Post-print of
J.K Vanclay, 2003. Realizing opportunities in forest growth modelling. *Canadian Journal of Forest Research* **33**(3): 536-541.

Realising opportunities in forest growth modelling

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Abstract

The world is continually changing: the emergence of new technology and new demands for pertinent information pose new challenges and possibilities for forest management. Are forest growth models keeping up with client needs? To remain relevant, modelers need to anticipate client needs, gauge the data needed to satisfy these demands, develop the tools to collect and analyze these data efficiently, and resolve how best to deliver the resulting models and other findings. Researchers and managers should jointly identify and articulate anticipated needs for the future, and initiate action to satisfy them. New technology that offers potential for innovation in forest growth modelling include modelling software, automated data collection, and animation of model outputs. New sensors in the sky and on forest machines can routinely provide data previously considered unattainable (e.g., tree coordinates, crown dimensions), as census rather than sample data. What does this revolution in data availability imply for forest growth models, especially for our choice of driving variables?

Introduction

From time to time, it is appropriate for a discipline to take stock, to appraise its current situation, evaluate where it wants to be, examine the way forward, and initiate plans to realize these targets. Forest growth modelling is no exception; models must evolve to remain relevant. The recent conference on Forest Modelling for Ecosystem Management, Forest Certification and Sustainable Management (LeMay and Marshall 2001) provided a unique insight into the present state of the art, and several authors (e.g., Landsberg 2001) offered useful insights into the development and evolution of models. This paper looks forward to consider what might be possible in the future, canvasses the utility of these possibilities, and considers how one might strive to achieve them. In doing so, it frames these possibilities in the context of the “big picture”, recognising the goals of institutions as a whole as well as those of individual workgroups; longer term goals as well as immediate targets; and the condition and functioning of forested ecosystems as well as the sustainability of timber supplies (Vanclay 1995).

Several emerging pressures and opportunities impinging on forest growth modelling can be identified. New technologies offer more efficient ways to gather traditional growth and yield data and create opportunities to collect new kinds of data. National and international attention to environmental issues provides both the expectation and incentive for commercial forestry enterprises to place greater emphasis on non-wood goods and services, including flora and fauna conservation, water quality and quantity, carbon sequestration and other environmental services. Increasing demand for timber from a finite land base means that industrial plantation forestry must become more intensive. All these issues impinge on the possibilities for, and demands on growth models, and indicate potential future directions for consideration.

Accessibility of models

Several speakers at the conference (LeMay and Marshall 2001) posed challenges for modellers. A recurring theme related to the foundations of science: Occam's principle of parsimony, Einstein's call for models to be "as simple as possible but no simpler", and Popper's exhortation to hypothesise and attempt to falsify. It is, unfortunately, easier to find the rhetoric than to find the evidence of rigorous tests of forest growth models (Leary 1991, Vanclay and Skovsgaard 1997). Few independent tests of models have been published (e.g., Soares *et al*. 1995), and authors and editors alike seem strangely reluctant to participate in this essential component of science.

One obstacle is that many models are personal creations, poorly documented, and written in a foreign language (Fortran, Visual Basic, etc). Few forest growth models are implemented in the more accessible diagram-based modelling environments such as *Simile* (Muetzelfeldt and Taylor 2001) and *Stella* (High Performance Systems 2001). *Simile* in particular has several modelling constructs well suited to forest growth modelling, and warrants closer consideration, both for what can and cannot be implemented and communicated in this medium.

Towards a better modelling environment

One reason that forest modellers persist with "old fashioned" and less popular computing languages may be that new software has not provided the constructs needed to represent efficiently the key concepts of forest growth and change. For instance, the fashionable programming language *Java* does not allow direct implementation of multi-dimensional arrays (Moreira *et al*. 2000); these can only be implemented indirectly as a vector of vectors. Needless to say, this is a great inconvenience for forest growth modellers attempting to model the growth of trees in two- or three-dimensional space, so it is no surprise that *Java* is not the language of first choice for most modellers. If current software is inadequate or deficient for modelling, then the shortcomings should be articulated clearly, and brought to the attention of software developers.

Muetzelfeldt and Taylor (2001) are developing the modelling environment *Simile* at the University of Edinburgh, and have deliberately tried to provide constructs useful for forest modelling. They welcome suggestions to further develop the capability of *Simile* in this direction. Like other systems dynamic software (e.g., Stella), the diagrammatic representation used in *Simile* replaces the code and serves as the documentation, thus avoiding the all too common problem that the code, flowchart and documentation diverge and become ambiguous or contradictory. However, unlike other systems-dynamic platforms, *Simile* combines the best elements of systems dynamics and object-oriented programming, providing capabilities particularly useful in growth modelling (e.g., multiple instance submodels; the ability to dynamically create and destroy submodels). Some of the more generic features provided by *Simile* are particularly innovative (Muetzelfeldt and Taylor 2001):

- *Simile* can generate hypertext descriptions of a model, allowing users to navigate a text representation of a model with a standard internet browser;
- Moving the mouse over a *Simile* construct causes a pop-up window to appear, revealing the contents (including constants and graphical relationships, any comments, and the current values);
- The “plug-and play” feature of *Simile* facilitates the substitution of submodels (*Simile* or DLL), thus encouraging experimentation.

Other capabilities may be forthcoming: automatic generation of meta-submodels; automatic sensitivity testing; and model-specific tutorials generated by the software. These facilities should enhance the capabilities of models, make modellers more productive and empower them to be more innovative. The modelling community should think carefully about additional constructs that may be useful and articulate these needs clearly, to lead the development of modelling environments in useful directions rather than relying on chance and the whim of others.

Fostering uptake of models

Presumably models are constructed to make a difference, either to the understanding of tree growth, or to the management of forests. In either case, models need to be adopted before they can make such a difference. This requires that models are available, accessible and appropriate for client needs. "User-friendly" code and consistent documentation are only part of the challenge of making models more accessible. They also need to be physically available. In theory, it should be easy to make models available freely via the internet, but this apears to be the exception rather than the rule. The University of Kassel maintains an internet-based Register of Ecological Models (Benz and Knorrenschild 1997, Benz 2001) with references to over 600 models, but most are accessed infrequently (only 45 documents record more than 50 hits/month). In a related project (ECOBAS), Hoch *et al.* (1998) have called for a common model interchange format, but it appears that very few modellers (<20) have risen to the challenge to participate in this initiative (Benz 2001). IUFRO is currently canvassing support for a model archive, and it will be interesting to observe support for this initiative, and monitor any increase in uptake of models made available in this way.

Botkin's JABOWA model (Botkin *et al.* 1972) offers an interesting case study, as it has been particularly influential, inspiring many variants (Botkin 1993, appendix VI), even though it, and its descendants, do not appear to have been used directly by forest managers. Why did it inspire so many variants – was it because of superior concepts, or simply because the source code (of JABOWA I) was readily available? Why did Shugart and West (1977) find it necessary to recode the model as *Foret* – was it to effect fundamental enhancements to the model, or merely to secure their intellectual property? Does this emulation and recoding reflect wasted effort, independent reproduction of results, or genuine scientific progress? Do the effort and the intellectual property reside in the concepts underpinning the model, in the code that implements the model, or in the interface that makes the model available to users – and which of these are of value to others? Why are there so few publications by scientists working with models constructed by other scientists? None of these questions have simple answers, but all deserve to be addressed before a model archive or a submodel library is designed and initiated.

The main uses of JABOWA and its offspring appear to have been in research and education, but not in forest management. Why did JABOWA not appeal to forest managers? Was it that they were unaware of its existence and capabilities, was it because it was "not invented here", or was it because it did not meet needs of potential users in terms of ease of use, inputs required, outputs produced, or accuracy of predictions? How do users identify and communicate their expectations of models? Experience suggests that many model users do not actively seek innovation, but look for a subset of the functionality that they have previously experienced. Modellers must catalyze the adoption of innovation to break this downward spiral, especially when models are used to support negotiations on major long-term commitments of land use or timber resources.

Adequacy of models

Are existing models adequate? In what respect, and for whom? The adequacy of a model can only be judged against a stated objective. A model may be judged according to its ability to convey a concept, its utility for production forecasting, or on the precision of its predictions. Others may be concerned with the extent to which a model can help assess sustainability of alternative land uses, or with the innovation achieved and the corresponding ease of securing publications. These aspects have been addressed elsewhere (e.g., Vanclay and Skovsgaard 1997), but two aspects warrant further consideration.

Dealing with risk and uncertainty

Many models in forestry are deterministic, and predict the most likely outcome. A few models include stochastic elements, but usually in a few components only, and often without taking full account of the correlation between these stochastic components. While this may not matter much in models for industrial plantations, it may be a serious deficiency in models that attempt to address succession. The recent wildfires in many parts of the world emphasize of the role of the fire in influencing forest composition and structure, but other less conspicuous forces that may be equally influential include severe cold, late frost, wind and ice storms, flooding and waterlogging. Recall the widespread destruction of forests by windstorms in Europe during 26-28 December 1999 (In France, the destruction exceeded four times the annual harvest). A more subtle example from Australia is the “dieback” of the indigenous conifer *Callitris columellaris* following an unusually wet summer, presumably due to waterlogging (Lamb and Walsh 1982). These few examples highlight the need to consider rare events in modelling (e.g., meteorological phenomena with an expected frequency of 1 in 50 years), especially when modelling ecological succession.

Untested and unstated assumptions

Models inevitably involve many assumptions, many of which are not formally stated and which remain untested. Some of these assumptions may be trivial, but others may have far-reaching consequences. For instance, most forest growth models use age or diameter (dbh) as the primary driving variable. There are good reasons for this – in part, because age is easily obtained from management records, and diameter is easily measured. However, it is possible to drive a growth model with other variables; for instance Mitchell's (1975) TASS, driven by tree height. To what extent does the choice of diameter or height as the primary driving variable influence model performance? This question is becoming increasingly relevant as new technologies make it easier to measure height (and other crown parameters), but it remains largely unanswered.

Ideally, publication and peer review of models should help to draw attention to untested assumptions and encourage independent testing by others, but this seems to be the exception rather than the rule (e.g., Soares *et al.* 1995). Publication is effective in bringing work to the attention of others, but remains rather ineffective in encouraging formal statements and tests of hypotheses and assumptions (Leary 1990), and equally ineffective in fostering independent scrutiny of models: even prestige journals suffer this weakness (e.g., Vanclay 2001). Modellers can contribute to the rigor of the discipline by explicitly stating assumptions and hypotheses, bringing them to the attention of colleagues, and inviting others to test the generality of these propositions. As Leary (1989) put it, "well stated is half solved".

Calibration of models

Ultimately, all models rely on data to estimate coefficients, to calibrate and evaluate models, and to initialize simulations. Most data have traditionally been derived from manual measurements of experiments, in observation plots, and from operational data. Emerging technology offers new opportunities to efficiently gather data previously considered unattainable.

Leary (1987) pointed out that during the past few decades, the cost of labor has increased steadily, while the cost of computer cycles continues to decrease. These opposing trends conspire to encourage the use of less-and-less data, with ever more cunning estimation techniques. While this approach may offer short-term attractions, eventually it leads to an information crisis. The only real solution is to find ways to use machine cycles rather than labour in the gathering of data. There are many opportunities, both in the application of models, and in the construction of models.

Data for "learning-models"

One of the great challenges for forest modellers is to ascertain the utility of the vast range of forest measurements now becoming available during routine forest operations. Two emerging technologies illustrate the possibilities: airborne remote sensing and machine-based data collection. Collectively, these technologies offer the possibility to work with census data (i.e., measurements on every individual in the population) rather than with samples.

Airborne LIDAR (Light Distancing and Ranging) fires a laser from an aircraft to the ground, records the return beam (possibly several return signals), and calculates the distance to the target(s). At present, these measurements can be taken every 2 cm along the flight line, offering a unique insight into tree positions and heights, crown dimension and density. The LIDAR can be implemented as a profiler to record a line transect, or as a scanner to record a swathe up to 100 m wide (e.g., Ritchie *et al*. 2001). With such data, it may soon be possible to initialize a model and offer prognoses of future harvests without using any ground-based measurements.

The increasing mechanization of forest operations is all too familiar. In some plantations, tree are harvested with feller-bunchers, many of which contain considerable computing capacity as well as an on-board GPS (global positioning system). It is a relatively simple matter to routinely record, for each tree felled, the position (x,y coordinates from GPS), diameter (with a sensor on the grab arm), and biomass (from a load cell in the hydraulic system – with an accuracy better than 0.1%). Such data from thinnings, coupled with LIDAR swathes prior to thinning, could provide an excellent basis for recalibrating “learning models” and improving forecasts of future harvests from the residual stand.

Many feller-bunchers have harvesting heads to delimb and buck stems, enabling limb sizes and stem biomass (after limbing and topping) to be recorded. Harvesting heads may also contain optical sensors that accurately record stem profiles (Johnson 2001). In the past, many modellers have argued that spatial models were inappropriate for forest management because of demanding data requirements. This no longer applies. With data effectively non-limiting, what is the appropriate resolution for plantation growth models? Can these data on tree position, crown size, and stem profiles be utilized effectively?

Data for model construction

Two issues require a re-appraisal of the databases on which models are based. Forest management is becoming more diverse: in some situations becoming more intensive with precision silviculture (i.e., for industrial sawlog production); elsewhere relying on non-wood products (e.g., community forestry in the tropics); and in other desolate localities, involving the establishment of trees that may never be harvested (e.g., restoration of mining sites). This diversity poses interesting challenges for practitioners and modellers alike. Can current growth and yield databases offer useful insights into these issues? This is a question that each workgroup needs to consider, not only for their present needs, but also for anticipated needs of the future. Beetson *et al*. (1992) and Vanclay *et al*. (1995) suggested some ways that databases could be compared with the production estate to examine the extent to which predictions are extrapolations rather than interpolations within the sampled data space. Such re-appraisals are warranted, especially in the context of changing circumstances.

Relevance of models

Two emerging issues in Australia are beginning to impact on forest management, and will influence the ways growth models are used to assess forest management options in Australia. The community at large now demands that Government forestry enterprises compete fairly with private forestry (Marsden Jacob 2001; cf. concerns about below-cost timber sales in USA), and that forests be managed holisticly for all environmental goods, services and values. Together, these pressures will discriminate three approaches to forestry. Industrial forests on productive sites close to markets will focus on profits through precision silviculture. Forests in less favourable locations will be managed extensively, for a range of goods and services, including wood, recreation, biodiversity and other values. And on derelict land, forestry will be practiced primarily for non-wood benefits (environmental services, including carbon sequestration).

Intensive industrial forestry

Competing land uses and other pressures require that plantation forestry becomes more profitable and reduces off-site impacts. This means that all forestry activities need to more efficient in every aspect. In short, it means precision silviculture, embracing:

- cultivation, herbicide, fertilizer and inventory when and where needed, and only when and where needed;
- rotation length and thinning regimes that reflect agency-wide optima (but not necessarily optima in terms of wood volume for an individual tree or stand); and
- full use of all the soil, all of the time, by relinquishing the concept of homogeneous compartments, and recognising that forest land may be viewed as a continuous (and heterogeneous) production surface, which may be replanting as soon as practicable after harvesting, even before a contiguous compartment is completed.

In these circumstances, and given the emerging harvesting technology discussed above, growth models should be integrated with on-line information systems, so that harvesting machinery can negotiate with the decision support systems of the forest manager and the wood processor. “These trees that I’ve just felled are below specification; do I continue to fell the rest of the stand? Is it preferable to leave the rest to grow for another few months? If so, where should I relocate to?"

Harvesting machinery may be equipped with on-board detectors for soil compaction, so that tradeoffs (e.g., between timely harvesting despite less than ideal ground conditions versus anticipated future growth depression due to soil compaction) could be examined in real-time. Are current models up to this challenge?

Multiple-use forestry

In other localities, multiple-use may be more profitable than intensive timber production, and non-wood products and services (e.g., water yields, grazing and hunting rights, honey production) will supplement the timber income. In such situations, the efficient forest manager will want to know about the tradeoffs between the various goods and services, and may consider the understorey as complementary rather than competing vegetation. These complementary products and services place different demands on a growth model, particularly on its ability to accommodate understorey vegetation and to correctly estimate tradeoffs with tree growth. This will cast a new perspective on issues like light interception and moisture deficits.

Non-timber forestry

There is increasing interest in growing trees on derelict sites, not for wood production, but for the environmental services the trees provide (and perhaps for the environmental credits that can be secured). In Australia, tree planting on recharge areas in salt-affected catchments seeks not to produce wood, but rather to draw down the watertable by maximizing evapo-transpiration, especially during the rainy season. A related practice is the use of trees in effluent treatment, with the objective to maximize both uptake of nutrients and evapotranspiration. Here, the question for the growth modeller does not relate (directly) to the size of the trees and the volume of wood, but rather, to the seasonal transpiration rates and any silvicultural interventions that can increase these rates.

One project in Western Australia uses mallee eucalypts to immobilize salt by controlling the ground watertable, to earn carbon credits for carbon stored in tree roots, to harvest stems as fuel for electricity generation, and to distil leaves for eucalyptus oil (Harrison 1999). The project has not yet attempted to optmize silviculture, but when adequate data are available, such an optimization study will place considerable demands on the underlying growth model.

A process-based growth model appears warranted, but the diverse objectives of the project may challenge current paradigms of root:shoot partioning.

Expanding horizons

In industrialized countries it is usually satisfactory to assume that forest use is controlled, and that models need consider only natural changes (e.g., growth, mortality, regeneration) and authorized harvesting. Other influences are usually considered externalities and are ignored. However, in many developing countries, land use decisions by people living at the forest margin may be crucial to the fate of the forest, and models to accommodate these broader socio-economic issues beyond the forest edge have been advocated (e.g., Vanclay 1998, Vanclay *et al*. 2000). Once the domain of modelling extends beyond timber production to environmental services such as salinity, it may well be necessary to use such models in an attempt to anticipate land-use and evapotranspiration patterns throughout the relevant environmental and social catchment areas.

Use of models

Most forest growth models are used primarily by their authors and a small group of technical experts, to explore growth patterns, devise optimal silviculture, and to forecast timber yields. That may well change, as the community demands a greater say in forest management. Modellers should respond to these pressures by developing user-interfaces that encourage others to explore fully the practical implications of models, and by devising ways to allow users to gain some understanding of the strengths and weaknesses of models. Several approaches warrant consideration.

Visualizing model predictions

Many critics of forest management are intensely sceptical of yield forecasts, and computer projections displayed as large tables densely packed with numbers do little to allay their fears. Models need to be more transparent to users, and outputs need to be displayed in an accessible way – one that empowers users to understand and visualize the consequences of forest management for the forest and for the community in both the short- and long-term.

Software such as World Construction Set (3D Nature 2001) makes it possible to portray model outputs as realistic-looking photos, videos and multimedia presentations. However, it may not be necessary, or even desirable, to achieve photo-realism in all cases, as users should be aware that model predictions are just that – predictions, not reality. Thus there remains scope for further research to assess how realistic simulated landscapes should be, what scale they should represent (or should they be scale-independent, so users can zoom to any scale), and how they can best be communicated to users (Sheppard and Harshaw 2000).

Supporting Mediation

A recurring theme in discussions with conservation groups is their desire that forest landscapes, especially “old growth” landscapes, should remain unchanged, in their primeval state. Growth models may have an important role to help demonstrate that forests are dynamic, and that any given forest may not retain its present appearance in the longer term. It may be useful to identify a desired future forest state, and to provide utilities to examine if the desired future is accessible from the current condition, and if so, what interventions may be needed to achieve the desired state. In this capacity, growth models may be particularly influential in helping to resolve thorny forest management issues.

Conclusions

Modellers, as information brokers concerned with the future, need to anticipate what information clients will want in the future. In turn, it is important to gauge what data are needed to satisfy client needs, what tools are needed to collect and analyse these data, and what tools are needed to deliver the findings. Unless these needs are identified and articulated, and actions to satisfy them are initiated, models may become irrelevant in the decision-making process.

Acknowledgements

Thanks are due to Valerie LeMay for provoking this paper, to several discussants at the conference who contributed ideas, and to two anonymous reviewers whose scepticism helped to add rigor to the ideas presented.

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