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Permanent Plots for Multiple Objectives: Defining Goals and Resolving Conflicts

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Abstract: Many research and monitoring activities rely on data from permanent plots, and the validity of results depends upon the quality and quantity of these data. Resources limit the number of such plots that can be established, so it is essential that all plots satisfy as many needs as possible. This requirement impinges on the placement, design and procedures for existing and proposed plots. The paper examines compatibilities and conflicts between the demands of growth model development, of ecological monitoring systems, and of ground truth for remote sensing. Whilst conventional procedures provide basic data for all these applications, some minor enhancements may improve the utility of the data with negligible extra cost. Guidelines indicate procedures for the optimal placement of plots, and for increased utility from a limited number of plots. These guidelines may enable us do more with less, to improve the quality of our data, and to make better inferences from these data.

Introduction

Some of the objectives of this workshop include:

"... promoting the establishment of a permanent sample plot network ...", and to
"... specify the data to collect ..."

Before we rush into this task, we need to consider carefully our information needs, and then to identify the data that are required to provide this information. "What to measure" is an issue which all too often precedes these more important considerations, with the frequent result that data collected may be sub-optimal. We should first resolve our information needs, translate these into data requirements, and then decide on the sampling design and measurement procedures with these needs in mind. Only then can we resolve:

- what, when and where to measure;
- who measures, who pays, and who uses these data;
- how to measure it, and
- how much data are required.

In formulating our information needs, we must be quite specific in defining what we need know and what we hope to infer from this information. For example, the monitoring of forest area, of forest quality or of environmental health involves very different procedures and enables very different conclusions. Optimal sampling for current status requires different procedures than for monitoring change. All too often the data available in an information system determine its users, rather than the reverse!

Our information requirements should be identified explicitly and stated clearly, concisely and completely. In the planning and design of a monitoring system, it is important to identify the real information needs and not to be constrained by the feasibility and costs of obtaining this information, as needs tend to be durable whilst technology continually alters the feasibility and cost of gathering the necessary data (Vanclay 1990a). Failure to identify the real information needs may lead to important attributes being omitted from measurement procedures, and may diminish the value of the system.

Applications demanding Permanent Plots

There is no doubt that permanent sample plots can be very useful, but efficiency may favour other forms of sampling for many applications. To qualify as permanent sample plots, there must be both an intention and a plan to remeasure them. This involves considerable additional cost over temporary samples, so why and where should permanent plots be used? In some cases, there is no alternative, but for many applications, temporary plots are both feasible and efficient, and should be considered. In general, permanent plots are necessary only where detection of change is required.

Where permanent plots are necessary, it is essential that they be managed efficiently to minimize costs and maximize benefits. This requires careful attention to information needs and to data collection procedures. We should not only focus on existing needs, but should also consider future needs. In many applications, measurement errors are relatively large compared to the rate of change, and five or ten years may be necessary to establish a trend (Vanclay 1991). We need to anticipate information needs ten or more years hence, and thus our plot measurement and management procedures must be flexible and robust. We should focus on basic stand variables which can be quantitatively measured rather than subjectively estimated. Those who design and initiate the system may not be the ones who use it, so the design and rationale should be carefully documented. Procedures and standards should be established, documented and maintained, and changes should be few and upwardly-compatible.

Plots Serving Many Purposes

One way we can increase efficiency is to make the same plots serve several purposes, provided that the objectives are compatible. Table 1 illustrates some fundamental differences in the design objectives of some applications. Whilst all these applications can be satisfied by permanent plots, two can be served most efficiently by temporary samples. Resource inventory differs from most other applications as sampling should maximize variance within plots and minimize variance between plots in any stratum. In contrast, most other applications require homogeneous plots. This different fundamental requirement may limit the efficacy of traditional continuous forest inventory schemes which attempt to provide estimates of both status and change.

Table 1. Characteristics of some Sampling Applications

Application	Permanence	Area	Plot Variance
Resource inventory	Temp or Perm	Variable	Heterogeneous
Growth estimation	Permanent	Fixed	Homogeneous
Site monitoring	Permanent	Fixed	Homogeneous
Ground truth	Temp or Perm	Big	Homogeneous
Silvicultural expts	Permanent	Varies	Homogeneous

Some useful information regarding environmental change and degradation may be provided by plots designed to provide data for growth model development (e.g. Vanclay 1990b), but additional variables should be measured to provide comprehensive site monitoring. The same sampling designs may be used in silvicultural experiments, but it is often preferable to customize the design to specific experimental needs. Ground truth for remote sensing can be provided by either permanent or temporary plots, but inaccuracies in image registration indicate larger plot areas than those customarily used in other applications. Since we may extract much useful information from existing plots, we should carefully appraise our information needs before we promote the establishment of additional plots.

Some additional attributes may be measured and recorded in existing permanent sample plot systems with minimal extra cost. Where this is possible, this offers a cost effective way to obtain additional information, and reduces the significant burden of plot maintenance. There are several advantages to such an approach, but we should not assume that we can satisfy our needs simply by freeloading on existing permanent sample plot systems. There are several issues that should be examined. Principal among these is the question: will the existing system efficiently satisfy our needs, or are we just trying to avoid paying for our own requirements? This question has a converse: would a new system for our specific requirements deprive other worthwhile sampling efforts of resources, or lead to the neglect of existing sampling systems? Both questions require that we look into the adequacy of existing systems and the resources devoted to them. We need to resolve the same issues that arise

when designing a new system, and we need to give special attention to two matters:

How were the plots located: Subjectively or objectively, systematically or randomly? Will placement of plots introduce bias into our sample? In short, will the existing (or proposed) system deliver the information we need?

How big is the sample? Are the plots the right size, shape and orientation for our needs? How many plots are there: are there enough or too many?

Whilst it sometimes is more efficient to work within an existing system, we should not blindly join an established system just to freeload on another budget, as we may not get the information we want. Sometimes it is more efficient to combine several needs into a single sampling system; sometimes it is better to adopt separate systems, and to combine the data later (Vanclay 1990a). Simple practical matters may be decisive. For example, timber inventory should be conducted in broad daylight for good visibility, whilst bird surveys on the same plots may be best conducted at dawn using survey crews with different skills.

Sampling Scheme

When we have resolved our information needs, the required permanence of the plots, and the scope for shared plots, we then have to face the difficult question of sampling design. The question is: what is optimal placement and management of these plots? There is no single best sampling scheme for all applications: the optimal design depends upon information needs and resources available, so this paper can only discuss some general principles.

Table 2 (adapted from H.C. Dawkins, pers. comm.) identifies some considerations which influence the selection of a sampling design. It takes the form of a binary key which may be used to select an appropriate method. For example, it indicates that if we seek a reliable estimate and require interpolation to prepare a site quality or forest type map, we should employ systematic sampling. Alternatively, if our estimate is critical, is to have known precision, and is to be obtained using a small sample, we should use stratified random sampling.

For many applications, some form of stratified random sampling may be optimal. Either statistical or geometric blocking may be used, depending on what prior information is available. Three principles offer the greatest possible precision for a fixed outlay:

- * 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 within the stratum.

Table 2. Some Considerations in Sampling Design.

	Criteria & Consequences	Alternatives & Optimal Sampling Method	
1	Nature of estimate Forest Characteristics Representative selection Time and resources <u>Bias</u> <u>Precision</u>	Critical Unknown/Diverse Unreliable Sufficient Objective ☞ Go to 2 Absent Can be estimated	Unimportant/Personal Familiar or Uniform Reliable Very limited Subjective Sampling Unavoidable Unknown
2	Periodicity Interpolation Estimate of Precision <u>Sampling Error</u> <u>Periodic Bias</u>	Possible/Unknown Not required Required Random ☞ Go to 3 Correct estimate Unlikely	Unlikely or Known Necessary Unimportant Systematic Sampling Probably inflated Possible
3	Pattern in population Sampling intensity <u>Inherent risks</u>	Clear or Likely Relatively low Strat.random ☞ 4 Misjudge pattern	Absent or Unlikely High Unrestricted random Sample clustering
4	Pattern in population <u>Calculations</u>	Obscure/Unknown Geometrical blocks Simple	Visible or Well known Statistical blocking Possibly complicated

Where a small sample is proposed, it may be desirable to deliberately sample to include extremes. Extremes are essential in regression analyses for growth models (Beetson *et al* 1991, Vanclay 1991). Extremes are also important in environmental monitoring, as it is at the extremes where many changes will be first manifested. Extremes may also be of interest in truthing of remote sensing, as the classification of these can then be considered explicitly. However, the "typical" stands should also be sampled, and the decision to sample deliberately should be documented.

Number of Plots Required

Statistical formulae often dictate more plots than the forest manager can afford, and this raises several questions. Are the appropriate formulae being used, is the specified precision really required, and if so, is there a danger that the system will cost more than the resulting data are worth (Hamilton 1979)?

Permanent plots usually provide worthwhile data, even if the precision does not reach the desired level. So a compromise may be to establish as many plots as you can afford. But don't overestimate your capability, as a few good plots are better than many incomplete or inaccurate plot records. The importance of this cannot be overstated, as too many monitoring efforts lie abandoned, rendered useless by insufficient attention to detail and inadequate clerical procedures.

Efficiency is further enhanced by making full use of existing data, and by ensuring that new proposals satisfy all existing and anticipated needs. When formulating a new proposal, discuss it with your colleagues and make sure that it satisfies all compatible needs of your own and other local institutions. Then document the proposal and have it reviewed by international experts. A little extra time and effort initially can save a lot of frustration and waste later!

What to Measure

If information needs are expressed clearly and concisely, and then translated into corresponding data requirements, the parameters to be measured will become obvious. Many papers (e.g. Adlard 1990, Curtis 1983, Vanclay 1991, Whitmore 1989) have considered what and how to measure, and their guidelines will not be repeated here. Their suggestions provide a starting point, and can serve as a check list for your own requirements.

Some attributes you should consider include those from the following four categories:

- 1) Plot establishment details should include descriptive location and numeric co-ordinates, plot dimensions and orientation, and full documentation.
- 2) Site variables should include full descriptive and numerical characterization of the plot, including forest type and site quality estimates.
- 3) Trees should be individually identified, numbered, tagged and mapped, and attributes recorded should include co-ordinates, species, size, vigour, etc.
- 4) Other species present (shrubs, herbs and other species) and their abundance should also be documented.

Direct measurement of some parameters of interest may be difficult, and it may be necessary to adopt an indirect alternative. For example, site productivity in plantations is difficult to determine directly from the soil chemical composition, but site index provides a suitable surrogate. Where a plantation has not yet been established, the presence or absence of certain plant species may provide a reliable indication of productivity (Vanclay 1992). These concepts may be extended to other aspects of assessment. Whilst it is easy to monitor the turbidity, salinity and acidity of streams, monitoring of other pollutants is more difficult, and there is always the difficulty that the real problem is the chemical

you're not testing for. An alternative may be to monitor the development of amphibians, either those occurring naturally in the stream, or some raised in water samples in the laboratory (Tyler 1983). Amphibian development could indicate the water quality in the same way as site index (tree height at a given reference age) represents the integration of many site factors. Surrogates may provide an efficient and effective way to monitor many aspects of the environment; the challenge is to find suitable surrogates for our needs.

Pivotal or keystone species are those which are critical to the functioning of an ecosystem, and which if lost, may trigger a domino effect leading to loss of many other species and a major change in the functioning of the system. Large mobile frugivorous fauna such as fruit bats, hornbills, toucans and cassowaries may account for many of the pivotal fauna in the rainforest. In turn, these species may be dependent upon a limited number of plant species, especially during periods when alternative foods are scarce. Other plant species may have a crucial role in nutrient cycling, through nitrogen fixing or retrieval of nutrients from deep in the soil profile. The health and abundance of these pivotal species may provide a good indication of the overall functioning of the forest.

Some Examples

Suppose we want to monitor the area of closed forest worldwide. We could do this remotely using satellite imagery, and would require ground truth data in several locations for calibration. Such ground truth need not comprise permanent plots; temporary plots would be sufficient. It remains critical that standard definitions (e.g. of forest) are used, that plots are of a reasonable size, and that the date of measurement is known. An unconstrained analysis of such data may provide different regional and global estimates of forest area than those obtained in other studies (e.g. FAO's survey data), and it may be interesting to conduct an analysis constrained so that the regional totals agree. If both such analyses are completed, it may be informative to conduct additional ground survey in areas where the constrained and unconstrained classifications differ. Again, such ground survey need not comprise permanent plots, and temporary plots will be adequate if the appropriate standards are maintained.

Stratification is more important in forest type and/or biomass assessment. Existing satellite sensors do not provide a good correlation between spectral signature and biomass, so multi-stage sampling within a stratification based on prior information may improve estimates. Suitability of prior information is determined mainly by its accuracy, and many kinds of information may be useful. Existing vegetation type maps may be employed, or strata can be generated from more basic data such as digital climatic, topographic and geological databases (e.g. Mackey et al. 1988). However, where such digital data are

utilized, it is critical to employ the right variables. In particular, it may be the climatic extremes (e.g. droughts, floods and frosts) rather than the averages, which shape vegetation patterns.

In contrast, monitoring for changes in forest type, biomass or biodiversity may require more sophisticated stratification, since political and socio-economic factors may be major determinants of such change. Thus for such monitoring, it may be wise to incorporate nations as a strata additional to environmental strata.

Summary

Permanent sample plots can satisfy most of the needs of most users, so all potential users can save time and resources by sharing, co-operating and co-ordinating. We should anticipate future information needs and data requirements, express these needs clearly and concisely, document methods, maintain standards, sample extremes, and not be too ambitious, but "do what you do do well".

References

- Adlard, P.G., 1990. Procedures for monitoring tree growth and site change. Tropical Forestry Papers No 23, Oxford Forestry Institute. 188 p.
- Beetson, T., Nester, M. and Vanclay, J.K., 1992. Enhancing a permanent plot system in natural forests. The Statistician 41:525-538.
- Curtis, R.O., 1983. Procedures for establishing and maintaining permanent plots for silvicultural and yield research. USDA Forest Service General Technical Report PNW-155.
- Hamilton, D.A., 1979. Setting precision for resource inventories: The manager and the mensurationist. Journal of Forestry 77(10):667-670.
- Mackey, B.G., Nix, H.A., Hutchinson, M.F., Macmahon, J.P. and Fleming, P.M., 1988. Assessing representativeness of places for conservation reservation and heritage listing. Environmental Management 12(4):501-514.
- Schumacher, F.X. and Chapman, R.A., 1954. Sampling methods in forestry and range management. Duke University School of Forestry, Bulletin 7 (revised). 222 p.
- Tyler, M.J., 1983. Natural pollution monitors. Australian Natural History 21(1):31-33.
- Vanclay, J.K., 1990a. Integrated resource monitoring: an Australian perspective of current trends and future needs. In: Global Natural Resource Monitoring and Assessments: Preparing for the 21st century, Proceedings of the international conference and workshop, Sept 24-30, 1989, Venice, Italy. American Society for Photogrammetry and Remote Sensing, USA. Pp 650-658.

- Vanclay, J.K., 1990b. Effects of selection logging on rainforest productivity. Australian Forestry 53(3):200-214.
- Vanclay, J.K., 1991. Data requirements for developing growth models for tropical moist forests. Commonwealth Forestry Review 70 (3), 105-111.
- Vanclay, J.K., 1992. Assessing site productivity in tropical moist forests. Forest Ecology and Management 54:257-287.
- Whitmore, T.C., 1989. Guidelines to avoid remeasurement problems in permanent sample plots in tropical rainforests. Biotropica 21(3):282-283.