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REMOTE SENSING-AIDED SURVEY OF RENEWABLE RESOURCES WITH EMPHASIS OF FORESTRY IN DEVELOPING COUNTRIES 1)

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Abstract

The concept of land use has become more complicated. One reason is that multiple use.idea has become more and more popular. This is linked with increasing standard of living in developed countries and with increasing population density in developing countries. Shifting cultivation, agro-forestry, and alternation of farming, grazing, and tree growing make it difficult to apply old standard methodologies used for forest assessments. The changes in land use, both rotating and trends, are essential and the methodology of assessment should be adopted accordingly.

Here, the role of accurate measurements in the field is emphasized for flexible classification of lands and for inventory of changes and for updating. Additional data from aerial photographs, satellite imagery, and maps are then to be used flexibly according to the situation. Sampling according to GIS principles is preferred to classification for compartments. The design is worked according to two phase sampling. Many stratifications can be applied parallelly resulting in several estimates for each first phase sample unit. The method is regarded as simple and flexible.

1. Introduction

There is a large number of alternative approaches to be applied to forest resources assessments. The approaches can be divided roughly into two main categories: (1) to area classification and (2) to sampling procedures. Differentiating of the above categories is not always unambiguous as many mixed combinations may exist.

In the area classification the whole area is to be divided into a certain number of different categories such as forests, woodlands, other land uses. Different categories, i.e. classes, are differentiated by drawing the borderlines on maps or other base material such as satellite imagery and aerial photographs. If remote sensing is used distortions should be known and eliminated. The areas of different classes can then be measured on the base material.

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Application of sampling means usually that a number of sampling units, usually circular plots or relascope points, are located in a systematic pattern on the inventory area, data are measured or estimated for each unit and the inventory results including area distributions and mean values as well as reliability estimates are calculated on the basis of the samples.

The principal advantages and disadvantages of the area classification and mapping may be listed as follows:
+ traditional, easy to understand
+ good for overall viewing
- borderlines between classes are often ambiguous
- leads to subjectivity
- variation within a class often large
- the classes often difficult to be measured accurately in the field (the estimates often based largely on ocular estimation)
- monitoring of changes difficult if based on more or less subjective area delineation

Generally, the application of a sampling technique is regarded as more recommendable for national forest resources inventories in order to get detailed and non-biased information for planning purposes. The purpose of this paper is to illustrate the possibilities to apply sampling techniques together with the use of remote sensing to avoid the disadvantages connected to area class assessments.

Three Global Forest Resource Assessments have been conducted since 1940:ies. The last one was dated on 1980. The fourth assessment is going on and should be finished by 1992. The reliability of worldwide forest resource data is all in all rather weak. According to Persson (1977) improvements are needed especially on the national level since international statistics will mainly rely on national statistics.

Special attention should be paid (as proposed by FAO 1980) to those areas where deforestation is either occurring or has a strong possibility of occurring (Grainger 1984). The inventory should lead to a forest resource data base, incorporating a coordinate system supplemented by information of other natural resources and overlaid with other economic/geographic data bases (Lanly 1983, Grainger 1984).

The techniques demonstrated is based on two-phase sampling. The first phase data may consist of many sets of auxiliary data to be obtained of many kinds of auxiliary data sources, such as maps, satellite imagery, aerial photographs, for example. The second phase data are usually measured in the field. The sample for the first phase data is an intensive one and the sample for second phase data is a sub-sample of the forst phase data sample. The final results are suposed to be the better the higher is the correlation between the first and second phase data.

The objective of this paper is to introduce a technique based on two-phase sampling to combine remote sensing and ground measurements for application of forest resources assessment and monitoring at national and thereby at a global scale.

The features emphasized specifically in the construction of the methodology are as follow:
+ good connection with Geographic Information Systems
+ flexibility in using all kinds of auxiliary data, e.g. satellite imagery when clouds exist
+ simplicity
+ statistical soundness

2. **Methodological description**

A combination of remote sensing and ground truth measurements has been used in form of double sampling or two-phase sampling. The principles of two-phase sampling were introduced by Neyman (1938) and applied to forest inventory in connection of remote sensing by Bickford (1952). Thereafter, designs have been described and applications illustrated by many authers, e.g. Frayer (1979), LaBau and Winterberger (1988), Mattila (1985), Peng (1987), Poso (1972, 1988).

Two-phase sampling may be a sensible method if there is access to inexpensive auxiliary, i.e. first phase, data, not necessarily remote sensing data, which is in good correlation with ground truth data. If many auxiliary data sources, possibly from many different dates, are used at the same time for stratification, e.g. Landsat TM, SPOT, NOAA, digital terrain model, old forest resources inventrory results, and general map data, the stratification and the whole system tend to become very complicated.

The technique here is based on the idea that each auxiliary data source is used either separately or in easy combination, e.g. combination of Landsat TM and general map, for stratification resulting in many different strata for each first phase sample unit. The principles of the technique has been described in specific applications used in Finland (e.g. Poso et al. 1984, Peng 1987, Härmä 1988). Accordingly, the procedure of using many different stratifications produces many sets of inventory data for each first phase sample unit.

The methodology is illustrated in Figure 1. First phase units have been defined on the basis of a homogeneous grid and stratified on the basis of Landsat TM imagery to 5 strata. Every first phase plot belonging to stratum 1 gets the same ground variable estimates from matrix M1 based on ground measurements. Correspondingly, those plots belonging to stratum 2 get the ground variable estimates from matrix M2. The procedure is continued to all strata and results formally complete ground variable estimates for each first phase plot which has been stratified.

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STEP 1: Each plot is supplied by first phase data

2	2	3	4	2
2	3	4	2	4
3	3	4	2	5
3	4	4	5	1
3	5	1	1	1

STEP 2: Each plot is stratified to homogeneous strata on the basis of first phase data, xi

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$$M_h = \begin{matrix} y_{11}, & y_{12}, & \cdots & y_{1p} \\ y_{21}, & y_{22}, & \cdots & y_{2p} \\ . & . & \cdots & . \\ y_{mh1}, & y_{mh2}, & \cdot & y_{mh'p} \end{matrix}$$

STEP 3: Measurement of ground truth data for each stratum, h, resulting in a ground truth matrix M_h, h=1,2,..5.

Y_2	Y_2	Y_3	Y_4	Y_2
Y_2	Y_3	Y_4	Y_2	Y_4
Y_3	Y_3	Y_4	Y_2	Y_5
Y_3	Y_4	Y_4	Y_5	Y_1
Y_3	Y_5	Y_1	Y_1	Y_1

STEP 4: Each plot is supplied by ground truth from the relevant matrix M_h to be used as the final estimates, Y_h (h = index for a stratum)

Figure 1. Steps of two phase sampling. An illustration.

The stratification of the first phase units can be repeated using different kinds of auxiliary data as many times as sensible. Each stratification produces a new set of ground variable estimates for each first phase sample plot. The result is illustrated in Figure 2.

1,2 3,4	1,2 3,4	1,2 3,4	1,- 3,4	1,- 3,-
1,2 3,4	1,2 3,4	1,2 3,4	1,- 3,-	1,- 3,-
1,2 3,4	1,2 3,4	1,- 3,-	1,- 3,-	1,- 3,-
1,2 3,-	1,2 3,-	1,- 3,-	1,- 3,-	1,- -,-
1,- 3,-	1,- 3,-	1,- 3,-	1,- -,-	1,- -,-

The numbers refer to stratification. Each of the 25 first phase plots may obtain four different sets of estimates when all stratifications are represented. Some plots are represented only in one stratification and hence get only one set of estimates

Figure 2. Final estimate vectors for the first phase sample units.

In the Figure 2, each plot can get four estimates at most. If no auxiliary data exists for a first phase plot it cannot be included in any stratum and it does not get any estimate directly. In this case some techniques of nearest neighbor, i.e., taking the estimates from the geographicly nearest neighbor plots may be applied.

In order to make decisions about the final estimates to be applied to a specific first phase plot the concept of reliability of the estimates should be introduced. The final estimates for the ground variables, e.g. site, mean height, basal area, volume, tree species distribution, volume increment, and technical quality of the growing stock, is to be calculated by weighting the separate estimates by the reliability of the estimate.

3. Discussion

The method based on one stratification, on combination of satellite imagery and map data, has been tested in Finnish conditions in several situations with positive results. The experiences include the inventory of two communes with forest areas of 18 000 and 120 000 hectares. The field sample plots have usually been relascope points with basal area factor of 2 sq.m.per hectare.

A study of the relevant possibilities and problems in getting final ground truth variable estimates on the basis of more than one stratification has been started at the University of Helsinki as a part of thesis for MSc degree in Forestry. The study deals with up-dating of old inventory data by the use of remote sensing, forest growth models, maps and remote sensing.

The applicability of the system to the conditions of developing countries has not been experimented. The key problem in the experimentation seems to be the availability of the good quality ground truth data. The field inventory problems are great in tropical conditions. A single hectare of closed tropical forest, for example, may include more than 100 tree species each with its own interdependent colony of plants and animals. According to Birdsey et al. (1986) tropical species tend to have a clustered distribution. Accordingly, the use of clusters as sampling units is recommended (eg. Vazquez Soto 1987). Another general recommendation for the tropics is the use of permanent sampling units (e.g. Schreuder and Singh 1987).

The methodology described may be simple enough to be used for forest resources assessment and monitoring. In most extreme cases only NOAA and some basic map information may be used for stratification. Landsat TM or corresponding data can be used whenever accessible. The biggest problem, however, is to get ground truth information which is located with good accuracy in order to obtain good correlation with auxiliary information and the ground truth data. The need for ground measurements may be especially high in the tropics if much weight is allocated for tree species estimation.

It is important that all material: plots, pixels, air photos, maps etc. are in the same coordinate and time system. The correspondence of different data should be tested. Studies with satellite imagery have shown that discrepances of some 20 m may cause severe decrease in the usability of remote sensing in the conditions where the average stand size is small, only 1-2 hectares. Problems may also originate from unreliable maps. Sometimes, it may be advisable to substitute maps for satellite imagery in the tropics.

Some difficulties originate from the date of data. The date of first and second phase data may differ. Procedures for updating second phase data are thus required. Forest data updating often requires application of growth models. The lack of reliable volume and biomass growth models and change models in land use emphasizes the need for permanent sample plots especially in the tropics.

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