

FSTY 405 Forest Growth and Yield

- Who?
 - Oscar Garcia
 - ...
- What?
 - Growth (& yield) modelling
 - Quantitative silviculture
 - Applied mathematics
- How?
 - ...

Read the Syllabus!

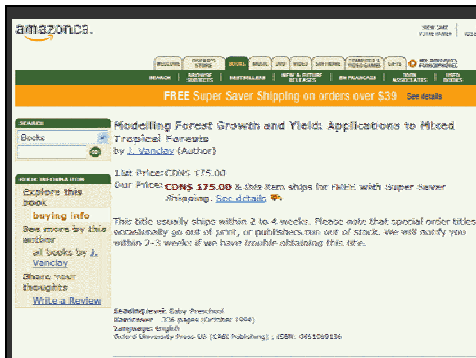
For the Introduction and Overview that follows read Chapter 1 of Vanclay, MoF's "*Guidelines for Developing Stand Density Management Regimes*", and MoF's G&Y web pages.

You might also find useful "*Growth Modelling – a (Re)view*":

<http://web.unbc.ca/~garcia/publ/view.pdf>

How? (Administrivia)

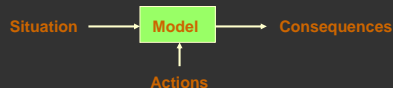
- Syllabus
- Web
 - web.unbc.ca/~garcia/FSTY405
- Course components
 - Lectures, Labs, Assignments
- Texts
 - Vanclay: "Modelling Forest Growth and Yield"
 - MOF, Clutter et al, Davis & Johnson
- Software
 - Excel, gnuplot, Vensim, BC growth models



Easy reading! (notice Amazon's *Reading level* rating).

Why??!

- Rational decision-making



Need to link actions to consequences.

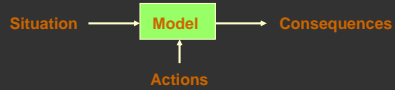
BC Forestry

- Prospects
 - Expansion is over, structural changes
 - Transition old-growth → second growth
- MPB
 - Log sizes, species mix
 - Pulp & paper: residues → roundwood
- Changes in logging, silviculture, G&Y needs

See <http://forestgrowth.unbc.ca/background.pdf>

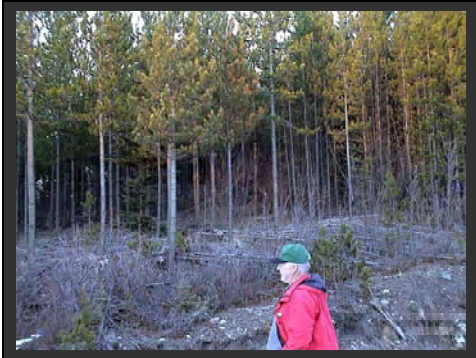
Why??!

- Rational decision-making



- Experience?
- Stand density management (stand level)

See MoF's "*Guidelines for Developing Stand Density Management Regimes*".



Lodgepole pine, thinned and pruned (left), control (right).





Aspen, thinned in foreground.



"Fred's Forest" demo, from BC MOF website. Note the decision variables.

Why??!

- Rational decision-making

```

    graph LR
      Situation --> Model
      Actions --> Model
      Model --> Consequences
  
```

- Experience?
- Stand density management (stand level)
- Forest estate management, SFM, AAC

Experience (trial-and-error) less useful in forestry than in other fields.

Modelling more important than in agriculture, for instance. Direct use of experiments costly or impractical.

Approach

- Button-pushing?
- Model builder?
- Model user
 - Principles
 - Limitations
- Lectures, labs, assignments

Limited usefulness in learning to use current models: subject to change.

Not appropriate here to go into model development. Specialized subject.

Intelligent use: general understanding, fundamentals, and caveats.

Models

- A (partial) representation
 - Mental
 - Material
 - Verbal
 - **Mathematical**
 - Computer?
- Forest stand models. Growth (& yield) models

Used all the time. E.g., mental pictures.

Realism not a virtue. E.g., colour, pilot name, interior, not relevant in an airplane scale model for wind tunnel testing (material model).

VCR manual, example of verbal model. Empirical, predictive (no internal workings, effect of pressing button).

Mathematical language: shorthand. Advantages: a) Conciseness, less ambiguity. b) Pre-packaged arguments (rules, theorems), no need to reason from scratch every time.

“Computer models” usually implementation of a mathematical model by a computer program (simulator). Straight from ideas to computer code not advisable. There may be several computer implementations of a same model, or one program that runs several models: model \neq simulator.

Stand (BC “polygon”) = patch of forest considered as homogeneous for a specific purpose.

An engineer thinks that his equations are an approximation to reality.

A physicist thinks reality is an approximation to his equations.

A mathematician doesn't care.

Anonymous





All models are wrong, but some are useful.

G. E. P. Box

Model use

- Understanding
 - Mechanistic (how)
 - "Process models"
 - Research tool
- Prediction
 - Decision-making (DSS)
 - Empirical, black box

When will it be dark?

"Models for understanding": Describe and put together current knowledge, identify gaps, test hypotheses. Mechanistic, "process models". For research. Benefits come mostly from building the model.

"Models for prediction": For decision making (decision support systems). Can be empirical, must match observation and produce good future projections.

Overlaps.

Forest growth {& yield} models

- Prediction (decision-making)
 - Forecasting, planning
 - Silvicultural regimes
 - Inventory updating
 - Wildlife, carbon sequestering, etc.
- Understanding (research tool)
 - Mechanisms (how), not black box
 - "Actions" not necessarily decision variables
 - Situation (state) not necessarily measurable

"G&Y" somewhat redundant, closely related.

Long-term forecasting for planning at forest, regional and national levels, e.g. timber supply, AAC.

Stand-level evaluation of silvicultural prescriptions (initial density, thinning, pruning, rotation age, etc.).

Estimating current condition from last measurements.

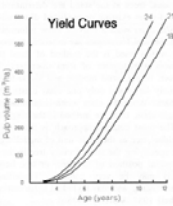
Examples of research models (plant architecture) taken from <http://algorithmicbotany.org/vmm-deluxe/Section-08.html>.

Overview

Big picture. Details later.

Yield tables

Age (y)	Site 10	Site 21	Site 24
3	1	2	4
4	11	17	20
5	26	30	35
6	79	102	133
7	124	169	215
8	201	246	301
9	276	310	395
10	350	418	491
11	430	507	586
12	520	594	679



Yield Equation: $\log(V+1) = -3.534 - 14.021t + 0.2319t^2$

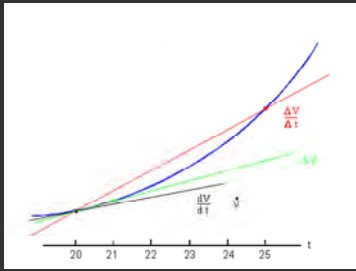
Yield tables (or curves, functions) oldest (late 1700's) and simplest. Good enough in many situations (e.g. VDYP for AAC in BC)

Even-aged stands.

Volume ("yield") and usually mean dbh, height, trees per hectare, etc., over age. For various site qualities.

From cross-sectional data: point (or short interval) observations from many stands at various ages, no need to wait full rotation.

Growth



PI
PAI
CAI
Rate
MAI

Growth = change in size

Periodic (PAI), annual (CAI), "instantaneous"

Growth rate = slope

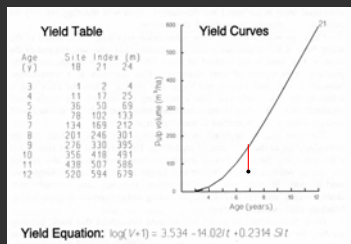
Change in other variables, not necessarily "growth", also important. E.g., trees per hectare ("mortality").

Mean annual increment (MAI) is the average growth from 0 up to a given age, i.e., $MAI = V/t$

See the interactive MAI demo in the website.

Some ambiguity in notation: ΔV may mean $V(t+1) - V(t)$, or $V(t+\Delta t) - V(t)$.

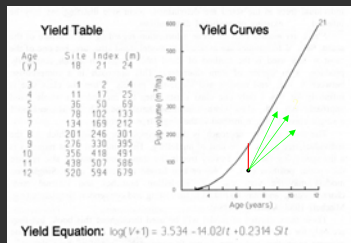
Yield tables



Run into trouble if we deviate from the predicted trend.

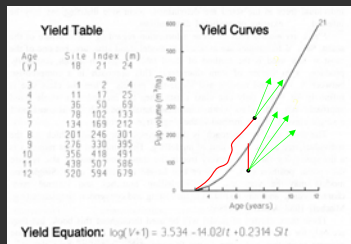
E.g. through a thinning.

Yield tables



Which way?

Yield tables



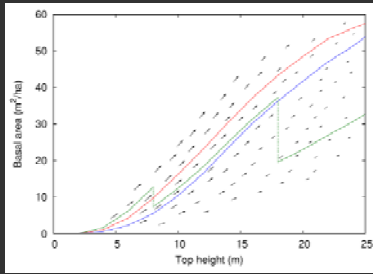
Even without treatments, stand may deviate from predictions due to weather, etc.

How to predict future of an existing stand?

Various adjustments and modifications have been proposed.

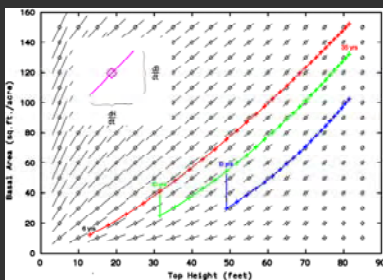
Better (when the yield tables are not sufficient) is to think in terms of growth rates, instead of the accumulated yield.

Dynamics



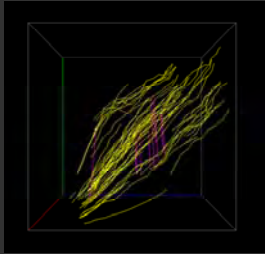
Growth rates associated to any point (state). They generate trajectories.
Think of fluid flow and streamlines.

Two state variables



Based on Clutter's 1963 model (Vanclay, p.28).

Three state variables



PSP data, with thinnings (purple lines)
Axes: blue = top height, green = basal area, red = average spacing
See the VRML dynamic graphics demo in the website (VRML viewer required).

Dynamical systems

1. Describe current state by a number of variables
e.g. (H,B)
State (vector), state variables
2. Model rate of change of these
e.g. $dH/dt = f_1(H)$, $dB/dt = f_2(H,B)$
Local transition function(s) → Global T.F.
3. Estimate other useful quantities from current state
e.g. $V = a + bBH$
Output function(s)

General, for any system evolving in time.
More generally, rate functions can also include (continuous) inputs. Inputs such as temperature and precipitation often used in research (process) models, rarely in forest management decision-support stand models.

Vectors

- $(H, B) = \mathbf{x}$
 $\mathbf{x} = (x_1, x_2, \dots, x_n)$
- $V = a + b BH = f(B, H)$
 $= f(\mathbf{x})$
- $\Delta H = f_1(H)$
 $\Delta B = f_2(B, H)$ $\rightarrow \quad \Delta \mathbf{x} = \mathbf{f}(\mathbf{x})$

Shorthand.

Dynamical Systems

$\frac{d\mathbf{x}}{dt} = \mathbf{f}(\mathbf{x}, \mathbf{u})$ or $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x}, \mathbf{u})$
(continuous or discrete time)

- E.g., stand:
 $\mathbf{x} = (H, B, N)$, \mathbf{u} null or weather
- E.g. tree:
 $\mathbf{x} = \text{dbh}$, $\mathbf{u} = \text{"growing space"}$
- E.g. forest estate model:
 $\mathbf{x} = \{s_{ki}\}$, s_{ki} = area in forest type k , age class i

Dynamical Systems

$\frac{d\mathbf{x}}{dt} = \mathbf{f}(\mathbf{x}, \mathbf{u})$ or $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x}, \mathbf{u})$
(continuous or discrete time)

- E.g., Physics: $\mathbf{x} = (x, y, z, v_x, v_y, v_z)$
 v_x = velocity = dx/dt
Newton: $F = ma$, a = acceleration = dv/dt
Therefore,
 $dx/dt = v_x$
...
 $dv_x/dt = F_x/a$
...

Dynamical Systems

Local transition function:

$\frac{d\mathbf{x}}{dt} = \mathbf{f}(\mathbf{x})$ or $\Delta \mathbf{x} = \mathbf{f}(\mathbf{x})$ (no input, for simplicity)

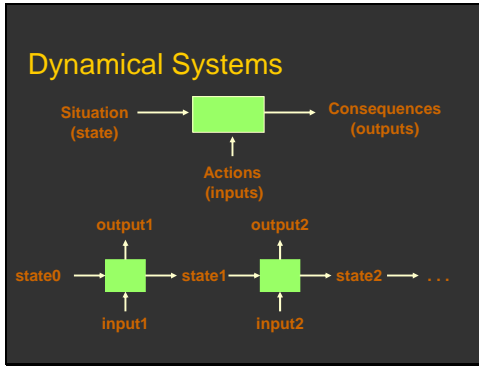
Integration \downarrow or iteration $\mathbf{x}(t+\Delta) = \mathbf{x}(t) + \mathbf{f}(\mathbf{x}(t))$

Global transition function:

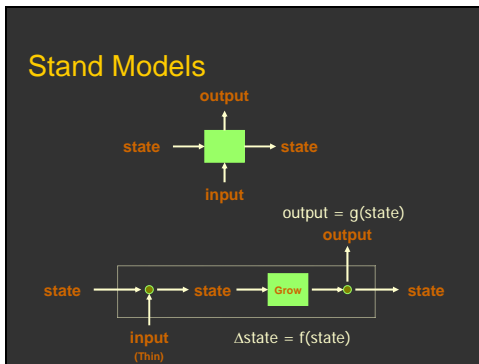
$\mathbf{x}_1 = \mathbf{F}(\mathbf{x}_0, t_1 - t_0)$

This article might or might not help to understand the state-space approach:

<http://web.unbc.ca/~garcia/publ/time-p.pdf>



Break-up into time intervals.



Growth models can be simpler:

Inputs are usually point actions, instantaneous changes, rather than continuous time functions.

Outputs functions of current state.

“Guts” of the model just needs to describe change of state (transition).

How many state variables?

- One? $dH/dt = f(H)$
 $V = g(H) ??$
 OK if only interested in H (site quality)
- V?
 $dV/dt = f(V, H, ...)$ NO
- Two? E.g. (H,B)
 $dH/dt = f_1(H), dB/dt = f_2(H,B), V = g(H,B)$
 Maybe
- Three? E.g. (H, B, N)
 OK for homogeneous, pure even-aged stands

State detail must be sufficient for:

- a) Estimating rates
- b) Estimating outputs of interest

Growth model types

(Goulding, Munro 1973, UBC)

1. Whole stand (stand-level)
2. Individual-tree (single-tree)
 - a) Distance-independent (non-spatial)
 - b) Distance-dependent (spatial, spatially explicit)
3. Size class (Vanclay)

Growth model types

- Continuous dx/dt
- Discrete Δx , $x(t+\Delta)$

- Deterministic $f(x, \text{known } u)$
- Stochastic $f(x, \text{random } u)$

Data

- PSP, stem analysis
- Estimation
- Validation, implementation, etc.

Program

- Site
- Yield tables
- Distance dependent
- Distance independent
- Whole stand
- Data, etc.