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Inventory and Yield Prediction for Natural Forest Management

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Summary

Information is essential to effective forest management and planning, and its value may be gauged by the potential costs of sub-optimal decisions. Efficient yield prediction demands an integrated approach, embracing many components. All aspects of data collection, storage and analysis must be accorded equal importance. This caveat applies to area estimates, resource estimates and to growth and yield models. Inventory data provide the core of the system, and the success of the system may depend on the cost and ease of data collection. The user interface is also critical, and the flexibility to customize reports to users' requirements is essential.

Introduction

One of several prerequisites for effective forest management is information, including descriptions of the forest and predictions of how it will respond to the various management options. Foresters and forest services commonly underestimate the value of reliable information, and fail to acknowledge the likely costs of an incorrect decision based on insufficient, incomplete or inaccurate information.
Forest management decisions may be based on information from various sources, and it is usual that each source may contribute different errors. Efficient information gathering requires that these errors be taken into account, so that each dollar invested leads to the greatest reduction in overall error. However, it is common in forestry to emphasize field inventory activities, even when this is not the weakest component. This may be because field work is conspicuous, so that it looks like something is being achieved. And because field work is enjoyable.

I will not dwell on the details of information needs assessments and error budgets (Gertner 1990), but suggest reappraisal of inventory activities and the value placed on them. Many aspects of resource inventory have been addressed elsewhere (e.g., Schreuder *et al* 1993), so I will concentrate on the collation of those data into useful information. I focus on inventory and forecasting of timber resources, but stress that the same principles apply to many non-timber products and services.

Overview of Resource Estimates

Figure 1 illustrates the basic components of most forest resource estimates. It illustrates very general information needs, and any attempt to formulate an optimal system requires more detailed and specific information. Therein lies the difficulty for most forest managers and systems analysts: it is very difficult to be specific about information requirements, and the main requirement for an inventory system may be that it is flexible. However, some general requirements may include reports detailing:

- stocking, basal area, log lengths and/or volume,
- by tree species, size (diameter or length) and/or commercial characteristics, and

- by individual inventory plots, user selected strata, and/or regional averages;

and forecasts estimating:

- the maximum sustainable harvest,
- the time that the present harvest can be sustained and the implications for the residual forest, and
- the nature (average stem size, species composition, yield per hectare) of future harvests.

This information can be compiled from three sources (Figure 1):

- area estimates of the existing forest,
- stand level inventory of the present forest, and
- growth and harvesting models to forecast the future forest.

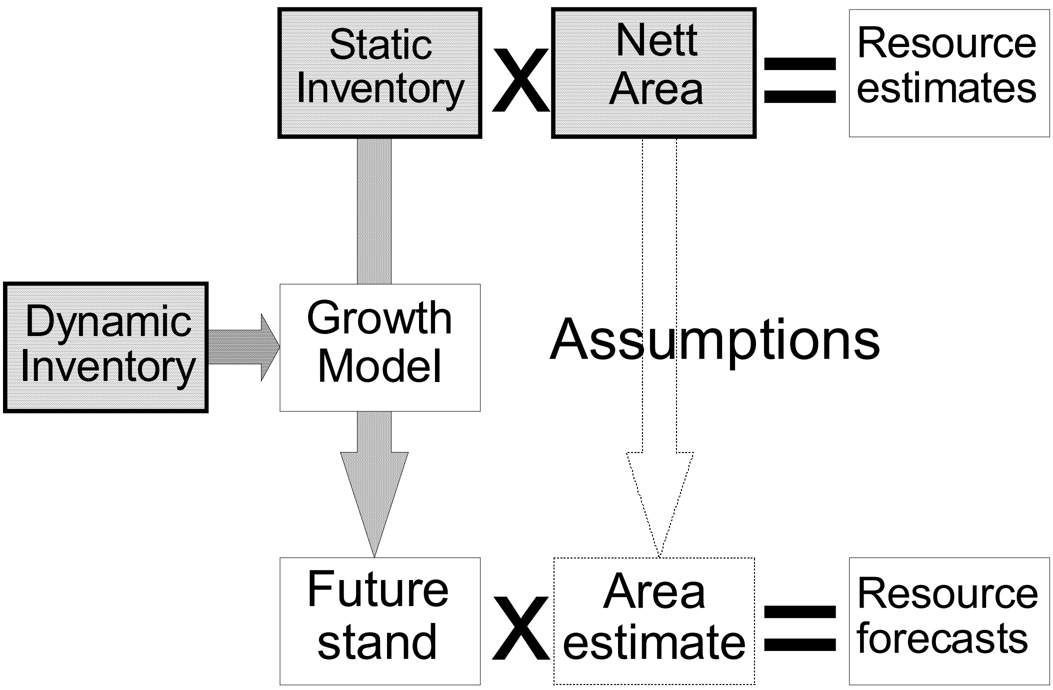

Figure 1. Components of a forest resource estimate. Primary data sources are shaded.

Some forest estimates may be prepared by total enumeration or from systematic strip samples, but a common and efficient alternative is to combine independent estimates of forest condition and area. Forecasts may also rely on independent estimates of condition and area.

Area Estimates

Estimates of forest area may be obtained in various ways. There is no universally superior method, and the best approach may depend on the local situation and resources. Changes in area are normally visible, so an efficient approach to area estimation is to use a systematic method which allows iterative refinement. It may be appropriate to commence with coarse area estimates, and gradually replace them with better estimates from dot grids, planimeters or geographic information systems (GISs). This approach demands that the area database records the source and reliability of each estimate. It also demands monitoring of forest areas, especially where encroachment by other land uses is likely.

GIS is not a panacea. Digitizing and validating maps and lines is complex and expensive, but there are no short-cuts as errors and oversights may have far-reaching consequences. GISs can be used to maintain area data, but should only be used where sufficient resources (financial and technical) to maintain the system are assured in the long term. The decision to use GIS should not be taken lightly, as the high cost (of hardware, software, data and staff) may not be justified by anticipated usage. Many of the capabilities of a GIS are not required for yield estimation and are not commensurate with the quality of the data (How precisely can you delineate forest type and stand density?). Do not be blinded by the elegant technology, but consider the difficulties of reconciling graphics from several sources, and remember the old adage "Garbage In, Garbage Out". The attribute database is important for forest management, but can be implemented in other ways without the expense of a GIS. One viable option is to use paper-based line-work to supplement a computerized attribute database (Vanclay 1990).

It is comparatively easy to estimate the gross forest area, but yield estimates rely on the nett area which may be more elusive. Suitable reductions must be made for protected, unproductive and inaccessible areas, and these may be dependent upon political, economic and technical factors. Despite the capabilities of digital terrain models (DTMs), it remains difficult to integrate these many limitations into an algorithm, and simple inventory-based methods may remain the best way to estimate nett areas. The importance of reliable nett area data should not be underestimated, as it has been a major bias in many yield forecasts (Vanclay 1993).

Static Inventory

Most foresters consider themselves inventory experts. We like doing it and can demonstrate progress, so revised yield estimates usually involve new inventory. Unfortunately, this seat-of-the-pants approach is rarely reliable. Static inventory (i.e., data on the present status of the forest, usually obtained from temporary sample plots) is rarely the weakest component in a yield prediction, and new inventory may not be obtained where it is most needed.

Stratification may be the most important thing you can do in inventory. Systematic inventory designs have their place, but where prior data exist, the best way to quantify a resource is with stratified random sampling. The best way to improve an inventory estimate may be to make more strata, provided that there are at least two plots in each stratum, and that strata can be drawn so that the between-strata variation is greater than that within strata. Strata may be drawn statistically or geometrically (Vanclay 1992), and in practice it is useful to use the administrative reserve and compartment boundaries further subdivided into relatively homogeneous sampling units. Sampling errors can be calculated to indicate units with high variability where additional strata and plots would most improve the overall estimate.

Simple logistics may determine the quality and efficiency of data collection. Travel is a major cost and can be minimized if inventory can be gathered in conjunction with other work. Training and supervision allow local field staff to gather much data efficiently during other forestry activities. There are several advantages with this approach. Field staff know the forest, and quickly recognise many errors not detected by those more remote from the forest. Disagreement between subjective and sampling estimates may dictate further sampling. Additional field work may have two effects: staff may change their opinion and inventory estimates will improve. However, the initial samples should not be discarded without good reason or bias will result. A sense of involvement and ownership by field staff may stimulate greater use of the data, and this should lead to a cycle of better data, better information and better management. But to avoid the "black hole syndrome" (nothing comes out), the system must provide useful information efficiently for field staff.

Resource information is not something you use every day, but when you need it, it is usually too late to go out and collect it. So inventory should be programmed for gradual but continual updating. Most forest stands change slowly and predictably, so that inventory data remain durable, especially where growth models allow estimates to be updated. Abrupt changes are usually conspicuous (e.g., management decision or natural catastrophe) and require new inventory to quantify the post-disturbance stand. Otherwise on-going inventory should supplement or replace existing but out-dated data. Such piecemeal data collection offers flexibility and efficiency.

The success of an inventory system relies heavily on the ease and cost of data collection. If either are limiting, the system will have a limited future. The system must include a well-designed and easily maintained computer database so that the data are available for immediate analysis. Local involvement in the system is essential, otherwise that there is little incentive to identify and rectify errors and gaps.

Dynamic Inventory

Effective forest management also demands estimates of growth and change in forest stands, and these may be obtained from remeasurements on permanent sample plots. Data from these plots may be summarized into growth models, but the reliability of these models and their estimates depends largely on the nature and placement of these permanent plots. These plots are of particular importance, as they may contribute, via the growth model, most of the error in resource forecasts and yield estimates (Gertner *et al*. 1993). Their importance is increased by the inevitable time-lag before data are available and the consequent need to anticipate information needs five or more years in advance. Unprecedented demands for static resource information (e.g., areas, standing volumes) can be satisfied quickly if enough resources are available, but better growth estimates inevitably require several years to monitor growth and change.

Dynamic inventory should not only provide data for modelling, but also for long-term environmental monitoring. This dual role means that details of plot establishment and management should be carefully documented. Response surfaces for growth models require sampling of extremes, and this requires stratified or subjective placement of plots. This strategy may be less suited for monitoring, and it is not clear if systematic (e.g., Palmer and Jones 1992) or subjective samples (e.g., Watson and Nimmo 1992) are optimal for monitoring. However, it is clear that forest services in Australia and abroad must devote more effort to environmental monitoring (Doley 1992).

Procedures for the maintenance and measurement of permanent plots are well documented (Alder and Synnott 1992, Vanclay 1991a), but other aspects warrant further comment. Forecasts inevitably involve extrapolation in one dimension (time), but extrapolations in other dimensions (site and stand conditions) are unsatisfactory and may provide unreliable predictions. Plots should be located and managed to sample the full range of site and stand conditions, and the data-space sampled within a database should be re-appraised periodically (Beetson *et al*. 1992).

It is customary but not necessarily desirable to remeasure permanent plots at regular intervals. The interval should be long enough that growth is larger than the measurement error, and short enough that plot and tree markers are not lost. For many natural forests, an interval of about five years may be suitable, but additional remeasures should be made before and after harvesting, and after any other major disturbance (e.g., wildfire) on the plot. Additional data may be collected before and after harvesting to allow the development of harvesting models (e.g., Vanclay 1989). Growth and change may be more rapid following disturbance, and it is appropriate to remeasure more frequently for several years after such events.

Many errors in permanent plot data are not detected until the data are incorporated in a computerized database, where validation is easy and comprehensive. Delays in data entry mean that many anomalies can no longer be resolved, so prompt and efficient data entry is an important component of data quality. It may be desirable to enter and validate data directly on computer in the field (Leech *et al*. 1989, Wood 1990), but the provision of effective software may be an obstacle. Ultimately however, many anomalies are not detected until the data are used, so on-going monitoring and revision of estimates remain an integral part of a yield prediction system.

Growth Modelling and Yield Prediction

Growth models and yield predictions can be prepared in many ways, and no single approach is optimal (Vanclay 1991b). However, skill and dedication are necessary to exploit the strengths of the available data and to limit possible consequences of any weaknesses. Good models are built on a knowledge of silvics and statistics, and we should not expect the "jack-of-all-trades" forester or uninitiated statistics graduate to build reliable models without specialist support. The growth model and yield prediction system have become central to the sustainability debate (e.g., Botkin and Talbot 1992) and it is crucial that forest services have reliable growth models and publish yield forecasts complete with error budgets.

Reporting: Turning Data into Information

Many resource assessment groups have been remiss in failing to communicate their results in an effective form. Too often the only output from a yield prediction is pages and pages of stand tables in a standard format. Users should be able to specify the details, format and level of aggregation for reporting, and all reports should include some statement of precision. The lesson from FORMIS (QFS' multi-million dollar Forest Marketing Information System which was never completed) is that systems should be modular and portable, and yield prediction systems can and should be built in this way.

The QFS Native Forest Inventory (NFI) system (Vanclay 1990, Anon 1993) has been in service for several years, and experience has shown that the central feature of the system is its flexibility; there is no single standard report which is requested repeatedly. A few utilities are heavily used, but are customized on each occasion to specific requirements. EXTR extracts a brief one-line summary of stand characteristics for each plot selected by users, who may request any size range, species mix, product class or volume equation. SECAL computes sampling errors for each stratum, zone and region so reported, and provides the basis for inventory action plans. RIP (Report on Individual Plots) creates stand tables aggregated as required and showing selected characteristics (volumes, log lengths, etc.) tabulated by species and sizes (any combination and range of diameter or length). SKED schedules timber harvests and forecasts yields under many options and constraints (Vanclay and Preston 1989).

These utilities write to a computer file which can be further processed (typically by 4GLs such as AWK) to trim and customize output to specific requirements. This not only provides information in the form desired, but also saves paper.

You may know the computer buzzwords of the 1980s (MIS, DSS, GIS, DTM, etc.), and some of these have delivered useful tools for forest management. If I were to nominate the buzzword for the rest of this decade, I would choose *visualization*. We have good capabilities for data storage, processing and reporting, but we have yet to satisfactorily solve the challenge of turning this data into information that can be readily comprehended. There is no place for big piles of computer-generated stand tables; that's not what forest managers and planners need. Information needs to be portrayed more concisely and clearly. It may be some years before we use virtual reality on an operational scale, but there is great potential to link yield prediction systems more effectively to graphics packages and GISs. We need more innovation in communicating estimates, in indicating the sensitivity of results to various assumptions and parameters, and in displaying the spatial and temporal distribution of predictions. Closer links between yield prediction systems, GIS and DTM systems offer some promise, but effective exploration of alternatives demands systems which forest managers and planners find efficient, easy to use and which deliver quick responses, and this argues for simplicity rather than complexity.

Conclusion

It is easy to state general principles and guidelines for yield prediction, but harder to put these into practice. Some Australian forest services have made good progress in implementing good systems, but all leave room for improvement. Hopefully the many recent re-organizations and efficiency experts have not crippled creative but fledgling systems. None-the-less, Australian expertise in this field remains equal to the best in the world, and we have much to offer others, in other land management disciplines and in forestry institutions abroad, especially those in developing countries.

The challenge remains to build good foundations for an integrated system, and to strengthen the weakest components of the whole system rather than to promote one particular component currently fashionable. The life of a datum spans its definition, collection, validation, storage, analysis and synthesis. All phases are equally important, and an efficient system requires a healthy balance between them. Finally, the most important thing is that the system should be easy to use, easy to understand, and easy to update.

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