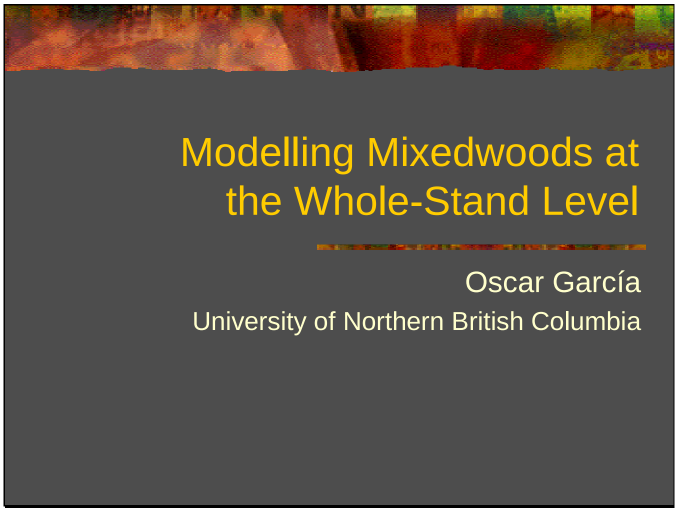

Modelling Mixedwoods at the Whole-Stand Level

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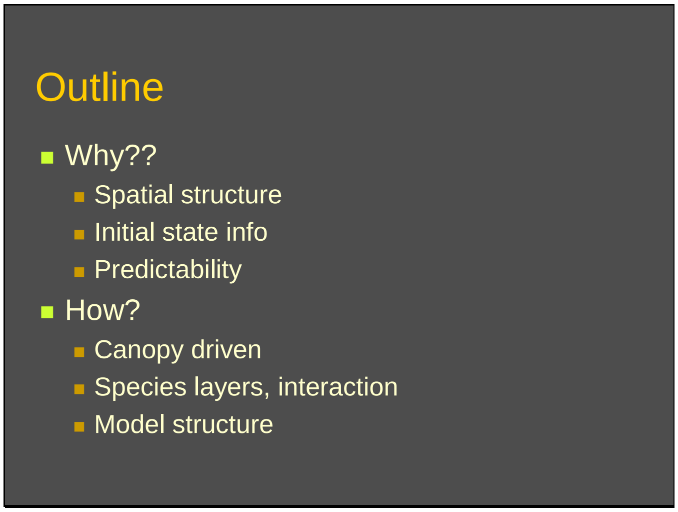
Presented at the
Western Mensurationists Conference
Hilo, Hawaii, July 2005.

I am talking about mixedwoods, but not very. Mainly aspen plus spruce, in north-eastern British Columbia. The usual story: Aspen used to be garbage, until relatively recently when it became valuable for OSB. The emphasis used to be on favouring spruce regeneration and on getting rid of the aspen; now there is interest in aspen-spruce mixedwood management.

There is a number of people working on individual-tree growth models for this, so I had to do something different.



Outline

- Why??
  - Spatial structure
  - Initial state info
  - Predictability
- How?
  - Canopy driven
  - Species layers, interaction
  - Model structure

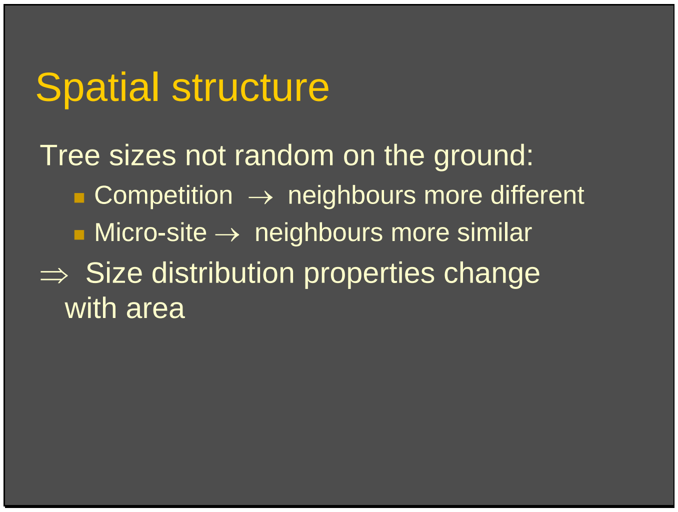
First, why on earth whole-stand modelling? We all know that individual-tree is the obvious way to go. Whole-stand models are only used by people who walks upside-down in the Southern Hemisphere, and a few other strange characters like that. So I will spend quite a bit of time arguing why whole-stand models can be a good complement, if not a replacement, for individual-tree models.

I can think of at least three good reasons (no need to explain the listed items right now).

If there is time left, I might go into some of the modelling details. I have not got very far on that yet.

Why??!

So, why?



Spatial structure

Tree sizes not random on the ground:

- Competition → neighbours more different
- Micro-site → neighbours more similar

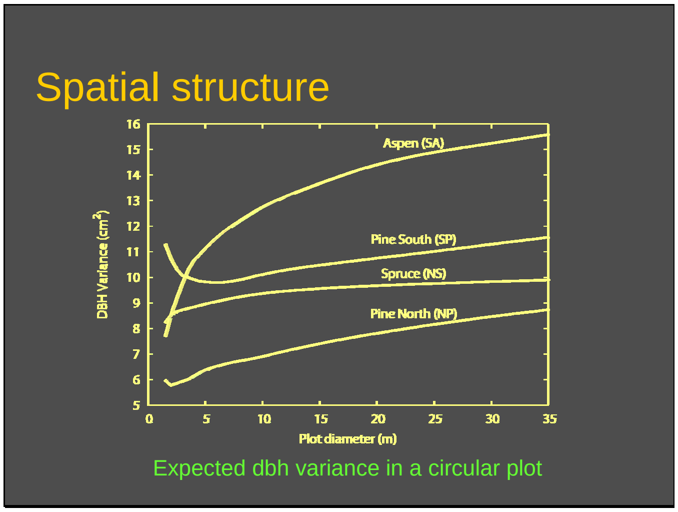
⇒ Size distribution properties change with area

My first reason is that things are not as simple as usually thought. Tree sizes are not independently distributed on the ground: trees interact.

Thinking of competition, a large tree would likely have small neighbours. Trees close-by would tend to be more different than average. A negative short-range spatial correlation. As a consequence, the size variance in small plots should be higher than in larger plots or stands.

On the other hand, the fact that soil fertility, etc., tends to vary smoothly over the terrain would have the opposite effect. Trees close together would be more similar than trees further apart. Positive correlation. Variance would be lower in smaller plots.

One or the other effect can predominate, depending on circumstances and distances. But in general, size distributions will vary with the extent of land considered.



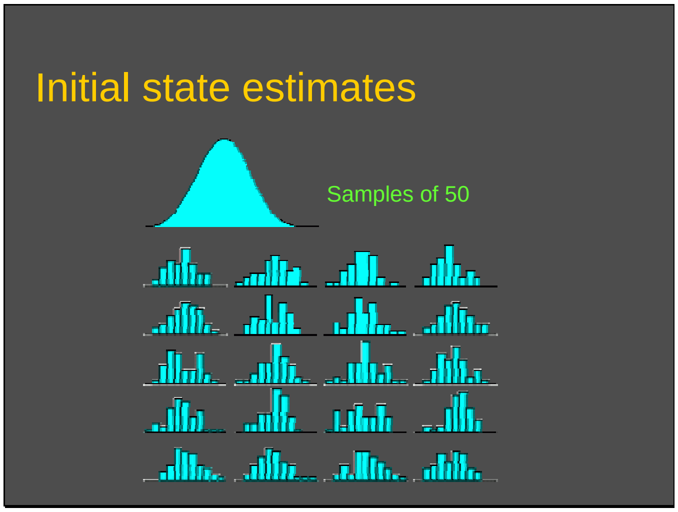
Spatial structure

Expected dbh variance in a circular plot

This is not of purely academic interest, the effects can be quite significant. I did some calculations using mapped tree data from Central Canada.

The graph shows expected dbh variances for circular plots of various sizes. Note than in aspen, for instance, the stand variance can be twice as large as the variance in a small plot. The larger effect on aspen may be due to its clonal structure, where nearby trees tend to be genetically related.

Distance-independent growth models ignore this, they assume horizontal lines. Distance-dependent models predict exactly the opposite: because of competition they generate larger variances over small areas. Competition indices will not work well here.

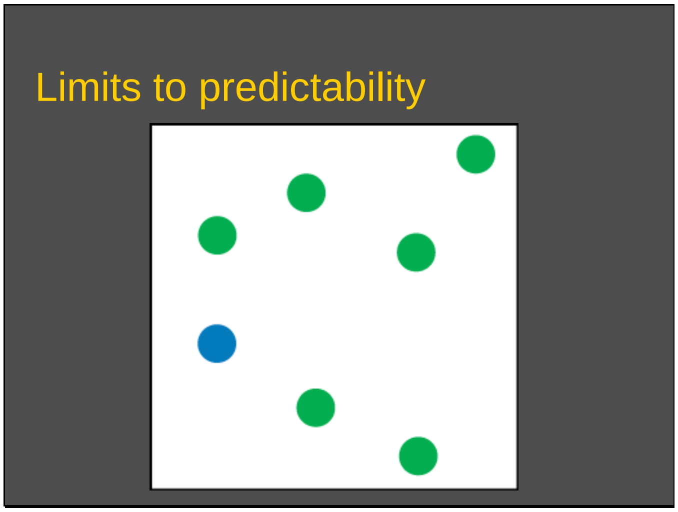


Initial state estimates

My second reason is the high variability in distribution estimates, even ignoring the autocorrelation. It tends to be underestimated.

This display is very easy to make. The histograms are random samples of size 50 from the distribution (a Weibull). 50 is a fairly respectable sample size for a forest inventory plot. Actually, I happened to save the best looking simulation, most look worse.

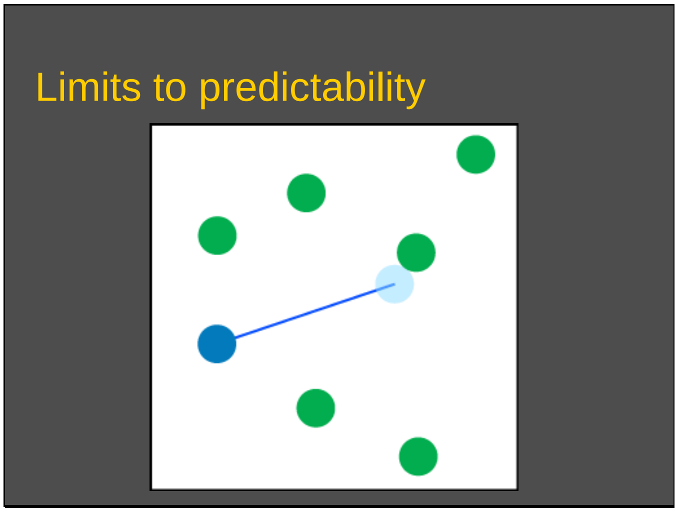
If we believe that we know fairly well the initial diameter distribution, I think that we are kidding ourselves.



Limits to predictability

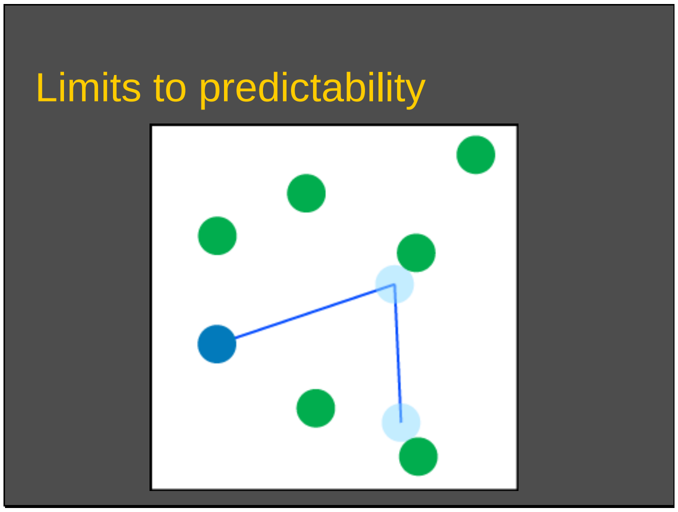
The third reason has to do with what can and can not be predicted.

Think of these as particles, or balls, or disks moving in the plane.



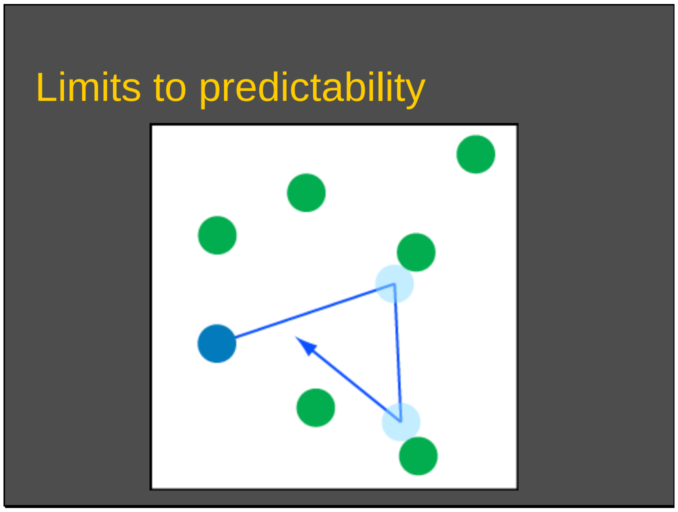
Limits to predictability

The blue one is launched in a certain direction.



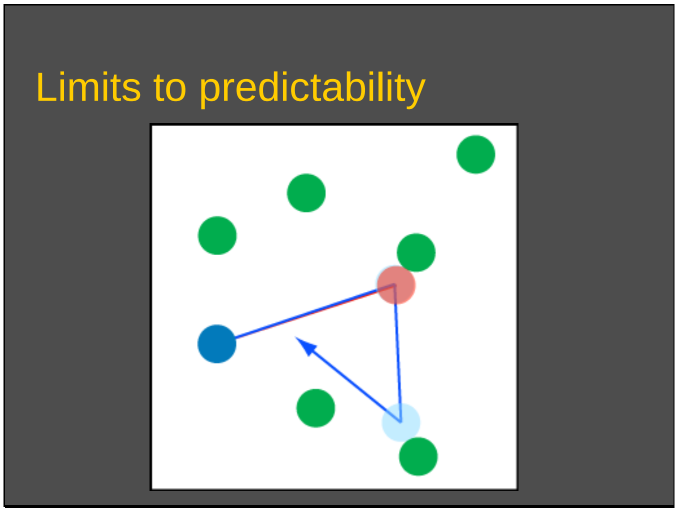
Limits to predictability

The trajectory after a collision is easy to calculate



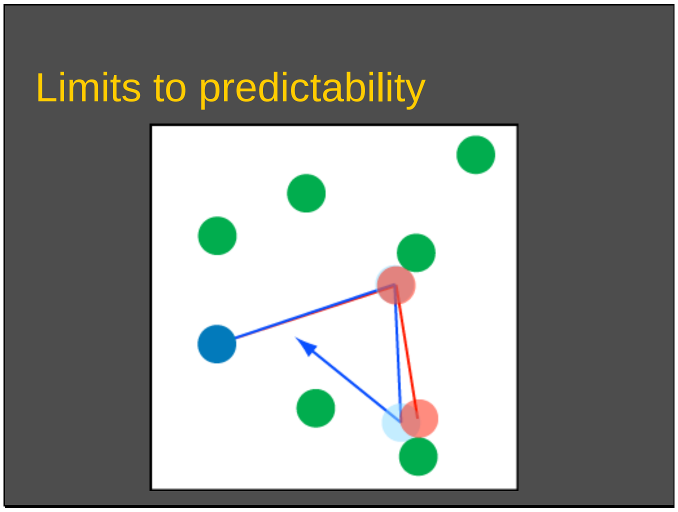
Limits to predictability

To simplify, assume that the green are fixed. If not, they start moving, but this does not change things substantially.

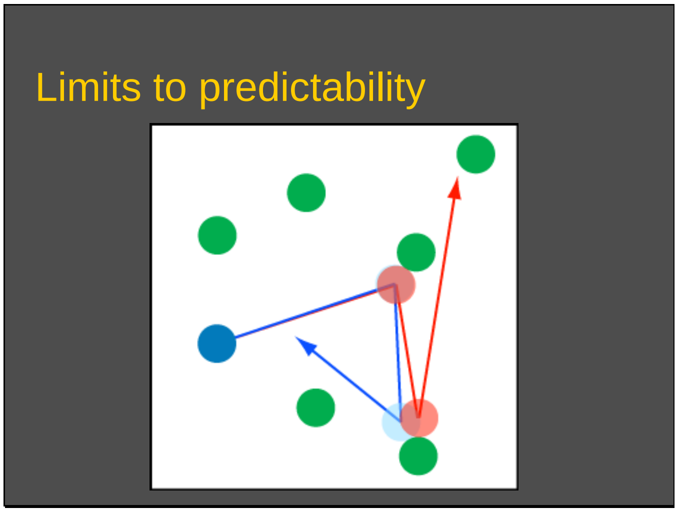


Limits to predictability

Now, what happens if we change slightly the launching angle?



Limits to predictability

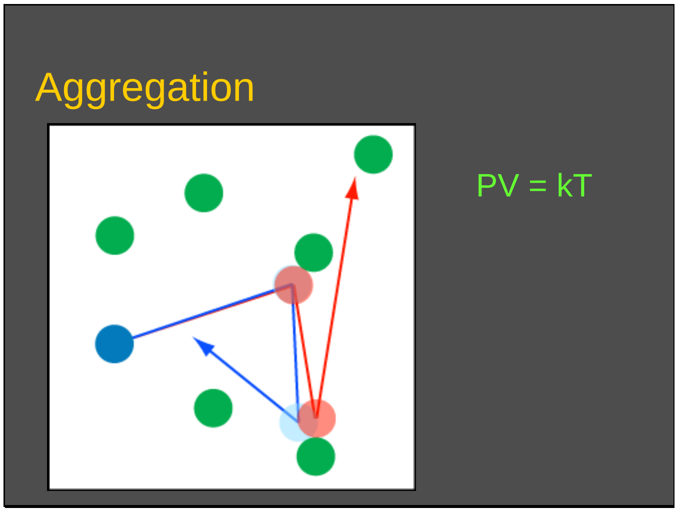


Limits to predictability

Even with an uncertainty of a millionth of a degree in the initial angle, the thing becomes completely unpredictable after a few bounces.

The butterfly effect, Chaos Theory, sensitive dependence to initial conditions.

Growth models may not be as bad as this. Or they might. Just for fun, in Prognosis BC I changed the initial dbh of one of the trees by 5 mm. OK, it did not explode, but after 5 iterations the difference had spread nicely to all the other 174 trees. We may not be able to predict individual trees as well as is usually thought.

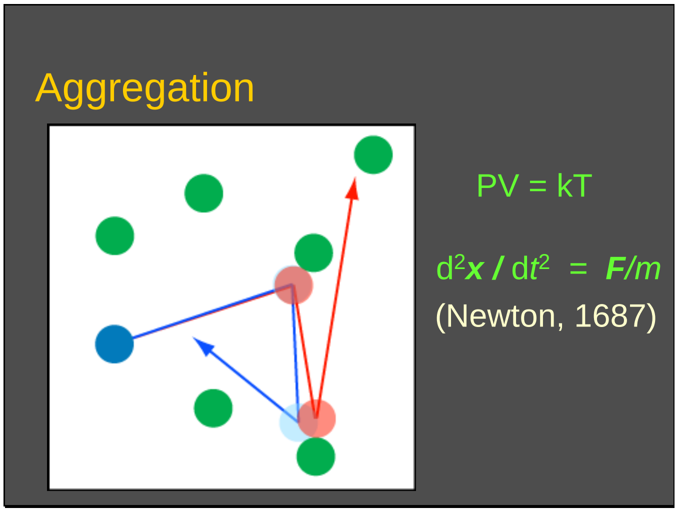


Aggregation

$PV = kT$

What can be done? If this were a simple gas, the over-all behaviour can be approximated by this equation: pressure times volume is proportional to temperature. Note that these variables are aggregate properties, they do not exist at the molecular level. Pressure and temperature are related to mean and mean-square speeds.

For an "ideal" gas, Statistical Mechanics can derive the aggregate equation from the dynamics of the individual molecules. For solids, relating molecular and bulk properties are still research questions.



Aggregation

$PV = kT$

$d^2\boldsymbol{x} / dt^2 = \boldsymbol{F}/m$

(Newton, 1687)

In designing a bridge or a car, in principle one could model the trajectory of all the individual molecules. In practice, one would probably use an average position, a center of mass, and apply an aggregated model developed by a guy in England a long time ago.

This is an empirical model, based on observations, it does not have any theoretical basis whatsoever. And it is an approximation: it breaks down if we go too fast or too small. But within a certain range, it is pretty good

Understanding, prediction

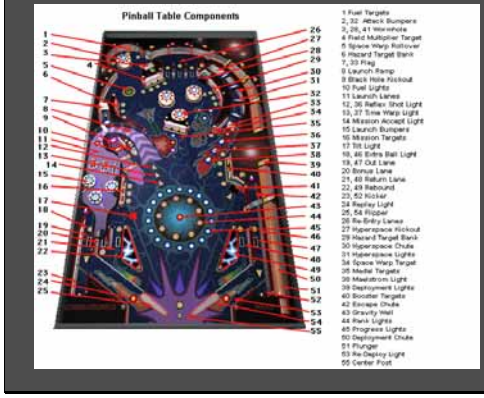
Explain

Predict?

For the younger in the audience, this is a pinball machine. A ball is thrown along the channel on the right, and it bounces its way down.

The theory is well-known, there is no mystery on how it works. Can we predict the ball trajectory? There is a difference between understanding or explanation, and prediction.

Simulation



Prediction?

This is an even better example. Hiding somewhere inside your computer is Microsoft Pinball.

As far as I know, it does not contain any stochastic elements. It is a fairly realistic computer simulation. Given how long you keep the finger on the space bar, the movement of the ball is perfectly determined. Can it be predicted?

Predictability

An apparatus sometimes used in probability demonstrations. Ball-bearing balls drop through an arrangement of pins, into bins at the bottom. Trying to predict the fate of any of the individual balls is hopeless. But we can predict reasonably well their average final positions, and to some extent, their variance. With a large enough sample, we can also have some idea of the distribution.

Complex systems require simple models

For prediction purposes.

Detailed research models can be good. It is nice to know how things work, and it might even help us to build better aggregate models. But they may not be directly useful for prediction.

Mixedwoods

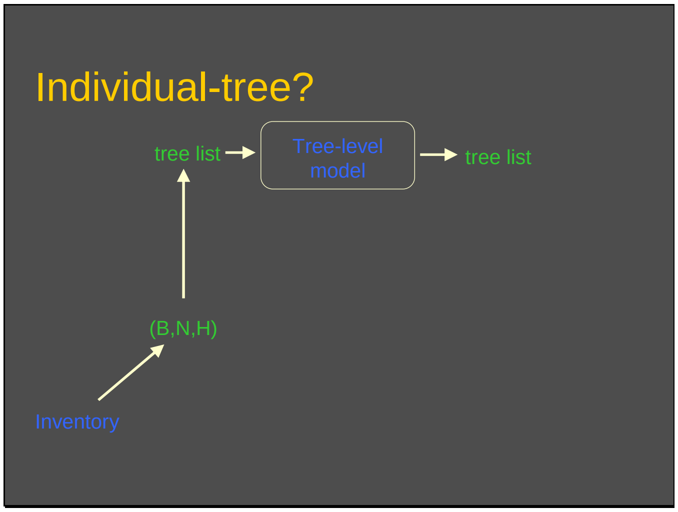
Back to trees. Aspen-spruce mixedwoods. Conventional wisdom is that the aspen takes off first, and then the spruce catches up, eventually replacing the aspen. We have indications that it may not be that simple, but that is another story.

Individual-tree?

tree list → Tree-level model → tree list

Forest stands are commonly modelled at the individual-tree level. These models project some tree size distribution (or equivalently for empirical distributions, a "tree list"), with or without spatial information.

Normally one does not know the initial distribution. Some kind of sample may be available, with all the problems already mentioned.

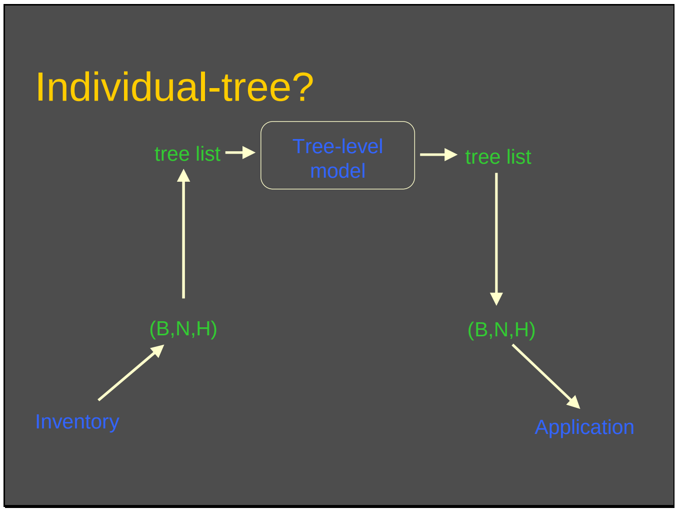


Individual-tree?

tree list
Tree-level model
tree list
(B,N,H)
Inventory

Most of the time, forest inventories provide acceptable estimates of per hectare or stand-level variables, such as basal area, number of trees, stand height. "Tree list generation" methods are used to produce an initial distribution or list using random numbers.

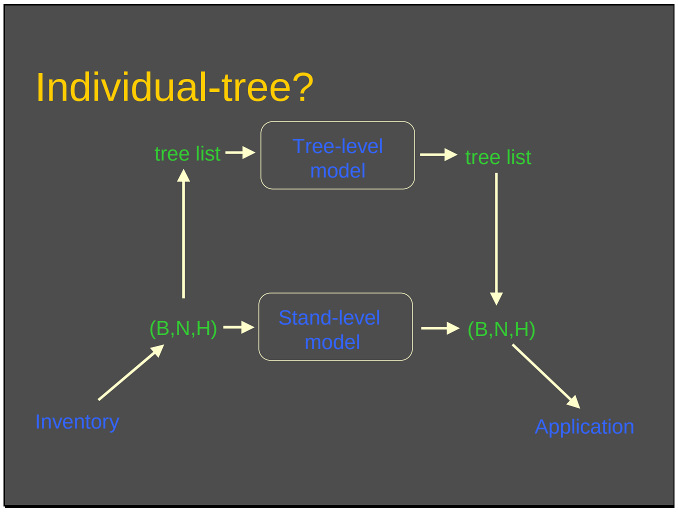
Sometimes, even the stand-level estimates may not be very reliable. In Canada, they are often obtained from aerial surveys.



Individual-tree?

tree list
Tree-level model
tree list
(B,N,H)
(B,N,H)
Inventory
Application

For decision-making and other uses, the projections are summarized into stand-level values.



Individual-tree?

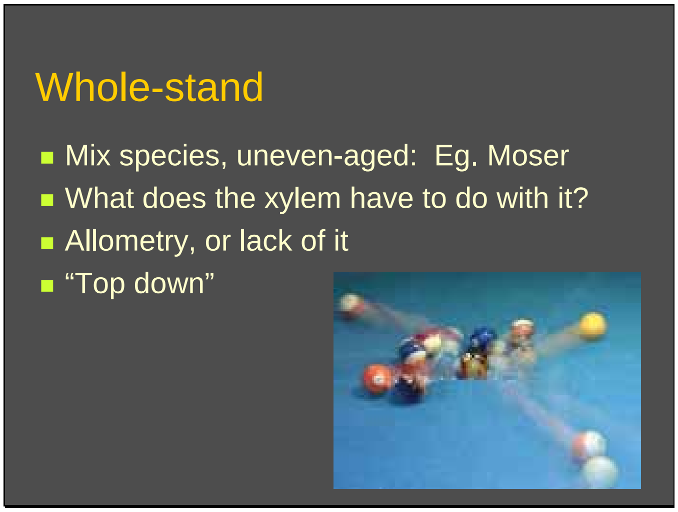
tree list
Tree-level model
tree list
(B,N,H)
Stand-level model
(B,N,H)
Inventory
Application

An alternative to tree-level models is trying to project directly aggregated stand-level variables.

There is nothing wrong with the individual-tree route, provided we do not believe that we are predicting individual trees. From a system dynamics point of view, both approaches are equivalent. They both project the same state variables, the individual-tree model just uses a more complicated (although conceptually simpler) transition function.

The relative simplicity of a stand-level model can sometimes be an advantage. For instance, when embedding it into other decision-support systems.

In principle, stand-level predictions may also be more reliable. Most modellers seem to be optimists, they tend to think that errors cancel out. If you are a pessimist, you might think that errors accumulate. If you are a statistician, you might say that the error grows with the square root of the number of components.



Whole-stand

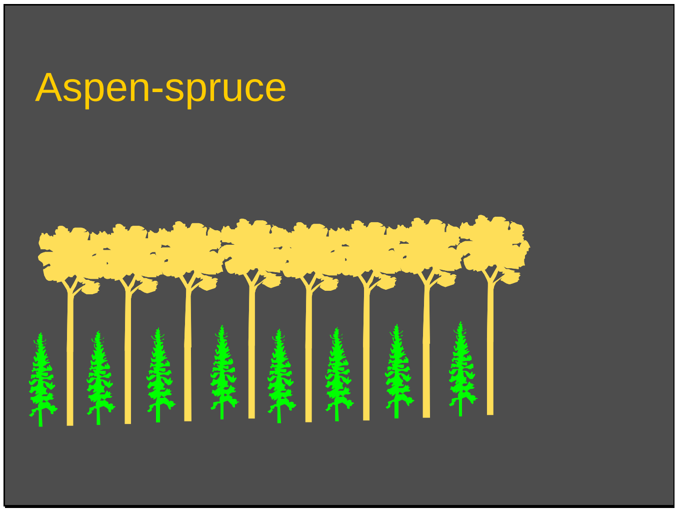
- Mix species, uneven-aged: Eg. Moser
- What does the xylem have to do with it?
- Allometry, or lack of it
- “Top down”

Whole-stand models for mix species and/or uneven-aged stands are not new. E.g., papers by Moser. They are not too different from single-species even-aged models, they just use more variables to keep track of the various components.

One characteristic of most current management growth models (both individual-tree and whole-stand) that I would like to avoid, is that they are diameter-driven. Growth is a function of stem size, which does not make much biological sense. TASS is an (the only?) exception. Admittedly, this is a relatively recent scruple, I did not use to question this before.

Yes, dbh is well correlated with everything else. In unmanaged stands. With stand density management the correlations break down. After all, the whole point of thinning is to produce larger diameters for a same height, so that using a fixed height-dbh relationship, for instance, seems questionable.

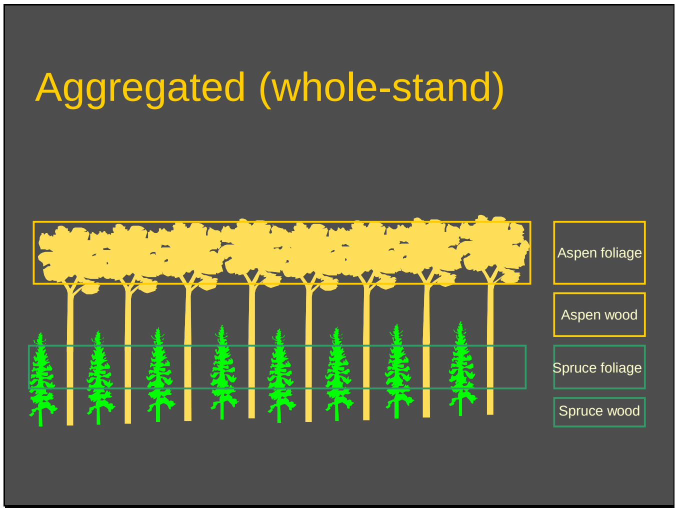
The model will be "top-down" in more senses than one.



Aspen-spruce

Current idea is to handle two components (layers): aspen and spruce. It may become necessary to have also a shrub/herbaceous element.

Initially, they will be assumed to be well separated. Horizontally sharing of growing space will be addressed at a later stage.



Aggregated (whole-stand)

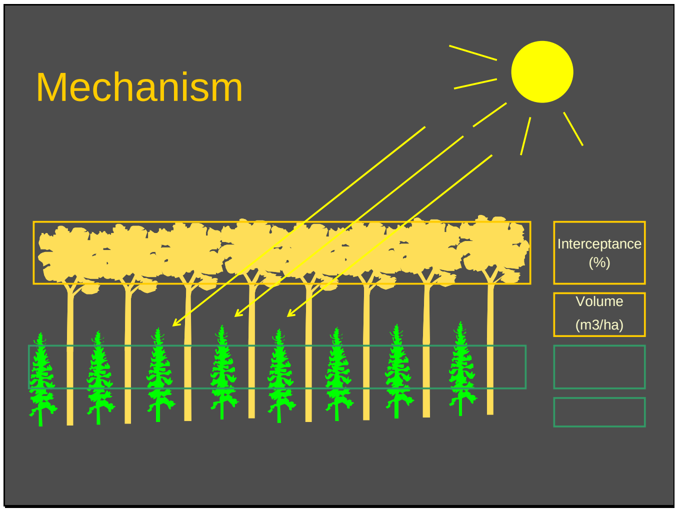
Aspen foliage

Aspen wood

Spruce foliage

Spruce wood

At the simplest possible level, there are two aggregate variables for each layer.



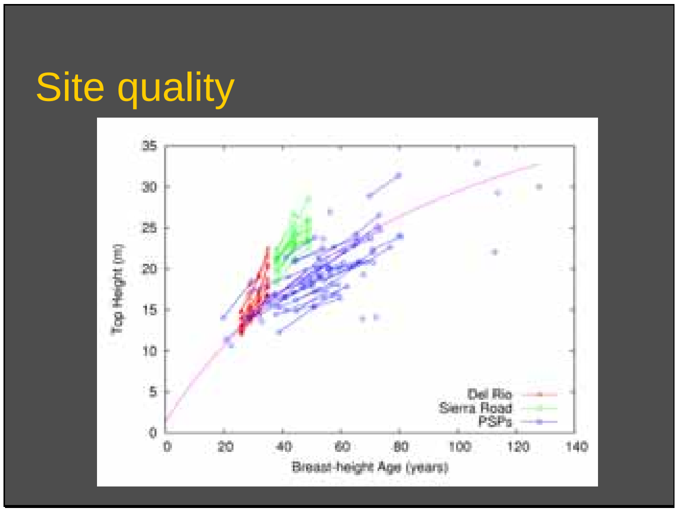
Mechanism

I have made one concession to fashion: a mechanistic approach. I have little data, so I have to make up a likely story.

It works the other way around too. In my experience, data destroys all your pet theories, so that for process modelling one should have no data ;-)

The driving variable is the amount of resources (e.g. light) captured. Stem growth is a consequence or side-effect of that. It is easier to think in terms of light, but in general a more abstract unobserved variable will be used, which can represent both above-ground and below-ground resources.

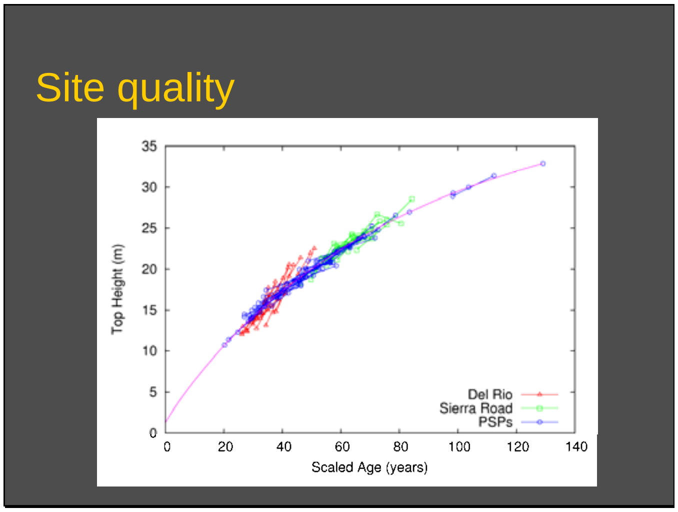
Initially, only aspen will be modelled. A similar model for spruce will be added later, coupled through the non-intercepted resource availability.



Site quality

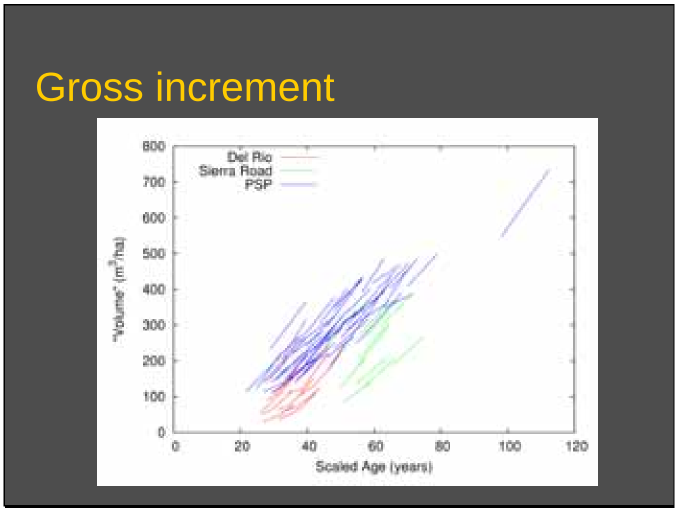
Data (so far): Some permanent sample plots, and two thinning trials.

First problem is how to handle site quality differences.



Site quality

A trick that has worked before is to apply a site-dependent factor to the plot ages.



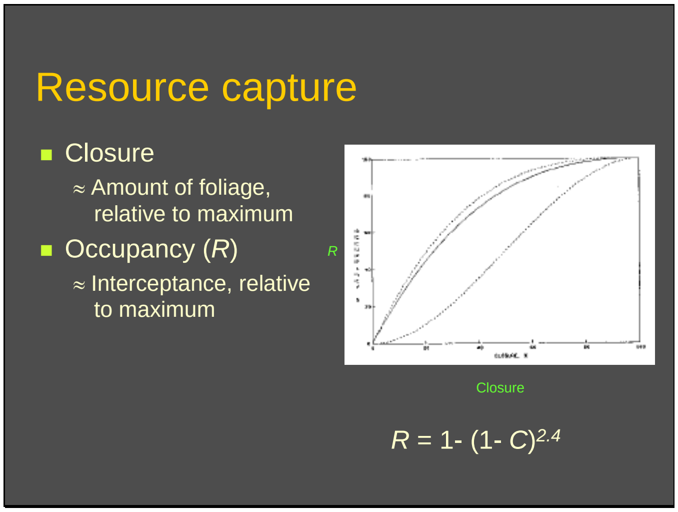
Gross increment

Volume (actually, half the sum of tree's basal area times height) plus volume mortality. One starts to wonder if this is predictable even at the stand level!

Tree physiologists have been having fun lately trying to find explanations for the strange phenomenon of growth decline with age. Textbook sigmoids. However, extensive sets of real forest data fail to show any such age-dependent decline in gross volume increment. Same happens reviewing old yield trials and forester accounts from the last couple of centuries.

No evidence of age related decline here either. Might as well assume for now a constant (site-adjusted) gross volume increment in closed-canopy stands. The hypothesis could be refined later, if necessary.

Note lower increments at low volumes in thinned plots, presumably with open canopies. Also, implied lower slopes on the left, for (unobserved) young stands before closure.



Resource capture

- Closure
  - ≈ Amount of foliage, relative to maximum
- Occupancy (*R*)
  - ≈ Interceptance, relative to maximum

$$R = 1- (1- C)^{2.4}$$

Two concepts, relative closure (C), and relative occupancy (R). Again, need not refer only to foliage and light.

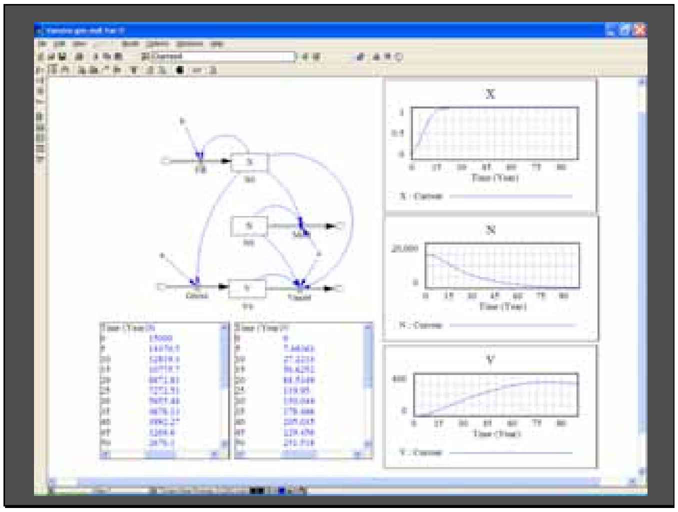
Graph derived indirectly from thinning/pruning effects (Garcia 1990). I know of only one direct determination of the R-C relationship under thinning (Hale,S.E., For.Ecol.Man. 179:341-349, 2003). Which, incidentally, shows that traditional light interception models do not work very well.

Simplest models

- First approximation:
  - $dV/dt = a$ (closed canopy, no mortality)
- Including open, no mortality :
  - $dV/dt = a R$
  - $dR/dt = b (1 – R)$ or $b R(1 – R)$
- Mortality:
  - $dN/dt = - c R N$ $dV/dt = a R - V\text{mort}$
  - $V\text{mort} = (\text{mean } V \text{ of dead}) (- dN/dt)$
  - $= - k N^{-1/2} V/N dN/dt$

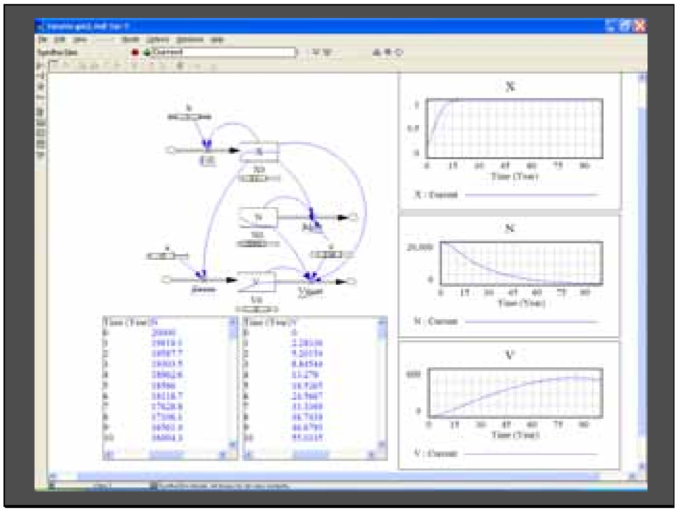
First cut at it. Simplistic (or parsimonious). Remember, little data.

In thinning, C is reduced in proportion to the % of basal area or volume removed. New R is obtained from the C-R relationship.



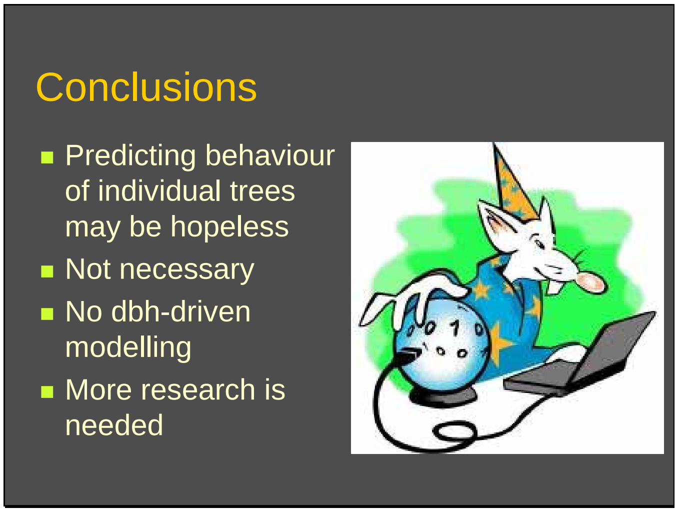
Visual dynamical modelling software, little used in forestry so far, found useful for communication and experimenting.

E.g., upper rectangle represents the relative occupancy level (used X instead of R here). The double arrow and "tap" on the left is for the foliage going in. The rate depends on the current level, and on a parameter.



Can tweak parameters ("calibration") by typing or dragging sliders, with graphs and tables changing in real time. To see if it makes sense, before doing a proper parameter estimation.

See the forest?



Conclusions

- Predicting behaviour of individual trees may be hopeless
- Not necessary
- No dbh-driven modelling
- More research is needed

What is the size of tree #26? The answer is the same as that of the teenager who was asked about the difference between ignorance and indifference: "I don't know, and I don't care".