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INTEGRATED RESOURCE MONITORING AND ASSESSMENT: AN AUSTRALIAN PERSPECTIVE OF CURRENT TRENDS AND FUTURE NEEDS.

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ABSTRACT

Trends influencing inventory practice include increasing labour costs, new technology and competing demands for land use. These trends challenge land managers to devise efficient mold-purpose inventories which yield durable data to assist land management rather than just timber management. For maximum utility, inventory design should allow integration of data collected in different places, at different times, by different agencies, or for different reasons.

Three things are essential for reliable integration of data: standardization, accuracy and locational information (geocodes). Clear objectives and sufficient resources (funds and staff) are also a prerequisite. Managers should try to anticipate future information requirements, and plan to meet them. Multi-resource inventories cannot be set up overnight. It is natural that ideas and procedures evolve and mature. One should start with the possible, but plan for the future.

INTRODUCTION

I would like to share with you some of my impressions on current directions and future needs in resource assessment and monitoring. So much has been written on these topics in recent years that I make no attempt to review all recent developments; rather my views are biased toward Australian and forestry related developments.

The following definitions paraphrased from an Australian dictionary summarise nicely the matters I wish to address in this paper:

- Integrated: to bring together parts into a whole.
- Resource: the collective (renewable natural) wealth of a country.
- Monitoring: check, observe or record the operation of a system without interfering with its operation.

Resource monitoring is not an end in itself, but a service providing information to clients. Who are those clients, and what are their information needs, both now and in the future? Past requirements and recent trends provide an indication of likely future needs. Some issues which may be important in shaping future needs include:

- The earth's ever-increasing population is making great demands on natural resources and the few remaining "wild places"; many species are under threat of extinction. The existence of the remaining few indigenous people in their traditional forested lands is threatened by deforestation. These and other conflicts challenge many irreversible land use decisions.
- There is an increasing public concern about the environment, which is becoming an important political issue in many countries. In particular, people and governments are becoming concerned about the loss of species, deforestation, acid rain, the "greenhouse effect" and the ozone layer. There is also concern that soils may degrade under intensively managed industrial plantations.
- Many agencies are taking a more holistic view of their responsibilities in recognition of the fact that regional, national and global consequences may need to be considered to properly assess the impact of a land use decision.
- Monitoring and assessment programs are being challenged to become more efficient as labour costs rise, availability of funds diminish and terms of reference become progressively broader.

- Technology is providing many interesting possibilities for more rapid and efficient assessment and monitoring, but it is not without some often considerable "up front" costs.

Foresters have lots of experience in the assessment of timber resources, and have performed inventories competently and well for many years. Many efficient procedures have been devised to facilitate these (e.g. point-3-P sampling), but these are often quite specific to the inventory of timber (Wiant *et al* 1989). Australia, like many other nations, does not have a national forest inventory, and national statistics are generally compiled by aggregating figures provided by the various States and agencies. Success depends upon the number of agencies involved, and their commitment to the project. Aggregating national statistics to provide global information is analogous to aggregating data to provide a national inventory, but the problems are compounded. Missing data and differences in definitions and measurement standards may cause difficulties in meaningfully aggregating data. Procedures for inventorying and aggregating non-timber and non-commercial values exist (Lund 1986), but are neither well established nor standardized. The value of the timber in a forest provides a context for the costs of timber inventory, but costs of assessment and monitoring of non-commercial aspects cannot be so easily put into perspective, especially where the forest produces no commercial harvest. Many forest managers resent the fact that inventory costs of non-commercial aspects are borne by the timber inventory.

Meaningful global data on renewable natural resources and environmental change requires careful thought about the *information* required, *how* and *what* to measure to provide this information, and how to collate and distribute it.

INFORMATION REQUIREMENTS

To establish the needs for resource monitoring and assessment, we must first identify our future information needs, without being constrained by current practice or feasibility. Technology is removing many of the barriers to effective assessment and monitoring of resources and the environment. It is reasonable to assume that this trend will continue, so we can speculate on future information needs without worrying about the feasibility of satisfying these needs. Current procedures for collecting data may not be the best way of satisfying information needs. The technical aspects of how to measure and collect data should also be ignored at this stage, as these matters can be resolved when our information requirements have been established. All too often the data available in an information system determine the users, rather than the reverse.

Information needs depend to some extent, upon the agency and the resource, but information generally required includes:

- The extent and nature of the resource and its regional, national and global significance. This requires reliable and complete inventory data of that resource and its surrounds.
- An indication of the external influences on the resource, including the demand for the resource, and impacts on the resource by other agencies (pests, diseases, pollution, etc).
- An ability to evaluate the impact of management alternatives on the resource under consideration, or other renewable resources in the region, and on the environment generally. This requires the construction of simulation systems.
- Ideas to help formulate viable management alternatives. Expert systems may be useful in this regard.

Thus it would seem that information requirements for resource managers and monitoring agencies are not changing greatly over time; it is merely the methods of providing this information which are changing. However, managers are taking a broader perspective of their domain: they are examining the national or global significance of their resource rather than just the regional significance, and they are examining the impacts of resource use on the whole forest environment rather than just on the wood supply. Thus inventory needs to become multi-resource inventory, not just timber inventory, as management changes from logging management to forest management, and so on.

As specific needs may vary according to the nature of the agency (private or public land, natural forest or industrial plantation), it is important that each agency identify its information requirements as clearly, concisely and completely as possible. In particular, each agency should know *what* it wants and *why,* including the accuracy it requires and the price it is prepared to pay (Lund 1987). Hamilton (1979) stresses that "if funds are inadequate, the inventory may produce information that has less value than the cost of collecting it".

Westoby (1987) argues that foresters (and presumably other managers of renewable natural resources) are expected to serve as the public conscience on matters of resource management and resource use, and should recognise the long-term public interest and ensure that it is not compromised by the short-term interest, public or private. In resolving land use conflict, a regional, national and global perspective of renewable natural resources and of threatened fauna, flora, habitats and scenery may be required to enable rational planning and utilisation. Even where there is no conflict, information requirements are no less demanding, and relate to monitoring the performance of the resource, as well as to an on-going commitment to iteratively refine land use zoning as more information becomes available.

Monitoring is more difficult than inventory, because a baseline needs to be established, and changes may not be detected until ten years or more have elapsed. Thus you need to know well in advance, what you want to detect by monitoring. For example, simply monitoring the diameter growth of trees on standard inventory plots is unlikely to provide timely warning of damage to forests from acid rain; foliar analysis may be a more reliable and immediate indicator. A better approach may be to conduct glasshouse "acid irrigation" trials to determine the symptoms of acid damage, and to specifically look for these in the field (as well as monitoring growth).

All too often, the analysis and reporting of data are overlooked or dealt with in a superficial way, to the detriment of the resulting information. If you can precisely define your information requirements, you should have no difficulty in defining the reports you want, and preparing prototype reports should be seen as part of defining the procedures for data collection and analysis. Computer software for analysing and reporting data should be flexible and able to accommodate a variety of needs (Vanclay 1989). Sampling and prediction errors should be calculated and explicitly reported. Remember, your computer is your slave, not your master; don't let it dictate the nature of your results. A lot of money is spent on inventory to provide reliable information, so don't try to save a few dollars by "making do" with existing but inadequate software.

Rose et *al* (1981) outline some important guidelines:

- Information should not be collected for its own sake, but should always be related to project objectives.
- Avoid generating more information than is needed at each stage of planning and decision making.
- Explore fully what information is already available.
- Explicit consideration should be given to the level of confidence of the information presented.
- Information should be generated on relevant variables in such a way that when the budget has been exhausted, the marginal benefit derived from spending the last dollar on increasing our confidence in (or reducing the error about) each variable is about the same. This relates three basic elements
  - the estimated error about a given estimate of a variable,
  - the impact of the variable on the output objective, and
  - the cost of generating information to reduce the error.

TECHNOLOGICAL OPPORTUNITIES

New technology offers exciting possibilities to accomplish more with fewer resources, but it can be expensive to introduce. The challenge is to make effective use of technology. This requires expertise, insight and teamwork. If you don't have the expertise, think seriously about getting it, either through training, recruitment or consultants.

Computers have exhibited exponential growth in speed and capacity while steadily becoming smaller and cheaper. We can expect this trend to continue, so we need not worry too much about computing costs. Similarly, improvements in computer programming languages allow greater productivity, and this should make it easier to ensure that computer programs are flexible enough to do exactly what we want of them - or be modified to do so. But don't economize on system design; a well designed system will pay dividends.

Compact hand held computers (data capture devices) may be used in the field for recording data, replacing pen and paper. 'Ibis enables immediate validation of data in the field and rapid downloading of data for further office analysis, as well as eliminating transcription errors. Validation may be especially important during remeasures of permanent sample plots, when data from previous measures may be stored to allow rigorous checking of current diameter measurements. Several manufacturers produce robust, waterproof versions of these devices enabling them to be used in difficult environments where paper would be impracticable. In addition to these considerations of data quality, the use of these devices may offer cost savings (Fins and Rust 1987).

Other portable computers (data loggers) can be used for automatic and remote recording of information. They can be used to record at pre-determined intervals (seconds, hours, or weeks) almost any variable which can be measured. They are widely used for automatic weather recording stations, to control irrigation systems, monitor stream levels, and may be used to record diurnal changes in tree diameters. They are most useful for monitoring short term changes in a system (object or environment), but are not practicable for the annual remeasure of a half hectare plot.

An interesting recent development is the use of computers to automatically determine the faunal species present at a site. Corben (1989) reports the use of a microphone and a computer to record the presence and behaviour of bat populations. Their inaudible ultra-sonic calls indicate not only the bat's species, but also behaviour (navigation, hunting, catching prey). This novel remote sensing technique avoids the expensive and time consuming need to trap, identify and release the animals, and may provide an efficient means of monitoring other animal species.

Digital remote sensing from satellites has come of age. Although early results a decade ago often failed to fulfill expectations, this technology is now being widely and successfully used for resource assessment and monitoring. Digital satellite data are excellent for monitoring major temporal changes such as fire or storm damage (Skidmore *et al* 1987, Preston 1987), but can also be used to assess stand density classes and site quality (Vanclay 1988b). In the near future, we can expect satellite data to provide reliable digital elevation models. Sensors with better resolution and improved analytical procedures may enable classification to indicate forest type, stand density classes, site quality, or disturbance. However, such analyses currently require, and probably always will require some reliable "ground truth" data for supervised analyses and validation.

One implication is that the geocode or location (latitude and longitude) of all sample plots should be described as accurately as possible. A single Landsat TM pixel (about 30 m) equals a second of latitude, so sample plots whose location is known only to the nearest minute of latitude and longitude will be little help in classifying or validating satellite data. In many areas, especially rugged or unsurveyed country, attaining sufficiently accurate geocodes is a problem. Global positioning systems (GPS) have been available for navigation for some time, and are now becoming small and cheap enough for portable field use. The constellation of satellites is presently incomplete and restricts use of GPS to a few hours each day. When the constellation is completed in 1991, geocodes accurate to within a few metres will be attainable 24 hours a day. CPS can operate instantaneously, enabling road locations to be digitized (for a GIS) by recording the output from a CPS within a moving vehicle, and smaller features to be digitized by a man wearing a CPS on his belt (Lange and Kruczynski 1989).

Geographic information systems (GIS) are another area where technology is assisting the inventory of our resources. GIS doesn't 'provide much that could not be done by hand, but makes it easier and quicker, especially to calculate and reconcile areas, create stream buffers, and so on. Digital elevation models (DEM) add the third dimension to the GIS, and simplify derivation of slopes and aspects. More advanced GIS/DEM packages model water movement and calculate catchment areas, streamflow and surface wetness.

Computer analyses also enable extrapolation of climatic data across entire continents. Such analyses have been used to interpolate species distributions (Busby 1986), identify suitable locations for establishment of exotic plantations (Booth *et al* 1989) and to classify climate and soil combinations to provide an indication of the rarity of habitats (H. Nix pers. comm.).

Mensurationists have for years dreamed and joked about having a "Dick Tracey" watch (which would tell them the geocode), and a dendrometer which would remotely and automatically measure the height and volume of trees and stands. CPS has already provided the Dick Tracey watch, although some further miniaturization is still required. Several devices in various stages of development (e.g. Nishikawa 1988) may advance dendrometry beyond the present benchmark, the Barr and Stroud optical dendrometer (no longer manufactured). Computer tomography also allows the non destructive detection of growth rings and internal defect, providing us with Superman's X-ray vision. But both these developments are, and will remain for many years, applicable only to individual trees - and because of the expense, special trees at that! Automatic dendrometry of stands is still the stuff of dreams.

The implication is that there remains a need for manual measurement of both temporary and permanent sample plots. Fewer of these will be needed, but the demands placed on these data will increase. As the number of plots decreases, the need for quality data increases. Plots must have a reliable geocode, and must provide data on an increasing number of parameters.

NEED FOR INTEGRATION

Integration simply implies combining two or more inventories conducted in different places, for different reasons, by different agencies, or at different times. It may mean combining regional inventories to provide national or global statistics; correlating timber inventories with soil or faunal surveys; aggregating data from private and public lands; or comparing successive inventories to detect any change in the resource. It enables a more holistic view of a resource (and very often the total is more informative than the sum of its parts) and may enable elimination of duplication (Lund 1986).

Integration means that data from different inventories can be meaningfully combined. It does not necessarily mean that you have to measure everything in every inventory. On the contrary, it is better to do a few things well than to do a lot inadequately. But it does require cooperation and coordination with other agencies to ensure that data can be integrated. The simplest example is to ensure that measurements are comparable. For example, two different standards for breast height prevail (1.3 and 1.4 m), so aggregating data requires either a change in procedure for some agencies, or the development of a suitable conversion factor.

Faunal inventories are usually more complex and expensive than timber inventories, so are usually conducted at lower intensities and less frequently. Habitat modelling may allow some extrapolation of results, but better data may be provided if specific nesting or feeding requirements are known. Such requirements can often be assessed during timber inventory without additional cost. Thus for example, inventories may note the presence of hollow branches providing suitable nesting sites for parrots at negligible extra cost, whilst providing valuable data for ornithologists. However, cooperation is required to establish a suitable basis (what size hollow, tree species, forest type?) to enable this integration.

It is essential to define a minimum set of essential parameters if a multi-national or multi-agency database is to be established. Three groups of essential parameters can be identified: physical environment (topography, water courses and bodies, climate, soil and geology, and seismic activity), natural environment (vegetation type, distributions of rare and/or endangered species) and anthropogenic factors (national boundaries, land use and tenure, transport routes, population centres, pollution sources). Of these, remote sensing provides the potential to capture information on topography, water courses and bodies, transport routes and population centres. Vegetation type and species distributions may be determined from remote sensing and factors of the physical environment. Perhaps the most important variables to collect relate to the climate and to soils and geology. Standardization between agencies and nations is a major difficulty with these and other variables (Mounsey and Briggs 1988) and must be addressed.

INVENTORY REQUIREMENTS - TEMPORARY PLOTS

Inventory requirements fall into two categories determined by the nature of the sample units - temporary or permanent. Where an initial assessment is desired and on-going monitoring is unnecessary as may be the case in virgin forests and for land use decisions, temporary plots are most efficient. In contrast, forest managers often require data to monitor growth and performance and to enable development of simulation models and expert systems, and this requires permanent sample plots to provide sufficient detail and accuracy. Although permanent plots could be used in any situation where temporary plots are used, they are more expensive to establish and maintain, and efficiency demands that temporary plots be used where possible. Temporary plots are an efficient way to define the present resource, but are not the best way to monitor change.

In any inventory which may be used in resolving land use conflict, information on any natural and cultural heritage, and on the environment generally, is required in addition to the "bread and butter" data on the nature and amount of, renewable resources. This means that field staff should be opportunistic in collecting information on species and habitats, and that the inventory reporting system should be capable of incorporating and processing these data. Unless this information is able and likely to be used, it is pointless collecting it! Such data may include information on fauna, flora, landscape, archaeology, recreation potential, etc. It also requires careful design of inventory procedures, recording forms and reporting systems. In particular, management should identify in advance what sort of information about habitats is relevant, and what can be readily recorded without incurring much extra cost. For much of these data, it may be necessary to provide training to ensure that the data collected will be useful, particularly for assessment of archaeology and karst landscapes.

One useful contribution that timber inventory staff may make is to assist in collecting information regarding species distributions, by collecting specimens of unusual species or common species in unusual locations, and lodging these with herbariums with detailed locational and habitat data. In the normal course of their work, many forestry field staff spend more time in the field, and explore much larger tracts of country, than many botanists and taxonomists can aspire to. A comparison of the distributions of some rainforest tree species in north Queensland based on forestry inventory data indicates a much more widespread distribution than that indicated by the official herbarium data. By providing well documented "voucher" specimens to herbariums, forestry staff can authenticate these wider distributions, and add to the knowledge of species distributions and habitat requirements.

Staff and funding restrictions experienced by many agencies challenge us to devise more efficient methodologies. The first step is to ensure we have clear objectives. Another important factor is to ensure that data are collected and stored in such a way as to increase their useful life - so they become more durable. This may be as simple as ensuring that data collected meet anticipated future needs as well as immediate needs. In Queensland, this is partly achieved by recording "visual thinning" (the inventory officer's assessment of which trees will be removed in the next selection logging), so that the data give an indication of the likely residual stand after the next logging. This also requires assessment of the potential (e.g. site quality) as well at the present status.

Other essential requirements are that all data are as accurate (precise and free of bias) as possible within cost constraints, and that the geocode is recorded. If mapping for the region is inadequate, a GPS should be used.

Systematic sampling has been widely used for forest inventory. While this approach is good for the detection of pattern and enables the preparation of maps, it is not efficient at quantifying the resource. Existing information should be used to design an efficient sampling scheme. Typically, this may involve stratifying on the basis of existing information and of use stratified random sampling and variable probability sampling. Even where no existing ground survey information is available, satellite imagery and aerial photography may provide a good basis for stratification. There are three further important principles which are often overlooked:

- The precision of the final estimate is influenced most by the initial stratification.
- Precision is gained by dividing the population into as many strata as expedient, even though each
- stratum may contain as few as two plots (Schumacher and Chapman 1954).
- Once stratification has been refined as far as practicable, further improvement can be achieved by sampling proportional to the variance observed in each stratum and by employing variable probability sampling.

Many older inventory manuals stressed that the precision of inventory could be improved by increasing within and reducing between plot variation, by using long narrow plots oriented parallel to any gradient. The recent emphasis on point and 3-P sampling avoids this debate on plot shape and orientation. However, it is appropriate to point out that there may be a need to update inventory using a growth model, and in such cases, it is preferable that the plot be homogeneous and approximately the same dimensions as the permanent sample plots on which the growth model was based.

Inventory of non-timber values poses three challenges:

- To estimate diverse values (flora, fauna, archaeological, etc.) from parameters which can be objectively and quickly sampled without the need for specialist equipment or expertise.

- To be able to collect relevant sample data and analyse them to provide timely information for the planning process.
- To be able to justify the costs on a rational long-term basis.

One solution is to record heights, cover and identities of all habitat components on a sample plot. Habitat components can be any objects on the plot including vegetation, rocks, litter, etc. These attributes are used to discriminate between habitat types. Since fauna distributions are closely associated with floral communities, changes in the flora will affect dependent fauna.

Inventory to determine the number of plant or animal species present at a site poses special difficulties. In order to obtain reliable data, special consideration should be given to plot size. The best approach may be to establish a series of adjacent 'small sub-plots, and to graph the species area curve after each sub-plot is measured. When the data provide evidence of an asymptote, the sample is large enough. The same approach may be applied to fauna, especially birds, if the number of species is plotted against time spent observing.

INVENTORY REQUIREMENTS - PERMANENT SAMPLE PLOTS

Permanent sample plots pose all the problems and challenges of temporary plots, with the additional dimension of compatibility through time, which may add considerably to the cost of plot establishment and maintenance. Because of the high cost of these plots, it is expedient to limit their number, and to extract as much information as possible from each plot. To achieve this, their intended purpose must be carefully defined. Traditional uses for permanent sample plots include applications such as providing data for developing growth and harvesting models, and for monitoring second rotation decline in plantations, etc. These applications require experiments as well as passive monitoring plots. "To find out what happens to a system when you interfere with it you have to interfere with it (not just passively observe it)" (Box 1966). More recently, these plots have also been used to try to detect the effects of acid rain and other forms of pollution, a function they may not be able to fulfill adequately without additional variables being measured.

To minimize the cost of these plots, you must know what you wish to detect by monitoring, and ensure you collect all the necessary relevant data. Remember the distinction: the role of temporary plots is to reflect past practice and current status, whereas permanent plots provide data to investigate future options. It is important to choose a re-measurement interval consistent with the rate of growth and measurement error. Thus for example, it is pointless to measure the heights of mature trees, every year, as any increment will generally be much less than the measurement error, remeasures every five to ten years would be more reasonable. Because the data must be consistent through time to provide monitoring information, measurement standards are critical. As changes in procedures may disrupt comparisons of successive measurements, these should be minimised, and any remeasure after a procedural change should employ both the old and new procedures..

Data collection procedures for PSP are specialized, and I refer you to the literature (Curtis 1983, 1988, Tennent 1988, Vanclay 1988a). To briefly summarize some important aspects, remember that these plots should be randomly located within homogeneous strata; should sample the full range of environmental conditions; should be approximately square to minimize edge effects; and should be regularly re-measured. Provided that plot measurement time remains less than travel time, additional information such as floristics and animal habitats should also be assessed and recorded. Trained staff are essential to ensure that the quality of the data is consistently high. Field staff will do a better job if they understand the equipment, the experiment, and the results. Precision should be recorded, and should suit instruments, crew and objectives.

EXPERT SYSTEMS

During the past two decades, a considerable amount of research has been expended in developing growth models. As a result, we now have a sound idea of the data required to develop and implement these models. During the initial detailed design of sophisticated simulation models, gaps in present knowledge and data are often detected.

During the next decade, I anticipate that many agencies will research and develop expert or knowledge based systems to assist management of their natural resources. The development of a new system (simulation or expert) frequently causes those involved to critically appraise the data at their disposal, the information required, and the way they evaluate the requirements and resources. This invariably exposes omissions, redundancies and inefficiencies, and indicates new directions, and is in itself a good reason to attempt such new and ambitious projects.

What data does an expert system need? That depends on what you want to do with it. Typically, the expert system is needed because access to experts is limited, and greater access to their knowledge is needed. If you can formulate the questions you wish to ask of the experts, you are well on your way

to defining the data needs of the expert system. Greater use of expert systems will certainly demand better software, and better integration of existing data (e.g. Smith *et al* 1987, Covington *et al* 1988). The main requirements are for commitment and cooperation by agencies and individuals involved, and the integration of quality data, derived largely from permanent sample plots.

SUMMING UP

If there were to be but one message for me to convey in this paper, it would be a plea for standardization of procedures, accuracy and reliable locational information (geocodes). I would also urge all resource managers to define clear objectives and ensure sufficient resources (funds and staff) before commencing any inventory. Managers should -try to anticipate future information requirements, and plan to meet them.

Do not be deterred by the fact that comprehensive multi-resource inventories cannot be set up overnight. The very nature of such inventories involves the cooperation of specialists from many different disciplines. So start small, but think big. Start with what can be effectively assessed now, but set up the frame-work for what should come later. Commence the rest when it can be effectively introduced (preferably to a time table). Some other important needs are to:

- define concisely and completely the information required;
- identify what and how to measure to provide this;
- identify the accuracy required and ensure adequate resources to attain it;
- ensure suitable computer support (hardware, software, staff);
- establish a reliable baseline if trying to detect change;
- consider the need for experiments in addition to passive monitoring plots;
- don't try to integrate too much into one inventory; it may be better to design single purpose inventories for later aggregation;
- make full use of existing information.

Techniques and technology are sufficient to enable comprehensive multi-resource inventories to be conducted and integrated to provide meaningful national and global resource information. The question is, do we have sufficient motivation and commitment to accept the challenge?

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