Forest inventories and biodiversity

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The prospect of modifying forest inventory processes to provide more information on biodiversity.

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Since 1992 – the year in which a large number of countries signed the Convention on Biological Diversity environmental programme in Rio de Janeiro – national and international nature conservation policies have been trying to promote biodiversity, especially with regard to forests.

Biodiversity can be defined as the diversity of the living world, and is seen on several levels: intraspecific genes (genetic diversity), species (interspecific diversity) and ecosystems (ecological diversity) (Leveque, 1994).

In broad terms, biodiversity covers a whole range of concepts – specific diversity, rarity, natural characteristics, vulnerability, etc. – which together suggest protective measures to be incorporated into forest management. Species diversity, which is the most usual indicator of biodiversity today, cannot alone justify protective measures, since it clearly varies widely depending on forest geography (boreal forest, temperate forest, humid tropical forest, etc.).

Inasmuch as the concept of biodiversity and its field of application are still unclear and are interpreted in many different ways, there is as yet no universally accepted way of measuring biodiversity. Representative and reliable information on the state and evolution or dynamics of forest biodiversity is, however, vital for sustainable management, which means that new perspectives have to be taken into account in forest inventories and in the methodologies used in drawing them up, depending on the given context. However, given the lack of knowledge on variables and information to be collected, apart from the general fact that they concern spaces and environments, is it really the moment to consider the actual relevance of forest inventories in the management of biodiversity? This article attempts to answer that question.

The following sections consider, in a general way, the definition of biodiversity proposed by the Helsinki (1993) and Montreal (1993) processes, recalling in this connection the importance of frames of reference of time and space to the major types of forest inventory, and the types of variable to be included in them when attempting to reflect the essence of biodiversity. The main influences on the methodological aspects of inventories are considered as well as the prospects of carrying out appropriate inventories. Finally, some recommendations and conclusions are proposed.

CHARACTERIZATION OF FOREST BIODIVERSITY

In the framework of the Helsinki Process, which is concerned with sustainable development, one criterion (No. 4) is specifically concerned with the maintenance, preservation and appropriate improvement of biodiversity. It involves a range of different concepts – representative rare and vulnerable forest ecosystems, endangered species and biodiversity in forests engaged in production – and the results of changes in area, type of forest and population and in the numbers and proportions of forest species.

In the framework of the Montreal Process, which is concerned with non-European temperate and northern forests, biodiversity includes elements of diversity in ecosystems – between species and genetic types – expressed in terms of area occupied, the number and status of forest species and their evolution over time.

The importance of the concept of time and space

Consideration of the question of analysis and monitoring of forest biodiversity entails not only establishing the limits of investigation but also defining the depth of analysis and the frequency of observation. Biodiversity is set within a dynamic and evolving context, and its process and composition are in constant flux as a result of natural and human-induced factors. Biotic sequences and soil development – and soils support plant life – are a result of complex ecological phenomena combining a number of biological, chemical and physical processes requiring years, and sometimes even centuries, to be seen (Jeffers, 1996).

The nature of the indicators can also vary depending on the specific dimension of time and space taken into account. Depending on the individual case, analysts look for general information in regional, national or continental terms, or confine themselves to target zones (for example, those designated as reserves). It is therefore important to have standardized biodiversity indicators if comparisons in space and over time are to be drawn.

TYPES OF INVENTORY

By their very nature, management inventories (full or by sampling) cover specific areas corresponding to management units (populations, plots, stands), while national and regional inventories cover wide areas, analysed on the basis of location-specific information (Rondeux, 1993; Rondeux *et al.*, 1996).

It is worth considering whether existing forest inventories can be used to assess forest biodiversity, since most of them already include elements directly pertaining to it – although supplementary measurements and observations (new variables) would be needed while, with adequate treatment of the variables already collected, existing inventories could also provide direct or indirect indications on biodiversity (derived variables). If existing inventories are to serve a useful purpose, it is vital to make them permanent, given the concern to monitor changes in biodiversity over the course of time.

Management inventories

If biodiversity and its monitoring are to be considered in relation to sustainable forest management in terms of the populations making up forests, landscape units (Oliver, 1992) or management units (plots ranging from several hectares to several tens of hectares), the following could be the essential features and key elements to be observed at regular intervals, especially in terms of forest populations:

- the diameter, height and features of the cover of all trees above a specified diameter, so as to obtain a precise picture of the structure of the population;
- the fertility index of populations in relation to location and conditions;
- topographical elements;
- the soils and geological substratum of the population, including the nature and depth of moisture horizons;
- ground vegetation, with special reference to all rare or remarkable species (the presence of fungi, bryophytes, lichens, etc., should also be recorded);
- the occurrence and extent of regeneration (seedlings or trees that have not yet reached a specified diameter);
- the nature and quantity of all fallen or standing dead wood and/or decomposing wood within the population;
- human influence and the history of the population (cultivation, rights of use, clearing, felling, hunting, etc.);
- unusual ecotones and species, particularly those associated with contact ecosystems (in forest-farming or forest-open land interfaces, for example).

So far as the inventory itself and its approach are concerned, the wide variety of observable elements means that a proposed methodology for assessing and monitoring biodiversity would, ideally, depend on sampling, inasmuch as it is important to provide information on spatial variability and the internal heterogeneity of the population. It would be helpful to stratify the sample units in order to ensure that areas with high biodiversity are correctly represented in the sample.

In more practical terms, observation should concentrate primarily on the following points, if necessary adapted to the particular conditions of the population in question:

- the main function of the population (production, protected area or biological, forestry and genetic conservation area);
- the past history of the population (silvicultural systems or previous situation, human impact);
- exceptional habitats (old wild forest, natural forest, special geomorphology, rare plant forms, etc.);
- landscape (open, closed, distant);
- health conditions (atmospheric pollution, damage from various sources, etc.);
- grasses, leafy plants, fruit and fungi;
- forest margins (structure, composition, length and breadth);
- other special features (special woods, unusual trees).

In a traditional forest inventory, variables relating to the environment tend to be assembled in terms of their influence on forest productivity (Pelz, 1995), but this does not, a priori, preclude their being put to other uses. Indicators of the structural diversity of forests can often be derived from information already easily available, such as distribution of diameters, distribution of tree species, height of trees, characterization of the levels of the population, social position of trees, numbers of living and dead trees.

It is also helpful to recall that the different variables relating to trees and the structure of populations are also directly connected with other elements in the forest ecosystem – soil, vegetation and animal life, which means that a large number of the variables already assembled in inventories focusing on timber resources can be turned to a wider range of uses.

National and regional forestry inventories

Most, if not all, existing national forest inventories produced on the basis of sampling have the aim of supplying information on forest timber production and the availability of timber, which means that they include very few data concerning forest biodiversity. However, over the past ten years, national inventories, especially if their methodology is being revised, have increasingly tended to include information not exclusively focused on timber production (Lund, 1986). Several variables relating to the environment already feature in this type of inventory, some can be partially or wholly deduced, while others require specific collection, and possibly the use of adapted methodologies (Lund, 1993).

Existing and derived variables

When dealing with sampling units (or sample plots of reduced area), inventories already gather variables – or can do so easily – that are an integral part of biodiversity and linked to the soil (depth, texture, amount of gravel, humus, etc.), leafy vegetation (indicative plants), tree composition by storeys, state of health and damage.

In terms of the individual (tree), other variables can also be introduced, apart from species, diameter and social position. These would concern origin, bark thickness, height of the green crown, increases in diameter and height, state of health and age.

New variables

It should, in principle, be fairly easy for a traditional national inventory focusing mainly on timber to incorporate new variables allowing the description of biodiversity in more comprehensive terms (Pelz, 1995). Such variables would include the following:

- characteristics of forest margins in the wider sense (length, form, structure, etc.);
- soil type (a more detailed description), including variables subject to change over time;
- description of vegetation in the grass, bush and tree strata;
- effects of other uses of the land (agriculture);
- history of land use (grazing, agriculture, special practices);
- characterization of small habitats (springs, moist land, land with a high biological value);
- quantities and dimensions of standing and fallen dead trees, and of rotten trees, and the extent of such rot;
- trees remarkable from the viewpoint of their phenotype.

ELEMENTS AFFECTING INVENTORY METHODOLOGY

The overall concept of forest biodiversity and forest inventories must normally entail a multidimensional approach ranging from the perspective of species to that of ecozone. These concepts must, first, be made operational and then it must be decided what can be measured within inventories, and what measurement and data processing techniques can be developed in order to assess biodiversity.

Inventory methods and applications

Observations and measurements in the field are still the best ways of ensuring a good inventory in terms of precision on the variables to be collected. However, the use of remote sensing from space (Poso, Waite and Koivuniemi, 1995) will be an increasingly useful tool and, in the near future, airborne captors will radically improve the quality of remote sensing and provide completely new sources of information. Such a technique should find a very wide field of application in the precise delineation of habitats and forest populations. For example, it could be used as a basis for a stratification, which would make the organization of field samplings much more efficient and precise, ensuring a better view of the levels involved in biodiversity.

An obvious question is whether forest biodiversity can be measured simply through forest inventories based on sampling. The comparative rigidity of such an approach is not always compatible with a more "naturalist" observation of the environments under analysis – a view that is also corroborated by the growing concern to assess biodiversity in terms of habitat. These two approaches can, in fact, be combined; while an inventory will uniformly cover the whole of an area and allow the variables collected to be mapped, the "target" approach will provide a more detailed and richer analysis of the diversity in a specific environment or habitat.

In current inventories based on sampling, fixed- or variable-range sample plots act as sampling units, thus implicitly accepting that the data collected do not necessarily reflect the characteristics of the population. The collection of data relating to biodiversity should not be restricted to the sample plots, but extended to adjacent areas (as is already done in order to typify the structure of a population correctly, for example).

Inventory methods will certainly be obliged to take account of the habitats and characteristics of the landscape as potential bases for stratification. Traditional-type forest inventories will also have to incorporate other sources of information, such as the mapping of ecosystems and habitats, and evaluation methods compatible with these variables will need to be developed.

Since the whole breadth of biodiversity can never be recorded in programmes of a realistic size, it is important to develop indirect approaches. These focus on key variables and habitats in order to quantify and qualify biodiversity (for example, study of the relations between the structure of standing material and other species such as ground vegetation, insects, fungi and mosses).

The role of geographic information systems

Studies of specific sites are the source of a great deal of data relating to biodiversity. However, such data are insufficient because there is a need for a set of spatially referenced data constituting an unweighted sample from a specific region or country. It is therefore important to gather data from objectively chosen sample zones in order to determine the spatial organization and dynamics of the various components of the ecosystem.

Whether quantitative indicators (areas occupied, their evolution, etc.), qualitative indicators (state of health, etc.) or even socio-economic indicators (exploited resources, infrastructure, type of land use, etc.) are concerned, information must be related to space in such a way that it is possible to specify the precise location and distribution of species, fragmentation of environments, type of forest, etc., resituating them within the context of their physical and biological environment (Poso, Waite and Koivuniemi, 1995).

It is also vital that the available information on biodiversity be stored within geographically referenced databases if it is to be made quickly accessible for mapping, analysis or modelling purposes. For this information

Case study: Monitoring of timber resources in the Walloon region of Belgium

In order to ensure the monitoring of timber resources in the southern part of Belgium (the Walloon region), a permanent inventory was produced in 1994 (Rondeux and Lecomte, 1996). This inventory was based on systematic, non-stratified sampling using four concentric circular units (with radii of 18, 9, 4.5 and 2.5 m) inscribed over rectangular networks of 1 000 by 500 m and covering the whole of the forested area (530 000 ha). Its ongoing validity is maintained by taking fresh measurements every ten years, with one-tenth of the area being covered each year.

As with other national inventories, this one was initially designed from an economic perspective in order to monitor changes in timber resources and to help establish guidelines for a new regional forestry policy. The data thus reflected these concerns and covered, in a non-exhaustive manner, the following elements:

- general and administrative information: identification and position of the sample point, ownership status, etc.;
- growth environments: topography, geology, pedology and phytosociology;
- populations: type, structure, quality, forestry interventions, age, etc.;
- main features of tree measurements: circumference at human height and various other levels, total height, etc.

Since 1997, various methodological adjustments have been made in order to incorporate, as fully as possible, the collection and processing of parameters connected with sustainable development and, especially, with plant biodiversity in the sense used by the Helsinki Conference (Anon., 1996). Several kinds of variable were therefore identified and then tested for feasibility of collection.

Within the inventory itself, significant indicators derived from direct *observations, estimates, deductions* and *measurements* were identified.

With regard to parameters derived from direct *observation* of the general conditions of environments, the following are considered in greater detail than in the first version of the inventory:

- status of the sampling point (forest, heath, abandoned, protected area, etc.);
- previous situation (forest, agriculture, other);
- type of forest or use (production,

to be really usable, it must also be integrated with a great deal of other information on environments, socio-economic conditions, types of natural resource, potential risks of degradation, etc. Geographic information systems (GIS) can be keys to integrating information with the desired degree of detail (Jeffers, 1996).

PROSPECTS FOR THE FUTURE AND CONCLUSIONS

Forest researchers are at a crossroads between what a forest inventory has traditionally collected and what it could collect to the benefit of the broader objectives of integrated forest management, including biodiversity. Although much forestry research rests on biological foundations, such information has not always been associated with silviculture and forest inventories. A compromise must be sought between what it would be desirable to measure and what is possible with the available human and material resources.

If a forest inventory is required to fulfil other functions than those of evaluating the quantitative and qualitative aspects of the timber resource over time, and especially if it is to contribute to a better knowledge and monitoring of plant biodiversity, specific variables must clearly be gathered, bearing in mind the constraints of both time and space.

Given the objectives and methods of most forest inventories and the present imprecision about the concept of biodiversity, and in view of the need to take the latter into greater account in all forest management, the following points are worth further reflection:

- much information is already available or can be derived from existing data;
- few new data need be collected on, for example, the forest ecosystem, particularly the distribution and prevalence of plant species or the structural characteristics of the population;
- traditional forest inventories should be expanded by adjusting their design to incorporate an appropriate

protection, conservation);
- **description of the physical properties of the soil and humus;**
- **natural region and ecological areas (geology, climate);**
- **topography (relief, exposure, slope, altitude);**

With regard to populations special attention was given to the following:

- **structure (storeys, distribution of breadths, etc.);**
- **type of population (based on the proportion of varieties encountered);**
- **age;**
- **phenotypology of trees;**
- **forestry management and visible evidence of intervention (spacing of trees, type and extent of clearings, drainage, ditches, etc.);**
- **tree health (defoliation, attacks by parasites, etc.);**
- **presence and size of trees with cavities;**
- **type and extent of regeneration;**
- **presence of stripped or empty spaces and margins (the latter being potentially very rich and diverse in plant life and, thus, requiring some changes in inventory methodology).**

Depending on its nature, this information is drawn from various types of map or gathered from sampling units and their immediate surroundings with a radius of up to 30 m from the sampling point.

Parameters derived from *estimates* based on a circular sample plot of roughly 1 000 m² (an 18 m radius) are essentially concerned with the following:

- **qualitative variables relating to botanical data, which should allow the determination of ecological or plant groupings reflecting both specific wealth and diversity;**
- **data on wood species divided into three height groups.**

Parameters derived from *measurements* are essentially quantitative, depend on sampling units and concern the following:

- **breadth (circumference at 1.5 m);**
- **height of standing live and dead trees;**
- **breadth and length of fallen dead wood.**

***Deduced* parameters are drawn mainly from the processing of gathered variables and are expressed as averages or values per hectare. They can be related to the wealth of habitats and, for certain variables, can concern both live and dead trees. The following can thus be calculated and interpreted for the potential wealth and diversity of the environments covered:**

- **population density expressed in numbers of trunks and basal area per hectare (extent of cover);**
- **wood volumes and biomasses per hectare (amount of standing material);**
- **total, average and dominant heights (vertical structure);**
- **average and dominant circumferences (stage of development);**
- **productivity index (class of site);**
- **number of dead trees per hectare;**
- **volume or quantity of dead wood per hectare and the period of death.**

On the basis of the variables considered, it becomes possible to provide tables or even maps summarizing the diversity of species and ecosystems, including plant composition and geographical distribution. When expanded in this way, the regional forest inventory becomes the foundation of a major database which can be used most profitably with careful processing.

methodology for collecting data on non-timber resources;
- it would be helpful to study the characteristics of the area to be sampled (using GIS, for example), before embarking on specific inventories or new inventory procedures;
- inventories based on multiphase sampling, combining analysis of elements from remote sensing and field activities should be promoted;
- the methods proposed must encompass the concept of monitoring over time and, thus, that of permanence.

Inventories based on systematic sampling in adequate detail still constitute a solid basis for analysis if it is recognized that the measurement of biodiversity is to a large extent already carried out in the areas covered by national or regional inventories.

It must be borne in mind that it is practically impossible to design a collecting method suited to all the elements present in biodiversity. It would be best to confine inventories to a well-defined body of variables and features, for example targeting the tree or shrub level rather than trying to observe the whole range of plant biodiversity.

If, for the sake of detailed and fuller estimates, specific inventories have to be drawn up for a number of variables that can reflect the quantitative and qualitative range of plant biodiversity, more traditional inventories focused on estimating timber generally also include many data allowing the extraction of information that is not confined to wood products (Pelz, 1995). For example, functions relating to the diversity of species and its evolution over time could also be calculated.

Aerial photography, field observations on sample plots and the analysis of forest/non-forest interfaces are three essential sources of data for assessing the main characteristics of diversity. The use of photo-interpretation combined with field sampling will allow characterization of wooded areas (species, structures, stages of development, special environments), insofar as a relevant and adequate typology has been developed, and will also provide valuable information on the fragmentation and structure of the forest cover. Apart from these more general observations, the height of cover, its thickness, the stage of development and the proportion of species can also be estimated – and these variables, in fact, allow the "structural" diversity of forests to be characterized.

Apart from the standard information that can be collected from sampling units, observations on measurements that are easily carried out within them, or in their immediate vicinity, could be used as indicators of habitats. Such indicators include: leafy vegetation, stumps, dead or rotten trees, heaps of stones, empty spaces, ditches, piles of branches.

An analysis or inventory of areas on the edge of forests or in contact with other kinds of space (pasture, empty spaces, aquatic environments) can reveal conditions especially favourable to plants, birds and insects. Unusual information may be collected within these transition zones between different elements of the landscape and habitats (Brändli, Kaufmann and Stierlin, 1995), for example the exposure or aspect, alignment, structure and density of the forest margin, the presence or absence of a belt of bushes and its width, and of a forest mantle (border trees above a specified diameter) and its width, and the type of environment in the marginal area.

The best compromise would certainly be to combine the principles for drawing up national or regional inventories, using grids of points, with those for management inventories, which are more concerned with analysis of areas.

In other words, it is quite possible to establish a biodiversity inventory covering the whole country by means of a detailed analysis of portions of the territory (for example, squares of 1 km x 1 km) centred on sampling points that are part of a regular network of points defined on maps (aerial photographs and/or satellite images). On the basis of such an analysis, a stratification according to actual use of the forest area, for example, can be established (Max *et al.*, 1996; Rondeux, 1994).

Care should be taken to establish a database that can be expanded and updated periodically. At regional or national levels, the use of conventional forest inventories supplemented with suitable ecological information would be the preferred solution to avoid wasting energy. In this way, comprehensive inventories will gradually be organized and these will be capable of answering a broad range of questions requiring the consultation and correlation of very diverse data (Max *et al.*, 1996; Rondeux, 1994). ◆

Bibliography

Anon. 1996. *Conférence ministérielle sur la protection des forêts en Europe. Compte-rendu de l'évolution des travaux.* Lisbon, Ministry of Agriculture, Rural Development and Fisheries, Portugal. 62 pp.

Barr, C.J., Bunce, R.G.H., Clarke, R.T., Fuller, R.M., Furse, M.T., Gillespie, M.K., Groom, G.B., Hallam, C.J., Hornung, M., Howard, D.C. & Ness, M.J. 1993. *Countryside survey 1990.* Main report. Countryside 1990 Series, Vol. 2. Department of the Environment, UK. 174 pp.

Brändli, U.B., Kaufmann, E. & Stierlin, H.R. 1995. Survey of biodiversity at the forest margin in the second Swiss NFI. *The Monte Verità Conference on Forest Survey designs. "Simplicity versus efficiency" and assessment of non-timber resources*, p. 141-150. Birmensdorf, Switzerland, Swiss Federal Institute for Forest, Snow and Landscape Research.

Brassel, P. 1995. Assessment of non-productive forest functions in the Swiss National Forest Inventory (NFI). *The Monte Verità Conference on Forest Survey designs. "Simplicity versus efficiency" and assessment of non-timber resources*, p. 78-96. Birmensdorf, Switzerland, Swiss Federal Institute for Forest, Snow and Landscape Research.

Brooks, D.J. & Grant, G.E. 1992. New approach to forest management. *J. Forest.*, 90: 21-24.

FAO/CEE. 1993. *Meeting of Experts on Global Forest Resources Assessment (Kotka II).* Research Paper No. 469. The Finnish Forest Research Institute. 214 pp.

Jeffers, J.N.R. 1996. Measurement and characterisation of biodiversity in forest ecosystems. New methods and models. *European Forest Institute, EFI Proceedings*, 6: 59-67.

Leveque, C. 1994. *Environnement et diversité du vivant*. Pocket Sciences, Collection Explora. 127 pp.

Lund, H.G. 1986. *A primer on integrating resource inventories*. Gen. Tech. Rep. WO-49. United States Department of Agriculture, Forest Service. 64 pp.

Lund, H.G., ed. 1993. *Integrated ecological and resource inventories*. Proceedings of a National Workshop, 12-16 April, Phoenix, Arizona, USA.

Max, T.A., Schreuder, H.T., Hazard, J.W., Oswald, D.D., Teply, J. & Alegria, J. 1996. *The Pacific Northwest region vegetation and inventory monitoring system*. Forestry Service Research Paper PNW-RP-493. United States Department of Agriculture. 22 pp.

Oliver, C.D. 1992. A landscape approach: achieving and maintaining biodiversity and economic productivity. *J. Forest.*, 90: 20-25.

Pelz, D.R. 1995. Non-timber variables in forest inventories. *The Monte Verità Conference on Forest Survey designs. "Simplicity versus efficiency" and assessment of non-timber resources*, p. 103-109. Birmensdorf, Switzerland, Swiss Federal Institute for Forest, Snow and Landscape Research.

Poso, S., Waite, M.L. & Koivuniemi, J. 1995. Assessment of non-timber functions: remote sensing technologies. *The Monte Verità Conference on Forest Survey designs. "Simplicity versus efficiency" and assessment of non-timber resources*, p. 239-245. Birmensdorf, Switzerland, Swiss Federal Institute for Forest, Snow and Landscape Research.

Rondeux, J. 1993. *La mesure des arbres et des peuplements forestiers*. Gembloux, Belgium, Presses agronomiques. 521 pp.

Rondeux, J. 1994. *Ressources naturelles et inventaires intégrés: la logique du possible*. Cah. For. Gembloux No. 12. Gembloux, Belgium. 18 pp.

Rondeux, J. & Lecomte, H. 1996. *Inventaire des ressources ligneuses de Wallonie. Guide méthodologique*. Gembloux, Belgium, Faculté universitaire des Sciences agronomiques, Unité de Gestion et Economie forestières. 208 pp.

Rondeux, J., Lecomte, H., Florkin, P. & Thirion, M. 1996. *L'inventaire permanent des ressources ligneuses de la Région wallonne: principaux aspects méthodologiques*. Cah. For. Gembloux No. 19. Gembloux, Belgium. 25 pp. ◆