https://www.fs.usda.gov/fvs Accessed June 5, 2023

Modeling the Forest

The Forest Vegetation Simulator (FVS) is a forest growth simulation model. It simulates forest vegetation change in response to natural succession, disturbances, and management. It recognizes all major tree species and can simulate nearly any type of management or disturbance at any time during the simulation. Outputs include tree volumes, biomass, density, canopy cover, harvest yields, fire effects, and much, much more.

BRITISH COLUMBIA

▾ Growth & Yield Modelling

- ▸ Tree & Stand Simulator (TASS)
- Table Interpolation Program for Stand Yields (TIPSY)
- ▸ Variable Density Yield Projection (VDYP)

Growth & Yield Modelling - Province of British Columbia (gov.bc.ca) Accessed May 31, 2023

Tree & Stand Simulator (TASS)

Last Updated on February 21, 2023

Last Updated February 21, 2023

The Tree and Stand Simulator (**TASS**) is a biologically based, spatially explicit, individual tree model. The TASS brochure (PDF, 1.3 MB) provides a brief overview. TASS currently exists in 3 main forms:

1. **TASS III** is the public-release Windows™ version, which begins to extend TASS into more complex stand structures with multiple-species and -age cohorts. The initial release is

Growth & Yield Modelling - Province of British Columbia (gov.bc.ca) Accessed May 31, 2023

ESSA

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Forest Vegetation Simulator

The Forest Vegetation Simulator (FVS; also known as Prognosis) is an individual-tree, distance-independent forest stand projection model. The model simulates the growth and mortality of a sample of a stand's trees, using characteristics such as species, diameter, height, crown length and relative size.

Key outputs are produced at the individual tree and stand level; including volume, density, species, diameter, height, annual increment, and crown length. Because of its internal structure, one of its great strengths is the ability to simulate complex stands composed of many species and many ages.

https://www.essa.com/explore-essa/tools/fvsprognos Accessed May 29, 2023

Prognosis^{BC} Modelling

- Main
- Summary
- Flow Chart
- Projects
- Extension
- People
- Links
- Workshop

UNIVERSITY OF BRITISH COLUMBIA

Faculty of Forestry, Forest Resources Management
2424 Main Mall, Vancouver, BC, V6T 1Z4
Tel: (604) 822-2727   Fax: (604) 822-8645

Questions? Comments? Please email us.

Western Boreal Growth and Yield Association

Faculty of Agricultural, Life & Environmental Sciences

HOME | MEMBERSHIP | LONG TERM STUDY | MIXEDWOOD GROWTH MODEL | W

Home

Western Boreal Growth and Yield Project

The Western Boreal Growth and Yield (WESBOGY) Association first met informally in the mid 1980's and e year business plan in 1996 with Dr. Steve Titus as chair. In 2020 WESBOGY membership included 7 forest Members share an interest in forest growth and yield, stand dynamics, inventory and planning. WESBOGY development efforts by facilitating data sharing; by supporting development of MGM and other growth an and by providing a forum for communication.

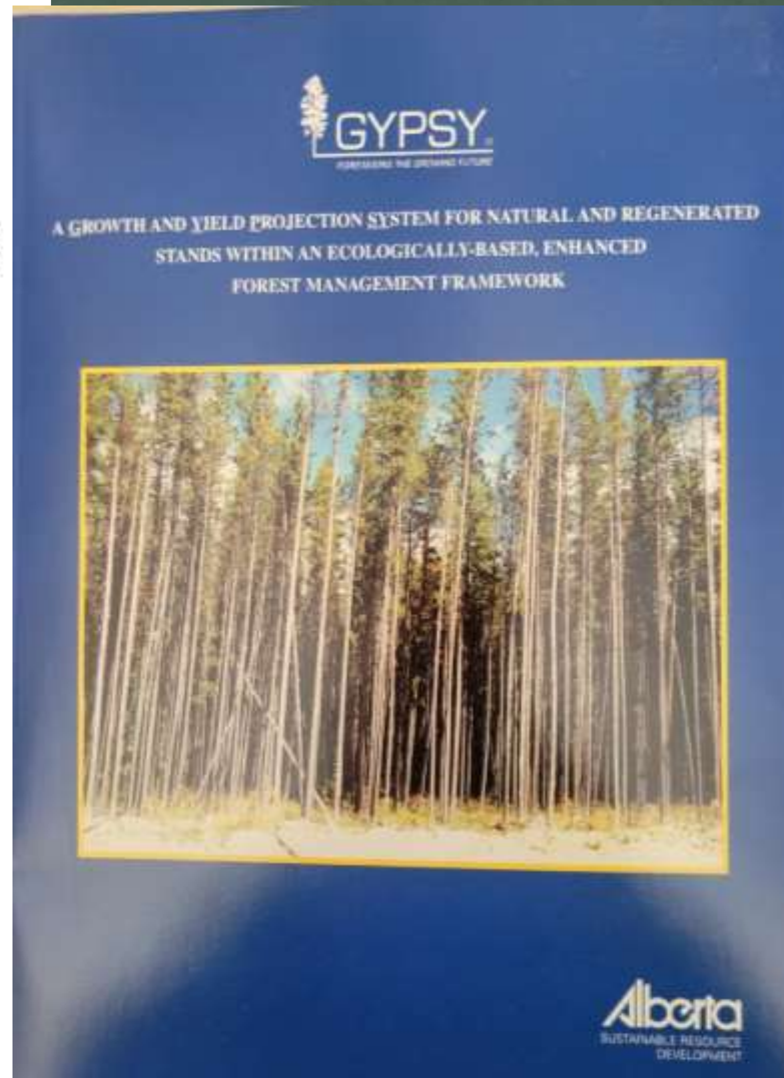
System versions

The first version of GYPSY was released in 2001. The forecasting capability of this version was limited to pure lodgepole pine stands.

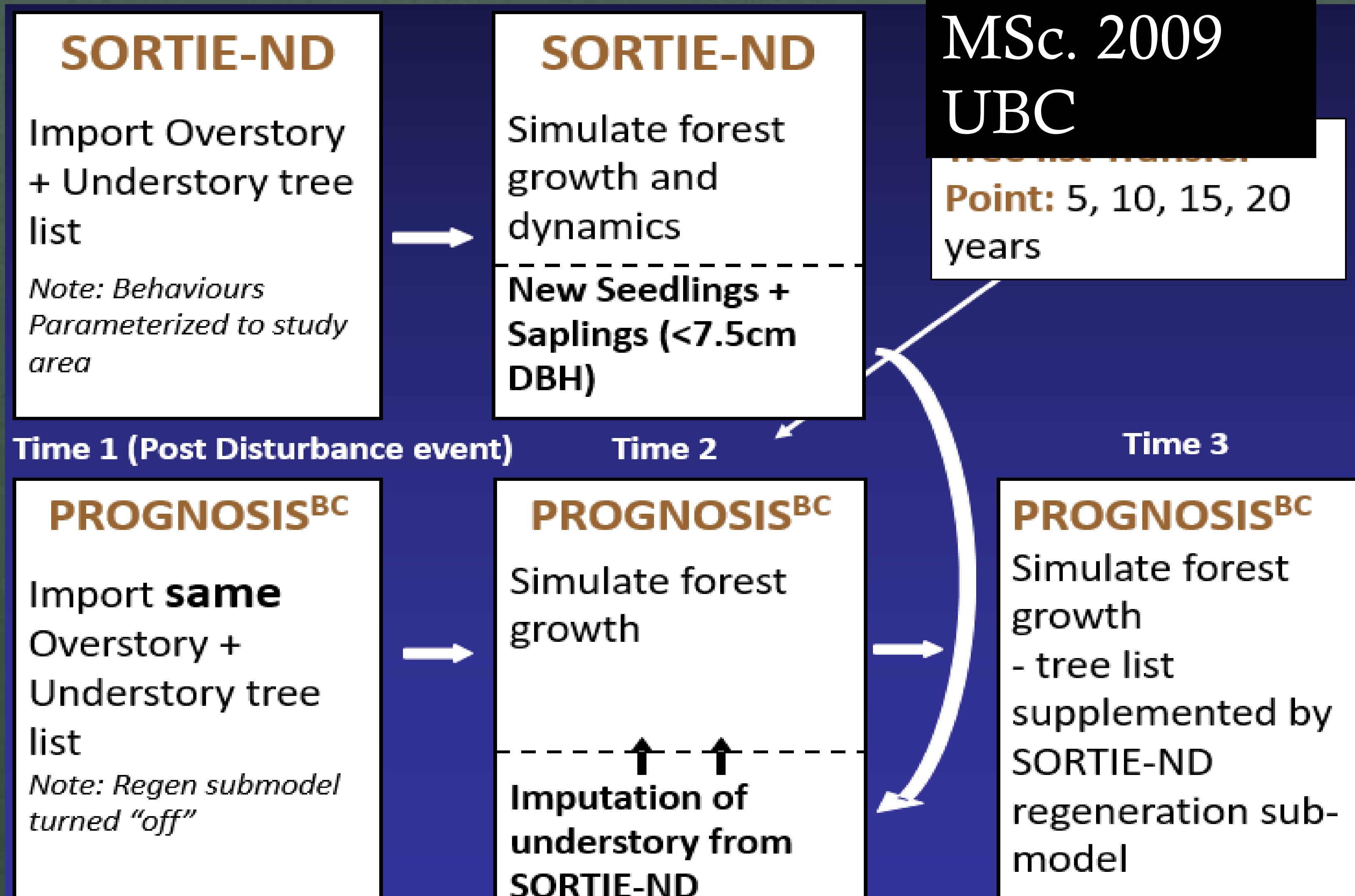
The 2009 version has been updated to include modelling capability for multiple species in pure and mixed species stands. It also enables forest managers to predict future growth based on reforestation survey results.

Tree species groups

GYPSY can forecast the growth of 4 tree species groups:



What about process and hybrid models?



Derek Sattler, MSc. 2009 UBC

Heritage Data Sets

1. PSPs now longer time periods covered 60 or more years
2. Experimental plots (EPs) such as those noted in the Stand Management Cooperative (SMC) managed by Eric Turnblom at U W also have more measures.

What are the changes in scope, forest inventories, and climate/ disturbance regimes? How does this impact GY models?

Changes in Scope: Increased Human Uses of Forest Ecosystems

- Population growth and movements closer to forest environments
- Biomass used as a source for fuels, fabrics, plastics replacements, etc.

This clearly affects forest inventory (FI), what about GY?

Timber Supply Area forest biomass analysis

FPInterface is an analytical tool used to conduct TSA residual forest biomass analysis. It contains forest productivity data and is used to estimate the cost of forestry activities. This data combined with harvesting and inventory projections allows for a biomass inventory graded by cost of delivery. FPInterface differs from most models which use averages to calculate both cost and amount of residual forest biomass. It accumulates the value of individual cut blocks on the landscape and calculates cost and time to a specified delivery point, such as a sawmill or pulp mill. These analyses provide carbon impact assessments which further inform bioeconomy development and climate action.

Tracking dead wood post-logging

https://www2.gov.bc.ca/gov/content/industry/forestry/supporting-innovation/bio-economy/biomass-technology
Accessed May 29, 2023

Energy for Sustainable Development 61 (2021) 196–205

Contents lists available at ScienceDirect

Energy for Sustainable Development

Forest, farms and fuelwood: Measuring changes in fuelwood collection and consumption behavior from a clean cooking intervention

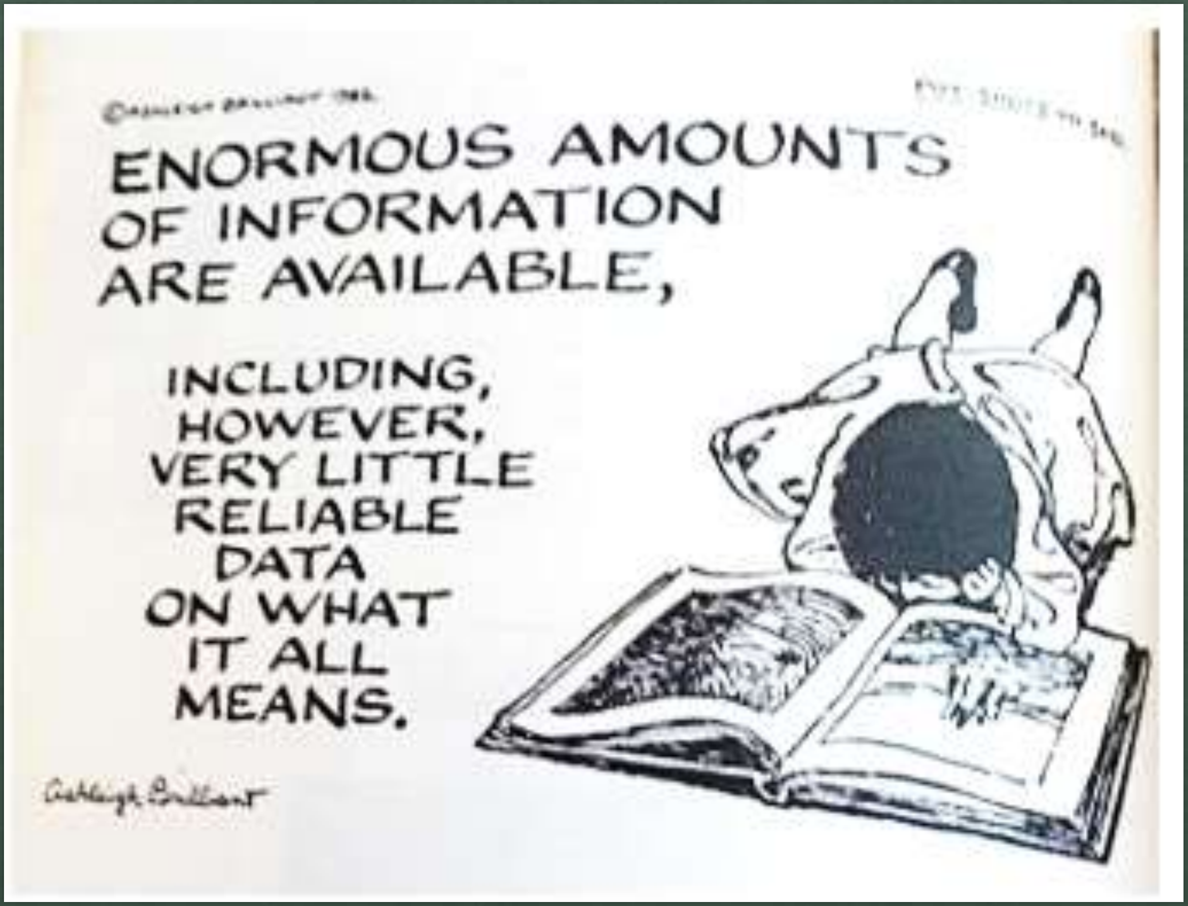
Devyani Singh[a,b,*], Hisham Zerriffi[a], Rob Bailis[c], Valerie LeMay[a]

- For fuelwood, need species, sizes, and dead wood. Need a tree-level model like FVS?
- For both of these, how will these removals impact site productivity?

Further Changes in Scope

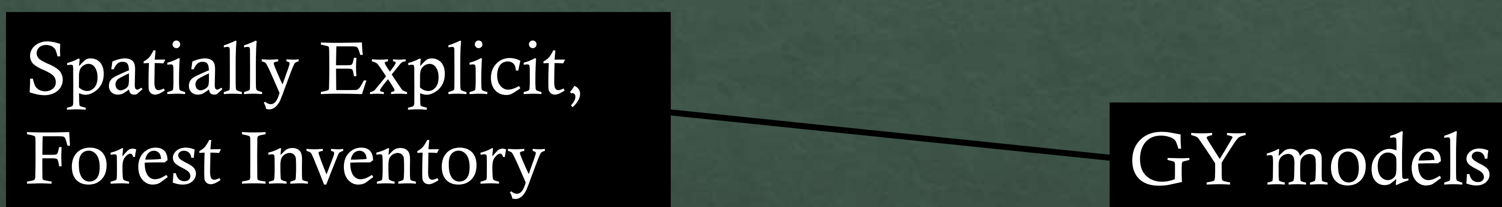
1. Fire risks: Need “dead wood tracking” in any future forest forecast with/without fuelwood reduction mitigation.
2. Habitat suitability: Need within stand structure including changing species composition over time.
3. Urban forests: Many, many species from anywhere in the world. Often isolated trees.
4. Carbon “sales”: Carbon tracking above and belowground.

Changing FI Technologies Under an Explosion of RS Data



Dr. Ashleigh Brilliant, 1985. (Copyright indicates restricted approval for use, up to 5 images).

GY models must be connected to forest inventory maps to forecast forest ecosystems under natural disturbance, and human disturbance regimes.



Imputing Tree-Lists

- The concepts of using variable-space NN methods to impute tree-lists was developed by Stage and Moeur originally
- This was later implemented into YaImpute by Crookston and Finley.

Imputing tree-lists from aerial attributes for complex stands of south-eastern British Columbia

By H. Temesgen, V.M. LeMay*, K.L. Froese, P.L. Marshall

Forest Ecology and Management 177 (2003) 277–285

Satellite Imagery

WikipediA
The Free Encyclopedia

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Satellite imagery

Article Talk

From Wikipedia, the free encyclopedia

Satellite images (also **Earth observation imagery**, **spaceborne phot**
images of Earth collected by imaging satellites operated by government
Satellite imaging companies sell images by licensing them to governme
and Google Maps.

Data characteristics
Imaging satellites
Public domain
CORONA
Landsat
MODIS
Sentinel
ASTER
Meteosat
Private domain
GeoEye
Maxar
Airbus Intelligence
Spot Image
Planet's RapidEye
ImageSat International
China Siwei
Disadvantages


https://canadiangis.com/fre...
CanadianGIS.com
Geographic Information
and Geospatial Resources
Canadian Lidar Data
Sources of Free
and
Open Data

LiDAR

INT. J. REMOTE SENSING, 1985, VOL. 6, NO. 1, 101–113

Automated measurements of terrain reflection and height variations using an airborne infrared laser system

H. SCHREIER

Department of Soil Science, University of British Columbia, Vancouver, British Columbia, V6T 2A2, Canada

J. LOUGHEED

Davis Engineering Ltd., Ottawa, Ontario, Canada

C. TUCKER

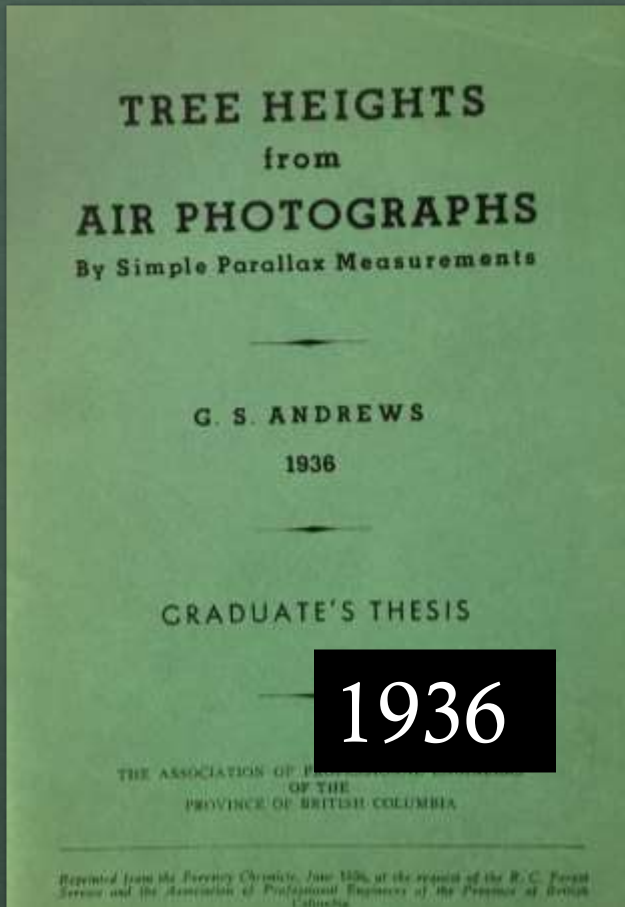
DSTI, Department of National Defence, Ottawa, Ontario, Canada

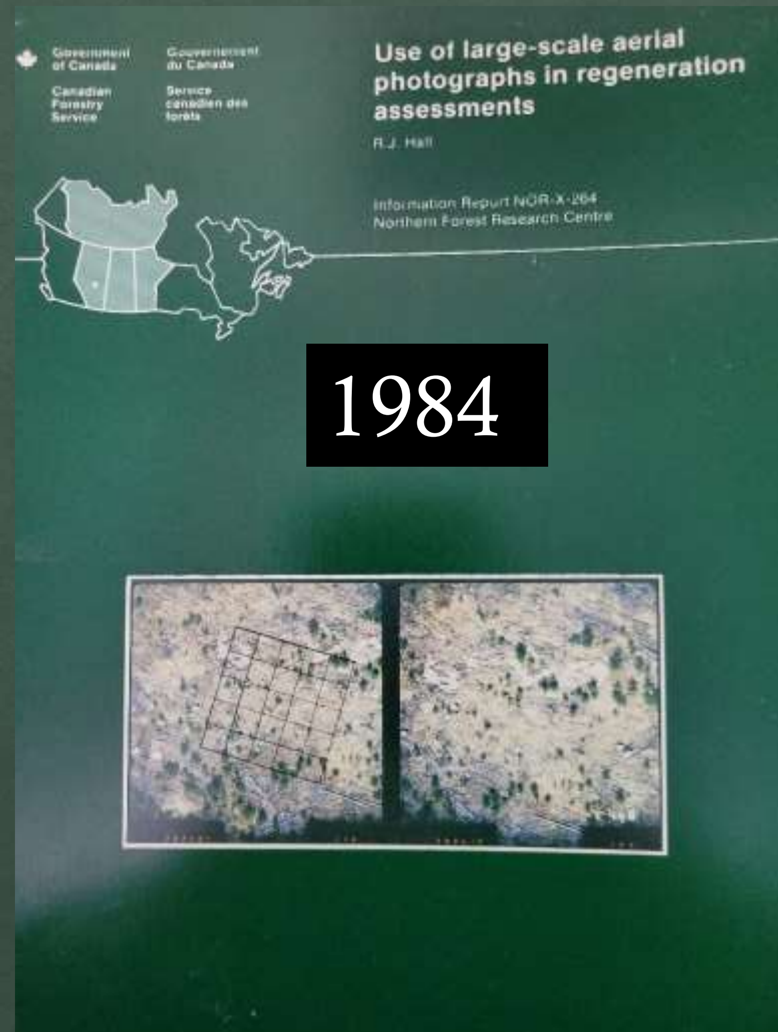
and D. LECKIE

Petawawa National Forestry Institute, Chalk River, Ontario, Canada

1985

Heights Prior to LiDAR





Digital 3D Aerial Photos

Scand. J. For. Res. 12: 00-00, 1997

Estimating Forest Characteristics in Sc
Photographs with Respect to Requiren
Forest Management Planning

PETER HOLMGREN[1], TOMAS THURESSON[2,*] and SÖ

[1]Department of Forest Soils, Swedish University of Agricultural Sciences,
[2]Department of Forest Resource Management and Geomatics, Swedish Un
Sweden

Holmgren, P.[1], Thuresson, T.[2] and Holm, S.[2]
of Agricultural Sciences, P.O. Box 7001,
Forest Resource Mangement and Geomat
S-901 83 Umeå, Sweden). *Estimating fores*
respect to requirements for economic fores
Accepted Dec. 1, 1996. Scand. J. For. Res.

The objective of forest management plan
economic yield. Methods used to collect in
include variables significant for economic

Scanned Photos 1997

Comparing Airborne Laser Scanning, and Image-Based Point Clouds by Semi-Global Matching and Enhanced Automatic...

Article in Forests · June 2017
DOI: 10.3390/f8060215

5 authors, including:

Sami Ullah
University of Freiburg
5 PUBLICATIONS 5 CITATIONS

Matthias Dees
University of Freiburg
60 PUBLICATIONS 174 CITATIONS

Pawanjeet Singh Datta
University of Freiburg
15 PUBLICATIONS 19 CITATIONS

Barbara Koch
University of Freiburg
224 PUBLICATIONS 2,750 CITATIONS

UAVs

ELSEVIER

Computers and Electronics in Agriculture

Volume 150, July 2018, Pages 289-301

Original papers

Automatic citrus tree extraction from UAV images and digital surface models using circular Hough transform

Dilek Koc-San [a d], Serdar Selim [b d], Nagihan Aslan [b], Bekir Taner San [c]

What are the minimum variables and accuracy needed to connect FI to GY?

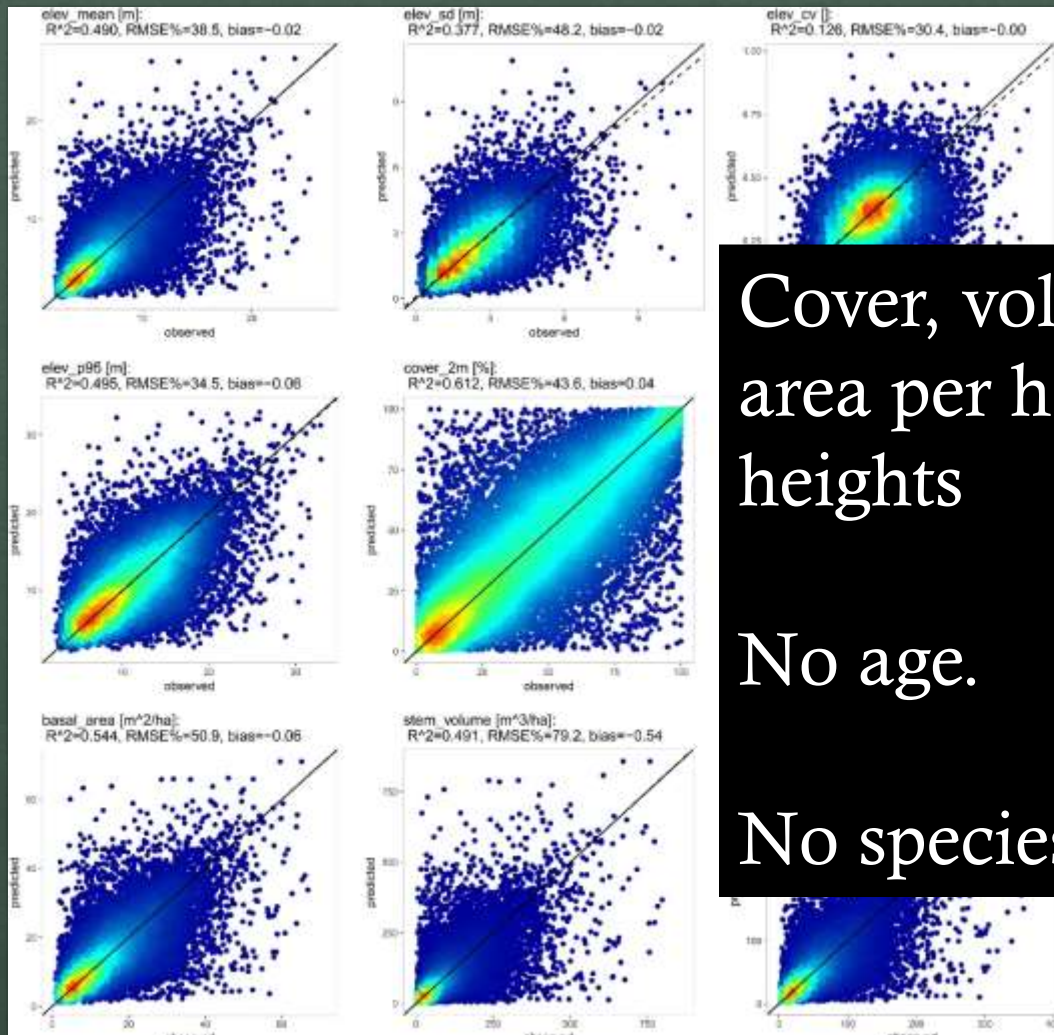
ELSEVIER

Remote Sensing of Environment
Volume 209, May 2018, Pages 90-106

Large-area mapping of Canadian boreal forest cover, height, biomass and other structural attributes using Landsat composites and lidar plots

Giona Matasci [a], Txomin Hermosilla [a], Michael A. Wulder [b], Joanne C. White [b], Nicholas C. Coops [a], Geordie W. Hobart [b], Harold S.J. Zald [c]

Missing Attributes to Connect to GY

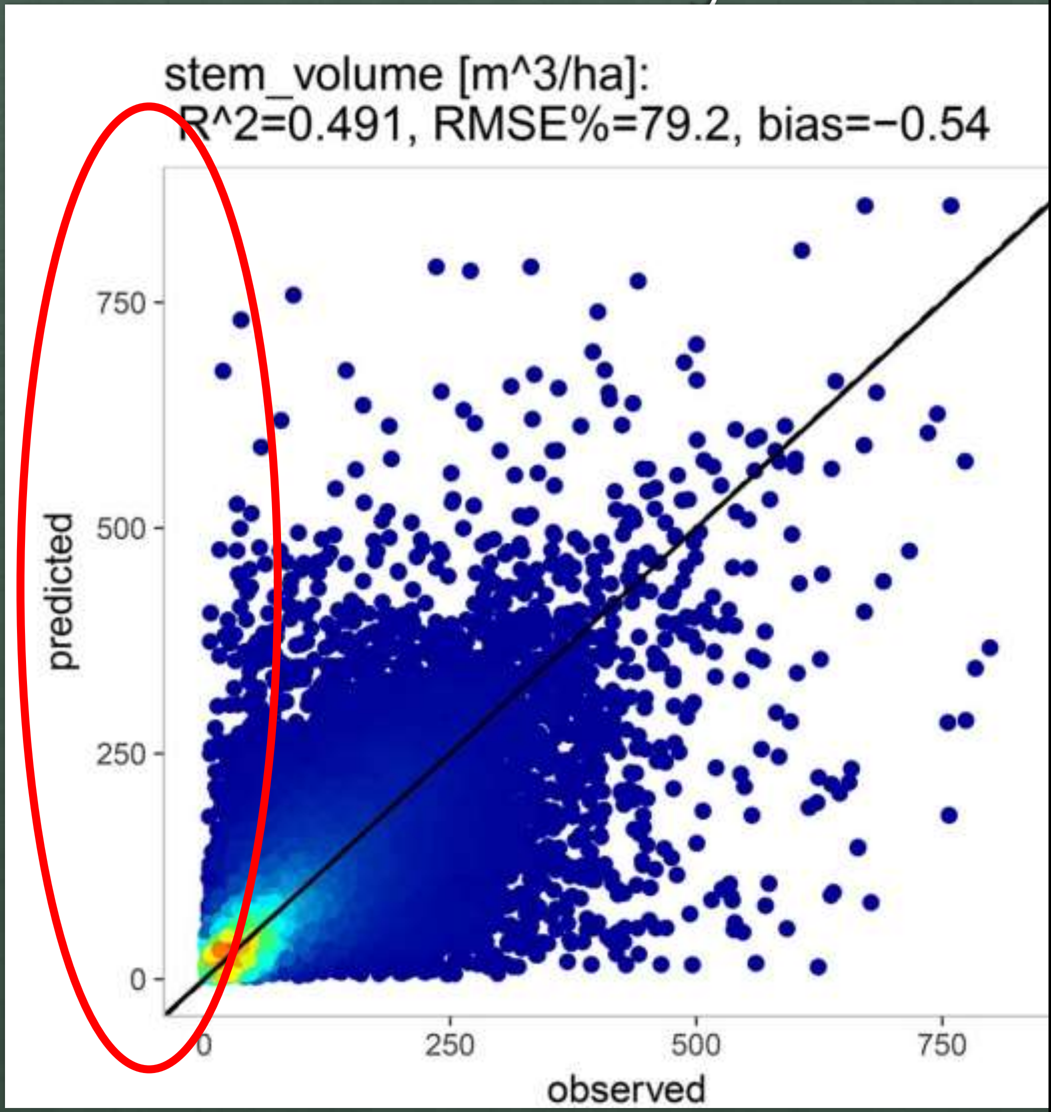


Cover, volume/ha, basal area per ha, biomass/ha, heights

No age.

No species composition.

Accuracy



Each dot: LiDAR plot ("observed") vs predicted using Landsat metrics + topography + spatial position + years since greatest change.

For GY forecasts, we need to be accurate for each particular spatial extent.

Forestry An International Journal of Forest Research

Institute of Chartered Foresters

Forestry 2017; **90**, 613–631, doi:10.1093/forestry/cpx014
Advance Access publication 24 March 2017

Estimating stand density, biomass and tree species from very high resolution stereo-imagery – towards an all-in-one sensor for forestry applications?

Fabian Ewald Fassnacht[1*], Daniel Mangold[1], Jannika Schäfer[1], Markus Immitzer[2], Teja Kattenborn[1], Barbara Koch[3] and Hooman Latifi[4]

345

NRC Research Press

Lochhead et. al 2018

ARTICLE

Multivariate estimation for accurate and logically consistent forest-attributes maps at macroscales

Kyle Lochhead, Valerie LeMay, Gary Bull, Olaf Schwab, and James Halperin

Can. J. For. Res. 48: 345–359 (2018) dx.doi.org/10.1139/cjfr-2017-0221

Landsat composites + photo-interpreted large-scale aerial photos + other GIS layers

Kriging with external drift

Crown closure, species percents, age, height, and volume per ha

New Climate and Disturbance Regimes

92% 11:42 AM

Storms, floods, other wea

ici.radio-canada.ca/rci/en/news/1820910/stor

rci CANADIAN NEWS IN 7 LANGUAGES EN

SCIENCE

Storms, floods, other weather disasters quadrupled worldwide since 1970s, UN agency says

Report shows weather disasters now cause 7 times more damage, but fewer deaths

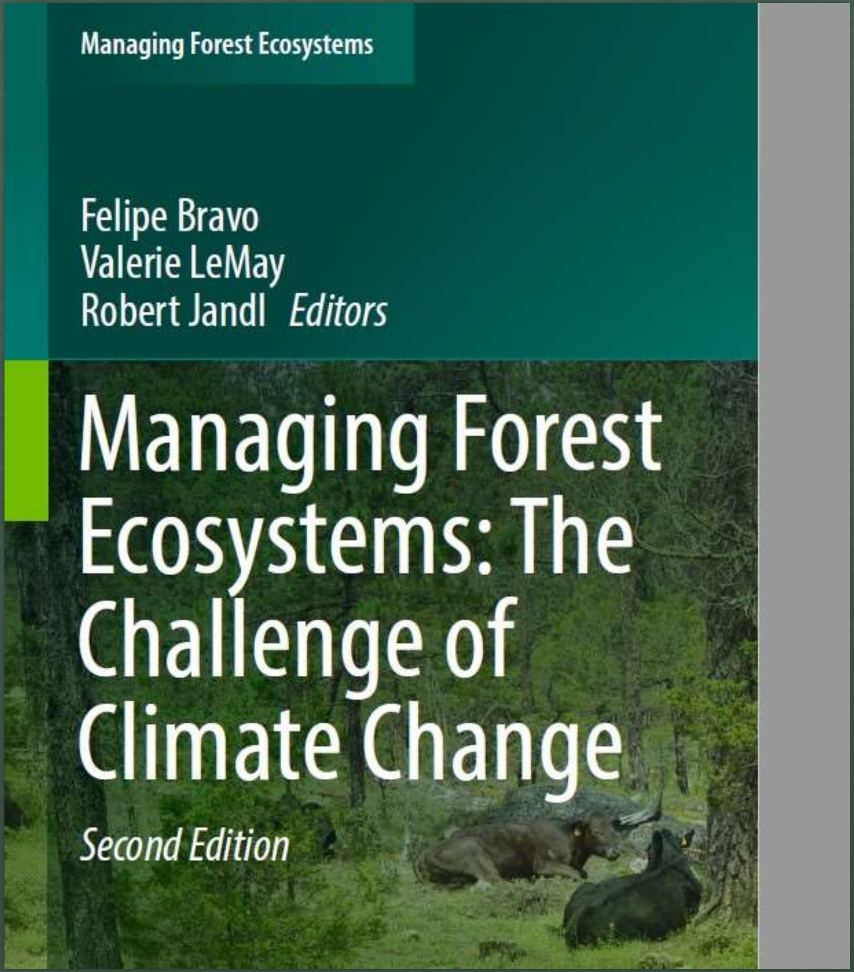
Report shows weather disasters now cause 7 times more damage, but fewer deaths.
PHOTO: (THILO SCHMUELGEN/REUTERS)

Posted September, 2021

Weather disasters are striking the world four to five times more often and causing seven times more damage than in the 1970s, the United Nations weather agency reports.

But these disasters are killing far fewer people. In the 1970s and 1980s, they killed an average of about 170 people a day worldwide. In the 2010s, that dropped to about 40 per day, the World Meteorological Organization said in a report Wednesday that looks at more than 11,000 weather disasters in the past half-century.

Mitigation



Managing Forest Ecosystems
Felipe Bravo
Valerie LeMay
Robert Jandl Editors
Managing Forest Ecosystems: The Challenge of Climate Change
Second Edition

Climate Sensitive Models
Climate-FVS (Crookston, 2014)

Crookston, Nicholas L. 2014. **Climate-FVS Version 2: Content, users guide, applications, and behavior.** Gen. Tech. Rep. RMRS-GTR-319. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 38 p.

Abstract

Climate change in the 21st Century is projected to cause widespread changes in forest ecosystems. Climate-FVS is a modification to the Forest Vegetation Simulator designed to take climate change into account when predicting forest dynamics at decadal to century time scales. Individual tree climate viability scores measure the likelihood that the climate

MGM Developments for Climate Sensitive Survival (2019 release)

Refining and improving MGM has been an ongoing focus of the MGM Development Team at the University of Alberta. The current version of MGM, released in July 2019, represents a substantial update that includes new climate sensitive tree survival functions, implementation of the "GYPSY" site index curves for Alberta, and support for additional species (i.e. jack pine and black spruce). This release has undergone extensive validation and behavioural testing and is currently undergoing a formal review by the Government of Alberta.

Climate & Genetics

Ecological Applications, 21(3), 2011, pp. 776–788

Modeling lodgepole pine radial growth relative to climate and genetics using universal growth-trend response functions

Sierra C. McLane,[1] Valerie M. LeMay,[2] and Sally N. Aitken[1,3]

forests

MDPI

Article

Meta-Modelling to Quantify Yields of White Spruce and Hybrid Spruce Provenances in the Canadian Boreal Forest †

Suborna Ahmed [1,*], Valerie LeMay [1], Alvin Yanchuk [2], Andrew Robinson [3], Peter Marshall [1] and Gary Bull [1]

Journal of Environmental Management 252 (2019) 109625

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

ELSEVIER

Research article

Examining the vulnerability of localized reforestation strategies to climate change at a macroscale

Check for updates

Kyle Lochhead[a,*], Saeed Ghafghazi[a,b], Valerie LeMay[a], Gary Q. Bull[a]

[a] *Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, 2424, Main Mall. V6T 1Z4, Vancouver, BC, Canada*

[b] *Natural Resources Canada, Canadian Forest Service, 1500 - 605 Robson St, Vancouver, British Columbia, Canada, V6B 5J3*

We only have measures on past climates, how is this done?

1. "Space=Time" assumption: Pooling time series data and/or published research results over a wide spatial range of locations
2. Biologically tractable models that can be extended beyond the range of climate data to higher (or lower) values
3. Heavy reliance on available climate models largely based on spatially interpolated climate data from widely distant spatial locations

Back to the question posed…

Can we meet increasing demands for forest growth and yield information under increased scope, changing inventory technologies, and uncertain climate and disturbance regimes?

Yes, we can …

1. Long history of GY modelling in response to information needs
2. Recent research on component models and modifying existing GY models
3. More attention is being paid to linking GY to FI
4. AI or AI-assisted technologies may improve data mining capabilities of heritage and other datasets.

… but no… the current GY models do not meet all of the needs, exactly. There are many changes needed and challenges to overcome…

GY Model Changes, A Partial List

1. Component models must be biologically tractable to extend beyond the data ranges. This is true even using the "space=time" assumption to extend climate ranges.
2. Interfaces to link GY models to FI must be flexible, since FI technologies are a moving target.
3. Formal (hybrid models) or informal connections of models may provide solutions.

GY Model Changes, A Partial List

4. Experimental trials data are still relatively “untapped”, but can be used to facilitate needed changes.
5. Dead wood tracking is needed, as well as species succession. This has been successfully done using FVS, but not in many other GY models.
6. There is a social desire for “lighter touch” changes to forests. GY models must be capable of single-tree partial removals.

Challenges, A Very Partial List

1. How do we obtain accurate inputs on spatial units to accurately forecast possible futures?
2. As in the past, computer capacity needs are increasing – can we achieve the level of AI (or AI-assisted) approaches we imagine?
3. What about expertise?

FOREWORD

However, because of the urgent need for yield tables in this forest type, it was considered unpractical to delay their preparation until more precise techniques and additional data were available.

Expertise

Assistant/Associate Professor In Biofuels/Bioenergy/Biorefinery/Forest Products Biotechnology

Univer
Vanco

Postdoctoral Fellowships In Forest Wildfire Real-Time Monitoring And Modeling

The U
Vanc

STO-RE 27R - Forest Carbon Modelling Professional

BC Public Service
Campbell River, BRITISH COLUMBIA

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