Preprint of: J.K. Vanclay, 1999. Management Advice from Tree Measurements. *In*: O. Gideon and F. Oavika (eds) Permanent Sample Plots and Growth Models for Natural Forest Management in PNG. Proceedings of Workshop, PNG Forest Research Institute, Lae, 10-13 November 1998. p. 93-102.

Management Advice from Tree Measurements

Jerome K. Vanclay
CIFOR, PO Box 6596 JKPWB, Jakarta 10065, Indonesia
Tel +62 251 622 622, Fax +62 251 622 100, J.Vanclay@cifor.org

Introduction

The ultimate objective of permanent plots and growth models is to provide management advice. We are often too pre-occupied with getting the data and building the model to think too much about providing practical management advice. But it is an important issue that should not be neglected, or postponed until the model is finished, because it should have an influence on model design and implementation. So, how do we turn tree measurements into management advice?

Do you know the word game where you turn one word into another by changing one letter at a time (and if necessary, shuffle the letters)? For example, a "tree" can be turned into "data" in 3 steps: tree - rate - date - data. To turn "tree measurements" into "management advice", you need to change eight letters, so it should be possible to do this in eight steps. I offer the following 8 steps, not as a solution to this puzzle (I offer one solution later), but as a critical pathway for turning tree measurements into management advice:

1. Tree measurements
2. Data management
3. Data analysis
4. Model construction
5. Model testing
6. Building a system
7. Making predictions
8. Management advice

Each of these steps is equally important in providing an objective basis for management advice, and those of us involved in any of these steps should bear in mind the ultimate objective. Note that it is not just the steps themselves that are important, but also the linkage between these steps. Let's consider each step in turn.

Tree measurements

Measuring trees is simple, straightforward, and usually done well. Procedures are well documented in both standard textbooks (e.g., Phillip 1994) and national guidelines (e.g., PNG FRI 1994). But this work should not be taken for granted, because these measurements provide the foundation for a lot of important research and in turn for some important recommendations, so sloppy work and measurement errors can have far-reaching consequences. Make sure that everyone involved appreciates the importance of their work.

Observations on the growth of a single tree are interesting, but don't tell us very much. It is only when we look at many trees in the context of a plot, or a series of plots, that we can begin to understand forest dynamics. And therein lies a challenge: we would like to measure lots of things, on lots of trees, lots of times, on lots of plots - but since we usually don't have lots of money, we have to make some tough decisions about what, when and where. We need to be pragmatic and focus on information that we need today, but we should also keep one eye on the future, and gather some additional data to help solve future, as yet unforeseen issues. One way to address this dilemma is to consider the cost, precision and rate of change of the attributes. Diameter at breast height changes relatively quickly and predictably, can be measured precisely (at least for medium-sized trees without buttresses), is inexpensive and easy to measure, and should be measured on every occasion the plot is visited. In contrast, measuring a diameter above a buttress or a crown diameter can be much more difficult, expensive and inaccurate, and such measurements can be done less frequently, perhaps once in every few remeasurements. Tree coordinates don't change, and need not be reassessed, although coordinates of recruits may need to be determined from time to time. Prioritizing measurements in this way can help to make plot enumeration more efficient.

Assessing recruitment is also time consuming, but our desire to gain a better understanding of regeneration and recruitment normally require an assessment at every measure. However, by assessing recruitment at a threshold below the desired threshold size (typically 10 cm dbh), it may be possible to assess recruitment less frequently. For instance, one of my students has plots in Peru in which recruitment is assessed at 7 cm dbh, so that recruitment at 10 cm can be reliably interpolated. Interpolation allows us to estimate the date at which each recruit reached the nominal size of 10 cm dbh. Measuring these smaller stems involves some extra work, but means that recruitment can be assessed less frequently.

Another way to add value to plot measurement records is to annotate them, for example, noting heavy flowering or fruiting, and pest or disease outbreaks (Vanclay 1991). Annotations can also indicate if a seemingly anomalous measurement has been checked and confirmed correct, or if a tree cannot be found and is presumed dead. It is important to discriminate trees that are missing from those that are confirmed dead.

The emphasis of permanent plots should be quality, not quantity. It is definitely preferable to have a few plots that are carefully and regularly remeasured, than to have many plots of an inferior standard. It is especially interesting to have plots with a long time series, as these allow more rigorous testing of a model, so particular care should be taken to maintain long established plots. Beetson and his colleagues (1992) offered some suggestions for the efficient placement of plots.

Data management

The first principle of data management is not to loose any data. That means that the original field sheets should be kept, that backups should be made and tested from time to time, and that duplicates should be kept off-site. I deliberately emphasize the need to keep original field sheets, even after the data have been entered onto computer and checked, because the field sheets can contain information that can help to clarify confusing analyses. For instance, nice clean field sheets can lend support to suspicions that data were fabricated, while particularly grubby field sheets can be indicative of difficult working conditions that may have contributed to fatigue. Many data analysts have experienced situations where the original field sheets helped clarify confusing results, because of annotations or other "non-data" information evident on the field sheet but not entered onto the computer.

Data should never be "massaged". Even if apparently anomalous data are detected during data entry, the original record should be maintained, as a comment, if not in the original data field. This is because one person's "noise" may be another's "signal". When we build a growth model, we are interested in the expected growth in the long run, and are not especially interested in short term anomalies and fluctuations. But the next person to look at the data may be interested to examine the effects of El Ninõ, and they may not be pleased if someone has adjusted all the diameter measurements to eliminate any apparent shrinkage.

Make sure that there is enough documentation for others to maintain the system when the database expert is not available. The best way to protect against lost data and wasted effort, is to document how to use the database, how backups are made and where they are kept, and any shortcuts or other special "tricks" used in building, using or maintaining the database.

Data analysis

Whole books can be, and have been written about data analysis (e.g., Weisberg 1985, Cook and Weisberg 1994). This overview is not meant to replace such books, but is intended to complement them, and remind you of some issues that may otherwise be overlooked. One of the most important issues is to understand the analysis, and to consult a statistician if you're not confident about analyzing the data yourself. However, don't let a statistician take over - you're the expert on the data and the forest, so work cooperatively to get the best from both disciplines. Use all available relevant data, even if this means borrowing data from colleagues. Know what you're looking for, explain your ideas carefully to the statistician, and work together to build a hypothesis that can be tested with the data. Make sure that you understand the test and the result, and ensure that it makes sense.

If you're doing the analysis yourself, be aware that r-squared tells only part of the story, and that there are other aspects that need to be considered (e.g., Vanclay 1994a, chapter 6). Note that an adjustment may need to be made to the usual r-squared formula if you compare several different models, and that without this adjustment, r-squared will provide an over-optimistic indication of the quality of the fit. Standardized residuals provide the best indication of the adequacy of a model, and standard texts should be consulted regarding their interpretation.

Model construction

The construction of a model and the analysis of data go hand in hand. Models come in many different shapes and sizes, and the "best" one depends on the specific situation. Decisive factors include the nature of the data available for calibrating and using the model, and the needs of recognized and potential clients. Thus it is important to ascertain the needs of clients before taking a decision on the modelling approach to be adopted, and before the data are analyzed. Take care that all relevant details are included in the model: increment, mortality and recruitment are obvious, but there are other aspects of growth and change in a forest. For instance, merchantable stems may deteriorate between the time of measurement and of harvesting, and that this may need to be modelled in medium- to long-term simulations. Delegating model construction to a consultant does not absolve you of involvement in these decisions - you should discuss your requirements with the consultants, and they should provide you with good reasons for their chosen approach, and reassure you that the model will fulfill your specifications.

Model testing

"All models are wrong; some are useful" (Box 1966). It does not matter that a model is wrong, provided that we know under what conditions it gives serviceable results. Einstein proved that Newton's laws of motion were approximations that apply only under special conditions, but nonetheless they are perfectly adequate for travel on earth, and form the basis for airline navigation. They don't apply for travel to the moon; for that you need to use Einstein's more complex equations. Fortunately, for most travel, Newton's more simple approximations are perfectly adequate. The same applies for growth models: some models may be more precise than others, and the role of model evaluation is to find out where and when the model gives adequate results (Vanclay and Skovsgaard 1997). Of course, accuracy is only one of the factors to take into account when appraising a model; it should also be easy to use, should work with data that is available or easy to collect, and should provide the desired information in a useful format. Tests of a model also offer insights into what can be done to improve the model.

Building a system

A stand-alone growth model can offer some interesting insights into forest dynamics, but it becomes much more useful if it is linked to other information systems, especially to inventory databases (Figure 1). It is not technically difficult to do this, but it does require planning and collaboration. It is worth making the effort to do this, because together, inter-linked inventory and prediction systems provide more than the "sum of the parts". It is only by carefully linking these systems that we can gain the best insights into the options for, and consequences of forest management decisions.

The minimal requirement is to combine the growth model with the inventory system. Additional benefits can be gained by linking both with a geographic information system to illustrate spatial arrangements, and with marketing systems to allow predictions to be cross-checked against stumpage receipts and to explore cash flow implications for the forest authority.

Figure 1 illustrates the basic links that need to be forged between inventory, growth models and spatial databases. However, this is just a generalized outline, and it is important that any system is customized to take into account specific requirements and institutions involved. This requires planning, negotiation and a willingness to collaborate. Make sure that all parties understand the proposal and are prepared to commit to it. It may be helpful to construct a mock-up or prototype to illustrate the concepts involved and the user interface advocated (Vanclay 1994b). This may seem like a lot of work, but it is well worthwhile, and will pay dividends.

Making predictions

An integrated prediction system that allows the growth model to extrapolate from inventory data is a powerful tool, but it must be used wisely to realize this power. Used wisely, it can provide powerful insights into forest dynamics and management options, but without sufficient care it can also alienate and confuse clients. It is not enough to package your model as a game that illustrates growth on a hypothetical one hectare of forest; to be something useful it has to be practical and offer management insights for real tracts of forest.

It is something of an art to choose the appropriate level of detail and flexibility; too much detail and flexibility, and you run the risk of baffling your client; too little, and your client may assume that your system is just a simple toy. To form a productive relationship, you should recognize your role as an information broker, put yourself in the shoes of your client, and choose an appropriate level of detail for both the options explored and information reported. It is critical that you are able to be able to explain predictions in a way that is appropriate and familiar to each client.

For instance, my own work in north Queensland allowed me to make quite detailed predictions about the nature of future harvests (Table1), and this level of detail was critical in negotiations with sawmill representatives, especially in discussions to establish thresholds for profitable operations (e.g., marginal yields per hectare, haul distances, etc.). However, politicians wanted much simpler and briefer output. Perhaps the most influential output from the north Queensland model was a simple graph (Figure 2) that concisely summed up the supply situation and the implications for the future.

The provision of predictions does not end the chain of steps, but provides feedback that can be used to improve on earlier steps in the process (Figure 3). For instance, we may wish to design experiments to test controversial predictions, or to conduct additional inventory to improve the precision of estimates in selected areas of interest. Predictions also provide the basis for prescriptions and policies.

Management advice

Build a good prediction system and consistently provide reliable advice, and you'll quickly become an indispensable part of the management team. But don't think that this will happen by itself; you have to work at it. Until your abilities are acknowledged, you have to be outgoing, recognizing situations where your predictions may offer helpful insights, preparing reports well suited to each situation, and being generous with your time and information. Don't be stingy with your data and information; if you don't share it, no one will realize what a treasure you have. Share it generously, and it will help you become an oracle. Don't become a "know-it-all", but offer insights into what may happen under different scenarios, and encourage your clients to define a diverse range of scenarios. Remember that in many situations, there may be more than one good solution (e.g., see Box 1). Don't tell clients what to do, but simply offer advice on what might happen under each scenario, and discuss possible implications. Do that well, and you will be an expert management consultant.

Synthesis

As foresters, we should see our role of measuring trees as a small part of our core business - providing management advice. We do need to gather data to provide reliable advice, but our responsibility does not end with data collection - it extends through the eight steps I outline above. Data form only one component; there are several other aspects to consider (Box 2). Generally, as a profession, we are pretty good at each of the eight steps, but we need to make the links between the steps smoother and more efficient. I hope that my suggestions help to achieve that efficiency.

Acknowledgements

This paper was presented at an ITTO workshop in Lae, PNG, during 10-13 November 1998. I thank all participants for the stimulating discussions that made the workshop so worthwhile. Special thanks to Forova Oavika for organizing things so well, and to Svend Korsgaard and ITTO for their support. My sister-in-law Lynda Vanclay offered a solution to my puzzle: tree measurements; gent measures tree; get me nearer stems; timer greens steam; meetings made rest; seen maids get team ; stage men and i meet; gin made me cant see; mend mean vice gate; management advice.

References

Beetson, T., M. Nester & J.K. Vanclay, 1992. Enhancing a permanent sample plot system in natural forests. *The Statistician* **41**:525-538.

Box, G.E.P., 1966. Use and abuse of regression. *Technometrics* **8**(4):625-629.

Cook, R.D. & S. Weisberg, 1994. *An Introduction to Regression Graphics*. Wiley, ISBN 0-471-00839-7.

Phillip, M.S., 1994. *Measuring trees and forests*, 2nd ed. CAB International, Wallingford, U.K., 310 p.

PNG Forest Research Institute, 1994. PSP Standards and Procedures: A permanent sample plot programme to predict growth and yield in previously logged forest. 4 volumes.

Vanclay, J.K., 1991. Data requirements for developing growth models for tropical moist forests. *Commonwealth Forestry Review* **70**:248-271.

Vanclay, J.K., 1994a. *Modelling Forest Growth and Yield: Applications to Mixed Tropical Forests*. CAB International, Wallingford, U.K. xvii+312 p. ISBN 0-85198-913-6.

Vanclay, J.K., 1994b. Sustainable timber harvesting: Simulation studies in the tropical rainforests of north Queensland. *Forest Ecology and Management* **69**:299-320.

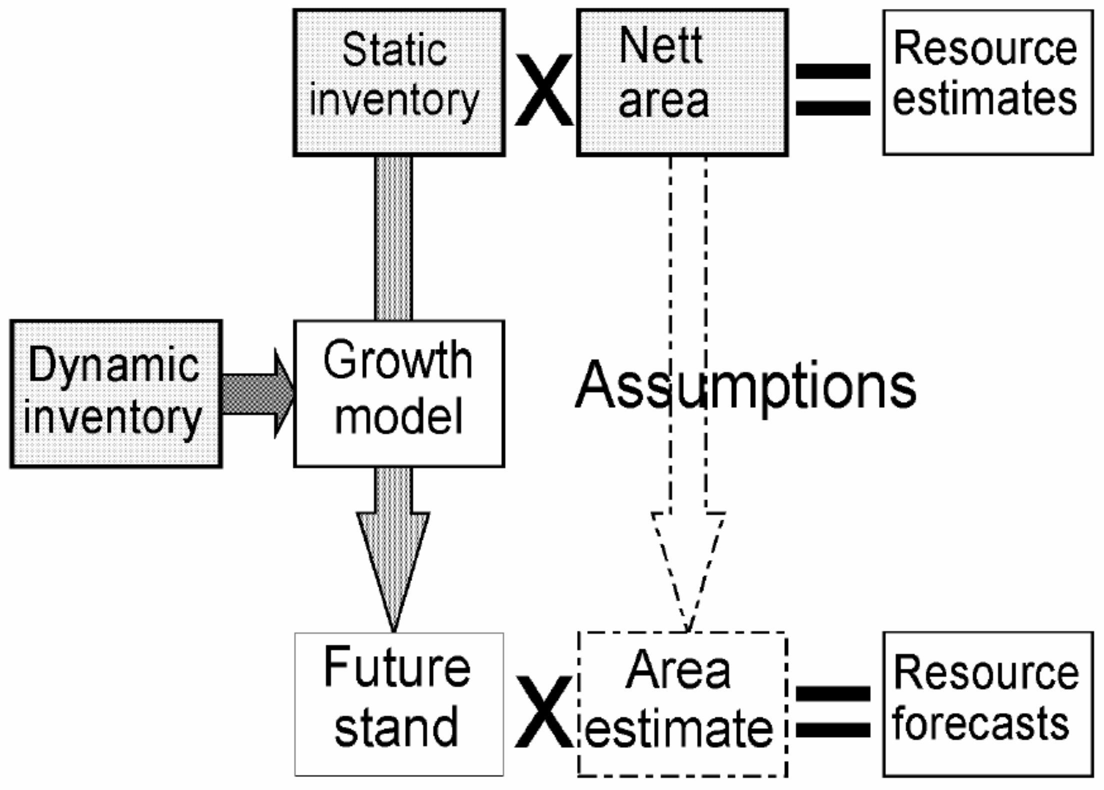
Vanclay, J.K., 1996. Estimating Sustainable Timber Production from Tropical Forests. CIFOR Working Paper No 11, 25 p.

Vanclay, J.K. and R.A. Preston, 1989. Sustainable timber harvesting in the rainforests of northern Queensland. *In:* Forest Planning for People, Proceedings of 13th biennial conference of the Institute of Foresters of Australia, Leura, NSW, 18-22 September 1989. IFA, Sydney, p. 181-191.

Vanclay, J.K. & J.P. Skovsgaard, 1997. Evaluating forest growth models. *Ecological Modelling* **98**:1-12.

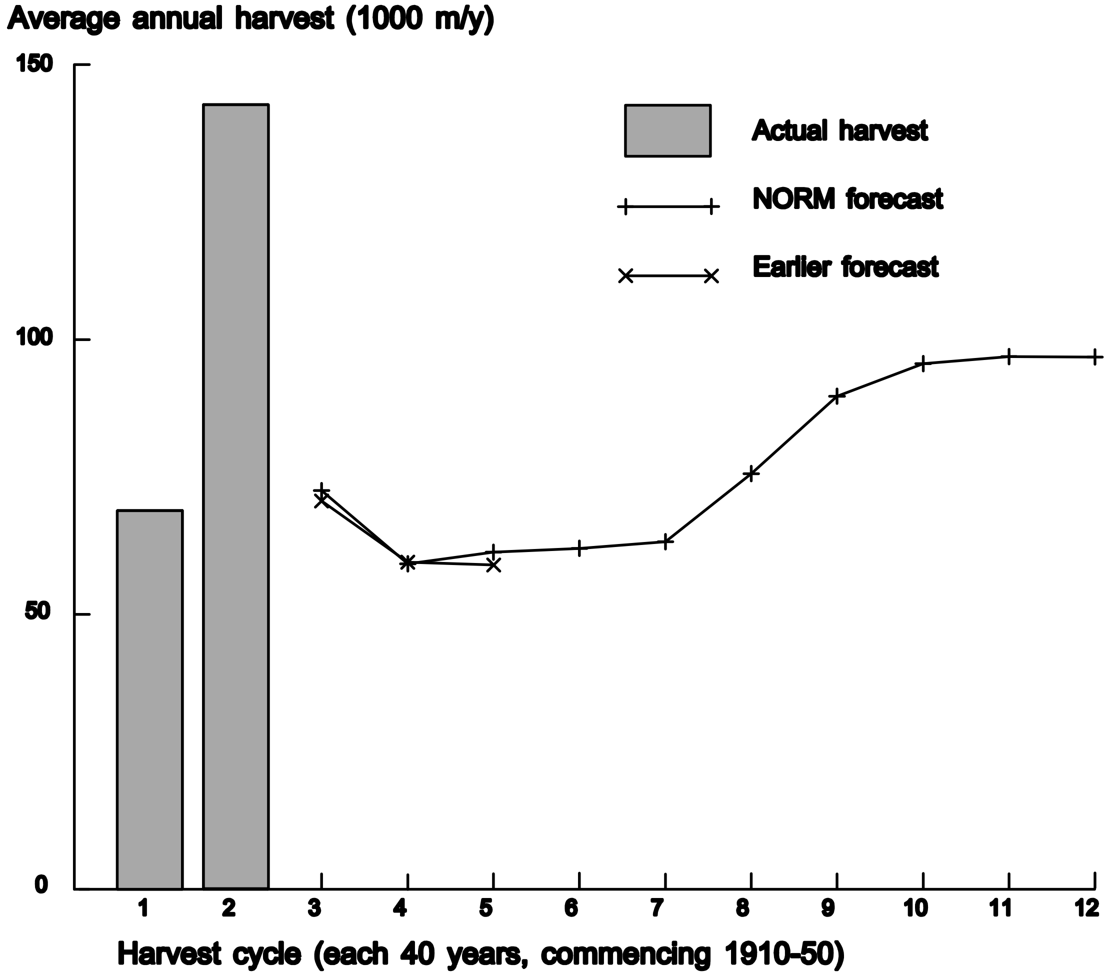
Weisberg, S., 1985. *Applied Linear Regression*, 2nd ed. Wiley, NY, 324 pp.

Figure 1. Components of a yield prediction system.



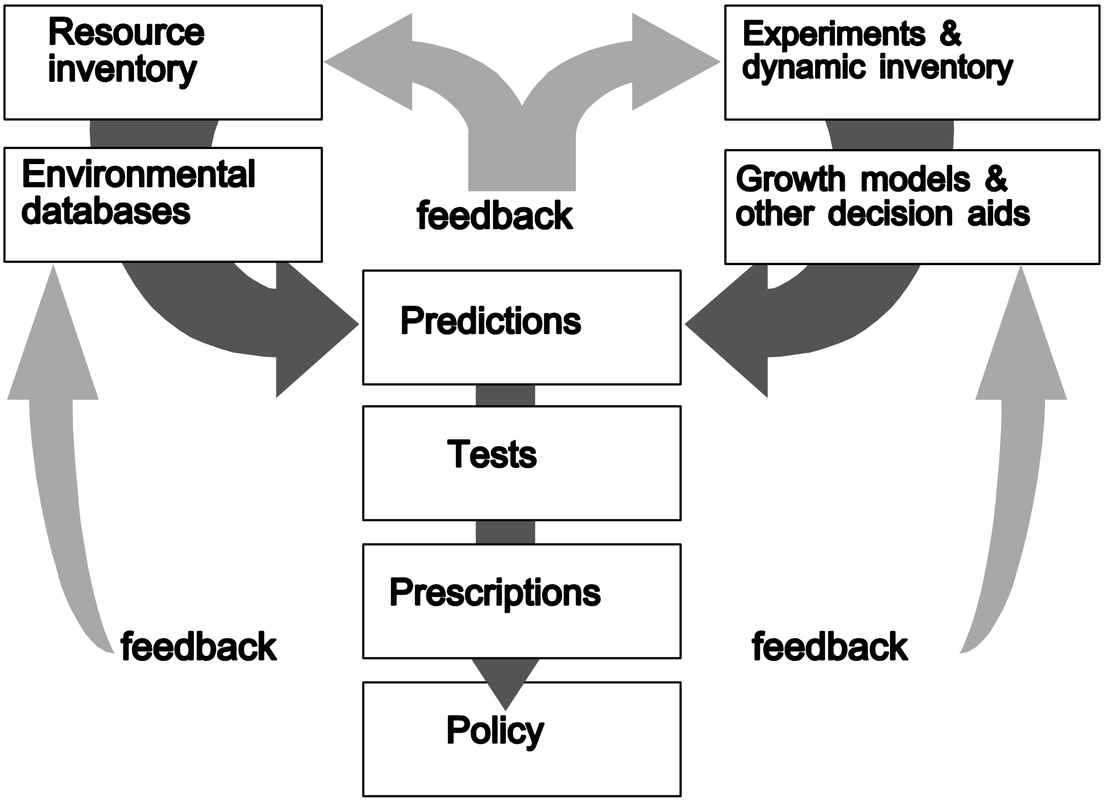
Redrawn from Vanclay (1994a) Figure 1.1

Figure 2. Past and projected timber harvests in north Queensland.



From Vanclay (1994a) Figure 12.1

Figure 3. Feedback loops in management information systems.



From Vanclay (1994a) Figure 1.2

Table 1. Detailed predictions of timber harvests in north Queensland.

Table 1. Predictions of future timber harvests from a Queensland rainforest, illustrating some capabilities of growth models (from Vanclay and Preston 1989).

Period beginning	Regional average		Average characteristics of simulated harvest			
	Basal area m^2ha^{-1}	Merch. volume m^3ha^{-1}	Harvest volume m^3ha^{-1}	Stem size m^3	Size dist. –60–100– cm dbh	Main species† in harvest %
1990	40	24	18.9	2.9	10:75:14	Y 21, M 13
2037	38	20	18.0	2.8	10:87: 3	S 22, M 14
2077	37	25	18.8	3.0	8:90: 2	S 21, M 16
2119	36	29	17.5	3.0	8:90: 2	S 20, M 17
2166	36	23	14.7	2.8	11:86: 3	M 17, N 17
2201	37	18	13.4	2.7	13:84: 2	M 21, N 16
2231	38	19	13.3	2.7	13:85: 1	M 22, Q 21
2253	39	21	14.4	2.8	13:86: 1	Q 22, M 19
2290	40	26	17.3	2.8	14:86: 1	Q 23, M 19

† M: maple silkwood (*Flindersia pimenteliana*), N: northern silky oak (*Cardwellia sublimis*), Q: Queensland maple (*F. brayleyana*), S: silver ash (*F. bourjotiana*), Y: yellow walnut (*Beilschmiedia bancroftii*).

Box 1. Allowable cut needs to be a flexible notion.

1. Effective management of the resource (cellar or forest) requires consideration of the current stock, accruals (new vintages or growth of trees and seedlings), and current market potential;
2. The volume of raw materials (grapes, timber, etc.) available depends on the quality demanded and the viable transport distance;
3. Some units (species, variety and site) may reach maturity more quickly than others;
4. General rules-of-thumb may offer a useful guide (e.g., sell a volume equal to that of the new vintage less an allowance for losses such as spoiling and evaporation, cf. mortality; sell a fixed percentage of the stock each year; or sell all stock over a nominal maturity age), but are not absolute and some flexibility may be necessary;
5. It may be advantageous to increase sales when the market is buoyant, and reduce sales during recessions, providing that the stock is maintained within certain limits;
6. If sales exceed accruals (vintage/growth adjusted for losses) too often, the stock will be compromised, and the viability of the operation may be threatened.
7. Sales can be temporarily increased to manipulate share prices, to the detriment of the unwary investor, but to the benefit of the principals.

From Vanclay (1996).

Box 2. Check list for yield predictions.

1. Are area estimates reasonable?
2. Have due allowances been made for inaccessible and unproductive areas?
3. Is the stratification reasonable?
4. Are growth estimates realistic?
5. Has due allowance been made for mortality and deterioration of merchantable stems?
6. Is the harvesting model consistent with field practice?
7. Has due allowance been made for breakage and defect?
8. Has due allowance been made for damage to the residual stand?
9. Are the volume equations reliable?
10. Do they allow for defect?
11. Are the cutting cycle and the timing of harvests realistic?
12. Are all assumptions clearly stated?
13. Finally, is the AAC being applied in a way which will achieve the desired objectives, rather than as a blanket rule which may cause instability in prices and communities?

From Vanclay (1996).