New ways for Forest Resource Surveys

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Abstract

The history of forest inventories goes back to the end of the Middle Ages when the heavy use of forest resources created a shortage of wood. Traditionally, field measurement based systems have been used. The information needs have increased rapidly during the last decades. On the other hand, new technology has given new sources of forest information and has made it possible to increase the cost efficiency of an inventory. This together with new methods have made it possible to change the forest resource inventories from a field measurement-based listing of articles into a multi-source monitoring of the whole forest ecosystem and so provide information about the structure of forests, their health and their biodiversity status for small and large areas. The results will provide the basis for planning a balanced utilisation of wood resources, the conservation of forests and the maintenance of forest ecosystems.

Keywords: Forest resources, Forest inventory, Satellite imagery, Digital map data

1 Definition of forest inventories

The history of forest inventories goes back to the end of the Middle Ages when the heavy use of forest resources created a shortage of wood. This shortage forced people to bring some form of planning to the forests near to towns and mines. The first information collected for the purposes of this early planning was an assessment of the forests area.

The term 'inventory' means the preparation of a detailed list of articles according to their properties. Similarly, forest inventory means tabulated, reliable and satisfactory tree information of forest and tree properties, used on a basis of an areal unit.

For foresters in the Nordic countries, the term inventory rings a special bell. It brings into our minds pictures of endless forests and of men roaming through them loaded with heavy equipment, persistently walking the line - from one side of the country to the other.

2 Development of forest inventories

Assessing the properties of an area of forest is an enormous task, given, for instance, that the total number of trees, with a height of at least 1.3 m, is,, e.g., in Finland 65 billion. It is simply not possible to measure each tree, nor is it necessary. Measuring a part of tree population and deriving properties of tree populations from the subpopulation, i.e. sampling, is more rational.

Sampling, though, immediately raises a number of questions. For example:

1) What is the smallest part of the population that can be measured and still provide reliable information ?
2) How can the mean properties of the population in the sample be assessed ?
3) How can it be guaranteed that, on the average, the right parameter value is obtained and that no bias exists ?
4) How can the reliability of the parameters be assessed, i.e. what can be said of the real parameter value if the estimate is derived from a sample ?

Inventory methods have been developed in order to be able to answer these and similar questions and to present a clear picture of the state of forests and the amount of forest resources.

Statistically designed forest inventories were introduced simultaneously in the three Nordic countries, Norway, Sweden and Finland at the beginning of the 1920's. In these countries, and especially in Sweden and Finland, the utilisation of forests has been of vital importance to the national economy while for Finland forests and their use form the very hearth of its national identity.

3 Recent information needs for forest inventory

The principal purpose of forest inventories has been to provide accurate information for forest management planning and the planning of forest industry investments. Accordingly, optional cutting possibilities with future forest development scenarios have been computed on the basis of inventory results. These scenarios have formed the basis for forest policy and forest utilisation. This is especially true in industrialised countries.

Timber processing and marketing practices have changed dramatically in these countries during the last decade. Earlier, there was a long time interval between harvesting and the delivery of the timber, panel or paper products to the customer. Harvesting decisions were mainly forest production driven, derived from long-term yield regulations and management plans, modified by operational logging schedules. Large timber and end product stocks had to be maintained and prices fluctuated rapidly as the market changed.

Today, mechanised mobile harvesting machinery, high speed processing facilities, and short timber drying or pulping schedules have reduced to less than one week the time between the decision to harvest and delivery of a specific timber end-product. Harvest planning has now the potential to become "market driven". On the other hand, forestry has increasingly to meet strict environmental demands and to achieve "sustainability" in its widest sense. Forest certification systems are today often seen as a solution to achieve and to show improved practices in forestry and forest industry. To achieve all these requirements, it is necessary to have up-to-dated georeferenced forestry data systems with precise knowledge about log specifications and the forest ecosystem. If inventories based on field measurement techniques alone are employed, they will require a very high proportion of the trees to be measured, and this is simply too expensive to be a realistic option.

An increasing concern about the loss of biological diversity, caused, for example, by deforestation in some parts of the world, human induced environmental and climate changes as well as the extinction of species, has increased interest in the whole forest ecosystem. There is wide agreement that some components and indicators of forest biodiversity can only be measured efficiently in the context of large area inventories. Examples of such components or indicators are the composition and structure of landscape, the existence of 'ecological corridors' between different habitat types, fragmentation of forests or land types, the areas and spatial distributions of important habitat types which support rich flora and fauna as well as the amount of rottening wood, in addition to the parameters already measured in forest inventories.

Forests have also been seen as having a role in reducing the effects of global warming by binding the increasing amount of carbon dioxide in the atmosphere. It has been estimated that the current forest area is only one half of the area that was forested 8000 years ago (under hypothetical similar climate conditions). With a proper use of wood resources and an increase of forests area have good a potential to decrease the amount of atmosphere CO_2.

In order to be able to satisfy the increasing and diverse demands for scientifically substantiated information, efficient methods are needed to measure forest resources, their status and the components of the whole forest ecosystem. The areal extent of forests is immense and the natural question is how to measure forests in a cost-effective way and how do that with sufficient frequency.

4 The role of Space Technology for Forest Inventory

The answer of the method I have developed is remote sensing and satellite images, combined with other information sources and applied in a new way. Remote sensing is the science of deriving information about the earth's land and water areas from images acquired from a distance, for example from space. Space technology originated after the Second World War and military applications accelerated its progress.

Remote sensing utilises photosynthesis, the process which maintains life on the earth. The chlorophyll in vegetation absorbs some components of light, mainly blue and red light, but also some green and infra-red, and reflects and emits some other components in a way which is specific to each plant species. Plant species and vegetation composition can in principle be separated by means of this information.

The first commercial satellite, suitable for forestry application, American Landsat 1 was launched in 1972. Landsat 5 with an improved imaging instrument followed in 1984 and the French-Swedish-Belgian Spot in 1986. These satellites are able to recognise objects on the ground with a diameter of 20 - 30 metres. The spatial resolution was high enough for the first Nordic forestry applications. New satellite sensors with a spatial resolution of 5 - 10 metres will be launched within few years.

In addition to remote sensing, the progresses which had earlier happened in mathematical-statistical methods as well as later in image processing and pattern recognition are necessary for my multi-source inventory technique.

5 Identifying the objectives of the method

Remote sensing research in forestry began in the 1970's and was accelerated after the mid of the 1980's. A real need to make inventories more cost-efficient existed. A common approach to utilise satellite images was to identify a few specific classes (for example, by means of dominant tree species or vegetation types) and to classify the forest area into those classes. The demands of forest management and forest industry require much more detailed information.

The number of variables measured in a forest inventory is usually very high, e.g. a few hundred. A classification based on different values of variables leads to an infinite number of classes and to an impossible solution, while the classification of variables separately, e.g. volumes, dominant tree species, site fertility class may lead to unnatural combinations of variables. The classification approach must therefore be rejected and a totally different approach adopted.

The research for introducing satellite images to the Finnish National Forest Inventory started in 1989 at the Finnish Forest Research Institute.

The first goal was to be able to estimate forest inventory information at the municipality level, instead of the earlier 10 to 100 times larger forestry administrative level. A method had to be chosen on the basis that it would be possible to estimate all forest inventory parameters, i.e. the state of forests, for the given units. The existing dependency structure of specific properties should also be preserved for further analysis.

6 Finding the method

The goal was to find a suitable method. It soon became apparent that in addition to satellite image information other digital information could noticeably improve the reliability of estimates. For example, the reflectance of grasses growing on regeneration areas is similar to that of arable land. A classification based solely on digital image analysis may therefore cause some errors in land use classification. The developed multi-source method permits a flexible use of digital base map data. Nonetheless, the method can be applied without the ancillary data, and the lack of such data can be to some extent compensated by using multitemporal data. The Finnish multisource system employs digital masks of arable land, built-up land, roads, single houses and swamps.

Land morphology also causes variation in the spectral values of satellite images which is not caused by variations in the structure of growing stock. Northern hill slopes often receive less light than southern aspects and therefore reflect less light. This means that, with the same growing stock, northern slopes look darker causing errors in digital image analysis if this has not been taken into account. The multi-source inventory method enables the use of digital elevation models to correct for the degrading effect of land morphology in image analyses.

7 Solution: mimic the human eye and brain

The method therefore employs three different main data sources, field data, satellite images and digital map data. How can all this data be put together in such a way that all demands are fulfilled? The method is in principle not complicated. The key is to transfer the entire field data set from some field sample plots, that is to say known picture elements of a satellite image, to unknown picture elements. No classification of the data is required, as was the case in older approaches. The basis for the data transfer is the similarity between picture elements, the similarity measures being based on satellite image properties. The method therefore mimics the process of the human eye and brain when comparing objects.

It was also noticed that if several 'almost similar' picture elements were used instead of only the most similar one, the accuracy of small scale estimates could be improved. The effect of errors caused, for instance, by the light scattering in the atmosphere and the small size of the field sample plots is reduced in this way. The method is therefore called the k -nearest neighbour (k -nn) method. I developed a computer algorithm which realised this idea and could take into account all data sets. The method also makes it possible to write an estimate of an arbitrary forest parameter in the form of a digital map.

The number of field sample plots in a forest area is usually high, and the consequent demand on computer time when analysing the forest area is huge. Initially, a CPU -time of one week was usual when analysing an area of about one million hectares. Today's computers are more powerful and the same work can be carried out within 24 hours.

The main advantages of the method are:

- compared to the inventory methods employing sampling and field measurements only, much more detailed information about forests can be obtained with very low additional costs
- the method is more statistically oriented than the earlier classification-based approach to use of satellite images
- in principle, all variables can be estimated for each computation unit, which is not possible with ordinary classification methods
- the method preserves the natural dependency structure between forest parameters
- the method can be applied with minor modifications to very different types of forests
- the method can directly be applied using different remote sensing material.

8 How the method can be improved

The prototype of the method was developed rather quickly. The method has been enhanced continuously and new features have been added when applied to foreign circumstances. I can still see some possibilities to further develop the system. Both technical and methodological improvements are possible.

Technical progress in satellite imaging will bring radiometrically and spatially improved sensors and imaging systems which are not sensitive to imaging conditions, such as the amount of light, atmosphere humidity or clouds. Active remote sensing is based on the idea of sending a signal and receiving its scattered reflection. Microwaves penetrate through clouds without changing and imaging is, in principle, possible under any condition. Research has shown, however, that the backscattering depends very much on the canopy and soil moisture conditions. Interferometry may provide a solution for applying the microwave technique.

Air-borne imaging spectrometers are at the moment under active research and have also been tested by my group. The smallest ground element is typically 1 m x 1 m and the number of spectral bands can be almost 300. This makes it possible to detect individual trees and small changes in the reflected light of vegetation and, for example, recognise early signs of stress in trees or ground vegetation. One advantage of the k-nn method is that it can directly be applied to these data as well.

The methodological development is related to improving the reliability of small area estimates. In developing the method, the first goal was to obtain results for the municipality level, i.e. for areas of approximately 10 000 hectares, but we noticed that the results were also applicable at forest holding level, i.e. at the level of 100 ha. Operative forest management planning needs information at the forest stand level, i.e. for areas of about one hectares. To achieve this goal, objects on images should be analysed instead of single picture elements. Methods from pattern recognition and stochastic processes can be applied. The computer must be taught to infer just like a human being does, to utilise the spectral, spatial and contextual information present in digital images.

The increasing demand for new and diverse information necessitates the further development of the method. The monitoring of ground vegetation and its changes may be possible only by means of remote sensing with indirect methods. The analysis of the landscape diversity of forests is a good solution for remote sensing data but presumes methodological development as well.

9 How the world's forests will be monitored in the future

Finally, I would like to leave you with a scenario as to how the world's forest resources will be monitored in the beginning of the coming millennium. In addition to traditional information concerning timber supply, wood resources and cutting possibilities, information about the forest biomass including both trees and soil, carbon balance, deforestation and afforestation rates, the status of biological diversity, the naturalness of forests, nature conservation and the socio-economic functions of forests will be needed. A relevant time interval for global inventories might be 5 years. Annual information will be required for operative inventories.

Data acquisition for such a task is possible at reasonable cost only if the whole measurement process links digital measurement in the field to remote sensing from air and space. Sampling at different resolutions will be applied. The sampling intensity will vary depending on the the area in question. Large scale inventories will form the basis for small-scale inventories. The sampling designs and ancillary data sources can be decided on the basis of these data. Old inventory data together with mathematical forest development models and new field measurements, as well as air- and space-borne remote sensing data will be applied in computing the results. Results will consist of statistics with reliability assessments and digital maps describing forest resources and the forest ecosystem. Data will be delivered through computer networks to all interested persons, especially to decision makers and researchers, while additional data will be easy to append. The multi-source k-nn method can be seen as a kind of prototype of this type of method.

References

Tomppo, E. 1997. Application of remote sensing in Finnish National Forest Inventory. In: Kennedy, P.J. Application of Remote Sensing in European Forest Monitoring. International Workshop, Vienna, Austria, 14th - 16th October 1996. Proceedings. European Commission, p. 375-388.

Tomppo, E. 1998. Recent status and further development of the Finnish multi-source forest inventory. In: Managing the Resources of the World's Forests. Lectures given at the 1997 Marcus Wallenberg Prize Symposium in Stockholm, Sweden, on October 14, 1997. The Marcus Wallenberg Foundation Symposia Proceedings 11: 53-70.