(Sub-)Models of Regeneration and Early Growth

Early growth, establishment

- Early growth
  - "Disjoint" models
  - Effect of establishment treatments (site preparation, fertilizing, planting stock)
- Recruitment

  Uneven-aged stands. Ingrowth (trees reaching measurement threshold)
- Regeneration models

Disjoint: separate sub-models for seedlings (or young trees), and for the adult stand. E.g., different models for "small" and for "large" trees in Prognosis.

Regeneration

- Seeding
  - Seed production

    number/tree = 3067 x (Basal area) x (seed mass)$^{-0.58}$
  - Dispersion

    proportion at distance $x = k \exp[-0.22 v^{0.75} x^{0.59}]$

    where v = falling terminal velocity
- Establishment
  - Probability of germination and seedling survival
- Seedling growth
  - Vegetation management (e.g. brushing), etc.

Seeding example relationships from Greene and Johnson, http://sfm-1.biology.ualberta.ca/english/pubs/PDF/WP_2001-9.pdf

The original SORTIE includes seeding/establishment sub-models.

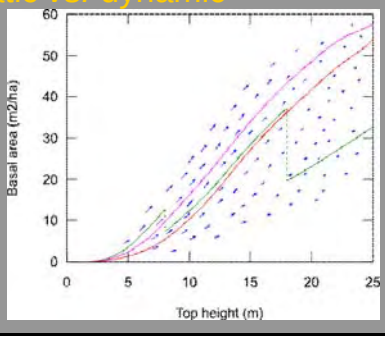
Summary of Growth Model Types (according to level of detail)

Synthesis

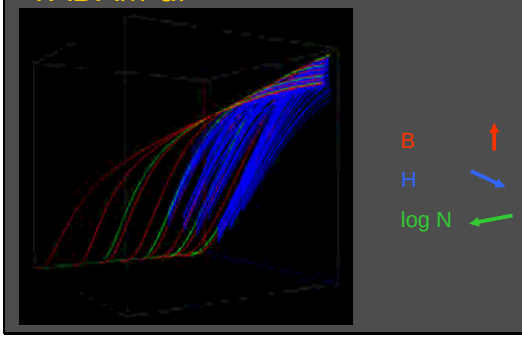
- Static (yield tables)
- Dynamic
  - State
  - Rates, local transition function(s)
  - Accumulation, iteration, integration:
    local → global transition function
  - Outputs

See the *Overview* notes.

Static *vs.* dynamic



TADAM-df



http://forestgrowth.unbc.ca/tadam/vrml.htm

Synthesis

- Dynamic model types (state detail, resolution)
  - Whole stand (stand level)
  - Individual-tree (tree level)
    - Distance independent (aspatial, non-spatial)
    - Distance dependent (spatial, spatially explicit)

Understanding -- Decision-making

Detail

More bias ← → Less precision

See *Overview*.

"A theory should be as simple as possible, but not simpler"

Albert Einstein

For prediction, use as few state variables as possible, but not less.

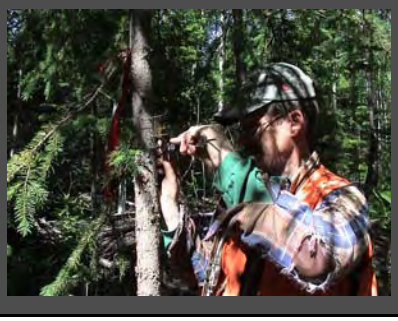
DATA

- Temporary sample plots
- Permanent (remeasured) sample plots (PSPs)
- Stem analysis
- Dendrometer bands

Dendrometer bands

Dendrometer bands

Dendrometer bands

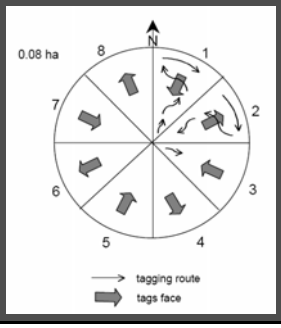


PSPs

- Continuous forest inventory (CFI, VRI)
- “Growth plots”
- Designed experiments

CFI requires representative sampling. For G&Y it is better to cover extremes.

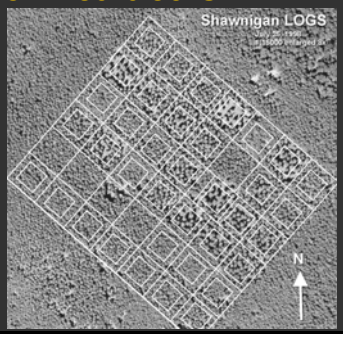
Permanent Sample Plots (PSPs)



PSPs

- Continuous forest inventory (CFI, VRI)
- “Growth plots”
- Designed experiments
  - Randomized blocks
  - Systematic spacing trials

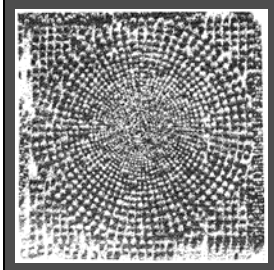
Randomized blocks



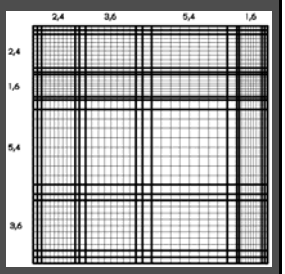
PSPs

- Continuous forest inventory (CFI, VRI)
- “Growth plots”
- Designed experiments
  - Randomized blocks
  - Systematic spacing trials

Spacing trials

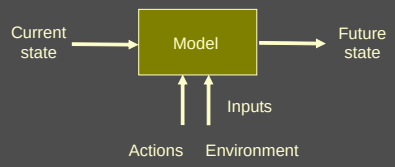


Nelder



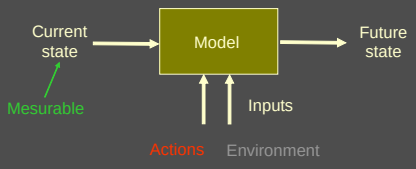
Lin-Morse

Management and Process Models



For decision-making (management, prediction), or for understanding (research, descriptive).

Management Models (predictive)



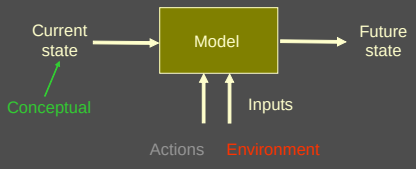
Emphasis on prediction

Ideally, linking as directly as possible actions and consequences.

Future environment usually unpredictable, taken as constant (most likely), or as stochastic. Mostly represented as “site quality”. It would not be difficult to have a time-varying site quality, if necessary.

Should be possible to estimate initial state reliably and at reasonable cost.

Process Models (descriptive)



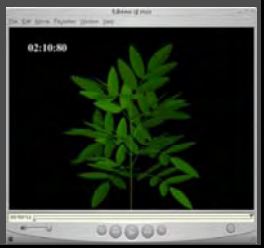
Emphasis on explanation

Usually focus on response to environmental variables (light, temperature, CO2, etc.), and on internal mechanisms.

State does not need to be simple or easily measurable.

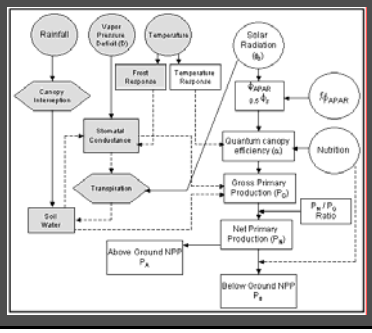
Process - Structural

- Morphology
- E.g., pipe theory (Pressler), L-Systems



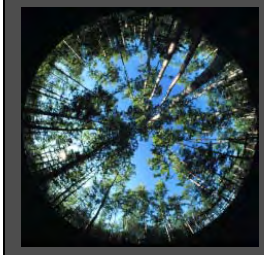
Plant architecture, e.g., http://amap.cirad.fr.
L-Systems: http://algorithmicbotany.org/

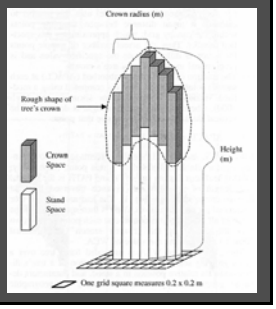
Process - Functional



From http://www.ffp.csiro.au/fap/3pg/background.htm
Different models tend to describe in more detail different processes: light interception, carbon allocation, nutrients, water, etc.
Some model whole canopies on an area basis, others at the individual-tree or even at the organ level.
Many collected in the *Register of Ecological Models*: http://eco.wiz.uni-kassel.de/ecobas.html

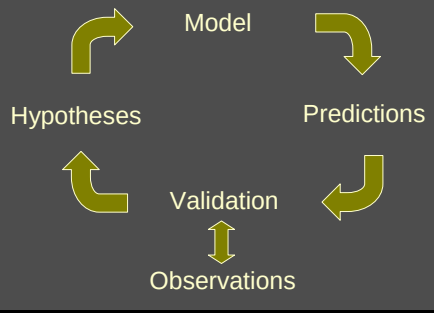
Process - Functional



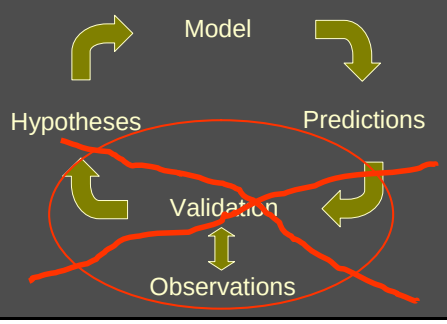


Tree detail varies. E.g. cylindrical crowns with dimensions determined by dbh in SORTIE, high-resolution structure in TRACY (TASS III, figure).

The Scientific Method



The Scientific Method



Breaking the loop can be unscientific and dangerous.

Broad goals

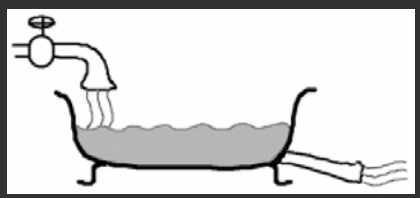
- Healthy disrespect for models
- Understand dynamics
- Quantitative skills

Systems Thinking

- Policy decisions often make things worse
- Cause → Effect
- Dynamic systems: often causes and effects widely separated in time and space
- Counterintuitive and poorly understood
- Concepts:
  - Accumulation (stocks & flows, states & rates)
  - Feedback
  - Delays

Forrester, J.W. "Counterintuitive Behavior of Social Systems", etc.: http://web.mit.edu/sdg
http://sysdyn.clexchange.org

Accumulation (states & rates)



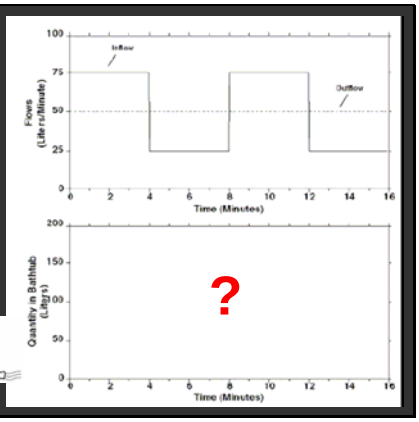
Draining at 50 liters/min

In: 4 minutes at 75 l/min, 4 min at 25 l/min, ...

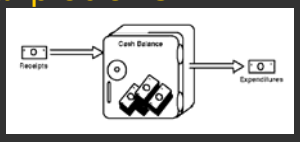
Start with 100 liters in bathtub. Contents over time?

Sweeney and Sterman "Bathtub dynamics: initial results of a systems thinking inventory": http://dx.doi.org/10.1002/sdr.198

Bathtub dynamics



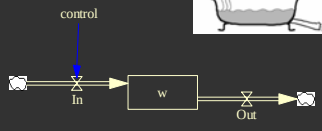
Similar problems



- Cash balance
- Greenhouse gases
- Growth & size
- Etc.

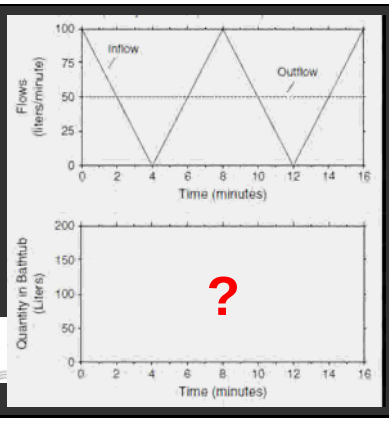
Sterman, J.D. “Cloudy skies: assessing public understanding of global warming”: http://dx.doi.org/10.1002/sdr.242

Notations



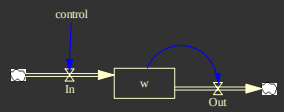
- Rate = In - Out
- dw / dt = f(t)
- w = ∫ f(t) dt

Bathtub dynamics



Sterman, J.D. http://dx.doi.org/10.1002/sdr.261

Feedback



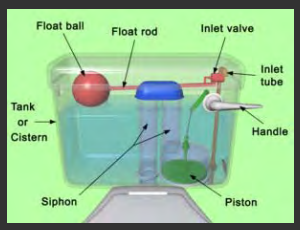
depends on water level

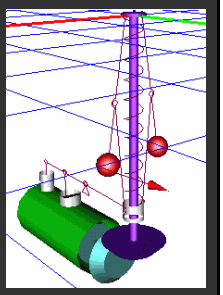
- dw / dt = f(t) - g(w)
- Δw = f(t) - g(w)

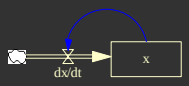
  → w(t+1) = w(t) + f(t) - g(w)

Rate depending on state (differential equation).
Discrete version easy to calculate by iteration.

Feedback







Negative feedback (dx/dt decreases with increasing x).
Control Theory (designing-in feedback). Instability, oscillations. Emphasis in near-equilibrium.
Positive feedback → often explosions, breakdown.
But also positive feedback in tree growth, financial investments, etc. ("slow explosions"). Interest in behaviour far from equilibrium. In biology, often equilibrium = death.
Apparent behaviour depends on state variables used: baby blob's growth in biomass was rapid, in diameter only linear (lab. 4).

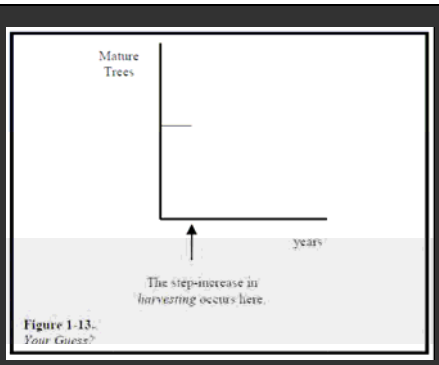
Delays

Forest problem in STELLA "Introduction to Systems Thinking", p.26 (STS → Stella 8.1):

- Harvest and plant constant number of trees
- No mortality, maturity in 6 years
- In steady-state

- Step up harvest and planting to higher level
- Number of mature trees over time?

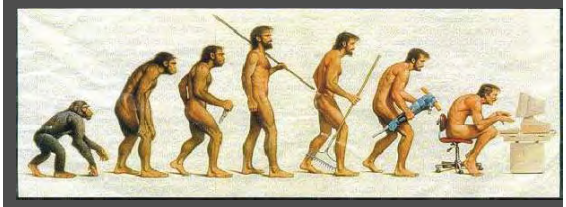
In UNBC student server, under "Stella 8.1".
Or
http://www.iseesystems.com/resources/Articles/STELLA IST - Chapter 1.pdf



mature(t) - harvest(t – 6)

Past, present, future

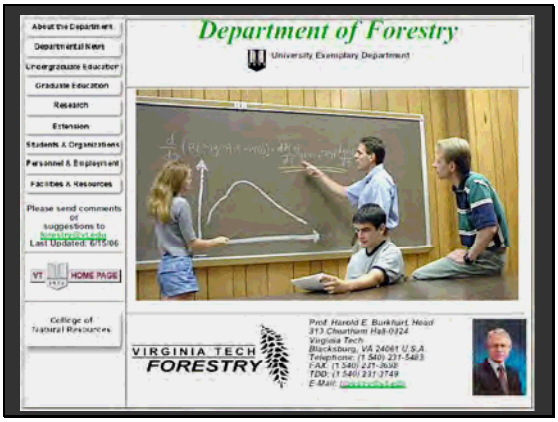
Growth models - Past and future



- Lung Ch'uan codes, China *ca.* 1640
- France – Germany, late 1700's. Reventlow ~ 1800
- German yield tables, late 1800's – early 1900's
- Statistics: 1930's

No need to wait a full rotation: assembling together info from stands of various ages.
Much of Statistics created in the 1920's-1930's by one man, sir Ronald Fisher (UK).
Tabular and graphical methods (largely) superseded by regression.

Foresters at the bleeding edge: mensurationists with sir Ronald in 1936 (photo courtesy of Prof. Larry Davis).
Recognize any names?
Next large impact from developments in computing.



Weird approach to student recruitment? Or is it?

G&Y in BC - (Some) history

- 1950's: Thinning Douglas-fir. Warrack (1956), etc.
- Around 1970: Individual-tree (JHG Smith's and Don Munro's students at UBC)
  - Distance-dependent: Newnham (1964), Lee (1967), Bella (1971)
  - Distance-independent: Goulding (1972)
  - Munro/Goulding classification (1974)
  - TASS: Mitchell (1969, 1975)

World firsts (or close).

G&Y in BC - Current models

- Yield tables: VDYP, TIPSY
- Distance dependent: TASS
- Distance independent: STIM, Prognosis^{BC}, MGM
- Whole stand: STIM, SDMDs, TADAM, VDYP7, Scube
- Process / research: SORTIE, FORCYTE / FORECAST / FORESEE (Kimmins)

STIM has both whole stand and individual tree components.
Classification of the last group might be arguable.
See http://forestgrowth.unbc.ca/bcgrowth05

G&Y in BC - Future? Ideally...

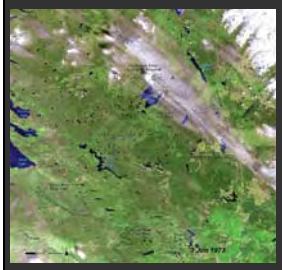
- Simpler models for simple stands (whole-stand)
- Increasingly complex models for complex stands
  - Growing space, not dbh-driven. Micro-site, etc.
  - For understanding. Eventually whole-stand?
- Estimation, not "calibration"
- Documentation. Cross-fertilization. No "brand names". Generic simulation software.
- Linking levels, empirical – mechanistic
- Carbon, climate change, etc.
- ...

www.unbc.ca/forestry/forestgrowth/background.pdf

But...

- Is there a demand for G&Y in BC?
- Licensees
  - Free growing. Forest management?
  - Compliance, AAC
  - Certification
- Government
  - Timber supply, AAC
  - "Defensible"
  - Government research
- Crown / Province, general public

Future?

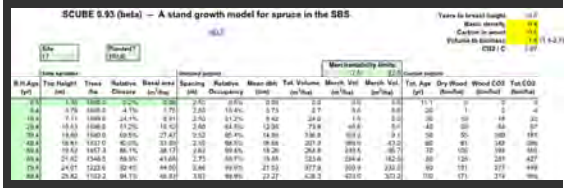


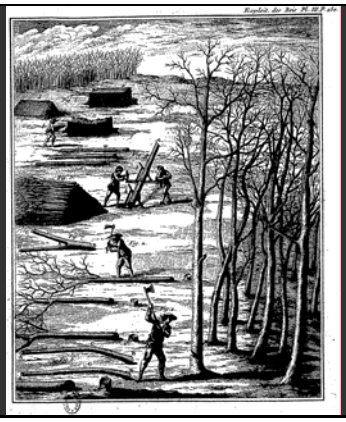
1973

1999

Prince George in UNEP horror picture book:
http://grid2.cr.usgs.gov/OnePlanetManyPeople

Carbon sequestration





Duhamel du Monceau 1764

http://gallica.bnf.fr