# Sampling in Forestry

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## 1. Introduction

Sampling can be considered the fundamental subject in the broad field of statistics. The importance of spending time and resources on ensuring a good sample design, and ensuring that the design is followed correctly, cannot be underestimated. We are all familiar with situations where very sophisticated analysis techniques have been used on poor data. The result is an answer that looks good - sophisticated analysis techniques have been used, but is not good - the data are poor.

As an example I recently attended a seminar by a respected biological mathematician who had developed an impressive model to predict the threshold for the population size of a certain predator species. The threshold was the level above which there would be an adverse effect on the associated prey population. The model looked like it could predict this relationship admirably. Unfortunately for the mathematician, I was familiar with the data used for the modelling process. The estimate of the prey population was from a survey where data were collected by driving along a road and counting the number of animals seen from the window of a car. The sample size for the survey was one - one road was surveyed. The road was 10km long but the sample size was still one. The prey species, as with almost all biological populations (Greig-Smith 1979), was not randomly distributed but occurred in patches or clusters. The scale of these patches was about the same scale as the sample unit (10 km). If the road happened to traverse through a patch the population size of the prey would be over estimated, and if the road happened to not traverse through a patch the population size of the prey would be under estimated. Either way the information on the prey population was biased. I would suspect that when this information was used to model the predator-prey relationship the model would be less than accurate.

I use this example because it is a simple illustration that sampling and collecting "good data" should underpin statistical inference. What are "good data"? Good data are data that are collected in a manner that allows their appropriate use in analysis and for the research question to be addressed.

## 2. Developments in Forest Sampling

Sampling is important. So what sampling techniques are we using in forestry? The history of forest sampling started well back in the 20$^{th}$ century. The idea of a national forest inventory in the United States was around in 1920 when Greeley (1920) commented on the loss of three fifths of the timber originally in the United States (Frayer and Furnival 1999). The history of sampling has its origins further back than this. For example, in 1898 Clements and Pound used quadrats in a survey to assess variation in terrestial vegetation (McIntosh 1991).

Sampling in forestry evolved from the use of plots to more sophisticated surveys with designs based on the concept of stratification, optimal allocation of effort among strata, multistage designs, systematic sampling, and designs with partial replacement of permanent plots. The most significant development in forest sampling was in the type of sample unit used. Point sampling (Bitterlich 1948), also known as plotless sampling, angle count sampling, angle gauge sampling or simply Bitterlich sampling (Shiver and Borders 1996) was introduced half way through the last century (Bitterlich 1948). I will briefly outline what point sampling is for the benefit of non-foresters because it seems to be a sampling technique that is only widely used by foresters.

Point sampling is sampling with probability proportional to size. This is the attraction for forest inventory surveys where the interest is in estimating volume. Large trees have large volume and it makes sense to spend more time sampling these compared with sampling small trees. A count is made of all the trees that can be seen from a point (in 360°) that have a diameter larger than a constant projected angle. Various devices can be used to project this angle, including prisms, relascopes and simple angle gauges made from rods. The estimate of the volume per ha is calculated from the probability of selection of each tree. The tree's probability of selection is proportional to its basal area.

Point sampling has been favoured by foresters but perhaps now we have come the complete revolution in the history of sampling because the US Forest Service have reverted to plots in favour of point sampling (Frayer and Furnival 1999). This brings me to my main message in this paper: use the KIS principal - Keep it Simple.

## 3. Sampling designs for large-scale surveys

With large-scale sampling programmes consistency in the survey method is crucial. Large-scale programmes include surveys that cover a large area and will be conducted by more than one survey team, and surveys that will be repeated through time and will be surveyed by different people at each time interval. Consistency is important to ensure that the data collected is representative of the same population. For example, if one crew measures trees along rows in a plantation and another measures tree across rows differences in estimates of stocking could be due to differences in survey design rather than differences in the true stocking.

The best way to achieve consistency is to have a simple, and practical, survey design. The fewer decisions that are made in the field the less chance things will go wrong, and the more chance the protocol will be followed. For example, systematic compared with random sampling has the advantage of being logistically easier (Ratti and Garton 1980). There are fewer decisions to make in the field because sample units are spaced at regular intervals. I have experience with the following situation that illustrates this point well. In New Zealand large-scale monitoring of a marsupial pest, the possum (*Trichosurus vulpecula*), is undertaken in forests by counting the number of animals caught in randomly located lines of leg-hold traps. Damage by possum browse in forests can be extensive and there is a nationwide possum control programme. There has been much debate about the statistical validity of the sampling design (Brown and Thomas 2000), and one of the questions has been about the use of random sampling. A typical survey may involve five lines within a 5000 ha area. It would not be uncommon to have, in the planning stage, four of these randomly placed lines near each other while the fifth is say, 5 km away. In practice the survey plan may not be followed. Even with the best training, human nature is such that chances are the fifth line is not located where it should be and is located less than 5 km away. This may introduce bias - if the field worker decides to not locate the line in the true location 5 km away then subjective judgement will be used with the actual placement of the line. With systematic sampling no one line would be a long distance from any other and the lines are more likely to be located in the correct position. We have recommended the protocol for possum monitoring be changed to use systematic sampling (Brown and Thomas 2000).

The difference between systematic and random sampling in the possum example is that the definition of the population being sampled has changed. Assuming systematic sampling is carried out according to the plan the entire study area should have equal chance of being selected (excluding edge effects). With random sampling the population being sampled will be smaller than the whole study area if the fieldworker never walks to the true location of where the most distant sample line should be.

Even with simple survey designs like systematically located plots there is room for error in the data collection and this error can have a significant effect when it is a large-scale survey involving many people (each with their own potential to create error). The common example quoted in forestry is measuring the diameter of the trees. If one person is more vigilant than the other in ensuring the tape measure is flat against the tree and horizontal then the differences in the measured tree diameters may not reflect real differences in tree size but measurement error.

**4. Complicated survey designs**

There are many survey designs that are more complicated than simple random sampling or stratified sampling. These designs are often used to reduce sample variance and most do this very well. However, the advantages of reduction in sample variance from using a complicated survey design can be outweighed by the disadvantages of extra error from poor use of the design in the field. This "extra error" is called non-sampling error and is the error associated with the data collection process rather than the sampling error measured by the variance of the estimator. Literature on sampling has focused on the sampling error. I argue that the non-sampling error should be considered.

As an example of a survey design that has proven statistical efficiency but is complex to undertake in the field is adaptive cluster sampling. This is a technique proposed by Thompson (1990) as an efficient method for sampling rare and clustered populations. It has been applied in the forest situation, and Roesch (1993) reported gains in survey efficiency (measured by MSE) over simple random sampling. In the forest application that Roesch used, when a tree with a rare characteristic was sampled by random sampling, the tree became the centre of the circle for point sampling. If any of the trees in the circle had the characteristic of interest these trees became the centre of a new circle. Selection continued in this sequential process until no new trees were found. The disadvantage of the technique is the fieldwork becomes complicated. The number of trees, or in this application, the number of point-sampling plots, is not fixed and can be quite variable depending on the spatial pattern and the number of trees with the characteristic of interest (Brown and Manly 1998). Planning for the survey can be difficult because the survey may be quick, or it may take a long time depending on the number of trees adaptively sampled. In practice keeping track of what trees have been surveyed or not in the field can be confusing and time consuming. There is potential room for error if trees are not sampled when they should be. This error is difficult to quantify and is usually ignored but I believe that it has a large contribution to the error of the estimate.

As another example of a complicated survey design Lowell (1997) investigated the use of sample units that were based on the spatial pattern of the trees using triangle-based probability polygons and triangular tessellations. These designs appeared to be interesting techniques for reducing sample variance. In his study he found that for there were no general conditions where these designs performed universally better than fixed area plots and point sampling. The field procedures were more complicated. Lowell gives as an example that in the spatially based techniques the *n* closest trees to the sample centre are measured. Measuring the 20 closest trees may be relatively simple but distinguishing between the $30^{th}$ and $31^{st}$ closest trees may be time consuming and in practice the tree closest to where the fieldworker is standing at the time would be measured. This bias may be random if there were no consistency in this error, but it may not be if there were a tendency to avoid standing in the denser side of the sample. I suspect the later would happen if this were used for large-scale surveys. While during the "testing" of the new sampling technique the field procedures would be followed perfectly, after time what happened in practice may differ from what the sampling protocol called for.

**4. Summary**

For large-scale surveys the humble, but simple fixed-area plots or point sampling seem to be the most widely recommended method for forest sampling. The optimal size and shape of fixed area plots may differ among forests but the basic idea of using a simple method seems to be the best approach. The design of the survey should be simple too. Stratified sampling, perhaps with systematic selection within stratum can be relied on, generally, to be the best design. With a simple design there is less error in the data collection phase. This error is not quantified but can be large. The message is keep it simple. With a simple design the field worker who collects the data has an understanding of how the data will be analysed and is likely to be the person undertaking the analysis. This creates a sense of "ownership" of the sampling process and more commitment to collect the data properly.

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**RESUME**


The importance of good sampling and data collection techniques cannot be underestimated. Sampling techniques in forestry have developed from simple plots. Point sampling made an important contribution and seems to be a technique that is only widely used in forestry. There have been other developments in survey designs that offer improvements in efficiencies. However, these efficiencies are based on measurements of the sampling error. In any complicated survey design there is potential for the non-sampling error to be large. The non-sampling error includes the error from not following the specified survey design. In large-scale surveys field operators can interpret the survey protocol in different ways and any differences in the variable being estimated may be due to differences in the sampling method rather than the variable of interest. Survey designs should be kept simple.