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The European Forest Ecosystem Research Network (FERN). This ESF additional activity begun in 1986 and now in full operation, addresses basic scientific problems associated with the forest ecosystems, with special emphasis on Europe. Besides the general topics devoted to the historical outlook on man-induced changes in European forests, and to specific problems of Mediterranean forest ecosystems, the FERN project focuses on the aspects of nitrogen dynamics, and on patterns. In the initial phase of the project it is aimed at inducing more coherence in the European research in forest ecology by arranging discussion meetings and workshops and by other means of information exchange. To this end the Directory of European Research Groups Active in FERN was published in June 1987 and distributed all over Europe. The first issue of the annual Fern Letter appeared also in November 1987. For more information about FERN, or related activities, contact Anne Teller, Scientific Secretary, CEC – DG XII, SDM 3/50, 200 Rue de la Loi, B – 1049 Brussels. Tel. +32 2 2358446.

Unification of European forest pattern research

Proceedings of a workshop organized by the Forest Ecosystem Research Network (FERN) of the European Science Foundation (ESF), held in Strasbourg, France, 24-26 April 1989

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Contents

STATE-OF-THE-ART REVIEWS AND DISCUSSIONS

Session 1 – Patterns in forest research

Session 2 – Pattern analysis for forest ecology

Session 3 – Pattern analysis for silviculture

Session 4 – Patterns as the basis for forest modelling

CONCLUSIONS

ABSTRACTS OF POSTERS

PREFACE

Ph. Bourdeau and A. Teller

This book arises out of a workshop on unification of European forest pattern research which was held in Strasbourg from 24-26th April 1989. It was organised by the European Science Foundation (ESF) in the frame of its Forest Ecosystem Research Network (FERN) activity.

It brought together most of the European experts in forest pattern research, including biologists, botanists, ecologists, soil scientists, foresters, modellers, etc. One of the most positive outcomes of this meeting was the interaction between scientists working in the field and those carrying out theoretical studies.

The structure of this book reflects the organisation of the meeting. There were four seperate sessions under different headings, each consisting of a state-of-the-art review, followed by a discussion. Besides, posters were presented.

The first session consists of a state-of-the-art review given by Professor Oldeman on the concept of patterns, which exemplifies the different approaches used in Europe.

The second session deals with the concept of patterns for forest ecological studies. After a critical review of current knowledge in this field, Dr. Grace gives as a practical example the computer model used in Edinburgh to simulate the present understanding of ecological functioning of forest ecosystems and to stimulate further research.

The third session deals with patterns for silvicultural purposes, i.e. the use of patterns to provide a scientific basis for management decisions. To illustrate this point, Dr. Oliveira describes a case-study frequent in Portugal, the cork oak forest, a complex agroforestry system.

The last session is concerned with the use of patterns for mathematical analysis. In this section, Professor Hari shows how biological parameters can be integrated in a computer model, what the limits are, and what kind of basic knowledge is still missing.

Finally, the conclusions attempt to synthesize the main issues which were raised during the extensive discussion sessions which took place throughout the meeting. Based upon this, some general guidelines for the direction of future research are also suggested.

To illustrate the four themes developed above, abstracts of posters are incorporated at the end of the book with examples all around Europe.

The organisers consider that their original objectives for the meeting have been fully satisfied. The meeting provided a basis for synthesis of current knowledge together with extensive discussions as important guidelines for future research.

The European Science Foundation has been very pleased to support this initiative and would like to thank the members of the Organising Committee, Professor Oldeman, Dr. Walter, Professsor Hari and Dr. Mutch, for the work they have done to prepare this Workshop and the excellent local organisation undertaken by members of the Laboratoire d'Ecologie Végétale at the Université Louis Pasteur of Strasbourg.

State-of-the-art reviews and discussions

Session 1 - Patterns in forest research

FOREST ECOSYSTEMS: PATTERNS, LIMITS, SYSTEMS

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Summary

After an introduction exemplifying some European approaches of the forest ecosystem, the means to distinguish patterns as symptoms of system's architecture are discussed. Grids, pixels and limits serve to compare artificial and natural patterns. The terms pattern and architecture are defined and placed in the context of hierarchical systems analysis. It is suggested to work from very fine-grained images "upwards" and from very coarse-grained images "downwards" until between the two the patterns emerge that are necessary to answer a specific question. The meaning of patterns is discussed. As a contribution to further unification of European forest ecosystem pattern research it is suggested to determine a common way to reach the optimal level for pattern diagnosis and systems description, to agree upon four integration levels as a frame of reference for all others combined with a basic package of data per ecosystem, and finally to carefully conserve the rich ideas of existing schools of research. However, when all is said, information and concepts still have to be verified with the touchstone of the living forest ecosystem itself.

Keywords: forest, ecosystem, patterns, pixels, limits, systems analysis.

Introduction: forest ecosystems

Miraculously, so many European forest researchers agree on the existence of forest ecosystems, that FERN could be founded. The litteral meaning of "ecosystem" is a home or homestead (oikos) that is orderly arranged (systematic). Metaphorically, it is the home range or territory inhabited by many organisms together in an orderly way. Particularly in forest ecosystems, this order is very complex. From these general points onwards, the ideas of researchers start to diverge.

Complexity, like beauty, largely is in the eye of the beholder. It may be said that every researcher looks at the forest ecosystem through a particular window. The field of vision is defined by the questions asked. Fortunately, these fields partially overlap, so that communication among the observers is possible. Let us consider some of the important windows on forest ecosystems research in Europe.

- Ecological order in the system. This classically is considered to be due to the interaction among the **biological species**. They are the carriers of inherited information and properties ensuring orderly interactions. The first requirement in research then is the **identification** of all species present (**taxonomy**). But there are so many, that in terms of interactions the theory, model or calculus becomes unmanageable. The second requirement therefore is the creation of groups of species in a limited number, e.g. **indicator species** of an ecosystem, **guilds** or **synusiae** as functional species groups, or **biological types** as strategic groups (trees, shrubs, herbs, climbers ...).

The grouping of species in such **compartments** allows to weight each of them in terms of its influence on ecosystem behaviour. In forest ecosystems, the woody plants come out as the preponderant compartment, i.e., trees and shrubs, or phanerophytes, or the woody primary producers. Among the indicator species, trees do not have the monopoly in syntaxonomical classifications of forests. But they remain important.

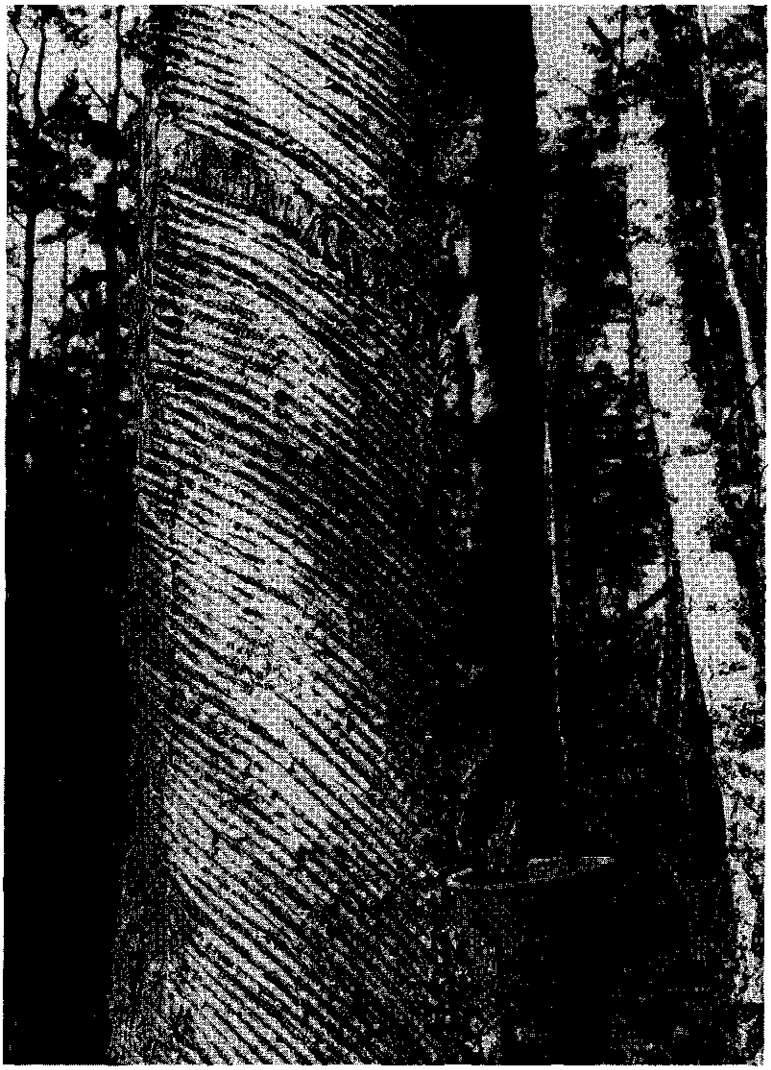
- Ecological processes in the system. These are considered of old to be linked to the **food chain** or **food web.** A functional grouping of species populations in **primary, secondary, tertiary producers**, etc., allows to trace the **flows of energy and nutrients** through the ecosystem. The claim that **production ecology**, resting upon this basis is **the quantitative form** of ecology par excellence is based on the use of counts and measures. Counts are necessary in population biology, in which **population numbers**, linked to birth and death rates and their explanation, are central. Measures are needed to establish the **quantity of solar energy** captured and transmitted by the forest, the **amounts of water and nutrients** flowing through the system and the **amount of biomass** stocked in different organs or organisms.

  All this information on forest ecosystems can be **expressed numerically.** It therefore can be processed by a person who calculates, or faster by a computer. From these calculated results, forest production rules are deduced, explaining the ecosystem in terms of production implemented or influenced by organisms or organs belonging to certain species. Primary producers, in forests mainly the trees, are very important in such calculations. Calculations of ecological production, obeying to the theoretical rules, can then be tested (validated, invalidated) in the forest ecosystem by additional measures.

- Use and management of the forest ecosystem. If forest lands were not cleared in the past for other, mainly agricultural use, the remaining forests yield many products and services. This window upon forest ecosystems gives a view of **timber stands or hedgerows** in **rectangular** shapes like other managed fields. They contain useful **species as the carriers of wanted products**, and other species which are either indifferent, or harmful if they replace useful species or live at their cost. If **medicinal** or minor **food** use is considered, e.g. in animals like rabbits or birds, in mushrooms or in pharmaceutical plants, **species identity** and conservation are very important. For bulk products, like **wood**, production is calculated for the tree trunks mainly. For intermediary products, like resins (fig. 1), calculations seem to be less precise.

  Groups of species, distinguished as "useful", "non-useful" and "harmful" (weeds, pests), or according to the "primary" or "secondary" forest products they provide, fall into categories that are weighted in the analysis of forest ecosystems for economical purposes. The calculated results often are in a form that is optimal for forest ecosystems managed according to a certain system. Yield tables are models serving monospecific wood plantations, normal diameter distribution curves are models developed for selection silviculture. The nature of the ecosystem often, and since a long time, is defined in all these models by lists of indicator species, always plants.

Figure 1. Pinus sylvestris, Stara Brda, Poland, April 1987. Resin tapping. No formal production models of resin in pine forest ecosystems are available, like they are lacking for most non-wood products.



The three windows presented here are not the only ones and they have not been described completely. A more complete image and bibliography can be found in Oldeman (1989, in press). The methodologies sketched here are sufficient, however, to consider the main themes that most European and other methods of forest analysis have in common. They are attributes of the forest ecosystem as most researchers see it.

The nature of such a forest ecosystem would be determined by the co-existing species populations in it, particularly the indicator species or otherwise "weightiest" ones. Please note that this makes the ecosystem **a derived system**, changing with every fluctuation or other ecological whim of an influential species (from pest to primary producer). For well-known reasons, pollination, seed dispersal and the success of seedling establishment are very much dependent upon abiotic events originating in climate or soil, reinforced by later biotic feedbacks. Such events start independently of the biocenosis, and therefore represent hazards. The predominant way of analysing a forest ecosystem composed from species populations hence is probabilistic.

The **system´s limits** as determined by this method are linked to the territory upon which the **indicator species** occur. If their distribution were totally **stochastic**, forest limits might change from year to year in a barely predictable way. But **species** are **linked to a substrate and a climate**, which are combined in an abiotic site pattern, displaying physical and chemical properties changing so slowly that they may be considered as constant.

Soils and climates can be mapped. **Forest ecosystem limits** then can be considered to **coincide** with **soil and climate limits**, circumscribing zones of high probability of the occurrence of indicator species. This way of describing forest types has been in use at least since Von Humboldt pioneered it in the Andes around the year 1800. It yields **accurate descriptions**, but after two centuries explanations sometimes still escape us, e.g., for the correspondence between the altitudinal and latitudinal sequences of vegetation types.

But such **explanations** have come closer with the development of **production models**. Soil and climate provide the inputs being processed in the forest ecosystem, e.g. energy, water and nutrients. In other words, they **determine** the **potential production pattern** of the species populations present, and the margins for the presence of secondary and higher-order producers without these being lethal for the primary ones. The **origin of species** populations is linked to selection of the fittest, in which the fittest are generally defined by "fitness traits". Mutual selection of species by profitable interactions is mentioned in such studies, but is imperfectly linked to the more often and more easily studied adaptations to abiotic conditions.

Maps and other models of forest ecosystems generally are expressed as if there were a **grid in some metric unit** superimposed upon the system. Hectares, ares and centiares (= m^2) are habitually used to express the scale of events, dynamics or species populations. This has also been done vertically (e.g. Godron, 1971) sometimes, in order to indicate strata or layers which, in other studies, are characterised by life forms (tree layer, shrub layer ... etc.).

Grids, pixels, limits

In summary, the forest ecosystem is often visualised as a superposition of grids, showing climate, soil, geomorphology, biological species composition (per hectare) and in modern cases, "disturbances", as patterns of different squares. The species composition currently is indicated as some colour corresponding to some species composition thought to be representative for the vegetation over larger regions, and another colour for squares representing another vegetation type. This kind of vegetation mapping is done in a very systematic way, for instance by the Institut de la Carte du Tapis Végétal in Toulouse.

Remote sensing images are built in this way. They are composed by picture elements, or **pixels**, each being a rectangular surface with a hue or tint, these reflected optical properties indicating some characteristics of the surface pictured (cf. Schmidt & Oldeman, this workshop). The composite images are read back and so can be interpreted, both as to their pattern and their optics. Satellite pixels once concerned surfaces of 80 x 80 m (LANDSAT, 1970´s) but now cover 10 x 10 m areas (SPOT, 1980´s). Interpretation requires ground truth. This was easy to harmonize with the essentially agricultural way of processing data, e.g., per square in a grid.

In contrast, the human eye produces images with huge amounts of pixels, corresponding to nerve ends in the retina. The image is integrated in the brain. This happens so thoroughly that pixels are smoothed out. What we "see" are images showing "natural limits", e.g., patterns of lines and surfaces which most often do not have anything in common with squares and grids. Natural limits from the outset were the ones determining morphological and anatomical analysis of organisms.

Pattern and architecture of forest ecosystems are **directly linked to** such perceived **limits**. They show the researcher where the inside of an ecosystem borders on the system´s environment. But the limits cannot be perceived unless an optimal spatial and temporal resolution prevails so that, according to precise criteria, researchers are not tricked in using clear but otherwise meaningless visual signals that suggest limits.

The terms pattern and architecture need to be defined in this context. The following circumscriptions are not final and absolute definitions, but tentative references.

- **Pattern** is considered as the visible set of lines, planes and other geometrical features which are the symptoms of architecture of a living system, and which can be mapped to scale to define the functional limits of that system.

- **Architecture** is the spatial and functional build-up of a living system at a well-defined hierarchical level, i.e., with the omission of more detailed or more encompassing structural features than those being operational at that level.

Still, these two preliminary definitions may lead us to suspect a circular reasoning, in which the living system determines the limits, which in their turn are diagnostic for the system. The way out of this cycle is the concept of systems hierarchy.

Hierarchies of living systems

In physics, the researcher has a considerable freedom in defining the size and limits of the system to be studied, and those of its subsystems (Hendekovic, pers. comm.). This is much less so in biological sciences. For instance, the polemics between those considering ecosystems like a kind of superorganisms (e.g., Mangenot, 1955) and their opponents have been long and bitter. The matter is more controversial for biological communities than for organisms and their parts.

This is, because the human eye discerns physical limits, with spatial and temporal dimensions, in organisms and on soil or climate maps. In between, no clear and uncontroversial spatio-temporal limits seem to exist in a vegetation on the same site, unless these limits are human-made. If no interior limits exist, then all ares (= 10 x 10 m) or hectares on the same site-surface are representative for that forest. They therefore may be characterised by dimensionless features, e.g., populations. A population is dimensionless, being characterised by a number only, unless an indirect spatial or temporal dimension is added in densities, death rates and such variables.

It is easier to explain the life and behaviour of a tree, which is a well-delimited living system, in terms of development and interaction of its organs, which also are well-delimited living sub-systems, than to explain a "gap" in the forest in terms of species populations. Gaps have rather unclear limits and populations in themselves are dimensionless.

In tree crop models (cf. Oliveira, this workshop), no such doubts exist. Limits are clear and so are the variables that can be used, not only as symptoms but as elements for calculation. This is summarised as follows (for a partial example: see Leersnijder, this workshop).

- **the wood** mass (tissue level) and its increment over time are a symptom both of the economical value and of the **cambial activity**, which is a parameter for the tree´s metabolical activity. Its corresponding parameter is trunk diameter. It is one explicative element of

- **the tree** (organism) and its resultant productive interactions among organs (leaves, roots, bark ...), which may be estimated by measuring the parameters of total height and free trunk height (cf. crown depth of Japanese researchers). The tree is one element explaining the

- **timber stand** and its productive interactions among all trees, possibly corrected by negative driving functions, e.g., those accounting for parasitic and pathogenic organisms. Measures needed are tree densities, mortality rates and replacements. The timber stand itself has a known surface, i.e., known limits. Its production

- depends on **site factors**, like radiation, water and nutrients, which are known through measurable properties of climate and soils.

In order to remove doubts about the wood, this usually is considered as a tissue, but might be seen as an organ (the xylem mantle). The first paragraph of the above enumeration therefore is not meant to supersede the organ level of organisation.

In such hierarchical models, the subsystems explain the behaviour of the system. The tissues and organs explain the functioning of the tree as their sum plus interactions. The trees explain the stand in a like manner. But the stand does not explain the abiotic site as presented here, except at the very long term (cf. Hengeveld, 1989).

The other way round, the abiotic site procures its environment (supersystem) to the stand. The stand is the environment of the trees. And there is no objective reason not to consider the tree as the environment of each of its organs.

For the definition of a meaningful biological system's architecture, this example of a simple hierarchy shows the usefulness of hierarchical models to avoid circular reasoning. The **use of patterns** to define the limits of systems is **not circular as long as at least two neighbouring systems levels** are concerned. Patterns should allow to distinguish both the outer limits of a system and the inner limits between its subsystems.

Intuitively and empirically, this should not give too many difficulties in organisms. Still, the authors **in** Sattler (1982) have shown that a bicentennial "tree of ideas" on the subject exists (Cusset **in** Sattler, 1982), and that the three lines sketched above for ecosystems may be distinguished also in studies on plant construction, i.e., deterministic, stochastic and empirical approaches.

What are the patterns that make sense in forest ecosystem analysis? Is it possible to devise easy ways to let useful patterns coincide in many different methods now being employed by European forest researchers? And is it necessary to be critical of such concepts as exist now, or may we use them as if they were true?

Resolution and meaningful patterns

The examples given by Schmidt & Oldeman (this workshop) show, that as spatial resolution increases by decreasing pixel size, the same object is portrayed with quite different visible patterns. With the 40 x 40 m pixels, no contours of subsystems can be traced on this image of a forest. With the 5 x 5 m pixels, contours are evident, and within the 20 x 20 cm pixels represented approximately by the millimeter paper on which a profile diagram is drawn, individual and rather small organisms can be found back from the depicted pattern as subsystems.

In the Nelder experiment shown by Schmidt & Oldeman (this workshop), the pixels may be conceived as variable along a sliding scale. Are the pixels adapted to the organisms to be studied as subsystems of this plantation, or are the organisms constrained to fit in ever smaller spaces due to the artifice of the plantation?

Leaving aside such fine-tunings in experiments, we may conclude that both the images with nearly no resolution and those with a very high power of resolution may convey messages on the forest ecosystem that can be recognised as congruent with classical studies. The signal in the large-sized pixels is rather their hue or tint than their arrangement or the pattern it forms. On the contrary, in the image built by tiny pixels, the arrangement says it all and colour does not matter as long as some contrast is clear enough.

The hue or tint of a large pixel may be made to convey a message concerning, for instance, the average species composition of the vegetation (Melio-Fagetum, e.g.), or the average production potential of the site (e.g., 8.5 m^3/ha/y of Douglas-fir wood). Once the key to the meaning of each colour is found, a machine may be "trained" to analyse remote sensing images accordingly. The subsystems leading to the diagnosis, i.e., plants for the vegetational association or trunks for the wood production system, do not appear as patterns on coarse-grained images, which therefore yield only overall descriptions. These are useful in many cases, but they are bad tools for the distinction of the architecture of subsystems.

By the arrangement of intermediate-sized pixels, about 10 x 10 m and smaller, the forest regeneration pattern, or patterns like those described for Mediterranean coppice woods by Romane & al. (this workshop) generally become clear. The architecture corresponding to these patterns is the one analysed in "gap-models", "modèles de chablis" or more generally "eco-unit models" in many studies since about 1975. For "forest patches" to appear as subsystems in the patchwork of the ecosystem, a certain pixel size is the optimal tool. Still, the image remains too coarse to distinguish individual organisms by clear patterns.

Finally, hand-drawn documents with very small pixels, that find their parallels in very detailed aerial photographs taken from ultra-light airplanes at low height, are unfit to represent the average values of the coarser images. They usually only depict a few eco-units (forest patches) with the main organisms (trees) that build them as subsystems. The classical Central European forest profile diagrams represent another variant upon this fine-grained image type. In general, they depict mosaics of forest patches with less attention to the patches than to the component tree species of the forest. This at least in part amounts to the visualisation of phytosociological data at the association level, but in addition it shows the real distribution of the participating species, allowing to visually check any hypothesis of randomness.

The second figure from Lady Park Wood (Schmidt & Oldeman, this workshop) shows how a simple reduction of the scale of the original drawing, on the photocopier, yields a coarser image. Here, the individual trees **and the forest patches** are still visible, but the undergrowth is indicated by a colour code for average values or properties. The remote sensing series becomes ever finer-grained by pixel size reduction. The inverse can be made to happen by reducing very detailed documents. For the meaning of the pixels and their role in pattern reading this makes no difference.

Finally, the map and the side-view of the Nelder experiment show that the same pixel size may not be optimal for pattern analysis of a forest ecosystem from different viewpoints. The sliding scale for decreasing pixel size is apt to help analysis in terms of crown width and crown projection. But it does not help with tree height.

- **The first suggestion for methodological unification** is to decide upon a simple common approximation from both sides of the scale. Sketches at landscape map level and at organism level, the latter including small organisms if and when necessary, would yield extreme images. Working downwards from one side, i.e. reducing pixel size, and upwards from the other side by reducing the image, the pattern needed for answering precise questions will appear somewhere in the middle and then can be linked both to a supersystem and a subsystem.

Patterns and approaches

If it is agreed that the architecture of a living system, in the sense defined above, is important to know before answering questions and making calculations, the next step is to select the data package needed to explain the system. For forest ecosystems, questions may refer to species richness, production of some tissue (wood) or organ (fruits), amounts of tortuous trees for recreation, regeneration dynamics, succession, fauna development, cryptogams, roots, and many subjects more.

The multitude of possible questions is compounded by the possibility to establish many images with meaningful architectural patterns at numerous, freely chosen hierarchical levels. This probably is the fundamental reason why in the early days of preparation of FERN there was complete agreement that no all-encompassing forest ecosystem model was within our reach, nor liable to be established. It is very easy to list a huge number of desirable levels to study, each with a huge number of facts to gather. The amount of work to be done then becomes irrealistic, the theory, model or calculus becomes unmanageable, and the improvement of ecological insight is doubtful.

This wide array of possibilities, combined with the justified pride of each researcher having found a method in this welter to describe or explain a chunk of coherent forest phenomena, account for the Babel that too often prevails among forest researchers. It is this battle of terms that has lead to the wording of the present text, taking nothing for granted that might be suggested by professional jargon.

There is only one solution if a contribution is wanted to the unification of European forest ecosystem pattern research. A common frame of reference should be developed. It should contain a few hierarchical systems levels that everyone can accept and for each of these levels a basic set of data should be united useful to every researcher wanting to either work with these data or to add others to answer more specific questions. If a **basic** research package could be suggested and accepted, **advanced** research would also be boosted by such a solid basis (cf. Brünig & al., 1986).

- **The second suggestion for methodological unification** hence is the adoption of four architectural reference levels in the analysis of European forest ecosystems. These might be 1) **site** level; 2) **mosaic** level, i.e., that of the patchwork of large or small stands (chablis, gaps, patches, eco-units ...); 3) **regeneration unit** level (a gap is a new, young regeneration unit; a stand is an artificial one; a patch is such a unit in an arbitrary state but not too large ...) and 4) **organism level.**

It does not matter whether all levels are used in all studies, if at least it is decided that common definitions be used, and that if levels *are used* **between** *these four, they are referred to them.* For instance, a tree population is an extra level between the regeneration unit and the organism. Regeneration units, as another example, might be of limited importance for zoological ecology and then can be left out, but they are of the utmost importance for the establishment of young woody plants.

With the more traditional theories on plant communities and the more recent gap model theories the acceptable definition of these levels, helped by architectural analysis, should not pose enormous problems.

As to the data to be gathered in a basic package, the rest of the present workshop will confront the list of desiderata of forest ecologists (Grace, Barkman, both this workshop), silviculturists (Oliveira, Szujecki, both this workshop) and mathematic data processors (Hari, Mohren, this workshop). The poster papers and discussions also will help to define these packages.

The richness of existing schools

Europe has yielded a treasure-house of methods and concepts for research on forest ecosystems and their management. One of the challenges in unifying but not standardizing the methods of research is to profit fully of the results of the existing schools. One practical reason is the possibility to continue existing time-series of forest counts and measurements into the future. A fundamental reason is, that our predecessors have produced a huge mass of well-arranged information and concepts well thought out. Finally, taking this scientific luggage seriously, without choosing one school, to a certain extent will buffer extremist attitudes in forest ecosystem research.

Of course, all concepts should be regarded with a certain reserve. They are scientific concepts and therefore open to falsification, whether they originate from a traditional "school" or a brand-new one, and in this latter case maybe a controversial "school" or one which represents the current fashion in scientific beliefs.

Both philosophically and practically, it is the object itself of our studies that should bring about unification of divergent methods and thoughts. The forest ecosystem is the ultimate touchstone of our ideas. During the excursions, the strength of the patterns we think we see will be tested, and the discussion will certainly touch upon the methods for population counts, the risks and possibilities in calculating values over average surfaces or volumes, or in approaching natural limits as though they were geometrical figures (squares, circles or ovals).

- **The third suggestion for methodological unification** is the adoption of a diagnostic approach, meaning that there should be symptoms or parameters in the forest which are **easy** to observe and to evaluate in order to check whether both the patterns we use to delimit our systems and the results of our analyses or calculations are correct.

The very richness of the forest ecosystems that we all study and, I hope, love should be reflected in a rich and elegant set of basic ideas and references for which FERN is an excellent environment to develop in.

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PATTERNS IN FOREST RESEARCH

E. F. Brünig and G. M. J. Mohren

The main topics in ecosystem research relevant to FERN were identified as: stability and diversity of forest ecosystems in a changing environment, stability and functioning of man-made forests, effects of climatic change on forest ecosystems, and patterns of forest decline throughout Europe. This was taken as a general problem formulation from which research aims were to be derived.

More detailed research objectives derived from the general problems mentioned above consist of increasing understanding of the relationship between pattern and functioning, interpretation or diagnosis of forest structure (diagnosis aiming at prognosis), and identification of changes by monitoring.

By definition, pattern is a regular form, design or order in space or time. A structure can be generally described as a set of elements with their interrelationships. In forest research, structure is predominantly used for the description of features such as morphology, composition, size, etc. of the forest ecosystem at a certain stage during its development. Horizontal spatial pattern of trees in a forest can be part of the description of forest structure.

From the objectives of research, hypotheses can be derived, applying to the problems formulated earlier. These research hypotheses are used to define experiments, sampling scheme's or models. During the discussion, the central hypotheses applying to pattern in forest ecosystem research was formulated as: "Forest pattern is the result, and hence one of the measures, of the interplay between organisms, populations and communities within the ecosystem, and the environment". Thus, more detailed ecosystem attributes such as spatial pattern of the trees in a forest, can be considered as the result of competition for limiting resources (light, water and nutrients). The spatial pattern itself determines in part resource partitioning and competition and hence future forest dynamics.

At another level in the ecosystem hierarchy, the structure of tree crowns and pattern of tree-crown distribution in a forest community together form the "canopy structure". Canopy structure is functionally linked to the intensity of exchange processes between the vegetation and the atmosphere. It is therefore an indicator of site potentials, risk and stress factors and tree-species tolerances, the dimensionless aerodynamic roughness parameter z_0 is consequently a good ecological indicator which has been used both as indicator and as planning aid in tropical rainforest in Sarawak and in temperate broadleaved and coniferous forests in Germany. z_0 was also found to be related to bird diversity in northern German forests.

Viewed in this way, canopy structure and spatial pattern can be used both for diagnosis and for prediction of forest dynamics. Based on such a general hypothesis, a number of sharply focused research questions have to be formulated as part of individual research activities. In order to formulate these research questions in such a way that it is feasible to study them within an ecosystem context, it is necessary to account for hierarchial organization of ecosystems. In forests, this may lead to distinction of hierarchical classes such as "site", "vegetation community", "regeneration unit", "gap" and "organism". At the different hierarchical levels of organisation, different techniques and research methods are available to study particular aspects of structure and function of forest ecosystems. From its general definition it follows that pattern analysis does apply to all hierarchical levels. Choice of research methods is largely determined by the objective of research, the state-of-the-art in the particular field, and the imagination of the investigator.

Session 2 - Pattern analysis for forest ecology

PATTERN ANALYSIS FOR FOREST ECOLOGY

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Summary

Techniques for pattern analysis are reviewed. In addition to Greig-Smith's method, several techniques are widely available from the field of time series analysis, and at least two modern text-books have been written on the analysis of point patterns in space and time. Pattern, once detected, may be used as a descriptive tool, to compare sites within the Forest Ecosystem Research Network. In addition, information from pattern analysis can provide structural information for use in predictive models of growth and carbon balance.

What is pattern?

The Shorter Oxford Dictionary gives 13 meanings of the word pattern, most of which relate to crafts like dressmaking, gunmaking and metal casting, in which the pattern is the design, archetype or model from which repeated copies can be made. It is only recently that pattern has come to mean an arrangement in space such as the floral printing on a dress or wallpaper. It is this second meaning that has usually been adopted in the natural sciences: pattern implies the occurence of organised units in space or time. Pattern analysis has been developed to detect and describe these structural units against a background of random 'noise'. The analysis of spatial pattern has been particularly used in vegetational science to demonstrate the inherent patchiness of vegetation, and sometimes to relate this patchiness to environmental heterogeneity (Greig-Smith 1952, 1979). The statistical problem of detecting spatial pattern is exactly analogous to that of detecting temporal pattern, but more work has been done on the latter, in the general fields of signal processing and time-series analysis (Chatfield 1984).

Detecting structure

Life itself consists of regions of order in a universe where disorder is the rule. Much of the order is self-evident: we can see that forests, trees, leaves or chloroplasts are highly ordered, and organised in a hierarchical way. If we want to, we can capture the information by photography and we can measure the physical dimensions or mass of the units (although, for practical reasons, we are usually restricted to one hierarchical level of organisation). This is often done in forest science, for example in hemispherical photography to record the general appearance of canopy, and in the stratified clipping technique to demonstrate the vertical distribution of foliage. Both of these reveal aspects of pattern. The former is relatively unprocessed information which must be optically scanned to extract relevant parameters. The latter is overprocessed: the histogram bars are the means and they give a false impression of horizontal uniformity perhaps leading us to overlook the importance of gaps in the canopy.

An important question is: in describing the pattern, how much detail do we really need? The answer is: it depends on what use we have for the analysis. Pattern analysis as used by botanical ecologists has concentrated on the description of pattern in the horizontal plane, perhaps because that is what the human observer sees when confronted with herbaceous vegetation, and consequently, that is what he or she wants to convey. Foresters, on the other hand, have had a greater interest in vertical structure, probably because trees are taller than people.

Classical pattern analysis of horizontal dispersal usually starts with the hypothesis of complete spatial randomness, the condition in which the location of each data point is independent of its neighbours (Fig. 1). Plants are not usually arranged like this; but, in uncolonised sites the 'rain' of seeds may well be random within a localised area. Alternative situations are those of the 'regular' condition, where each individual tends to repell its neighbour (Fig 1) and 'aggregated' where individuals clump together.

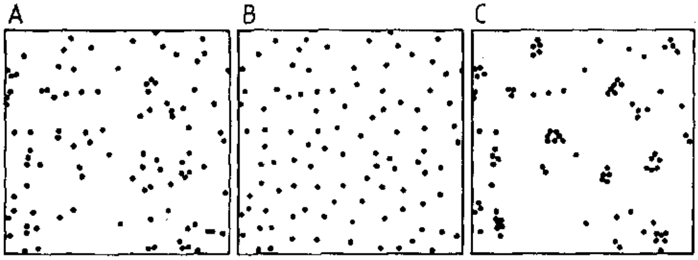

Fig. 1. Complete spatial randomness (a), regular distribution obtained by adjusting the location of near neighbours (b), aggregated distribution obtained by moving lone individuals nearer to a cluster (c).

Greig-Smith (1952) employed the variance: mean quotient as a test for departure from randomness. To do this test, a suitably-sized square grid is superimposed over the scattered data points, and the number of individuals caught in each square is recorded. In the random case, the quotient variance:mean is around one (a *t*-test can be used to test the significance levels of any departure from one). If aggregated, the variance exceeds the mean, and if regular, the variance is less than the mean. The same data can be used in more informative ways: for example the number of cells containing 0, 1, 2......*n* plants may be compared with the numbers expected in the random case, as defined by the Poisson distribution. Greig-Smith's main contribution, however, was to apply the variance:mean quotient for use with data collected from a grid of sampling squares. With a 4x4 grid, the data could be analysed as 16 separate squares, then grouped to make 8, 4,and 2 larger squares, and finally subjecting the grouped data to a nested analysis of variance. This technique is much more revealing, as it detects not only departure from randomness, but also the scale at which the aggregation takes place. When variance is plotted against block (pixel) size, peaks appear when block size corresponds to the scale of pattern (Fig. 2). Since Greig-Smith's original paper, it has become common to work with just a line of contiguous quadrats instead of a grid. Some simple worked examples are given in Kershaw (1973), and many cases are brought together in Greig-Smith (1979).

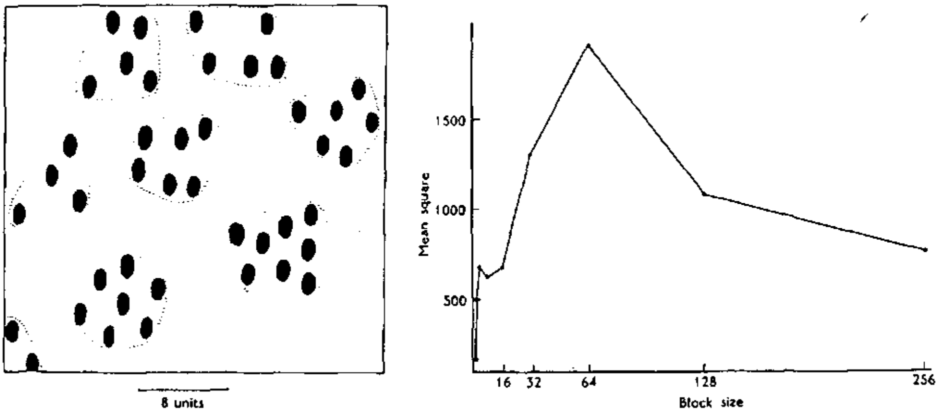

Fig. 2. Greig-Smith's pattern analysis (redrawn from Kershaw, 1973). The mean square shows a peak wherever the block (pixel) size of the sample coincides with the scale of pattern. Here there are two scales of pattern, at block sizes 4 and 64, corresponding to areas of individual plants (shown as black blobs) and groups of plants (broken lines)

In forest ecology, techniques which require the use of sample squares are very laborious in the field. Squares have to have a scale of tens of meters to capture sufficiently large numbers of plants. Plotless sampling has been widely used. In plotless sampling one measures the distances from each tree to its nearest neighbour, or the distance from a series of random points to the nearest tree. The frequency distribution of these distances can then be tested against the distribution which would be expected if the trees were random (a Poisson forest). Several tests of significance have been proposed (Ripley 1981, Diggle 1983). Often, forest survey leads conveniently to a map, as for example when the forest is being surveyed from the air.

Once a tree-map has been made, several operations become possible. It is certainly biologically useful to define the available area from which each tree obtains its resources. The mapped area may be divided up into cells or tiles which define a territory (Fig 3). The definition of each tile is that all places within each tile are closer to that tile's tree than to any other tree. The construction is known as the *Dirichlet tessellation,* and the overall scheme may be thought of as an optimal packing design for the tree crowns to adopt (Fig 3).

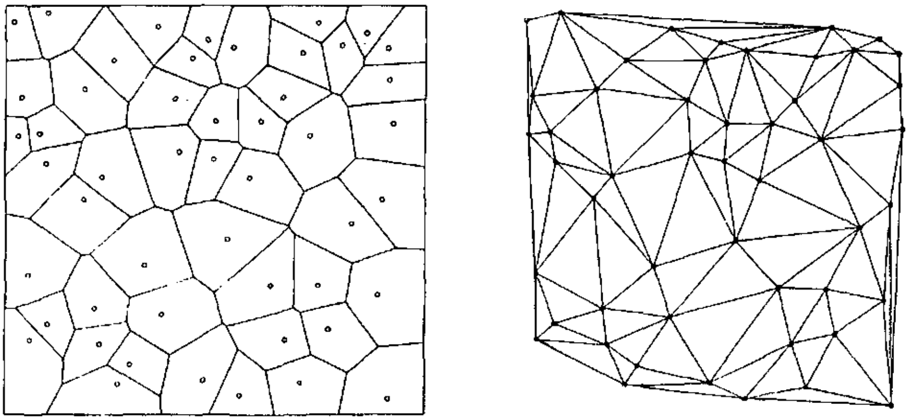

Fig. 3. Division of space into tiles (territories), one for each plant, using the Dirichlet tessellation (a); construction of putative functional links between plants using the Delaunay triangulation (b).

The counterpart of the tessellation is the *Delaunay triangulation,* obtained by joining points for which the associated tiles have a common edge (Fig 3). A map of a forest block, after tessellation and triangulation, might reveal much more information than the map alone, or a figure of the mean stocking rate. The construction is facilitated by a computer program, and areas of tiles could also be computed (Green & Simpson 1978).

Spectral analysis is replacing Greig-Smith pattern analysis as a tool for identifying the scale of patchiness in data taken from a grid or from a line of contiguous quadrats. Many statistical packages have a program for spectral analysis, because it is very widely used in the physical sciences. The technique is designed to apportion the fluctuations in a signal to wavelengths. Spectral analysis was originally conceived for the analysis of on-line electrical signals by passing the fluctuating signal (a voltage) through a series of filters, each of which would let through a particular wavelength (or frequency). Modern instruments achieve the same result operating with digitised data, using an algorithm which is based on the Fourier Transformation (Chatfield 1984). Similar algorithms are used in computer packages for Time Series Analysis. For use in biological pattern analysis, interest is usually centered on spatial distribution, but the analysis is the same as for temporal distribution.

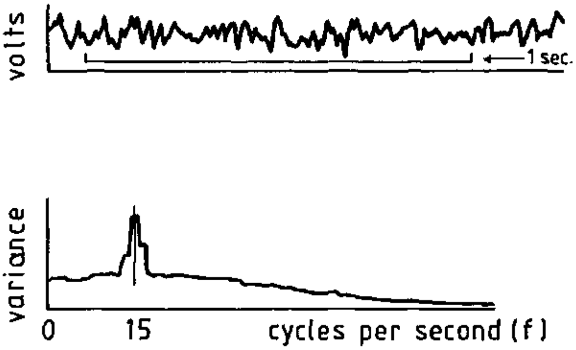

Fig. 4. Detection of pattern using power spectrum analysis (after Chatfield 1984). A fluctuating voltage (upper) is transformed to the frequency domain to produce a diagram in which the variance is partitioned according to frequency (lower). In this case a strong tendency of repetition at 15 cycles per second is indicated

Two functions are commonly used in spectral analysis. Both require a contiguous set of X values in time or space, $X(t)$. The autocovariance function describes the correlation coefficient between X_t and X_{t-u} where u is a lag. Thus, to take a trivial example, if canopy crowns were 10 m apart, the function would show a peak at u = 10 m, since the X value at any point t will always tend to be similar to that at t-10 m.

The second function is the power spectrum, which partitions the total variance between wavebands or frequency bands, and so is very similar in concept to Greig-Smith's method, except that the function is continuous.

The forest researcher may wonder which group of techniques to use. Ripley (1981) presents analysis of several data sets, some of them made being arrays of buttons, and some of them being real vegetational data. He uses several forms of pattern analysis, not only Greig-Smith's but also one proposed by Mead (1974) which overcomes one of the objections to Greig-Smith's method. Ripley comes to the conclusion 'these analyses are rather disappointing but spectral analysis seems the most reliable'.

The application of spectral analysis to canopy data collected on a 2 dimensional grid can be seen in Ford's study of Scots pine canopy (Ford 1976). Ford mapped a rectangular block (120 x 36 m) within a 39-year old plantation which had been thinned every 5 years from the age of 20 years. The intention of the thinning would have been to remove very small individuals and large trees in the few cases where two large trees were very close to each other. The general appearance of the canopy was illustrated as a crown projection map and as a three-dimensional image.

The power spectrum revealed a peak in the row direction of period 1.06 m and a peak in the column direction of period 3.2 m reflecting a rather ellipsoid shape of individual canopies. The author concluded that preferential crown development may have occured on the south side of the canopy, and speculated on the nature of the environmental patterns within the canopy that could have caused this.

The causes of pattern

One of the most widely-cited and influential papers in the British ecological literature is that by A S Watt, at the time when he was President of the British Ecological Society, called simply *Pattern and Process in the Plant Community*. In this paper, the author was concerned with the interpretation of the *patchiness* of vegetation. He noted that individual plants often aggregate with others in a patch, that a series of patches form a mosaic, and that this overall mosaic is what constitutes the plant community. Using the examples of Beechwoods, grasslands and mountain vegetation, he showed how the patches as we see them are dynamically related, that they are in fact phases in a cycle of change, related to the age and vigour of the constituent plants, each plant characteristically going through stages of life history, from juvenile to mature, and finally senescent and degenerate.

Pattern and process *sensu* Watt is seen very clearly in some forest vegetation, and particularly vividly in the wave-regeneration forest. This is a type of forest found in windy climates, where wave-fronts of active forest regeneration progress across the landscape. Within the wave, there is a gradient of tree age, and the wave consists of different stages in the succession from a young forest to an old degenerate one. One example is described by Robertson (1988). The cause of the waves is not clear, and there is even a difference of opinion as to whether the wave-front progresses in the direction of the wind or at right-angles to it. In Robertson's case, the balsam fir forest of Newfoundland, the wave-front moves at right-angles to the wind, and an interesting aerodynamic effect is proposed to account for the wave (Fig 5). In this scheme, the taller older trees would suffer more from all kinds of wind damage, and this may account for their premature demise; whilst the younger shorter trees are in a relatively sheltered zone. This scheme is very like the one proposed by Watt (1947) in relation to the striped appearance of *Calluna-Arctostaphylos* vegetation.

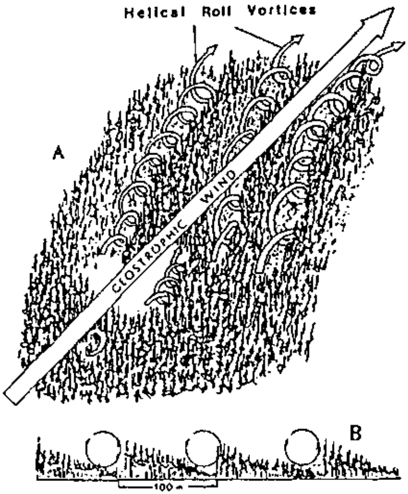

Fig. 5. Wave regeneration forest (Robertson 1988), and its supposed relationship to aerodynamics. Each wave contains a gradient of plant vigour, from young to old and senescent.

Greig-Smith's pattern analysis has often been used to relate vegetational patchiness to patchiness in the environment. The soil may have developed on a boulder-strewn parent material, causing differential fertility or drainage. Plants themselves may have acidified the soil, causing a mosaic of soil reaction which remains after each plant has died. In general though, forest researchers more often encounter an overall gradient on fertility and vigour, rather than a patchiness.

Greig-Smith (1979) discusses many possible causes of pattern. Perhaps the most important in the context of forests is that arising from the interrelations between plants. Competition for light between forest trees leads to the differentiation of 'dominant' and 'supressed' individuals. The importance of neighbourhood effects in a plantation is shown by Cannell and Ford (1984).

In wild forests, patterns of species may be the result of poor dispersal, as Ashton (1969) showed for the Dipterocarp forest of Sarawak. In other cases, extreme climatic fluctuations may favour clumping, as in some high altitude forests (Payette, Filion, Gauthier & Boutin 1985, Grace 1989). One possible mechanism here relates to the influence of canopy on freezing of the soil. Underneath a tree, the ground is frozen less frequently during the winter, and so young trees establishing there are less likely to suffer winter desiccation. Thus, trees occur in groups.

In the context of forest modelling, it is important to emphasise that much of the spatial pattern of the forest canopy is the outcome of the growth-pattern, or architecture, of the tree itself. Most of the forestry literature on this subject relates to tropical trees, because of their inherent variability in this regard (Halle, Oldemann & Tomlinson 1978). However, physiologically-based models of tree growth also require a knowledge of the modular construction of the plant, including the 'rules for branching'.

One of the most disturbing realisations of recent years, with repurcussions in all branches of science, is that random processes can themselves give rise to pronounced pattern (Gleick 1988). Another is that a very small event may cause a large-scale change, perceived as a catastrophe. Of course this is not new. The possibility of sensitive dependence on initial conditions was appreciated by the author of this old rhyme

> For want of a nail, the shoe was lost,
>
> For want of a shoe, the horse was lost
>
> For want of a horse, the rider was lost
>
> For want of a rider, the battle was lost,
>
> For want of a battle, the kingdom was lost.

Thus, we should bear in mind that we cannot expect to find the cause of every ecological phenomena.

Toward a mechanistic-structural view of the forest

Pattern analysis as discussed so far is valuable as a descriptive tool, and may also aid our interpretation of plant-environment relationships. It may generate hypotheses, especially when exploring completely new vegetation. Many of us would like to go further than this, we would like to be able to predict how structural variation in canopy might affect the performance of the forest. This is not merely an intellectual excercise, it is a prerequisite for any scientifically-based management.

There are two main areas in which notable progress has been made. The first relates to light interception, and the second to heat and mass transfer.

Pattern and light interception

The potential of hemispherical photography has long been appreciated, but only now do we have the technical support, in the form of powerful image-analysers, to extract efficiently the necessary information from the image. There remains a problem of spatial resolution, as distant pine needles form such a minute image on the photographic emulsion that they are invisible to it. Moreover, the smallest images on the emulsion are invisible to the image analyser. The current state-of-the-art may be seen in the recent paper by Becker, Erhart and Smith (1989).

A novel sensor, the LAI 2000 (Li-Cor, Lincoln, Nebraska) incorporates a 'fish-eye' lens and a series of five concentric rings, so that the light from five zenith regions can be separately measured. Thus, the sensor achieves in 'real-time' some of the data which is captured more laboriously by the photograph. The importance of these techniques is that they enable canopy structure to be linked with light interception (Campbell & Norman 1989). Indeed, the Li-Cor system comes with software which enables the leaf area index to be calculated from the field measurements of light (although, it should be said that the technique is as yet unverified in forest vegetation, and is unlikely to work well in markedly non-random canopies).

Models of light interception were initially developed for homogenous canopies of random leaves. More recent models enable the tree crowns to be specified, for example as concentric ellipsoids, and leaves to be distributed within zones of the crown (Grace, Jarvis & Norman 1987). Photosynthetic functions, usually derived from laboratory studies can be used to compute the photosynthetic production in each of several regions within the crown (Fig 6). Such models have been used to examine differences in the performance of tall thin, as opposed to short fat, crowns. Moreover, whole stands of trees can be specified, so it is becoming possible to investigate spacing and thinning practice.

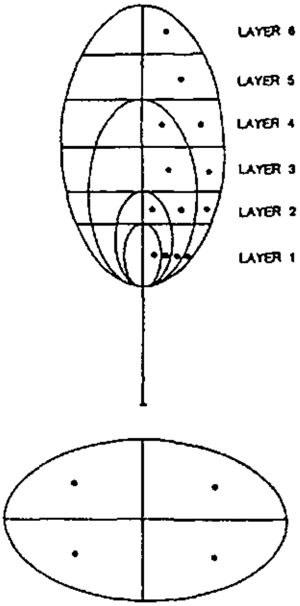

Fig. 6. Division of a tree crown into zones for the calculation of light interception and rate of photosynthesis (after Grace, Jarvis and Norman 1987).

Pattern and turbulent transfer

The second area in which great advances have been made towards exploring the relation between structure and function is in the heat and water balance of canopies. Turbulent transfer of entities like heat, CO_2, water and pollutant gases over the forest depend of the roughness of the canopy and on the meteorological conditions. The parameter r_a which is used to calculate rates of transfer can be estimated from structural parameters, such as the height of the trees h and their silhouette area S. To do this it is necessary to use the micrometeorological approach known as *flux gradient theory*, in which fluxes are proportional to concentration gradients and inversely proportional to resistances to turbulent transfer in the atmosphere immediately over the canopy. Assuming neutral stability:

$$r_a = \{\ln(z - d)/z_0\}^2 \;/\; (k^2 u(z))$$

where d is the zero plane displacement, k is von Karman's constant, u is wind speed, z is height above the ground and z_0 is the roughness length.

For most herbaceous crops the values of z_0 and d may be estimated from the plant height using empirical relationships, found from numerous field observations (Grace 1983):

$z_0 = 0.1\ h$

$d = 0.7\ h$

However, these simplest relationships only hold over a restricted range of plant densities, and more complex (still entirely empirical) relationships have been suggested for stands at other densities (Jacobs and van Boxel 1988).

These relationships hold because the turbulence in the air flowing over any surface is scaled according to the extent of the surface's roughness, a very rough surface causing large eddies and therefore effective turbulent transport.

The resulting value of r_a may then be used to explore fluxes of heat or water to and from the canopy. With a few additional assumptions, surface temperatures may be calculated; for a *Pinus sylvestris* canopy the temperatures of terminal meristems, calculated in this way are usually within 1 ^{o}C of those measured with fine thermocouples (Grace, Allen and Wilson 1989).

Flux gradient theory is currently under some strain, following the realisation that much, if not most, of the total transport of heat and water vapour to and from a canopy occurs in large 'bursts' as downward and upward sweeps of air. The patterns of these are presumably related to the distribution of gap sizes within the canopy, but no work has yet been done on this aspect.

Forest patterns in the landscape

Finally, there is a feeling that the landscape should be *designed*. In an environmentally conscious Europe, it is generally believed that this design should not be optimised simply for production, but that conservation should be facilitated and biotic diversity should be encouraged. But how can this aspiration be translated into a design? One solution has been proposed by Harris (1984). The forest blocks are all in contact with an old-growth stand, which provides a reservoir of seed and acts as a refuge for wildlife. The regrowth blocks are placed so that the edges create the maximum structural diversity. The size of the enterprise is large; so that, according to principles of island biogeography, a large number of species including top predators can occur.

The biophysical characteristics of the landscape (albedo, roughness and surface resistances), infuence regional climates, and so they are required for models of weather patterns, climatic change and regional deposition of pollutants. In such models, the vegetation is a 'green carpet', the activity of which is dependent on the properties of individual leaves and the way in which these elements are organised in space and time.

Conclusions

1. In the context of FERN, pattern analysis serves two essential functions. As a descriptive tool, it will enable comparisons to be made between stands at various locations within Europe. If this is to occur, we need to collect data in an appropriate manner, with this in mind. Secondly, pattern analysis reveals the structural units (crowns and gap sizes) which may be needed as inputs for models of canopy photosynthesis and growth.

2. Several techniques are available, though there is divergence of opinion as to which is the most suitable for the analysis of forest pattern.

3. At the level of the landscape, the consequences of pattern for fundamental transfers of heat and mass can be explored through modelling and by making direct measurements using techniques such as eddy correlation which measure fluxes of water and carbon dioxide. It is perhaps this scale of phenomena which will be of most interest to our governments over the next decade, as they seek to understand the effects of land use patterns on the atmosphere.

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SOME REMARKS ON THE TEXTURE AND STRUCTURE OF FORESTS AND THEIR IMPLICATIONS FOR THE FUNCTIONING OF FOREST ECOSYSTEMS

J.J. Barkman

Introduction

In the first draft of the FERN-project (letter of the Secretary-General of ESF, dated 6-1-1986) the scientific task of FERN consisted of two central themes, one of which was called "The investigation of ecosystem structure and patterns". Within the scope of this theme such topics were mentioned as growth patterns and structure, crown and leaf architecture, patterns of microorganisms, key organisms for mineral and energy processing (e.g. mycorrhizal fungi) and organisms with strong diagnostic value (e.g. grasses, mosses, and nitrophytes). It is well to remember this in the light of recent activities of C1. Although the number of research topics was later (March 1986) extended to five (A 1, A 2, B 1, B 2 and C 1), the C 1 topic, then called "Architectural patterns in European forest ecosystems", remained the only one dealing with structure in the widest sense, including plant architecture and vegetation texture. In the "Research Plan for Fern Project: Patterns in European Forests", drawn up by Hari, Grace and myself as a result of the October 1986 meeting of C 1 in London, the study, among other topics, of external and internal stability of forests was recommended. For both it was thought necessary to study the complexity of vegetation texture and structure, including all niches and microhabitats (pattern elements) and all vegetation layers, as well as the degree to which a forest creates its own internal environment (soil, microclimate). These studies can be both descriptive and experimental, for instance by creating gaps of various sizes and by removing a shrub or herb layer and study the effect on other layers and on the forest as a whole. Since air pollution is one of the major and most acute threats to European forests nowadays, these experiments can well be combined with such experiments as artificial pollution and/or removal of the polluted upper humus layer. It was also proposed to include in C 1 both quasiprimeval forests and production stands.

The Fern C 1 programme, as it is carried out at present, in particular the Scots pine project, seems to have drifted far away from this scope. The modelling is restricted to monocultures and within these cultures to the tree layer only. It does not or insufficiently pay attention to the role of the soil flora and fauna, the root structure and turn-over, to mosses, herbs and shrubs, to vegetation texture, to leaf inclination, to the mutual effect of leaves in a crown with regard to wind brake and reduction of transpiration, to the degree of sclerophylly and chlorophyll content of leaves in their vertical gradient in the crown, in their annual variation and (in case of pine needles) in their change during the years. We cannot leave these factors out, just because lack of data, mathematical problems or limited capacity of our computers do not allow to include them in the model. Some of these parameters, it is true, can be included later, but in view of our rapidly changing forests time is pressing. Other parameters cannot even be ignored at the moment.

In contrast with the Scots pine model Grace in his lecture laid much emphasis on horizontal variation. His model tries to cope with heterogeneous forests, including various tree species and age classes and gaps of different sizes. Promising new techniques are proposed. But in this model, too, the undergrowth is ignored and, most important of all, the subterranean structure is not taken into account. This is the more surprising as recent investigations have clearly demonstrated the importance of soil processes. For instance Fogel & Hunt (1983) have shown that in a Douglas fir forest the annual production of roots is four times larger than the above ground production of organic material (needles, twigs, cones). Total litter production by all vascular plants (above and below ground) is equalled by the production of fungi in the soil (saprophytes, parasites and symbionts). Since fungi contain much more nitrogen than vascular plants, we may calculate that in this forest 81% of the annual N turn-over is through fungi, 17% through roots and only 2% through above-ground biomass. For phosphorus 50% of the turn-over is through fungi. Most of the turn-over of N and P is through ectomycorrhiza (ECM) fungi. Since the latter have recently been shown to be able to decompose litter, the recent decline of ECM fungi in Western and Central European forests must seriously affect nutrient cycling in the soil and therefore tree growth as well.

The importance of vegetation texture

Just like soil science vegetation science may profit much by a distinction between texture and structure. Vegetation texture is defined as the qualitative and quantitative composition of the vegetation as to different morphological elements, regardless of their arrangement (Barkman, 1979), whereas structure is concerned with the spatial and temporal arrangement of these elements. As species composition is often regarded to be distinct from structure (and therefore also from texture), we might in that case designate texture also as "the non-floristic composition of vegetation". A spectrum of a forest stand, giving the absolute quantities or percentages of different morphological classes, expressed either in numbers of individuals, cover degree, biovolume, biomass or caloric value, is a typical feature of forest texture. The classes may refer for instance to height classes, age classes, growth forms, architectural types, life forms, hydrotypes, pollination and dissemination types, leaf sizes, leaf inclination, leaf consistency, presence of thorns, etc. Already these purely descriptive spectra often give insight into the functioning of a forest community or at least generate working hypotheses for further research. They allow a better comparison with other stands, which is important for a coordinated European research network. They also permit a typology and classification of stands on a textural basis. In that case spectra may be averaged for community (forest) types.

The importance of vegetation structure

Textural characters and spectra gain much information value if applied to all vegetation layers or eco-units (microcommunities) separately, in which case we are dealing with (vertical resp. horizontal) structure. Some examples are given here.

Leaf size affects temperature and therefore rate of transpiration. As the danger of overheating and wilting is greatest in full sunlight, we may consider a decrease of leaf size in a forest with height above the ground to be an adaptation to the vertical light, temperature and humidity gradients. in this respect Quercus robur, where sun leaves average 77% of the size of shade leaves, is less adapted than Quercus rubra with sun leaves only 39% of the size of shade leaves (Barkman, 1988). Pinus sylvestris is probably even less adapted.

Leaf size gradients apply not only to single crowns or tree layers, but also to forest stands. In a black alder marsh wood (Carici elongatae-Alnetum) in the Netherlands I found an average leaf size of 20 cm^2 in the tree and shrub layers, 38 cm^2 in the herb layer (for the sake of brevity averages are given here instead of full spectra of leaf size classes). Small leaves create small sun and shade spots, which enable plants to photosynthesize at lower total flux densities and vegetation to develop a larger leaf area index (Horn, 1971). For this reason, too, it is advantageous to have small leaves in the upper crowns, larger leaves in the crown base and in subordinate vegetation layers.

Similar considerations apply to leaf inclination. As full sunlight surpasses the optimum light intensity of even sun leaves by a factor 2-4 and full sunlight may cause damaging of chlorophyll, overheating of leaves and excessive transpiration, it seems advantageous to have sun exposed leaves not at right angles to the sun rays. In many herbaceous plants of unshaded habitats the upper leaves are erect indeed, the lower leaves are more horizontal. In many trees and lianas the upper leaves are hanging down, the lower are less inclined. In Quercus robur the upper leaves are sphaerical: $+90^0$ to -90^0 (Barkman, 1979), the lower leaves are erectopatent to decumbent: $+45^0$ to -45^0. In Alnus glutinosa the upper leaves are hemisphaerical: $+90^0$ to 0^0, the lower are horizontal. This does not apply to all tree species. In Pinus sylvestris all leaves are sphaerical, in Larix spp. all leaves are hemisphaerical (Barkman, 1979). So again the Scots pine seems to be less adapted to the light gradient than the pedunculate oak. Inclination gradients can also be observed in a forest as a whole. In the above-mentioned alder forest the average inclination in the tree layer (12 m high, cover 35%) was 45^0, in the shrub layer (Salix cinerea, 5 m, 3%) 0^0, in the tall herb layer (1.6 m, 15%) 49^0, in the low herb layer (0.5 m, 5%) 10^0, in the moss layer (2 cm, 1%) 4^0.

The situation is, however, more complicated as the angle of the sun rays varies during the daytime and so do temperature and air humidity and consequently leaf hydrature and opening conditions of stomata. The sphaerical leaves of Quercus robur receive 62% of the maximum direct solar radiation throughout the day, the decumbent leaves of Quercus rubra (inclination -10^0 to -50^0) get about the same percentage (56%), but it varies from 49% at 6 and 18 h. local time to 70% at noon. As stomata are often closed at noon and light intensity at noon is far in excess of what is required, whereas it is limiting in early morning and late afternoon, Quercus robur probably exploits sun light more effectively than Quercus rubra. This, however, applies only to sunny days and to the upper canopy. On cloudy days Quercus rubra is at an advantage.

The two species also differ in their sun and shade leaf ecomorphoses. In Quercus robur sun leaves mainly differ from shade leaves by increased thickness of mesophyll and veins and by a higher water storage capacity, in Quercus rubra by smaller size, increased total vein length and greater stomata density (Barkman, 1988). In order to make a full balance of the efficiency of light exploitation by woods we must make a rather complicated model, which also takes into account the macroclimate of the stands (for instance ratio sunny/cloudy days) and vertical gradients in leaf area index, leaf size, leaf inclination and leaf consistency.

In forests a shrub layer may be an important stabilizing factor in case of a major disturbance. When a forest is clear-cut or all trees are felled in a heavy storm, the forest herbs and bryophytes are exposed to full sunlight and high temperatures. Most of them will die. In tropical climates it has been observed that even the ectomycorrhiza fungi in the soil are killed by the high temperatures after clear-cutting (forests of Dipterocarpaceae in Kalimantan, Indonesia; Smits, 1983). This may hamper or even prevent recolonisation by trees. In the Netherlands it has been observed that after felling of a mixed oak-hornbeam forest the shrub layer of scattered hazel shrubs rapidly expanded, thus forming a closed layer protecting the herbs, bryophytes and soil life and keeping the ecosystem more or less intact.

A splendid example of functional structure is the Crataego-Betuletum, a birch wood of the calcareous coastal dunes in the Netherlands. The dissemination types of the various layers are well adapted to the transport agent that prevails at each level. The wind-exposed tree layer consists of anemochores (Betula). The shrub understorey, where many song-birds nest in spring and feed on berries in autumn, when they assemble here in masses before turning Southwards or across the North Sea, consists entirely of ornithochorous shrubs (Ligustrum, Berberis, Crataegus, Viburnum, Hippophae, Rosa, Sambucus, Euonymus, Rhamnus) and ditto lianas and climbing herbs (Bryonia dioica, Lonicera periclymenum, Solanum dulcamara, Asparagus officinalis). In the tall herb layer we find a number of therochores with barbed seeds or fruits, dispersed by rabbits which are extremely abundant here (Cynoglossum officinale, Galium aparine, Anthriscus caucalis, Echium vulgare, Arctium pubens). In the low herb layer we find myrmecochores (Viola hirta and odorata). Their seeds have elaiosomes and are dispersed by ants.

Vegetation structure and air pollution.

The study of the mycorrhiza fungi and the herb layer is indispensable, if we want to model the effect of air pollution on forests, even in case we are only concerned with tree growth and tree vitality (fig. 1). Recent, partly unpublished research has demonstrated that textural characters, viz. roughness of the upper canopy surface and leaf area index of the tree layer, determine how much of the incoming air pollutants (wet, moist and dry deposition) is actually absorbed by the tree crowns. This has a direct effect on vitality, as sulphuric acid, nitric acid and fluoric acid damage wax layers, cuticula and stomata and denaturate chlorophyll. Nitric acid and ammonia poison the cells by accumumulation of aminoacids.

Part of the pollutants reach the forest soil in the form of throughfall and stemflow. Again vegetation texture and structure are important, controlling as they do the ratio between the two components. This ratio does not only depend on leaf area, but also on number of leaves, as each leaf tends to retain one drop of rain water at its tip, which may evaporate before falling off. As trees with small leaves (conifers!) have a higher LAI than broad-leaved trees (for reasons explained above), their number of leaves is much higher and so is their water retention capacity. The ratio throughfall/stemflow determines the chemical composition of the water reaching the soil, for throughfall is partly unaltered acid rain (free throughfall), partly changed by the tree (throughfall dripping from

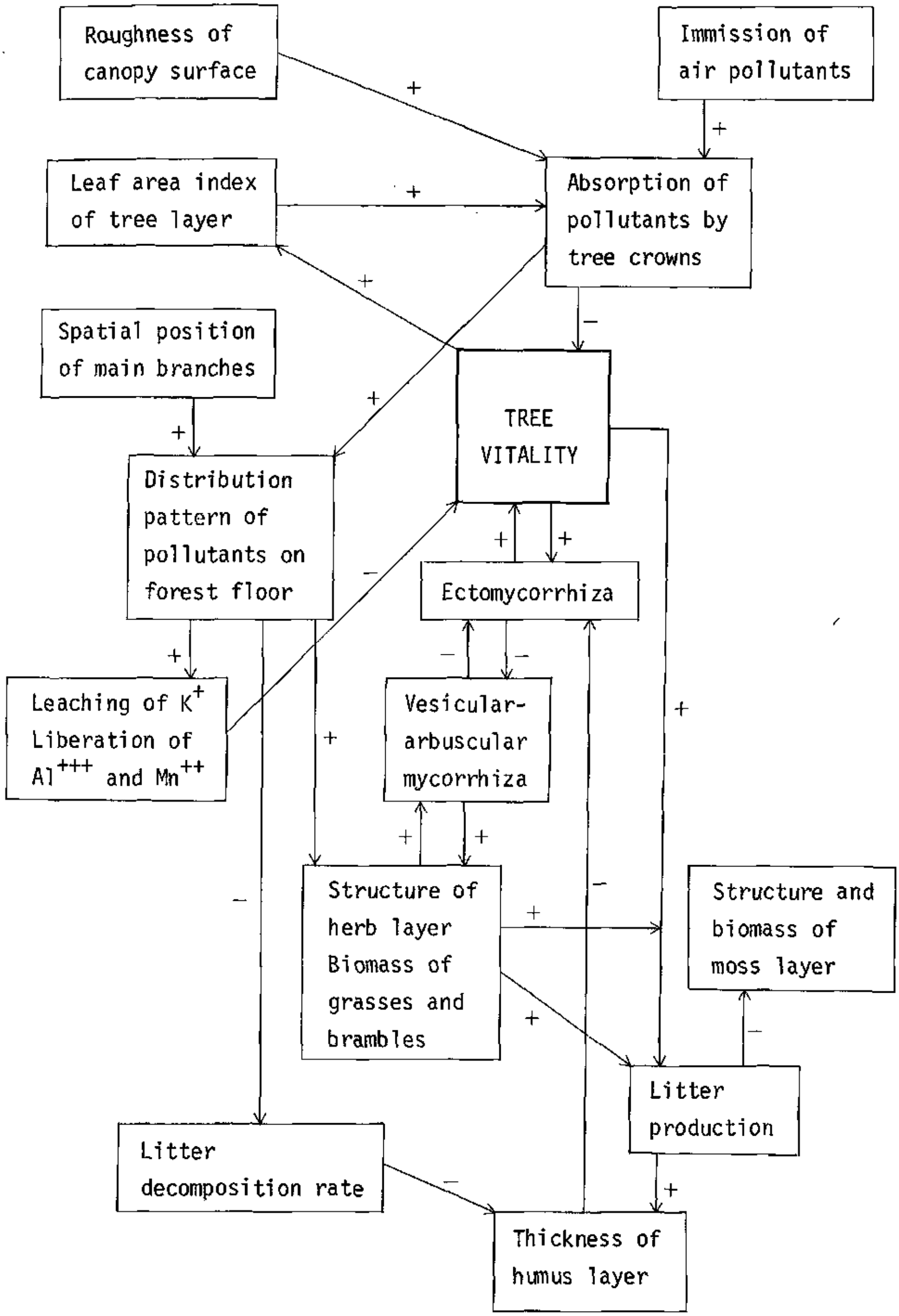

Fig. 1. Forest ecosystems and air pollution.

the leaves), whereas the chemistry of stemflow is always modified by the tree (contact with leaves and bark) (see e.g. Miller, 1986).

The distribution pattern of acid rain on the forest floor is mainly controlled by the spatial position of the branches: in case of centripetal crowns as in Fagus, Carpinus, Populus, Salix and Quercus rubra, the deposition is concentrated in the stemflow, which may be considerable, in particular when the crowns are large and the bark is smooth (Fagus!) (Barkman & Stoutjesdijk, 1986). The distribution pattern is then very uneven. At the base of beech trunks in industrial areas extremely low pH values (pH $CaCl_2$ of 3.1) and high concentrations of aluminum (up to 36 mg per 100 g dried soil, NH_4Cl extraction) may be reached (Wittig & Neite, 1985). It is to be expected that in the case of centrifugal crowns (Picea, Abies, Pseudotsuga) a slight concentration of pollutants will occur at the periphery of the crowns, where most rain water drips off. There is hardly any precipitation near the dry stembase in these trees (Mitscherlich, 1971). In the case of "neutral" crowns with horizontal branches as in Quercus robur, Alnus glutinosa, Pinus sylvestris and Larix spp., a more or less homogeneous distribution of pollutants can be expected.

Both amount and spatial distribution of pollutants on the forest floor are therefore controlled by vegetation texture and structure. This deposition has at least five different effects.

1 Ammonium ions oust potassium ions from the soil colloids, which are thereupon leached out and lost from the root area of the trees, thus causing a potassium shortage.

2 Through nitrification ammonia is converted into nitric acid. Together with the nitric and sulphuric acids, already present in acid rain, this lowers pH drastically and frees aluminum (and possibly manganese) ions, toxic to tree roots.

3 Acid rain, especially nitrogen compounds, seem to harm mycorrhiza fungi directly, which is disastrous for ectomycorrhiza trees, in particular those on poor and dry soils. These trees are entirely dependent on ECM for their existence and no sensible model of tree growth can be made without taking the ECM into account.

4 Nitrogen pollution seems to reduce the rate of litter decomposition.

5 Nitrogen pollution has a drastical effect on the herb layer. In the last fifteen years, in which nitrogen air pollution has reached high values in the Netherlands, many woods that only had a moss layer or a scattered layer of slowly growing herbs (k-strategists, stress tolerators) now have a dense undergrowth of nitrophilous herbs (Corydalis claviculata) or ditto halfshrubs (Rubus fruticosus s.l.), both of them ruderals (r-strategists), or a dense felt of the grass Deschampsia flexuosa, a competitor and stress tolerator, resistent to SO_2 and heavy metals. In these woods the moss layer has disappeared because it has been directly suffocated (Deschampsia) or indirectly: herbs and brambles effectively brake the wind and catch the falling tree leaves. The latter shut out the light from the bryophytes. In oak, beech and dry birch woods on poor, acid soil a continuous moss layer only develops where the wind blows away most of the litter. In oak woods there is a very strong positive correlation between terrestrial

bryophytes and ECM fungi (Jansen, 1981). On the other hand a dense grass layer, and particularly the felt of dead grass on the forest floor, probably hampers gas exchange between air and soil, thus creating less aerobic soil conditions. The mycelia of ECM fungi of dry woods, however, are known to have large oxygen demands.

The grass roots also compete with the tree roots for water, oxygen and nutrients and, according to recent observations, this seems to be true in particular for the VAM (vesicular-arbuscular mycorrhiza) fungi of the grass roots and the ECM fungi of the tree roots. VAM fungi, however, are much less influenced by acid rain than ECM fungi and in some cases even stimulated by input of ammonia (B. Heijne, pers. comm.).

The retention of tree litter by the herbs and the production of their own litter increases total litter production. In combination with the reduced rate of decomposition (see above) this leads to a considerable increase of the humus layer. In a pine wood in the Netherlands for instance this layer increased from 0.5 cm in 1958 to 5.5 cm in 1984. Research in Wijster has demonstrated the existence of a significant negative correlation between the thickness of the humus layer and the number of ECM fungus species in oak and coniferous woods of the Netherlands (Jansen, 1981 and De Vries et al., 1985). This holds equally true for the frequency and number of carpophores (fruitbodies, mushrooms) per species, with a few exceptions. These exceptions, f.i. Lactarius hepaticus, are the very species that have increased in the last thirty years, whereas most other ECM fungi have decreased in the Netherlands (Arnolds, 1985). The relation humus - ECM is probably a direct causal one, for if the humus layer is removed by cutting sods, the number of ECM fungi immediately increases (unpublished experiments by De Vries in Dutch pine forests).

This presentation of the state of the art clearly shows the complexity of the problem and the important role of fungi and vegetation structure, including herbs and mosses. Air pollution affects forests in many - direct and indirect - ways, but among them the influences through ectomycorrhiza fungi, which are also manyfold, seem to be of the utmost importance. Many problems, however, remain to be resolved. Their investigation by means of field observations and field and laboratory experiments is of paramount interest and should have priority in the FERN programme.

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DISCUSSION

P. Schmidt

After the opening lecture by Barkman, stressing the importance of ectomycorrhiza and of the herb and moss layer, the discussion zooms in on the question, which components should be taken into account and in which way in modelling forest ecosystems. It is stated that not all components can be included in the models developed and used nowadays. Not even if components are combined in compartments (herb and moss layer) or in guilds and not even if more is known than published (ectomycorrhiza). These components should be considered as black boxes or - for instance nutrient flows, which are only very poorly understood nowadays - used in very rough models that can be refined in the future. Others argue that when not all aspects can be put into a model at present, these aspects should be monitored starting from now.

What we want to know now are the inputs and the outputs in the system, the fluxes inside and how structure is controlling those fluxes. The importance of fluxes between a limited number of compartments in the model can be determined by simulating. Submodels based on new knowledge can be built in later.

As money is short, however, and not everything can be measured, we need a focus, sharp questions, of which the answers are important for, and needed by, politicians and / or practioners. The first ones want to know the consequences of changes in the forest ecosystem (carbon dioxide, acid rain), the second ones need practical tools. The former requires fundamental research, the latter more practical, a choice which has to be made. Without sufficient fundamental knowledge, no practical advice can be given, however. The research therefore must proceed simultaneously along two lines. It is repeated that the current models based on mass flow are, and must be, very rough models. However, some speakers considered them to be good tools for predicting effects of acid rain. Not all aspects can be predicted, which has to be accepted. In conclusion it is emphasized that even if for the time being not all aspects can be included in models, these aspects should be studied as well, starting this moment.

Session 3 - Pattern analysis for silviculture

ESSENTIAL SILVICULTURAL DATA FOR MANAGEMENT - A CASE STUDY

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Summary

After the presentation of the traditional silvicultural data for management the different classifications for field plots, in stand structure and yield research, are presented. Special attention is given on measurements for natural regeneration and crown structure studies.
The cork oak forest in Portugal, a special type of an agroforestry system is used as a case study, according the research that, in the moment is done in Portugal. The measurement of stand structure parameters and the necessary data for natural regeneration studies and cork production are refered. A possibility for the quantification of the herbaceous component of this management system is also pointed.
keywords: cork oak; field plots; field data.

Introduction

A rational and sustained forest management requires not only information on the production of the existing stands but also the knowledge of its future development taking into account current and future stands conditions and management regimes.
While the forest inventories can give estimates of present stand volumes and growth rates, under a specific management, only silvicultural experiments can support a sound choice between all possible management regimes (CURTIS, 1983). Since the 19 th. century, the lay out and measurement of field plots, where different types of thinnings, spacings and fertilizations are tested, allows a sound practice of a more intensive, but sustained, forest management. In fact, as pointed by CURTIS (1983), the former distinction between yield and silvicultural research is no more valuable. The new yield tables are not more than simulation models based on the results of silvicultural experiments for a wide range of regimes.
For the time being, there is no single classification for field plot types. On one hand CURTIS, (1983) suggests three groups:

1. Temporary (single - measurement) plots
2. Temporary plots with supplementary growth information as by inventory plots.
3. Permanent (remeasured) plots

On the other hand, GALLAGHER (1976) proposes the following types, used in Ireland, for crop structure and yield research:

1. Replicated experimental plots, generally a randomised block, used in thinning and fertilization experiments
2. Individual unreplicated sample plots, a yield plot reflecting the local management

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3. Single tree plots confined to treatments on individual trees, for example, pruning.

In Portugal CARVALHO OLIVEIRA (1980) presented the following classification:

1. Permanent plots, more than four times remeasured
2. Temporary plots, where only single measurements are done
3. Semi-permanent plots, maximal four times remeasured
4. Control plots, yield plots reflecting local management or special treatments.

The permanent plots provide the necessary information to establish a real growth series, with a complete history of stand development, stand treatments and mortality (CURTIS, 1983). Only by long term observations and measurements it is possible to compensate the variations in growth caused by short term climatic flutuations, which is extraordinary important in mediterranean type climates.

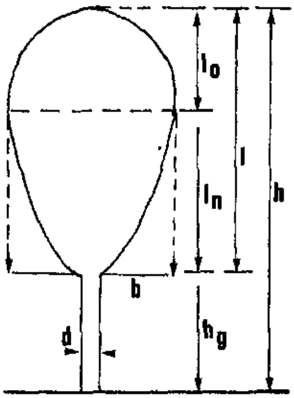
Data Source

According to the objectives to be attained in silvicultural and yield research, we chose between the different types of field plots.
Plot size is influenced by intended purpose, by stand conditions, by expected duration of the study and by cost considerations (CURTIS,1983). Within each plot stand conditions should be homogeneous, in particular what concerns soil properties, natural vegetation type and vegetation distribution (grasses and shrubs). In Portugal for relatively uniform pure even-aged stands we use plot sizes about 0.1-0.2 ha (one hundred trees at the end of experiment). As pointed out by CURTIS (1983) mixed species stands and uneven - aged stands will require larger plots to characterize stand structure and growth, for example about 1 hectare for mixed tropical forest (CURTIS, 1983).
In table I, we present the basic measurements on main crop and thinning trees, required to describe, per unit area, the structure of a forest stand. When these measurements are made in permanent or semi-permanent plots, each tree is assigned to a permanent identification number, to make possible the determination of all components of forest growth as, for example, ingrowth and mortality.
Stem mapping is recommended, with rectangular or angular coordinates,when installing new field plots, in particular the permanent ones. Particular attention should be paid to crown measurements. The crown dimensions, as an indicator of competition and future growth potential, are more and more employed in growth and yield modelling.
Special methods habe been used to get the necessary crown measurements on aerial and ground plots, but the ground measurements, requiring the vertical projection of crown margins using special instruments constructed for this propose, are still used more frequently. In Table 2, we present the main crown parameters and the indices we get from them.

Table 1: The structure of a forest stand. Principal parameters for compilation of yield data (VAN SOEST et al., 1965).

SYMBOL	DEFINITION	REMARKS
t	AGE	
c	CIRCUMFERENCE OR GIRTH, AT 1.30 m	
d	DIAMETER OF A SINGLE TREE, AT 1.30 m	1 or 2 measurements at right angles
d_g	DIAMETER CORRESPONDING TO MEAN BASAL AREA OF A STAND	
g	BASAL AREA OF A SINGLE TREE AT 1.30 m	$g=(d^2/4)\times\pi$
N	NUMBER OF TREES PER HECTARE	
h	TOTAL HEIGHT FROM GROUND TO TIP OF A TREE	
h_g	HEIGHT CORRESPONDING TO MEAN BASAL AREA OF A SATND	
h_{dom}	AVERAGE HEIGHT OF DOMINANT TREES	
f	FORM FACTORS	$f = \frac{V}{g.h}$
K	FORM QUOTIENTS	$K = \frac{d_{o.ih}}{d}$
v	TOTAL STEM WOOD FROM GROUND TO TIP OF A TREE	
v_7	TREE VOLUME ABOVE 7 cm DIAMETER	
G	BASAL AREA PER HECTARE	$G=N.g$
V	VOLUME PER HECTARE	$V=N.v$
i	INCREMENT OF A TREE IN ONE YEAR	
i_d	DIAMETER INCREMENT IN ONE YEAR	
i_g	BASAL AREA INCREMENT IN ONE YEAR	
i_v	VOLUME INCREMENT IN ONE YEAR	
I	INCREMENT OF A STAND (1 ha) IN ONE YEAR	
p	INCREMENT PERCENT	

Table 2: Classical crown measurements and indices exemplified in a beech crown model (ASSMANN, 1961).

CROWN MODEL OF A DOMINANT 88-YEAR-OLD BEECH	DESCRIPTIVE MEASUREMENTS
	1. Height to the base of the crown (hg) 2. $\frac{\text{Crown length (l)}}{\text{Tree height (h)}}$ x 100=crown percent 3. $\frac{\text{Crown width (b)}}{\text{Tree height (h)}}$= Degree of spread 4. $\frac{\text{Crown width (b)}}{\text{Crown length (l)}}$= Crown fulness ratio 5. $\frac{\text{Crown width (b)}}{\text{Stem diameter (d)}}$=Crown projection ratio
l_o-parte of the crown exposed to sunlight l_n-shaded part of the crown	6. Crown projection or ground cover area 7. Volume and surface area ofthe crowns 8. Crown leaf quantities 9. Branch diameter

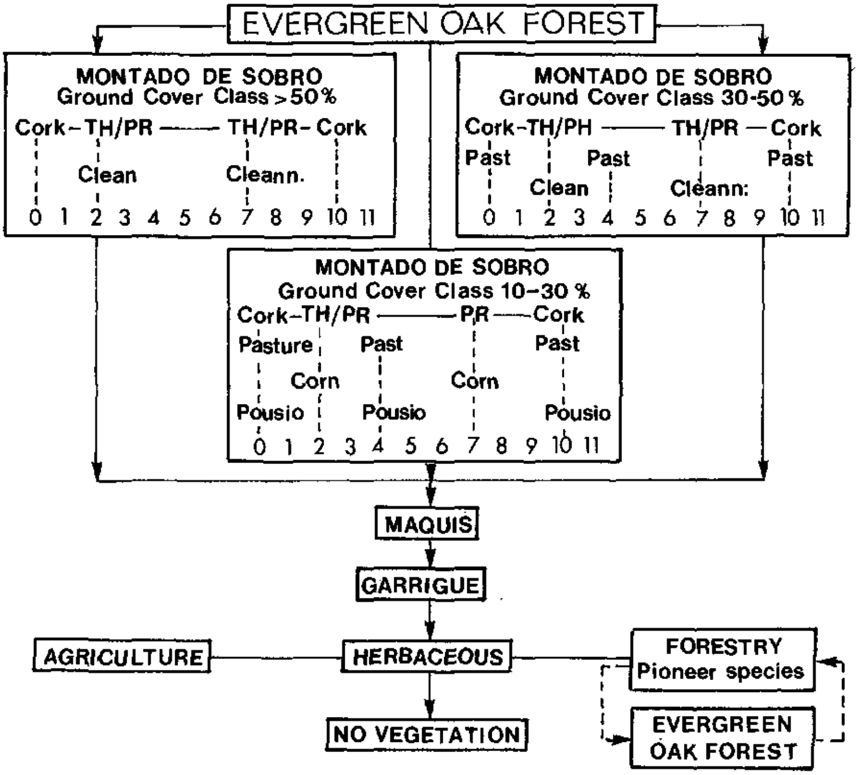
For the crown projection we need to measure between 16 (very irregular) and 4 crown radius (regular crowns, generally free grown trees). ROHLE (1983) recommends the use of eight radius as a standard to insure a good level of precision. In thinning and spacing experiments, the mean crown percent (an indicator of stand stability and past treatment history), the ground cover area (giving information about the competition status), the crown surface area and the crown leaf quantities (correlated with stand and tree increment) are particularly important. The measurement of crown branch diameters are usual in spacing and pruning studies and for crown biomass evaluation.
A new generation of silvicultural experiments are being laid out in Europe and North-America dealing with the development of natural regenerated mixed stands, (cf. PREUHSLER 1979 and BURSCHEL et al, 1985).
These experiments will give the possibility to examine the process of natural regeneration and, on the other hand, data of growth and yield in mixed structures will be available for modelling.
The measurement procedures for natural regeneration studies are not yet normalized. Each plot represents a specific situation and different methods

have been employed to describe it. The big variation in number and dimension of the regeneration gives a special emphasis to measurement costs , what must be considered when choosing the field procedures to be used.

A case-study: the cork oak forest in Portugal

The cork oak, a western mediterranean tree, is very common in Portugal. In fact we have the biggest cork oak area (670 000 ha) and cork production (1 200 000 ton) of the world. Cork industry and exportations are, after pulp, the second major source of forest exportations.
In the 18 th century (1970) the first cork oak silviculture was published in Portugal by FRAGOSO DE SEQUEIRA (NATIVIDADE, 1950). The author presents there the basical silvicultural practices in cork oak stands (Figure 1):
-cleaning of the natural forest, leaving only the best cork oak trees and improving natural regeneration.
-regulation of stand density, using a low number of trees per ha., to allow the practice of agriculture or pasture under cover (Table 3).

Figure 1: The principal types of management in cork oak stands.
(TH-thinning;PR-pruning;Clean-cleanings;Past-pasture;Pousio-fallow land)

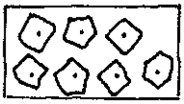
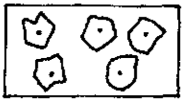


-the generalization of pruning practices to stimulate fruit production in mature trees, used as cattle forage.

-the training of young trees, by formation pruning, for cork production, to get a straight stem (2-3 meters height) and 3 or 4 main branches.

In the last fifty years a lot of yield studies concerning cork production were done in Portugal. As the stands present a wide range of variation in density (Table 3) single tree equations were genearlly adopted for cork yield models.

Table 3: Ground cover classes in cork oak stands

CLASS(1)	GROUND COVER (G.C.)	STEM MAPS (1000m^2) FOR EVEN-AGED STANDS (c=1.50 m; b=10.14) (2)	MANAGEMENT PURPOSES
I	G.C. > 50%	N=70 G.C.=57% 	CORK PRODUCTION
II	30% - 50%	N=50 G.C.=40% 	CORK PRODUCTION WITH PASTURE
III	10%-30%	N=30 G.C.=24% 	CORK PRODUCTION WITH AGRICULT.
IV	<10%	N=10 G.C.=8% 	SOLITARY TREES (AGRICULT.)

(1) according to National Forest Inventory

(2) after the measurements of NATIVIDADE (1950) for crown dimensions

In 1985 the Department of Forestry of the Technical University of Lisbon begins to lay out a set of permanent plots in cork oak stands (G.C.>30%), for the best portuguese cork oak regions, with the following aims:

1. To build new cork tree weight tables, at a regional and national level.
2. To propose a cork yield model, per unit area, simulating different stand structures and ground cover classes.
3. To study the development of cork oak natural regeneration and to have a first approach of the pasture value of the stands.

The measurement problems in these plots were very stimulating, so we decided to present it as a "case-study". In fact, for other forest tree species, we generally measure the timber production of the stands not taking in account its pasture and agriculture values.

Structure parameters and pattern analysis in cork oak stands

Permanent plots were laid out in mature cork oak stands. These plots have, in general, 20-25 trees and variable size, in accordance with stand patterns. The usual plot description must include a complete overview of stand management, in special, of what is concerned with pasture and agriculture practices.

The specificity of a bark production, as in the case of cork,explains the development of special tree parameters to be measured in each tree (Table 4). These tree parameters, measured in sample plots all round Portugal, are being used to build a new type of cork yield model.

In the case of the new cork weight models that are being adjusted, everything points to the superiority of the allometric type models as, for example,

$\ln p = 2.38518 + 1.49915 \ln c + 0.8688 \ln Hdc$

(R2 adjust. = 0.92; SQRES = 559.5)

where p is cork weight (kg), when the trees are barked; c is the circumference at 1.30 m and Hdc the height of bark stripping in each tree (FERREIRA et al. 1986).

To build a cork yield model per unit area, the typical cork stands structures are being identified, considering the different ground cover classes, already presented in Table 3, for the most representative management goals. The yield models are of single tree type and distance independent (MUNRO, 1974).

Pattern analysis in cork oak stands

Permanent plot nº6 in Serra de Grândola, Ground Cover Class I (G.C. I), was elected for a first approach in pattern analysis.

To find the minimal plot area we used the crown maps (FIGURE 2) of the plots. In Ground Cover Class I the crowns should cover more than 50% of plot area. We do not succed to use other stand parameters, as for example diameter distributions, in pattern characterization.

In fact the low density of the stands would increase enormously the plot areas.

The perpetuity of cork oak stands is generally assured by natural regeneration. The natural regeneration of these stands is easy but the relationship between ground cover classes, the presence and abundance of natural vegetation (Cistus sp., Calluna sp., Lavandula sp. etc.) and the pastures management have not been deeply investigated.

In Plot nº6, tree coordinates and eight crown radius were measured(N/NE/ /E/SE/SW/W/NW) and crown maps designed (Figure 2). Each plot was then covered with a net of square mesh, 5m x 5m, were the natural vegetation

Table 4: Special tree measurements for cork oak.

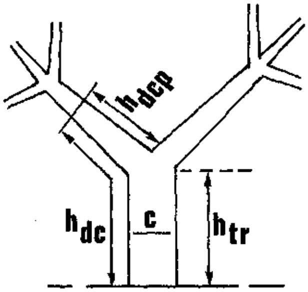
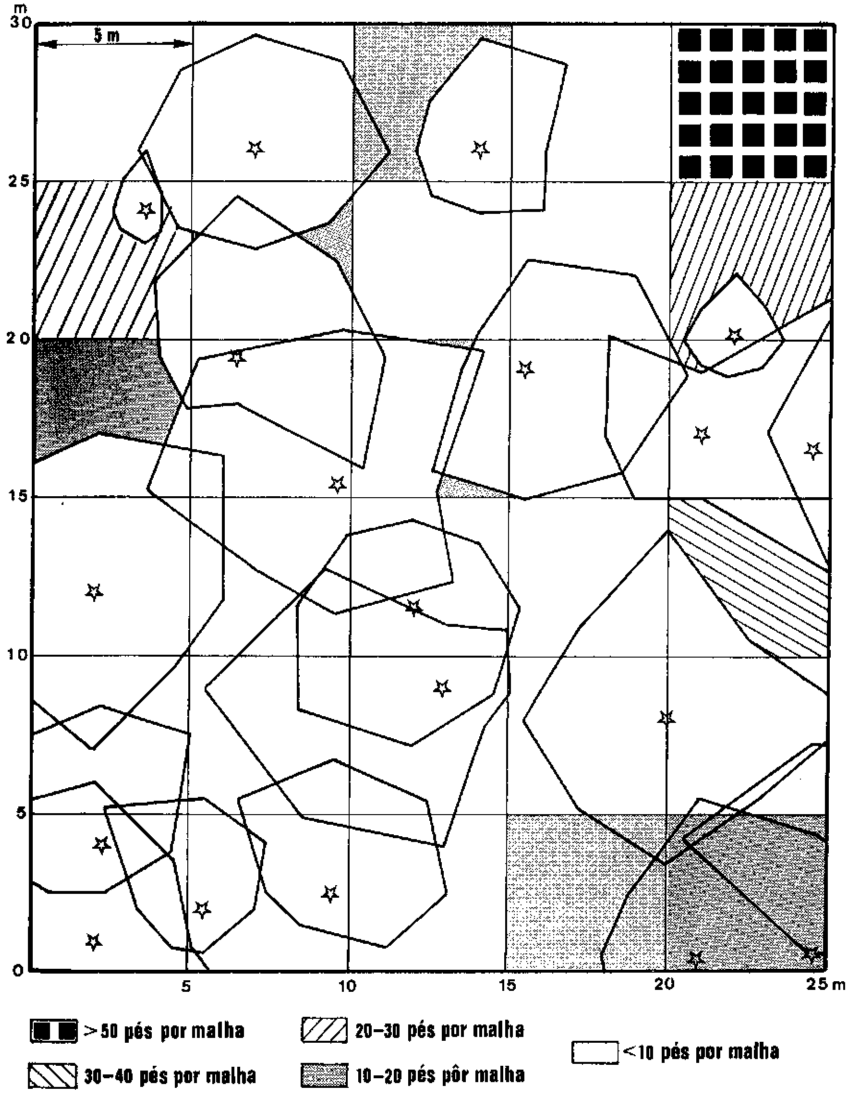
COMMON PARAMETERS	SPECIAL CORK OAK PARAMETERS	
	DESCRIPTION	COMMENTS
t		Possible to find only in new installations
C or d	C (with or without cork)	Diameter determination in old trees is not feasible
h		The trees are pruned. Difficult to measure.
"Crown description" hg b		Generally no more than 2,3 meters Minimal 8 crown radius
		h_{tr}-stem height h_{dc}-barking height h_{dcp}-main bough barking height
	e	CORK WIDTH (at 1.30 m)
	p	CORK WEIGHT PER TREE (kg)

Figure 2: Stand and crown map of field plot nº6 of Serra de Grândola

PLOT STRUCTURE						
AREA (m^2)	$n_r^{(1)}$	$\bar{c}$ (m)	$\bar{h}$	G (m^2/ha)	$p^{(2)}$ (kg)	GROUND COVER (%)
750	20	1.12	8.33	26.68	39.54	63.3

(1) number of trees with plot

(2) mean cork yield per tree (kg)



and cork oaks were in great number, only the individuals bigger than 1.30 m, in height, were numbered,

Table 5: Natural regeneration in permanent plot nº6 (Serra de Grândola), according to CARVALHO OLIVEIRA _et al._ (1986).

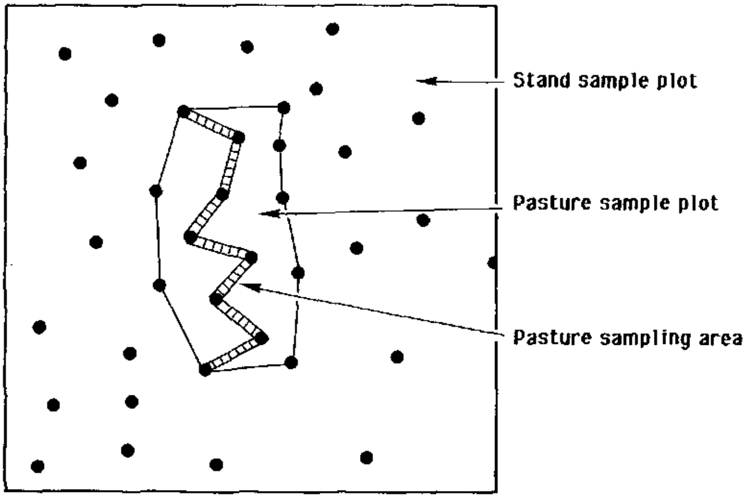
PERMANENT PLOT Nº6 (SERRA DE GRANDOLA)	
Natural Regeneration	Shrubs (Matos)
n_{rg} = 334	n_m = 77
N_{rg} =4453	N_m =1026

n_{rg}, n_m - number in the plot

N_{rg}, N_m - number per hectare

If methodologies for natural regeneration studies are not yet settled, we must consider the determination of animal occupation and stand pasture levels, in oak agroforestry systems, even more incipient. Pasture value determinations are to be found in Spain, for example in _Quercus pyrennaica_ coppices (SAN MIGUEL, 1983) and in _Quercus faginea_ coppices (SAN MIGUEL AYANZ, 1986). In Portugal similar studies are now being made for _Quercus suber_ high forest. In these procedures the sampling of the herbaceous vegetation, Figure 3, allows the determination of spatial distribution of each species and the knowledge of the number of plants per unit area and its variation during the year.

Figure 3: Sampling of herbaceous vegetation, according to SAN MIGUEL, 1983.



For the determination of animal occupation levels in sylvopastoral systems interdisciplinary teams are needes. As the economical importance of the animal component in mediterrannean sylvopastoral systems is increasing, his correct evaluation will be more and more necessary, to establish correct goals n forest politics.

Conclusions

Essential silvicultural and yield data are measured according to generally accepted rules for the common forest types.
A case study is presented here, a cork oak sylvopastoral system, in which the special type of tree product - a bark - and the determination of animal occupation and stand pasture levels will lead us to the development of new procedures for Field measurements and pattern characterization. These should be thoroughly discussed for the establishment of a padronized measurement methodology.

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PATTERN ANALYSIS FOR SILVICULTURE

A. Szujecki

The human strategy in the ecosystem is the theory and practice of all activities aimed at mastery, organisation, exploitation and protection of the given ecological system with a view to the multiple requirement of civilisation (Szujecki, 1984). The strategy presented by Dr. A. M. Carvahlo Oliveira concerns organisation of a mixed woodland and pasture system and its exploitation in the case of a cork oak forest from hundreds of years ago. For this purpose he worked out the measurement procedure in which analysis of the crown model, distribution of the oak trees in the stand and cork production play an important role. Utilization of the herb layer by domestic animals, being the second exploitation aim in an ecosystem so constructed is not clear. Neither is it clear how both these aims can be realized as persistent strategic purposes in this agroforest.

This model of forest management is more a tree or stand model, not a model of forest ecosystem management. It does not take into account ecosystem protection and continuity. Of course human strategy differs in various forest ecosystems according to their function in human society. This is so even if the classification of forest ecosystems is based on general principles. The more precise the taxonomy of the ecosystems, the more important are the tasks of human strategy in these ecosystems and the more precision they require (Szujecki, 1981).

Classification of ecosystems is at present imperfect, since it is based on one-sided descriptions of the component parts of the ecosystems. If understanding of ecosystems lies at the base of achieving strategic aims by man, this should be about their understanding as cybernetic systems. In order to ensure the correct role of man in ecosystem management, a correct and full system taxonomy based on pattern is an important problem from the outset.

Taxonomy of ecosystems should, therefore, in the first place, take into account the material and energy resources of the ecosystem, the pathways and the rate of matter turnover and energy flow and the resulting balance. Furthermore, the state of biomass and productivity are essential. To supplement this data, in the second place, the taxonomical description of the ecosystem should contain lists of organisms that are in particular responsible for the economy of material and energy resources and of dominant interactions between them. Thirdly, ecosystems' taxonomy should deal with steady state mechanisms of such systems, indicating the bioindicative parameters defining the homeostasis of the ecosystem, which can be readily and currently controlled by man (Szujecki et al, 1983; Szujecki, 1987).

Theoretically, all of this information is available and can be presented numerically. In practice, the discovery of homeostatic mechanisms is only in the mind, because any system is stable but its patterns and functions are changing over time due to the impact of natural and anthropogenic factors (Fig. 1). This constrains us to choose only some of the descriptive elements of ecosystems for measurements and modelling. But which ones?

Contemporary systems of forest management are based on the premises advanced by Austrian and German foresters in the 18th and 19th Centuries. This system has, at least theoretically, rationalized the principle of timber (sometimes other products, e.g. cork) production in the forest, and this changed the exploitation character of the process to a process of timber harvesting in a continuous cycle. This model, although one-sided, was very progressive in the past. It is limited to one element of the ecosystem only - trees - but it does not take into account rational management of other components of these ecosystems. Above all it neglects chemical elements and their turnover. In no country in the temperate zone can it warrant protection of the forest management and the continuity of forests as viable ecosystems. Thus, the system of exploitation continues to be applied 'de facto', whatever the good intentions may be. So these systems require thorough revision. They may solely solve problems in emergencies when sustained timber production is menaced. Such a limited vision of the functions of forest ecosystems existed many years ago.

Hence, there is a widespread tendency to introduce a model of forest management which includes not only rational (mostly schematic and orthodox) treatment of tree stands, but of whole ecosystems. These also produce timber on which they are dependent. A model would take into account the ecological, social and economic consequences of infrastructural functions of forests. Thus the main causes for the revision of contemporary models of forest management are:

- a marked increase in the need for infrastructural functions of the forest;
- general transformations in the forest environment through the effect of anthropogenic pressures that threaten the biological production of forest ecosystems;
- the great advances in biological and technological knowledge allowing a revision of the basic technologies applied to date in forestry (Szujecki, A. et al, 1989).

The question now is, along what lines development of forest management, silviculture and forest protection particularly, should advance to fulfill the requirements of a new model?

It would seem that this development should be based on principles of ecological forest engineering. The main strategic purpose of ecological engineering in protection of forest ecosystems is enhancement of the efficiency and development of the steady state (homeostatic) mechanisms of managed forests, determined by the structure, patterns and functions of the biocenosis (example, see Fig. 2). A secondary aim of ecological engineering is elimination of factors destabilizing ecosystems (Szujecki, 1984, 1987).

One of the most important questions in preparation at the beginning of the XXI Century, which has to be considered not only by ecological forest engineering, is optimalisation of the assimilation processes in the phytocoenosis as a unit. It is not only a problem of production increases, but also a problem of restoration of sufficient quantities of biomass on the Earth's surface, which could prevent the accumulation of CO_2 in the atmosphere. In this respect the relation between tree crown, leaf surface of trees, and assimilation possibilities of shrub and herb layers, plays an important role. The very valuable contribution by Dr. Carvalho Oliveira to existing knowledge on the crown patterns, the way of their construction and the utilisation of biomass produced (tree crop model) has to be enlarged however by other elements of the biocenosis which are also responsible in the feedback system of the functioning of the forest.

The tree crop model of Dr. Oliveira for cork oak stands as well as other similar existing models were involved by current system forest management disposed on timber production. Timber is however in major part a construction for trees only, but not the live tissue. A new system of forest management, which has to take protection of the global environment as a predominate function, should also involve a new model of managed forest ecosystem. In this model production of living biomass of various organisms, between them the plants, will have the principle role.

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Session 4 - Patterns as the basis for forest modelling

THE CONSTRUCTION OF EUROPEAN PINE STAND MODEL

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Summary

The structure of the European Scots pine stand model is proposed. The equations of the model are derived from flows of carbon, water and nutrients. The proposed model is operational since it can be implemented in a computer.

Keywords: European Scots pine stand model, process based, föow of carbon, flow of water, flow of nutrients

Background

The Steering Committee of the ESF FERN Project accepted the plan to develop the European pine stand model at its yerly meeting of 1988 . The goal is to generate a Scots pine stand model which is able to predict the growth and development of a Scots pine stand in any place in Europe from a given initial state under alternative thinnings.

There are various approaches for tackling the modelling problem, with the final outcome being strongly dependent on the choices made during the initial phase. If the model can be constructed from theory, it will have clear advantages when compared with purely empirical models. The theoretical orientation is especially important when making the geographical generalization spatially over Europe.

The construction of the model is based on flows of material in the system formed by trees, soil and atmosphere. Carbon is the dominating element in the biosphere. The flow of water is prerequisette of carbon intake. In addition, trees require nutrients to construct the biochemical machinery for metabolic functions. These three different types of flows of material are the theoretical basis of model construction.

There are pronounced differences in the structure of Scots pine stands growing in Lapland with those in Central Europe. Despite these differences, there are regularities covering the development of Scots pine stands throughout Europe. The most important regularities are covered by the following three hypothesis:

Hypothesis 1. The basic functions of Scots pine trees are similar in all stands throughout Europe.

Hypothesis 2. The Scots pine trees have adapted to the climates prevailing in the different parts of Europe.

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Hypothesis 3. Environmental conditions are regionally strongly characterized in Europe.

These hypothesis can be translated into modelling language as follows:

Corollary 1. The model structures to be applied for describing the growth and development of Scots pine stands in different parts of Europe should be the same for each stand.

Corollary 2. The values of the parameters in models describing functional properties can be expected to have different values in different parts of Europe.

Corollary 3. The submodels and parameters describing environmental properties are geographical in character.

The above hypothesis and corollaries form the framework for generating the European Scots pine stand model. The problem can be solved in three steps.

Step 1. Construction of the structure of the model on a functional basis.

Step 2. Determination of the geographical properties of the values in the parameters describing the functions of trees.

Step 3. Determination of the geographical properties contained in the submodels, and in the values of the parameters describing the environment.

In the present paper, we describe a suggestion for the structure of the European Scots pine stand model. The proposed model structure is based on the experiences gained in the Department of Silviculture, University of Helsinki (c.f. Hari et al 1982, 1985, Mäkelä and Hari 1986 and Mäkelä 1988). It is clear that there exists no fundamental problems in the construction. Thus the European Scots pine stand model can be realised. It is also clear that the European stand model can be constructed using other modelling experiences, say based on the Dutch tradition (Mohren 1987).

The stand model

General

There are three hierarchical levels in a stand: 1. tissue element, such as needles branches, stem etc. 2. tree and 3. stand level. Each of these levels has its own characteristic features. Each level of the hierarchy will be treated separately. The connection between the different levels of hierarchy are important for the structure of the model.

Stand level

Functional masses form the natural basis for description of a stand. The functional differences between different compartments of trees generates the need to separate different components. The needles and fine roots are the productive parts which provide carbohydrates water and nutrients for the tree. The branches, stem and coarse roots can be considered to be connection between the two productive organels. Let Y_n denote the needle mass in the stand, Y_b the branch mass, Y_s the stem mass, Y_c the coarse root mass and Y_r the fine root mass. The goal is to construct a model to describe the development in time of the mass components of any Scots pine stand growing in Europe.

The stand is formed by individual trees, which carry out the basic metabolic processes. This is why a process-based causal stand model has to consider invidual trees. The simplest alternative is to use a mean tree and convert it to the stand level by multiplying by the number of trees. The most complicated approach is to describe the properties and location of each tree in the stand. The first alternative is too rough, while the latter results in to a very complicated solution. The consideration of size classes provides a compromise between the two extremes. Let assume that the stand is formed by several size classes. Let N_l denote the number of trees in the l^{th} size class, X_n^l the needle mass of the tree in the size class l, X_b^l the branch mass, X_s^l the stem mass, X_c^l the coarse root mass and X_r^l the fine root mass. The stand level and tree level are connected as follows

$$Y_n = \sum N_l X_n^l \qquad (1)$$

$$Y_b = \sum N_l X_b^l \qquad (2)$$

$$Y_s = \sum N_l X_s^l \qquad (3)$$

$$Y_c = \sum N_l X_c^l \qquad (4)$$

$$Y_r = \sum N_l X_r^l \qquad (5)$$

The height of the tallest tree in the stand is also needed for describing the stand. Let h_{max} denote this height.

Tree level

Growth and senescence are the two processes which are able to change the masses of each compartment of a tree. Let G_n denote the growth of needles, G_b the growth of branches, G_s the growth of stem, G_c the growth of coarse roots, G_r the growth of fine roots, S_n senescence of needles, S_b senescence of branches, S_s senescence of stem, S_c senescence of coarse roots and S_r senescence of fine roots. The masses of successive years are connected as follows:

$$X_n(k+1) = X_n(k) + G_n(k) - S_n(k) \qquad (6)$$

$$X_b(k+1) = X_b(k) + G_b(k) - S_b(k) \qquad (7)$$

$$X_s(k+1) = X_s(k) + G_s(k) - S_s(k) \qquad (8)$$

$$X_c(k+1) = X_c(k) + G_c(k) - S_c(k) \qquad (9)$$

$$X_r(k+1) = X_r(k) + G_r(k) - S_r(k) \qquad (10)$$

Let G denote the amount of carbon consumed on growth. It consists of the carbon consumption of the different compartments of the tree.

$$G = G_n + G_b + G_s + G_c + G_r \qquad (11)$$

Carbon is the principal chemical component of a tree structure. This is why it is natural to base the analysis of the masses in a tree on carbon flows. This is expressed by the so called carbon balance principle. From this principle it follows that the growth is equal to the difference between carbon gain in photosynthesis and loss by respiration if no reserve is assumed. Then it is assumed that the size of carbon pool does not change.

Let P denote the photosynthetic production of a tree during a year and R the amount of respiration. Then

$$G = P - R. \qquad (12)$$

The use of the carbon balance requires the analysis of photosynthetic production and respiration losses. The former cannot be carried out at the tree level since strong temporal and spatial variations are a characteristic of photosynthesis.

Leaf element level

Photosynthesis is an extremely regular process. The dependence of the photosynthetic rate of a leaf element on irradiance and on its stage of development in non water-stressed conditions is very clear. Let p denote the photosynthetic rate per leaf area, I irradiance and Q the stage of annual development. The following simple model covers over 90% of the variance of photosynthetic rate

$$p(x,t) = \frac{p_{max}\, I(x,t)}{I(x,t) + \alpha} f_Q(Q(t)) \qquad (13)$$

$$\frac{dQ}{dt} = \frac{100}{1 + \beta_1^{-(T(t)-Q(t)/\beta_2)}} - \frac{100}{1 + \beta_1^{(T(t)-Q(t)/\beta_2)}} \qquad (14)$$

$$f_Q(Q) = \begin{cases} Q(t)/\beta_3 & \text{when } Q(t) \le \beta_3 \\ 1 & \text{when } Q(t) \ge \beta_3 \end{cases} \qquad (15)$$

where β are parameters. The predicative power of the above equations is demonstrated in Figure 1.

The effect of water deficit on photosynthesis is an essential feature in most European Scots pine stands. This effect is omitted in the above equations. It can be introduced into the models, for example, as shown by Korpilahti 1988. An other alternative is provided by the solution of optimal control problem of gas exchange (cf. Hari et al 1986).

The linkage between photosynthetic rate and photosynthetic production by a tree during a year is obtained by integration

$$P(k) = \int_V \chi(x) \int_{t_k}^{t_{k+1}} p(x,t)\, dt\, dV \tag{16}$$

where $\chi(x)$ is three dimensional needle area distribution. Because irradiance explains a high proportion of the variance of the photosynthetic rate, the quantitative analysis of the interaction between trees is possible.

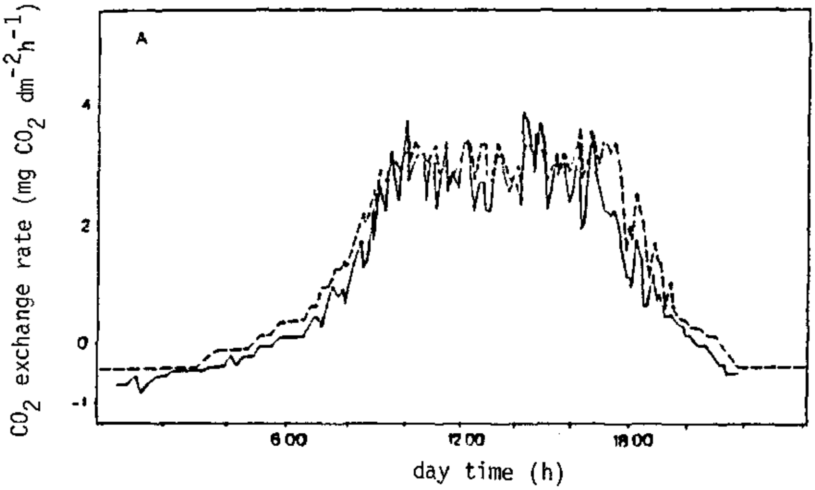

Fig.1. Example of the prediction power of Eq.(1) according to Korpilahti 1988. Measured photosynthesis (solid line), predicted photosynthesis (broken line).

Measure of interaction

The Eq(16) for annual photosynthetic production can be reformulated as follows

$$P(k) = \int_{t_k}^{t_{k+1}} p(x_o,t)\, dt \int_V \chi(x) \frac{\int_{t_k}^{t_{k+1}} p(x,t)\, dt}{\int_{t_k}^{t_{k+1}} p(x_o,t)\, dt}\, dV \tag{17}$$

where x_o is a point located above the canopy.

The first integral in the above equation corresponds to the annual photosynthetic production in unshaded conditions per unit area of leaves. Let us denote this by p_0. The ratio of the two integrals is a measure of the change of photosynthetic production caused by interactive shading. For this reason, let us define the degree of interaction i as follows

$$i(x) = \frac{\int_{t_k}^{t_{k+1}} p(x,t))\,dt}{\int_{t_k}^{t_{k+1}} p(x_o,t))\,dt} \qquad (18)$$

The rate of photosynthesis within canopy is determined to a great extent by irradiance I. This fact allows further development of the degree of interaction

$$i(x) = \frac{\int_{t_k}^{t_{k+1}} \frac{I(x,t)}{I(x,t)+\alpha}\,dt}{\int_{t_k}^{t_{k+1}} \frac{I(x_o,t)}{I(x_o,t)+\alpha}\,dt} \; . \qquad (19)$$

The above integral includes only integration of irradiance over time. A device can be constructed which measures the degree of interaction using the above equation (Kellomäki et al 1979).

The degree of interaction is defined at a point but it can, however, be extended to the tree level by integration. Let i* denote the degree of interaction of a tree. It is obtained as follows

$$i^* = \frac{\int_V \chi(x)\, i(x)\, dV}{\int_V \chi(x)\; dV} \qquad (20)$$

Homogeneity assumption

In a homogeneous canopy, the degree of interaction depends only on the shading leaf area above the point in consideration.

Let χ^* denote the one dimensional height distribution of needle area. The homogeneity assumption permits us to simplify the treatment of interactions. The shading leaf area, LAI(z) above height z is now.

$$\mathrm{LAI}(z) = \sum N_l \int_z^{h_{max}} \chi_l^*(z)\, dz \qquad (21)$$

The relationship between the shading leaf area LAI and degree of interaction can be determined empirically, as in Fig.2. Let f_i denote the dependence shown in Fig.2. Then

$$P^l(k) = P_o \int_z^{h_{max}} \chi_l^*(z)\, f_i(\mathrm{LAI}(z))\, dz \qquad (22)$$

The above expression enables the interactions between trees to be modelled as changes in photosynthetic production. It plays a fundamental role in generating the differences in the development of the different size classes.

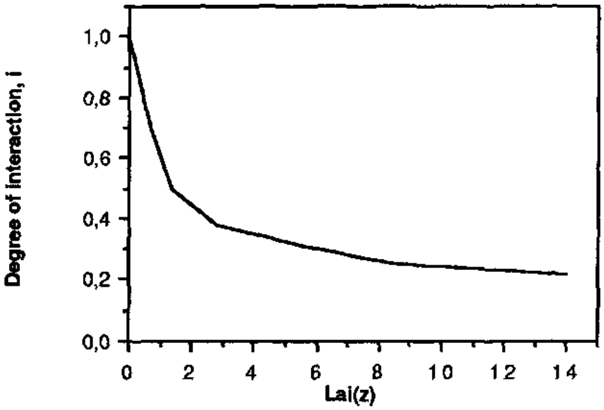

Fig.2. The regression of degree of interaction on shading leaf area.

Respiration

The amount of carbon consumed in respiration is an important carbon sink. Only rough estimates can be applied since the respiratory losses are poorly known. Divide respiration into components according to the type of releasing tissue. Let R_n denote the annual amount of respiration by needles, R_b respiration by branches, R_s respiration by stems, R_c respiration by coarse roots and R_r respirations by fine roots. The respiration of the tree R is

$$R = R_n + R_b + R_s + R_c + R_r. \qquad (23)$$

Each component of respiration has to be approximated separately. Only the simplest possible alternative is justified at the present level of knowledge. The respiration is formed by two different processes, maintenance and growth. Assume,

$$R_r = r_r X_r + q_r G_r \qquad (24)$$

$$R_b = r_b X_b + q_b G_b \qquad (25)$$

$$R_s = r_s X_s + q_s G_s \qquad (26)$$

$$R_c = r_c X_c + q_c G_c \qquad (27)$$

$$R_r = r_r X_r + q_r G_r \qquad (28)$$

The values of the parameters r and q have to be determined experimentally. Since respiration depends strongly on temperature (Kramer and Kozlowski 1979), this should be considered in the model. This means that in determing the values of the parameters r and q the annual temperature regimes should be considered.

Nutrients

Nutrients are necessary for growth, since the active parts of cells require several elements for constructing the biochemical systems required to carry out metabolic functions. The nutrients have to be treated separately in a later phase, but here they are pooled. Let N(k) denote the amount of nutrients available for growth during year k.

There are two sources of nutrients, a.) uptake from soil and b.) reuse from senescenced structures. The nutrient dynamics are also rather poorly understood, which is why only simple model structures can be applied. Let assume that the nutrient uptake is proportional to the amount of fine roots and that reuse is proportional to the amount of dying structures, then

$$N(k) = aX_r + u_n S_n + u_b S_b + u_s S_s + u_c S_c + u_r S_r. \qquad (29)$$

The parameters a and u have to be estimated.

Formation of structure

The formation of tree structure has so far received very little attention in the modelling of stand development and growth. Hari et al 1985, Valentine 1985, and Mäkelä 1986 have considered the implications of pipe model theory on the carbon allocation. When similar analysis is taken further applications of new methodologies and understanding of the functional properties of different compartments are required.

The regularities based on functional requirements play a key role in the analysis of the structure of trees. There are several strongly interconnected processes operating simultaneously in a tree. The driving forces of the processes are, however, different. The primary driving forces are: irradiance for photosynthesis, water vapour pressure deficit for transpiration, pressure gradient for water flow in the stem, etc. It is clear that trees are able to build a well balanced system in which the capacity of each structure meets the requirements generated by the functions in other parts of the tree.

At present we consider following functional regularities to essential for the undisturbed functions of trees. These are:

1. The nutrient uptake is in balance with the requirements of nutrients for new tissues. This balance results in constant nutrient concentrations which are specific for each compartment.

2. The water transport capacity is in balance with the needles' water requirements. This balance results in constant relationships between the amounts of needles and the cross sectional areas of the water transporting structure as stated by the pipe model theory (Kaufman 1981 and Long 1988).

3. The crown form develops towards efficient photosynthetic production. It is clear that the density of the stand has a major effect on crown form, but the the observations on its dynamics are scarse. At this juncture, therefore, this assumption is more like a hypothesis .

The dynamics of the structural properties such as masses, stem diameter and allocation coefficients can be modelled using the above three regularities. The construction of a leaf element at height z also requires the construction of a twig, as well as the growth of branches, stem, coarse roots, and fine roots. Let g(z) denote the density of carbon used to construct leaves at height z, as well as the supporting water transport and fine root systems.

Let $\Delta\chi$ denote needle area density of new needles and g_n the needle mass density. The third regularity can be expressed as a maximization problem as follows

$$\max\left\{\int_0^{h_{max}} \Delta\chi(z)\int_{t_k}^{t_{k+1}} p(z,t)dt\,dz\right\} \qquad (30)$$

when

$$\int_0^{h_{max}} g(z)\,dz = P - R \qquad (31)$$

The needle area mass ratio depends on the degree of interaction i. This results in the Equation

$$\Delta\,\chi(z) = f_A(i(z))\,g_n(z), \qquad (32)$$

where f_A is an empirical function.

The solution of the above maximization problem requires additional assumptions, which more exactly describes the carbon consumption by the transport structure. The assumptions deal with the needle density, formation of water transport structure and nutrient concentrations in the tree.

The supporting structure is formed by five components: wood in the twigs carrying the needles, g_t; wood in the branches, g_b; wood in stem, g_s; wood in the coarse roots, g_c, and the amount of fine roots, g_r. The density of consumed carbon, g(z), is the sum of the components in the different parts of the tree,

$$g(z) = g_n(z) + g_t(z) + g_b(z) + g_s(z) + g_c(z) + g_r(z) \qquad (33)$$

Additional assumptions are needed to allow the determination of the relationships between different components of the supporting structure and the needle density.

Assumption 1. The new needles form a cylinder on the surface of old needles. The needle density is constant within the space which they occupy.

Let lb(z) denote the mean length of branches at height z. The increase of branch length $\Delta l(z)$ can be solved using the constant density assumption.

$$\frac{g_n(z)}{2\,\pi\, l_b(z)\, \Delta l_b(z)} = C_n \qquad (34)$$

where C_n is a constant. The consumption of carbon by the twigs is

$$g_t(z) = A_t\, g_n(z)\, \Delta l_b(z), \qquad (35)$$

where A_t is a constant.

Assumption 2. New needles require a water transport system in the branches. The water transport capacity of the dying needles in a branch is partially reused within the living crown. The ageing of tissues decreases the water transport capacity.

This results in

$$g_b(z,k) = \rho_b\, A_b\, l_b(z,k)(g_n(z,k) - b_b\, s_n(k)), \qquad (36)$$

where s_n is the density of dying needles, A_b is a parameter determined by the needle mass - sap wood area relationship, (Fig.2), ρ_b is the density of wood in branches, and b_b is a parameter describing the decreased water transport capacity in reused wood.

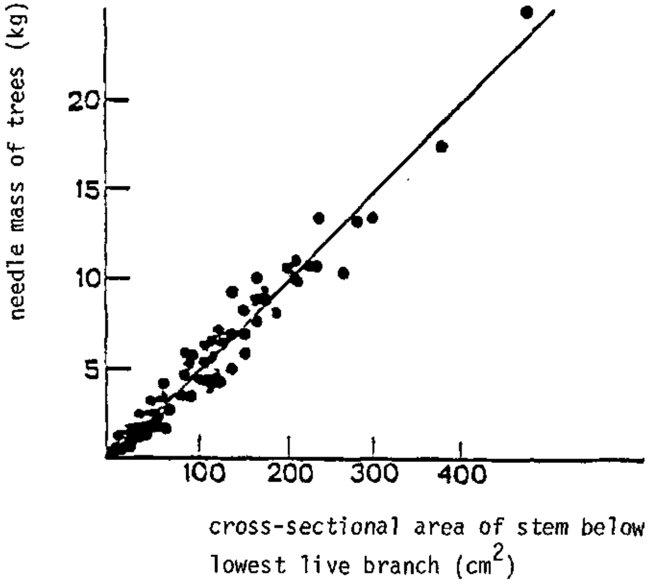

Fig.3. The regression between needle mass, X_n and *cross sectional area of stem*, Z_s. The line is $X_n = A_s Z_s$.

The formation of stem wood is analogous to that of branches.

Assumption 3. New needles require a water transport system in the stem. The water transport capacity of a stem with dying needles is reused within the living crown. The aging of tissues results in a decrease in the water transport capacity.

The above assumption can be formulated as follows:

$$g_s(z,k) = \rho_s A_s z (g_n(z,k) - b_s s_n(z)) \qquad (37)$$

where A_s and ρ_s are parameters analogous to those in the equation for branches. Below the lowest living branch, g_s equals zero.

The fine roots are the other productive component of a tree, besides needles. It is natural that they are treated in a similar way.

Assumption 4. The density of fine roots depends on the soil properties but in similar conditions remains constant.

As in the case of branches, the length of transport roots, l_c is also determined by assumption 4.

$$\frac{X_r}{\pi l_c^2} = C_r \qquad (38)$$

Assumption 5. The amount of wood required for the transport system in coarse roots is proportional to the product of the change in fine root mass and the length of coarse roots.

The model based on assumption 5 is very similar to that for branches, i.e.

$$g_r(k) = \rho_r A_r l_r(k)(G_r k) - S_r(k)), \qquad (39)$$

where A_r is a parameter relating fine root mass and cross sectional area of coarse root, ρ_r is the density of wood in coarse roots.

The formation of a tree's structure includes two unknown state variables, needle and fine root mass. The development of crown form can be introduced with one unknown parameter. On the other hand, there are three equations from which the unknown quantities can be solved. These three equations are: 1) The sum of allocation coefficients equals one, i.e. all carbon is used for growth, 2) nutrient concentrations remain constant and 3) maximization of photosynthetic production.

The equation binding together the amount of nutrients available and nutrient consumption is

$$c_n G_n + c_b G_b + c_b G_b + c_s G_s + c_c G_c + c_r G_r = N, \qquad (40)$$

where the parameters c desribe the nutrient concentrations.

Senescence

A tree, or the organels of a tree, may die during the development of the stand. The productive parts, needles and fine roots, live for a rather short time. Assume that from each age class a proportion dies, then

$$S_n(k) = u^n_{k-1}X_n(k-1) + u^n_{k-2}X_n(k-2) + u^n_{k-3}X_n(k-3) + u^n_{k-4}X_n(k-4) + \ldots \qquad (41)$$

$$S_r(k) = u^r_{k-1}X_r(k-1) + u^r_{k-2}X_r(k-2) + u^r_{k-3}X_r(k-3) + u^r_{k-4}X_r(k-4) + \ldots \qquad (42)$$

The parameters u have to be determined empirically.

A branch dies when it no longer has any needles. The deaths of trees affect the number of trees in a size class, N_l. This self thinning of the stand is introduced by symbol D and by the effects of prescribed thinnings by T. Then

$$N_l(k+1) = (1 - D_l(k) - T_l(k))\ N_l(k). \qquad (43)$$

The prescribed thinnings, T, are given functions of time for each size class. The self thinning, D, has to be connected to the dynamics of the stand. The self thinning process is not well understood, but it seems reasonable to assume that when the needle mass in a size class is decreasing, then natural deaths of trees occur, i.e.

$$d\,(X_n(k) - X_n(k-1)) \qquad \text{if } X_n(k) \leq X_n(k-1)$$

$$D_l(k) = \begin{cases} \\ 0 & \text{if } X_n(k) \geq X_n(k-1) \end{cases} \qquad (44)$$

where d is a parameter.

Height growth

The dynamics of height growth is not well understood. This is why very simple model structures have to be applied. Let H denote the height of a tree and h the height increment. Then

$$H(k+1) = H(k) + h(k). \qquad (45)$$

Ek 1971 has found a linear relationship between the diameter and height of trees growing without the shading of neighbouring trees. The interactions between trees disturbs this linear relationship because in shaded conditions trees accelerate their height growth. The linear relationship found by Ek and the interactions are introduced into the model

$$h(k) = r(k)\,(e_1 + e_2(1 - i^*)), \qquad (46)$$

where r(k) denotes radial increment and e denotes two parameters.

Concluding remarks

Process based models, as the one suggested in this paper, have the advantage that the values of most parameters can be determined with focused measurements. This fact reduces the number of the parameters to be estimated from the behaviour of the stand model. In an ideal case no parameter value is estimated on stand level. The proposed model is rather close the ideal case since only tree mortality and nutrient uptake parameters are to be estimated on stand level.

According to corollaries 2 and 3 the values of parameters are stand specific in different parts of Europe. It is clear that the geographical character is more pronounced in some sensitive parameters. The field work should be focussed on studing the geographical properties of these sensitive parameters. We consider that the parameters relating needle mass and cross sectional area of sap wood, wood density, height growth parameter e_1, needle senescence parameters and potential photosynthetic production P_0 should be in the primary focus.

The reducing effect of water deficit on photosynthesis has stand specific character, although water deficit is less pronounced in the Nothern than in Central Europe. Reduction of transpiration results also decrease of photosynthetic production. This effect can be introduced into the stand model with the parameter describing potential annual photosynthetic production P_0. A rough model should be constructed which links P_0 and the amount of water in the soil in the spring, potential evaporation and rainfall during growing season.

The expected results are demonstrated in the Figs 4 and 5 , which refer to the conditions in Southern Finland on poor sandy soil. The behaviour of the model is rather reasonable, although there are several points, which require more information in order to get a reasonable description of the process in consideration. The goodness of the generalization to European level is still an open question. We are optimistic. Our work within FERN will ansver this question.

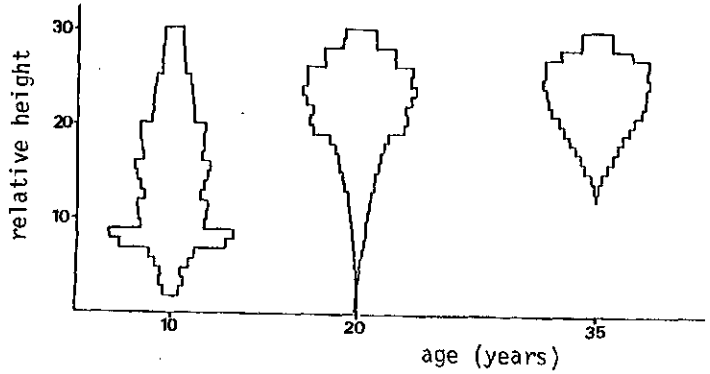

Fig.4. Simulated development of crown form

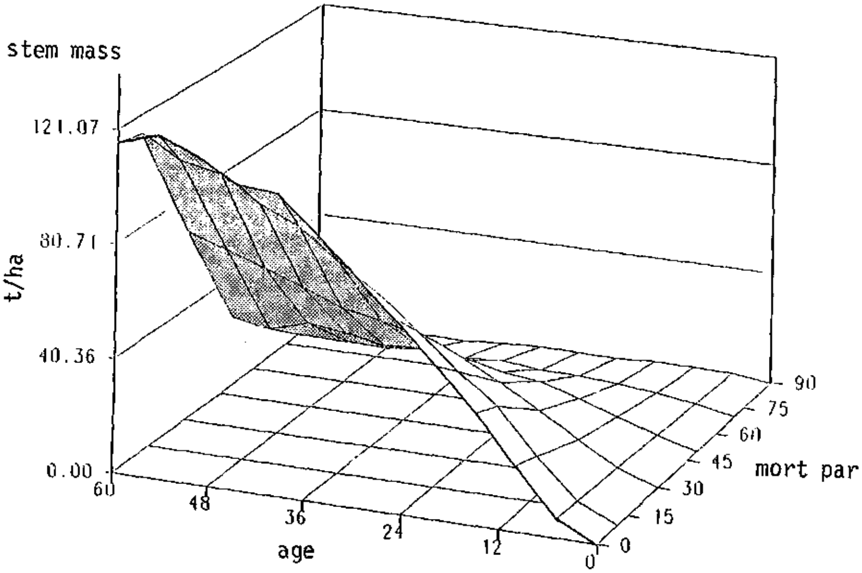

Fig.5. Example of the development of simulated stem mass when the root system has varying efficiency of nutrient uptake.

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PATTERNS AS THE BASIS FOR FOREST MODELLING

E. Nikinmaa

The previous discussions on pattern analysis in forest research addressed aspects such as problem formulation, the derivation of research objectives, and the construction of hypotheses. In the discussion of pattern analysis in forest ecology, several ways to deal with ecosystem structure and forest spatial pattern were highlighted as part of the methodology of forest ecosystem research. The combination of research objectives, state-of-the-art in the field, and experience of the analyst leads to a model choice that is strongly determined by the aim of the model. This requires sharply focused research questions for individual model applications. Within FERN, emphasis lies, among others, on analysis of effects of change in growing conditions on forest ecosystem stability and dynamics: which are the patterns in forests; how are they formed as a result of physiological processes and how can they be expected to change under changing environmental conditions. Effects of climatic change on forest development and succession are part of this.

In order to deal with different growing conditions throughout Europe, the European pine stand model such as presented by Hari and Nikinmaa, was developed as part of this analysis. Such a general, elementary carbon-balance approach to ecosystem dynamics may constitute the connection between processes and pattern in ecosystem research. Using a carbon-balance approach as the central feature, different models can be coupled for specific purposes.

To describe forest structure in these simulation models, we can have several degrees of simplification. The choice of the level of simplification depends on the focus of the model. In its most elementary form, a model only contains amounts of dry matter, divided in the main biomass components. This may very well suffice for studying some ecological problems, such as the accumulation of soil organic matter during ecosystem development. For such a model it is sufficient to know the basic processes that affect the flows of material. If a more complex model is required, more detail needs to be added, such as a detailed model of microbial activity. Still more detail may be added: a micro-meteorological model will incorporate aspects of the vertical distribution and orientation towards the sun of the main canopy elements. Before going into details in a model, it must be evaluated how much is gained by the increase in detail, compared to the limited knowledge that is available in the description of the phenomena involved.

To deal with competition, a model may distinguish between species and can have size classes. To deal with canopy interactions one may have to account for branching structure and leaf area distribution to characterize the micro-climate inside the canopy. In conventional forest growth and yield research, there has been a development towards individual tree models, where each tree's position in the forest is known. At that time it was thought necessary to go into even more detail of stand structure with the progress of computer modelling. At this moment, the movement seems almost to be in the opposite direction, going towards more specific models with less overall detail but better suited for particular purposes.

In order to be able to link together these different models, it is essential that summary models are developed from large research models. The summary models should include as little detail as possible, while maintaining the essential behaviour of the larger model. A good example are the models developed for simulation of primary production in plant canopies. Here, complex multi-layer models have been used for a number of years, but lately rather simple general summary models have emerged from this. An example is the calculation of dry matter increment from absorbed radiation only, where site influences are accounted for in the value of LAI and in the value for the conversion efficiency.

In general, the requirements for process description in a particular modelling approach will define the degree of detail in the description of spatial pattern and forest structure in the model. In case only large scale effects are taken into account, a big leaf model may very well suffice. On the other hand, when the purpose of the analysis is to relate the development of micro habitats for underground vegetation at the forest floor to canopy structure of the main stand, it may be necessary to go into considerable detail as regards canopy roughness elements, crown shapes, distribution of leaf area, and three-dimensional position of individual trees and tree crowns. Models used in the analysis of silvicultural problems have to incorporate individual trees in the stand.

Considering the gap between the state-of-the-art of modelling conifer ecosystems versus mixed broadleaved forest ecosystems, it was decided to form special task groups within FERN-C1 that deal with both approaches. The group that will further develop and test the European pine stand model will be coordinated by Prof. Hari, the parallel group on mixed broadleaved stands will be headed by Dr. Grace. The pine-model group will organize a small meeting in Sweden in the fall of 1989 to compare model applications under different growing conditions. At this meeting, details for testing the pine model in a range of growing conditions throughout Europe will be discussed, as well as the sensitivity of the model to changes in growing conditions. With this information, a procedure can be established to use the model for assessment of effects of changing growing conditions on this type of forest ecosystem, which was requested by FERN. The group concerned with modelling mixed broad-leaved stands considers organizing joint field work in an experimental stand to focus the modelling activities.

Conclusions

IN GUISE OF A LAST WORD

Yves Birot

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I would like to express my thanks to the organizing committee for the invitation to give the closing address, to draw the conclusions of the meeting and to make some recommendations to FERN C1. When I was asked to conclude this workshop, I had the feeling of a difficult task for at least two reasons:

- my background is not ecology but genetics. Therefore, and in advance, I apologize if some of my comments appear naive or provocative,

- the word ´pattern´ (as for the word ´model´) is a confusing one and some of the discussions we had in the last two days confirmed this pessimistic view!

I am not going to sum up all the information contained in the papers, field trips and in the discussions, that resulted, but rather I will highlight the major facts that could be of practical interest for the future activities of FERN.

During our workshop, the discussions clearly revealed two different tendencies:

- there is a group of ´naturalists´ that looks at all compartments of the ecosystem and tries to integrate all possible mechanisms into a general scheme,

- there is also a group of biometricians or modellers that tries to devise a simplified (or over-simplified) and tentative representation of a complex system.

I would say that the right place lies somewhere in between: we need both approaches. I can make a comparison with forest genetics. It has been proven that quantitative genetics is a powerful tool of selection, although it is like a black box (it is not very explanatory), but it works. However new progress in genetic gains will come from a more mechanistic approach relevant to the expression of a single gene or group of genes.

It is clear that pattern analysis is still a necessity. We really need to have a global description of the structures involved in the ecosystem. But this phase must be considered as prerequisite, as a first step. We now have to investigate the main functions, especially those related to patterns such as water transfer, photosynthesis, etc ... These studies on physiological processes will allow us to proceed toward a mechanistic, structural view of the forest.

In pattern analysis for forest ecology, it seems that there is still a lot of work to be done; in the field of structural analysis Dr. Nikinmaa presented very interesting data on Scots pine. I think that we are in great need of this type of basic information for many species, conifers as well as hardwoods. It is obvious that progress in forest growth modelling, but also in the knowledge of mechanisms involved in ecosystem functioning, closely depends on this type of data. It seems to me that cooperative efforts could be undertaken on a European basis.

Another related topic, which has not been touched upon much during this workshop, concerns the modifications in forest growth patterns due to environmental changes. It appears that a lot of fruitful information can be obtained from dendroecological studies such as those developed in the Federal Republic of Germany and in France. I suggest that more emphasis be given to this scientific approach as a powerful tool for assessing the modifications on the long-term. Cooperative efforts between countries could be very helpful for evaluation on a European scale.

In his talk on growth studies in cork oak, Dr. Oliveira has emphasized the importance of a permanent-plot network. I strongly support his idea. I think we still need to go on in pattern analysis for silviculture in Europe, and a permanent-plot network is a basic tool for achieving this objective. The data captured in these plots are useful not only for silvicultural application but also for a better understanding of ecosystem functioning. They can be used also in forest growth modelling, for calibration as well as for validation. Contrary to a wide-spread belief, we do not have in Europe - not even for a limited number of species - a consistent network providing proper and adequate data. We do not have long series of standardized date concerning the same traits, and reflecting environmental effects (site, climate) as well as silvicultural effects (diversity in the silvicultural regimes). We urgently need to set up growth data cooperatives, not only on a national basis but also on a European basis, for species of common interest (for example beech, Douglas fir, Scots pine, etc...).

Patterns for forest modelling obviously has priority. However we should not oppose stochastic models and deterministic models, or deal exclusively in deterministic ones. It is clear that the stochastic types will still play a major role because of their potential of applications to forest management as a tool for decision support, and also because there will always be background noise, which can only be taken into account by stochastic approaches.

Of course deterministic models will progress at the same rate as our understanding of the physiological processes, that affect the functioning of the ecosystem; There is still much to be done. For example, the passage from the individual-tree level to the stand level is difficult. It seems to me that there are intermediate models, such as the individual-tree, distance-dependent models based on structural competition and growth analysis that mimick the interactions between trees in a stand. Such models as those developed by K. Mitchell in Canada for Douglas fir or by R. Leersnijder in the Netherlands for Scots pine (see poster and computer programme presented at the workshop) can be very powerful in prediction and simulation.

In conclusion, I think that, in addition to the general remarks mentioned above, the final proposals for the future activities of FERN C1, can be summarized in three main points:

1. Continuation of the very interesting work undertaken by Dr. Hari and co-workers on the deterministic Scots pine growth model.

2. Initiation of a working party on growth, structures and functions of mixed broadleaved hardwoods, which cover large areas in Europe.

3. That we accept the kind invitation of Prof. Szujecki, to hold the next FERN C1 workshop in Białowieza (Poland) as a joint meeting with the Polish group. The proposed title of the workshop is ´Ecological Basis for Forest Management´. The suggested time is mid-May 1990.

FUTURE DIRECTIONS

Roelof A.A. Oldeman

The meeting in Strasbourg of the FERN C1 group, whose subject matter is the patterns and architecture of European forest ecosystems, has been postponed several times. It may just be that researchers interested in this subject have fuller timetabels than others or that they are more difficult to extract from the forest, where one can often find them. As a matter of fact, many of the C1-members are field ecologists. The Strasbourg agenda reflected this. One third of the time was passed in the forest.

And why the harping upon harmonisation of scientific methods? As expressed in the keynote papers, one part of the answer is clear. If in FERN this matter of harmonization is not addressed, within a short time forest ecologists will be divided in schools which cannot even communicate very well any more for want of a common language. The use of computers cannot be a remedy, because the concepts and languages are invented by the users of these machines.

Computers may become the ersatz of politeness between people with different views of forest ecosystems, who, everyone of them, thinks his or her view to be the true or the most useful one, depending on his more or less positivist attitude. Schools of thought have been manifest both in forestry and in ecology over long periods. The virulence of such schools may be taken to be squared in forest ecosystem research. But so is politeness.

From the outset, FERN has been an uneasy mix of researchers with quite different views and methods. In order to keep all of them united under one umbrella it was necessary to divide the umbrella in five bars of different colours which corresponded to different approaches. The C1-group contains many people of a "naturalist" temperament, who prefer the forest to the model and the drawing or the word to numbers. This is as much as they have in common, because the lot contains more or less traditional foresters next to population scientists and more unconventional architectural analysts.

In the Strasbourg meeting, the mix was enriched in an interesting way by several production ecologists and younger researchers with new models creating bridges between several existing methods. Arguments of physical geography, for instance, and the mimic growth of a pure pine stand with genetically mixed trees showing natural and, if so chosen, induced mortality, were newcomers.

The discussions among these researchers, as much in the field as at the poster sessions and during the plenary exchanges of views were quite lively. However, as was to be expected, they did not lead to a brillant proposal for one common approach, resolving all methodological problems among European forest ecologists. On the contrary, as the discussions progressed, it became all the more difficult to maintain a common platform of ideas. Was the meeting held in vain? Did it end with some methods as winners, others as loosers?

The results are neither as negative, nor as vague as that. One clear fact that emerged was of that the time is not ripe to merge the FERN subgroups of pattern and process researchers, in plain words, the naturalists and the modellers. But on the other hand, the new projects that were proposed, i.e. the pine forest model, the mixed forest study and the Białowieza meeting in 1990, have clearly shown that these groups can work together from their respective viewpoints and on the condition that all methods are allowed to contribute.

It is hoped that the meeting in Finland taking place now, in June, and which enters the matter from the process viewpoint of modellers, will conform these tendencies. In any case, the Strasbourg meeting was clear and has considerably contributed to fruitful scientific discussions enriching the participants as well, it is hoped, as the readers of the present proceedings.

Abstracts of posters

DYNAMICS IN PINE FOREST ECOSYSTEMS, EVALUATED BY TRANSECT ANALYSIS

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Summary

In Flanders, spontaneous settlement of broadleaved species in first generation Scots pine plantations can be widely noticed. Investigating this event, can lead to management techniques for converting even-aged Scots pine plantations into mixed forests. Transect analysis was conducted and stand characteristics at different levels were surveyed.
As a result of this, an abundant spontaneous ingrowth of *Quercus rubra* L. and *Prunus serotina* Ehrh. was noticed. The ingrowth of red oak started earlier than for black cherry. Contrasted with red oak, black cherry mainly displays a shrubby habitus. It can be stated that indirect conversion towards a red oak dominated second generation forest is perfectly possible and should start early. Autochtonous species can best be underplanted (lack of seed trees) and require protective measurements against browsing.

Introduction

Before 1000 B.C., man had already destroyed large parts of the virgin forest for different purposes (energy, agriculture, settlements). Instead came vast areas of heath lands. Natural reafforestation was prevented by the large herds of sheep grazing on the heather.
At the end of the 19th century-early 20th century, important parts of the heather were afforestated with mostly Scots pine (*Pinus sylvestris* L.) to supply the local mining industry with pit-props.

Study area : current situation

The study area is situated in northeastern Belgium, known as the Campine region. The soils are mainly dry podzolic and the climate is rather continental.
The original vegetation type for this region was an oak-birch forest (medium dense) and heath.
In the second half of the 20th century, coal mines closed down because of the high production costs. This made the pit-timber superfluous. So the rotation time became much longer (± 70 years) which gave the opportunity to the spontaneous processes to occur (e.g. natural regeneration). The last decades, social pressure on the Flemish forest increased impressively and the overall call for more natural, mixed forests became widely spread.

Case study : 75 year old Scots pine stand in the State forest "Pijnven"

History and inventory of the stand

For 4 years (1909-1912) a lupine culture was established for a better fixation of nitrogen in the soil.
In 1913, after ploughing and a fertilization with 1200 kg/ha scoria and 300 kg/ha kainite, Scots pine was planted. Total stand area is 3 ha 76 a. The total stand is surrounded by a fire belt (width : 5 metre) originally

composed out of different deciduous tree species but nowadays widely dominated by red oak (Quercus rubra L.), mixed with some pedunculate oaks, birches and black cherries. Black cherry was introduced in 1954 after a light ground preparation and a fertilization of 1500 kg/ha lime-marl. Between 1962 and 1986, 6 thinnings with a total thinningvolume of 558 m^3 (2608 stems) were removed.
To conduct the inventory of the stand 4 plots of 5 are were established. The inventory of the stand is shown in Table 1.

Table 1. Inventory of the stand.

Species	N/ha		$\bar{h}$	dbh	basal area		stand volume	
	dbh>8cm	h>2m	m	cm	m^2/ha	%	m^3/ha	%
Pinus sylvestris	220	220	20,6	29,1	14,95	70,6	134,7	80,0
Prunus serotina	80	510	8,1	6,7	1,15	5,4	2,4	1,4
Quercus rubra	340	1020	4,8	4,5	5,06	23,9	31,4	18,7
Total	640	1750	8,7	8,8	21,20	100,0	168,5	100,0

N=number of stems; $\bar{h}$=mean height; dbh=diameter at breast height

Transect analysis

The stand characteristics at different levels were surveyed. The following measurements were carried out: 2 perpendicular diameters at breast height, total tree height, height of the first living branch, height at the maximal crown width, crown dimensions, age distribution, small sketch of each tree. Furthermore, the soil vegetation and the spontaneous regeneration within the transect surface were mapped. By means of these data a visual approach was realized and basic information was gained on successional dynamics in pine plantations.
In both transects an important spontaneous ingrowth of broadleaved species under a canopy of Scots pine can be noticed.
In the first transect the upperstratum consists entirely of Scots pine in contrast with the other where some red oaks have already reached the uppermost canopy. In the middle layer, red oak dominates, accompanied with some black cherries. In the understratum, the situation is just the opposite with black cherry dominating the other species.

It is clear that the spontaneous ingrowth of broadleaved species is rather abundant. By using tree ring analysis, it appears that the ingrowth started early (especially red oak), namely when the pine plantation was only 35 years old. Its's evident that under the canopy of a young Scots pine stand only shade tolerant species are able to establish themselves. In this case red oak and black cherry are the only established species and are still the most important species who manage to regenerate themselves. Probably, red oak is originated from the fire belt and was distributed in the stand by animals like squirrels, jays,... Nevertheless, no abundant spontaneous regeneration of autochtonous species can be noticed. Several factors play an important role: light,browsing by game, ground vegetation, moisture, but the absence of seed trees seems to be decisive. Several seedlings of red oak in the transects were browsed by roedeer.

From the transects, it can be seen that red oak will dominate the future stand, although they have been living under a rather closed Scots pine

canopy. On the other hand, black cherry displays rarely a tree habitus and mostly has a shrubby outlook and will fulfil a cultural function in the future forest.
The advantages of a mixed forest are numerous. E.g., when red oak is introduced in a pine plantation, the variety in nature will increase considerably. Furthermore, the financial profits will ameliorate even if the quality of red oak is not very high. Also, recreation becomes more pleasant in a mixed forest than in an even-aged pine plantation.

Hence, management techniques can be derived out of the foregoing. Converting an even-aged Scots pine plantation into a mixed forest on basis of red oak is perfectly possible and should start early. Shade tolerant autochtonous tree species can best be underplanted because of the lack of seed trees and require also protective measurements against browsing.
For the success of the conversion, the canopy closure has to be managed very cautious.

AN EXAMPLE OF SPATIAL PATTERN VARIATION AT SMALL SCALE <u>QUERCUS ILEX</u> L. COPPICES IN SOUTHERN FRANCE

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Summary

The structural and tree mensuration heterogeneity of a *Quercus ilex* coppice in southern France (Mediterranean climate) is described and discussed at different scales with concluding remarks about the unification of european forest pattern research.

Introduction

Unification of European Forest Pattern Research should include also forests and coppices of the Mediterranean area. But these Mediterranean ecosystems often appear to have a complex spatial pattern at small scale ; we try to illustrate this point with results of a holm oak (*Quercus ilex* L.) coppice in Southern France.

The first explanation for this kind of pattern is probably the influence of man. The vegetation around the Mediterranean basin has been strongly affected by longstanding human activity (Aschmann 1973, Naveh & Dan 1973, Pons & Quézel 1985).

Many authors consider that the abundance of holm oak, an evergreen sclerophyllous tree, is solely the result of human activity over the past several thousand years, and that *Quercus pubescens* Willd., a deciduous malacophyllous tree, would be the most abundant natural species without human influence (Quézel 1981).

About 5,000 years B.P., the relative proportions of the two species reversed in favor of holm oak, whereas *Q. pubescens* had previously been dominant. It is thought this inversion of dominance was due to the fact that over these thousands of years *Q. ilex* has been more useful to man than *Q. pubescens*.

Due to this human activity, small parts (i.e. several hundred square meters) of the forests with more fertile soils have been often used for cultivation ; this creates a heterogeneity by later modifying the behaviour of the forest for a long period of time.

Another explanation is the very high heterogeneity of the karstic area where the *Q. ilex* coppices are a big part.

The soil heterogeneity is probably extended by the climatic heterogeneity. Indeed, even if the area is, for some authors, on the fringe of the mediterranean climate (Aschmann 1984), this interannual variability could increase the heterogeneity during dry years, by creating very high stresses for the vegetation on the shallowest soils.

Study area

The experimental site (250 m a.s.l.) is located 35 km NW of Montpellier (3°35'50"E, 43°44'30"N) on calcareous rocks (Floret et al. 1989). According to Emberger's classification the climate is mediterranean subhumid (annual rainfall 1 000 mm). This site appears to be representative of these southern French coppices, in which *Quercus* ilex is the dominant species. The coppice is 43 years old, the mean height of the tree crown is about 5 m, and the density of Q. ilex stems per hectare is 977 ± 71 counting stems larger than 7.5 cm in DBH. The estimated above ground biomass of Q. ilex is 65 ± 9 metric tons of dry matter/hectare. The observed part of the forest was chosen because it was apparently homogeneous.

Some results

Structural heterogeneity

These environmental factors create a heterogeneity for different points of view. The first of them concerns the vegetation structure which is very irregular at different scales (Floret et al. 1989).

An analysis of transects of two lengths (230 m and 40 m) with respectively two size of segments (5 m and 1 m) shows in the two cases a high heterogeneity of the vegetation.

The first type of transect (230 m) was analyzed by a factorial analysis based on structure criteria (e.g. stem height) and environmental factors (e.g. stone cover). The variations of axis 1 (ordinate) vs the position of the segment (abscissa) along the transect emphasize (Fig. 1a) the high variability of this vegetation which was apparently homogeneous.These variations appear also by a simple description of the canopy along the transect (Fig. 1b).

At a smaller scale (8 transects of 40 m) the factorial analysis was based on occurences of the species in vertical strata (0.5 m each of them) along the 40 segments of this transect. The results for three transects (Fig. 2) are good examples of the various behaviour which we obtain with this analysis ; any of these transects can be regarded as homogeneous according to this analysis.

Other heterogeneities

Probably linked with structural heterogeneity creating variations for environmental factors (light, evaporation, ...) other criteria are changing in this ecosystem (e.g. floristic composition, tree mensuration, biomass, ...).

Tree mensuration, as an example, has been observed in 10 plots, systematically designed, with a radius of 10 m. We give the description for density, basal area, height, and biomass (Table 1). Even if the variability level changes from one criteria to another (the minimum is for the height), the range of variation is quite large. The extrapolation of such observations must therefore be done carefully and the comparison with heterogeneity of another ecosystem is difficult to do.

Concluding remarks

Looking at these results some questions arise : is the site which was chosen "apparently homogeneous" well representative of Quercus ilex coppices in the region ? In order to answer to this question we sampled 103 plots strictly at random in Q. ilex coppices in an area of about 40 Km by 80 Km. The percentage of clearing (Fig. 3) in each plot shows that only 20 % of the plots are without clearing. There is no evidence that these coppices are more homogeneous than in the Puéchabon site.

With this example we attempt to emphasize the difficulties of a unification of pattern description and analysis.

First of all it is necessary to take into account different scale of observation. This is evident in the case study which we have described here and moreover evident also if we try to compare this ecosystem pattern with other ecosystems outside the Mediterranean climate area.

Nevertheless it is perhaps possible to improve the unification of the methods to describe and analyze the vegetation structure. The diversity of the methods used is actually very high and the comparison of the results in different sites is quite impossible.

It was clear to see the diversity during the symposium on quantitative structural analysis of forests (Chessel 1979). The numerous methods of describing the structure and data processing of these observations often prevent the authors from comparing the homogeneity pattern of the studied ecosystems.

As an example, for vegetation pattern description, several means were used : grids (David et al. 1979, ...), transects (Walter 1979a, ...) or other (Oldeman 1979, Walter 1979b). The mathematical methods were also very numerous : factorial analysis, mathematical morphology (Bachacou et al. 1979, ...).

We should avoid falling into the trap of having only one method to describe the pattern of all forests including coppices, but nevertheless improve the quality of the result comparisons.

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Table 1. Variations of some tree mensurations for 10 plots in the experiment station of Puéchabon (after Floret *et al.* 1989).
(Number between parentheses indicates the relative value, in per cent)
ø = DBH (cm) at 1.30 m N = Number of stems per hectare
$G_{1,30}$ = Basal area ($m^2\ ha^{-1}$) at DBH
H = Stem mean height (m), for stem ø > 7.5 cm
B = Above ground biomass (dry matter ; $Mg\ ha^{-1}$ or metric tons ha^{-1})

	N ø 4.5-7.5	N ø > 7.5	$G_{1.30}$ ø 4.5-7.5	$G_{1.30}$ ø > 7.5	H ø > 7.5	B $Mg\ ha^{-1}$
Plot 5	4 170	923	11.66	6.35	4.7	77.9
(%)	(145)	(94)	(145)	(99)	(101)	(120)
Plot 6	2 610	1 273	7.09	8.08	4.7	67.3
(%)	(91)	(130)	(88)	(125)	(101)	(104)
Plot 7	2 992	573	8.39	3.58	4.4	54.0
(%)	(104)	(59)	(104)	(56)	(94)	(83)
Plot 8	2 928	700	7.93	4.60	4.6	58.0
(%)	(102)	(72)	(98)	(71)	(99)	(87)
Plot 9	2 833	987	8.10	5.95	4.8	63.4
(%)	(98)	(101)	(100)	(92)	(103)	(98)
Plot 10	1 973	987	5.77	6.32	4.3	48.8
(%)	(68)	(101)	(72)	(98)	(92)	(75)
Plot 11	2 706	923	7.91	6.20	4.9	66.4
(%)	(94)	(94)	(98)	(96)	(105)	(103)
Plot 12	3 120	1 305	8.62	8.21	4.7	71.4
(%)	(108)	(134)	(107)	(127)	(101)	(110)
Plot 13	3 088	1 050	8.51	8.23	5.0	78.7
(%)	(107)	(107)	(106)	(128)	(107)	(122)
Plot 19	2 388	1 050	6.65	6.89	4.6	60.7
(%)	(83)	(107)	(82)	(107)	(99)	(94)
Mean	2 881	977	8.06	6.44	4.7	64.7
St. Dev.	543	213	1.41	1.45	0.2	9.2

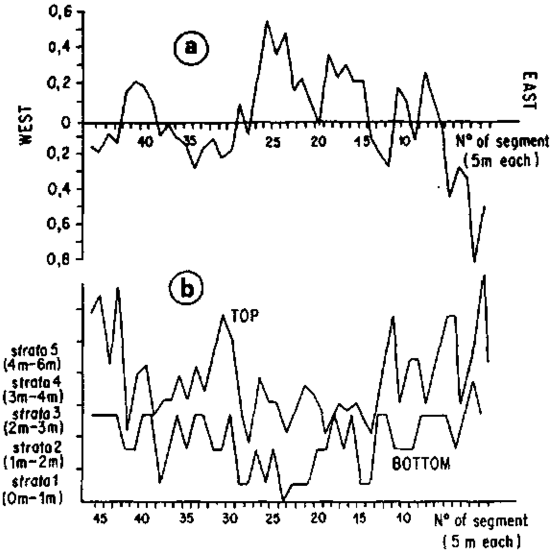

Fig. 1. Horizontal and vertical pattern of the transect n° 2 (230 m)
(a) Factorial analysis ; axis 1 along the transect
(b) descriptive profile of the canopy.

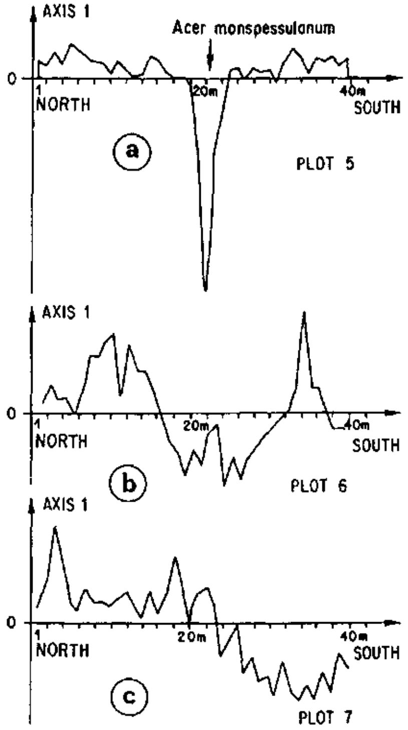

Fig. 2. Factorial analysis for 40 m transect.
(Plots 5, 6, & 7) ; axis 1 along the transect.

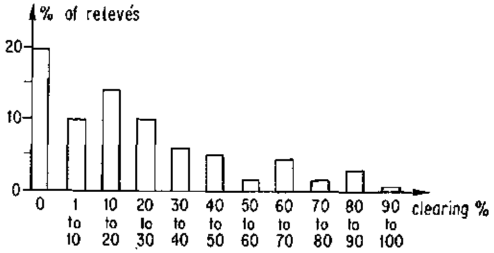

Fig. 3. Distribution of the clearing percentage in 103 plots of Quercus ilex coppice in a large area.

STUDY OF AN ALLUVIAL FOREST THROUGH LANDSAT TM DIGITAL DATA PROCESSING : THE ERSTEIN FOREST, RHINEGRABEN PLAIN (ALSACE, FRANCE).

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Summary

The Erstein alluvial forest grows in the Rhinegraben plain, on Holocene fluvial deposits made of gravel bars and clayey-loamy channels. Digital processing of Landsat TM data from 30th July and 18th October 1984 yield two series of results : 1. by a Principal Component Analysis, a PC related to the soil wetness : it separates humid and seeping areas. 2. by a Stepwise Discri-minant Analysis on seven bands plus the PC "wetness", a vegetative ground cover classification.

Keywords : alluvial forest, Remote Sensing, Rhinegraben plain, Alsace.

Introduction

The Erstein alluvial forest (about 20km on the South of Strasbourg) grows in the Rhinegraben plain, on Holocene fluvial deposits made of gravel bars and clayey-loamy channels. There is no detailed map of these alluvial formations : geomorphological mapping is not easy in such an environment. Therefore we tried to give a first approach about the relations between the forest and its site through Remote Sensing data processing. We had at our disposal two Landsat TM CCTs (30th July and 18th October 1984); the data were processed using the CARTEL Software Package (Hirsch & Schneider 1983). This work is part of a research project financed by the Groupement Universitaire de Recherches sur l'Environnement (GUREN) at the Université Louis Pasteur, Strasbourg.

Methods and results

Landsat TM data own numerous qualities : a good spatial resolution (30 x 30m pixels) and a large radiometric spectre : seven bands, from the shortest visible (0.45 to 0.52µ) to the thermic one (10.40 to 12.5 µ). To take advantage of these radiometric performances we prefer to use multivariate statistical methods rather than a simple three-band colour composite image which is useful only for visual interpretations.

By processing a set of six TM bands (excluding the thermic one) through the Principal Component Analysis (PCA), we extracted three interesting factors : the first one (PC1) is generally interpreted as a brightness equivalent; PC2, opposing bands 3 and 4, may be considered as an equivalent of the vegetation index. The most interesting one for our purposes is PC3 : it shows an opposition between the medium infra-red bands (5 and 7) and the visible ones, mainly band 1. According to former results (Vogt 1987, Schneider & Vogt 1988) we consider that this PC provides a good information concerning soil wetness. This PC component has the great asset of being independent from vegetal cover.

Colour composite image made of the three PC scores is an interesting picture, showing the areal variations in vegetal, geomorphological and hydric features. Nevertheless, the best results are obtained from the October CCT processing; at this date the meteorological conditions preceeding the satellite record were better than in July (ten days of sunny, warm weather in October, contrasting with a series of heavy rains in July). Therefore, the picture of PC3 scores for the October date shows a better contrast between wet (loamy) soils and seeping (gravelly) soils.

From this factor scores colour composite image we chose training samples for classification. We retained at least one training sample for each surface type. Classification was performed by Stepwise Discriminant Analysis (BMDP Statistical Software), using in a first attempt the seven TM bands (July 1984). After a series of experiments, we obtained 15 classes (11 forest groups, 2 meadows groups, bare soils, water). For a better display of the relations between the forest cover and its site, we added to the seven TM bands the PC3 obtained by performing a PCA on October data. In such a manner the grouping of different classes was improved. The forest classes are associated in four forest types : a dense alluvial Rhine forest growing on wet soils (paleo-channels); a less dense (partially copsed) Rhine forest growing on gravelly soils; a wet Ill forest on fine alluvial terrace deposits; a dense Ill forest on gravelly terrace deposits. This classification is

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- ■ 1. Spruce-fir ; mixture of vegetation and water
- ■ 2. Dense forest on wet soils (clayey-loamy channels)
- ▩ 3. Dense forest on seeping soils (gravel bars)
- ▨ 4. Poplars
- ▒ 5. Meadows and cultures
- ░ 6. Bare soils
- 7. Water.

Fig. 1. Classification through Stepwise Discriminant Analysis of seven Landsat TM bands plus factor three (PC 3) obtained by a Principal Component Analysis. Date: 30 July 1989. Scale 1 : 50 000.

not a botanical or an ecological one, but a statistical expression of radiometric data processing.

Conclusion

This is only a first approach. The ground-truth is not easy to check, because the meaning of the infra-red radiations is not obvious. It is an integration of known and unknown physical cha-racters, therefore we have to consider it as a step for a better knowledge of environment, if we use it as a working document, not as a final picture.

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ARCHITECTURE AND GEOMETRY OF AN ALLUVIAL FOREST CANOPY ALONG THE RHINE

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Keywords:alluvial hardwood forest,architecture,canopy openness,eco-unit, forest dynamics,forest mosaic,geometry, hemispherical photographs, leaf area index,mean leaf angle,patch,phase,phenoseason,profile diagram,skylight,structure,sunfleck,system hierarchy.

Introduction

A study was conducted in a temperate deciduous mixed forest to assess the Photosynthetically Active Radiation regime (interception,penetration), in relation to canopy structure and dynamics.Only structure is emphasized here.

By structure is meant 1)architecture,a morphological and developmental concept, which analyses the growth dynamics of individual plants,as well as their spatio-temporal arrangement within the patchy network forming the forest mosaic,2)geometry, a physical approach based on the quantitative distribution of organs like leaves, trunks,allowing mathematical modeling of radiative transfers and ecosystem processes.

The question is how to merge these approaches to explain 1)radiation environment experienced by species in relation to forest architecture and dynamics, especially for the ecophysiology of forest species and management,2)energy exchanges at the forest/atmosphere interface and the monitoring of biosphere resources (Hutchison & Matt, 1977)?

Study Area

The study plot was located in a small remnant of hardwood alluvial forest,about 30 km South of Strasbourg (lat.48°25' N,long.7°45' E,alt.149 m) in the braided stream zone still with a steep slope (0.07-0.05%),on well drained gravel and sandy loam river banks,characteristic of the middle course of the Rhine.Flooding was stopped in the late sixties.The vegetation structure of this old-growth farm forest (Querco-Ulmetum) has been strongly influenced by selective cutting.The canopy displays heterogeneous features,both structural and floristic.It shelters some of the richest dendroflora of Europe.The floor is covered with a dense brush of Equisetum hiemale.The area (some 100ha) is now protected as an alluvial forest reserve (Carbiener et al.,1985;Walter,1982).

Theory and methods

The patchy functioning of forests,the patch being the spatial equivalent of the phase,is still poorly understood.In this study,a hierarchic system was used,involving different interactive levels of organisation and functioning,on the same homogeneous site (Oldeman,1989):
1)silvatic unit (succession mosaic p.p.)
2)chrono-unit (forest mosaic)

3)eco-unit (innovation,aggradation,biostatic and degradation phases)
4)components (functional compartments:potential trees, trees of the present,trees of the past).

Although unrealistic,due to grouping effects,random canopy models were used to assess leaf area index and mean leaf angle:
1)Bonhomme's method,assuming uniform distribution of leaf angles,
2)Suit's extremophile model, using vertical and horizontal projections of leaf areas,
3)an adaptation of Miller-Lang's approach,based on the transmission of solar beam radiation (Bonhomme,1973;Jupp et al.,1980;Lang,1986).

A vertical profile diagram was elaborated and a 10x120m transect was mapped to reveal the forest mosaic status on the river bank.This architectural analysis was only partially carried out.It mainly served as a basis for ascertaining the amount and distribution of openings,leaves, trunks,sunfleck dynamics and the penetration of uniform skylight.

Hemispherical photographs were taken at floor level,during fully leafed summer and leafless winter phenoseasons.The sampling procedure,despite using regular intervals,paired photographs 1m away,every 10m along the transect,was always strongly related to the forest mosaic pattern.Their computation required the solving of systems of equations,regression techniques and eigen-analysis,which gave useful statistics,not however presented in this study.

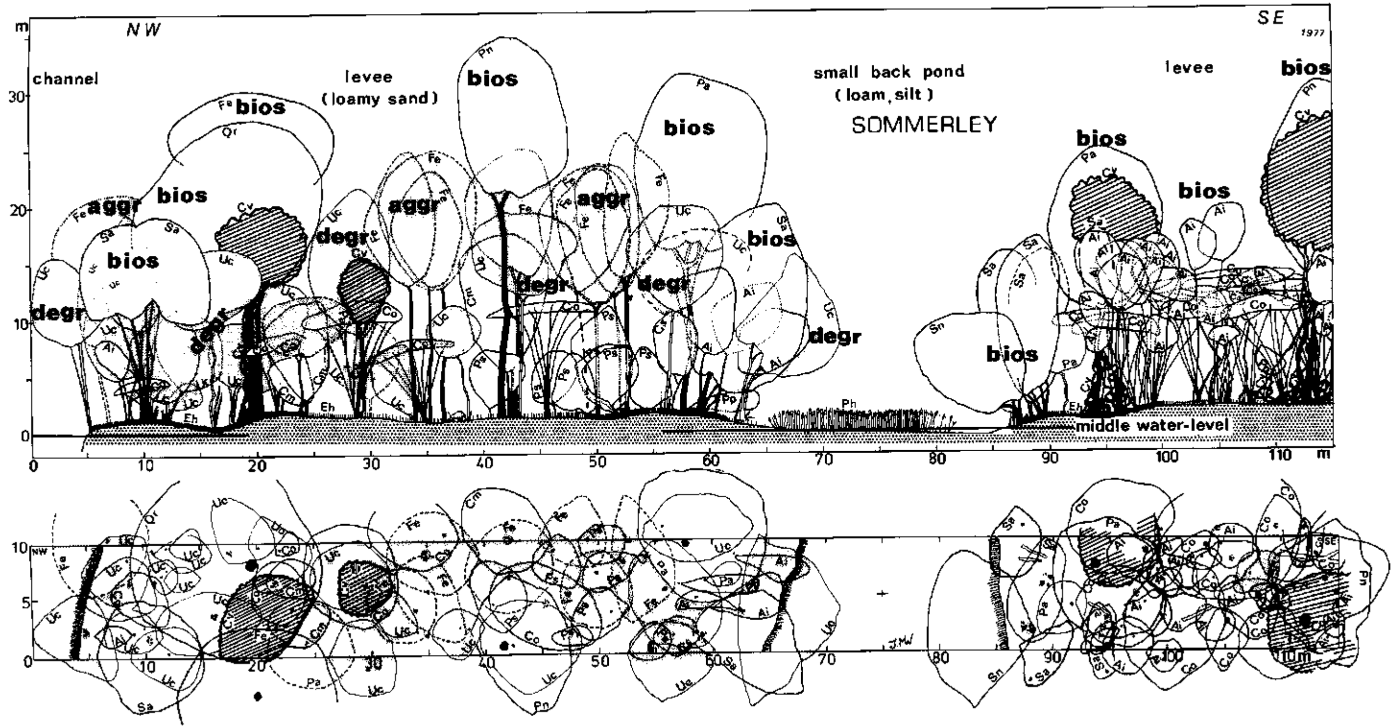
Results and conclusion

The profile, graphs and Table 1 are self-explanatory.Each graph represents the average of a pair of photographs.Although at least 19 intertwining patches were identified,from the river banks to the forest interior,the lack of tree-ring data prevented more detailed analysis of eco-unit limits and forest development.It is important to recognise different scales of heterogeneity in forest structure,in order to adjust observations to them.For example,radiation regimes in a gap,under canopies of Populus,Quercus,or Corylus,will be quite different,which brings out the importance of species composition and stand development.

Not only the quantity of foliage and trunks,but also the architecture and the arrangement of tree crowns are of prime interest in explaining the distribution of radiation reaching different microsites in the forest (Torquebiau,1987).Due to the wide spatial integration of hemispherical photographs and the short distances between them,these results should be interpreted as the outcome of "ecological interferences" (Oldeman,pers. com.).Further investigations are needed on these lines.

Fig. 1. Architectural profile of the river-bank forest.Vertical diagram with trees above 5cm dbh.Horizontal plan of stems and crowns.Thick lines:trees of the present.Closely dotted and shaded:potential trees.Fine lines and shaded:trees of the past.Thick lines and dashed:liana crowns. Eco-units:aggr,aggradation;bios,biostatic;degr,degradation phases.

Ai Alnus incana (L.) Moench.,Cm Crataegus monogyna Jacq.,Co Corylus avellana L.,Cs Cornus sanguinea L.,Cv Clematis vitalba L.,Eh Equisetum hiemale L.,Fe Fraxinus excelsior L.,Pa Populus alba L.,Ph Arundo phragmites L.,Pn Populus nigra L.,Pp Prunus padus L.,Ps Prunus fruticans Weihe,Qr Quercus pedunculata Ehrh.,Sa Salix alba L.,Sn Salix nigricans (Sm.) Enander,Uc Ulmus campestris L.


NW
SE
1977
SOMMERLEY
channel
levee
(loamy sand)
small back pond
(loam, silt)
levee
bios
aggr
degr
middle water-level
m
0
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J.M.W.

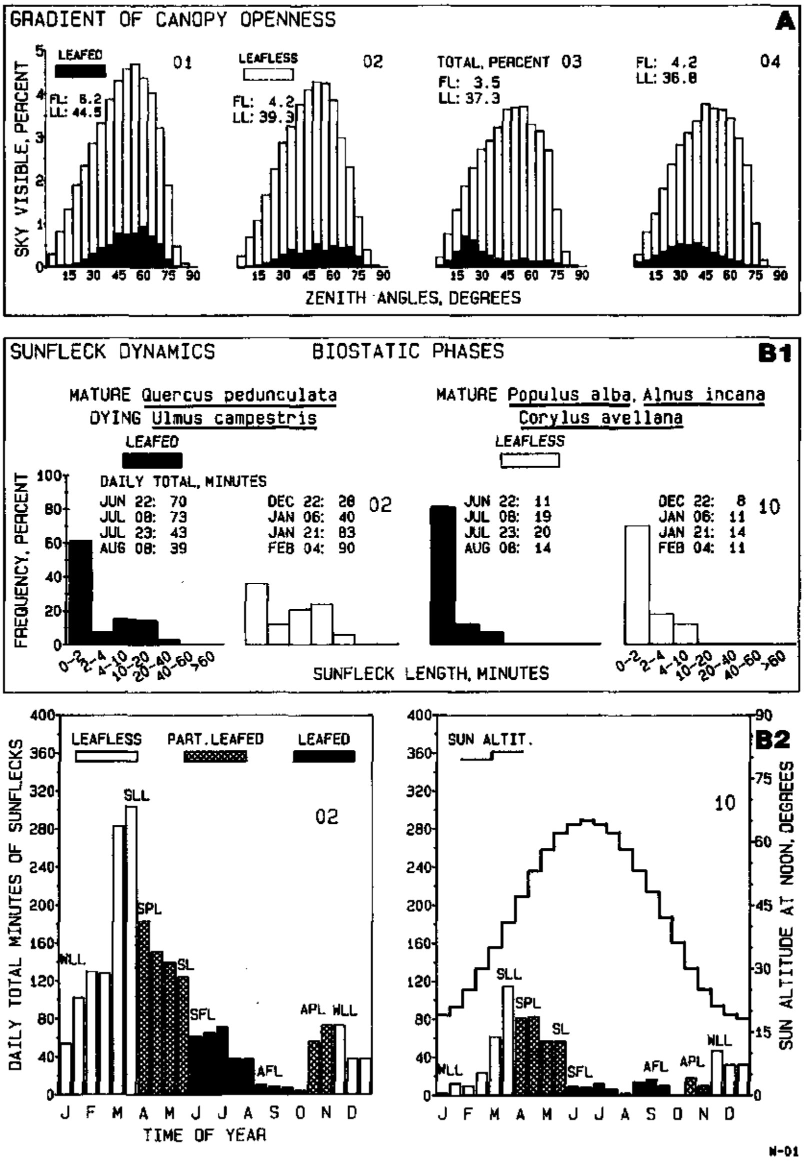

Fig. 2. A:Canopy openness during leafless (LL) and fully leafed (FL) periods,after polar projection of hemispherical photographs.Percent open sky,based on area only.B:Sunfleck dynamics.B1:Analysis of solar tracks. Histograms of sunfleck length (minutes) and daily total minutes of direct irradiance for leafless winter and leafed summer periods.B2:phenoseasons and daily duration of sunfleck activity,each fortnight.

WLL:winter,leafless;SLL:spring,leafless;SPL:spring,leafing;SL:summer, leafing;SFL:summer,fully leafed;AFL:autumn,fully leafed;APL:autumn,partially leafed.

Table 1.Geometric properties of a hardwood alluvial forest canopy.

	Canopy openness % 1)	Diffuse light 2) penetr.%	Daily total minutes of sunflecks 3)	Plant area index			Mean foliage angle 5)	
				Bonhomme	Suits 4)	Lang	Suits	Lang
Forest interior (n = 14)					Total			
I	3.2± 1.4 6)	5.4± 2.2	32.4± 14.8 (11 - 73) 7)	3.3± 0.5	3.4± 0.3	4.0± 0.5	20.9± 13.1	27.5± 11.8
				Stem area index			Mean stem angle	
II	29.3± 10.1	47.4± 14.3	29.3± 20.9 (5 - 90)	1.0± 0.4	1.4± 0.5	1.3± 0.5	78.2± 11.8	70.2± 10.5
			LAI	2.3	2.0	2.7		
Forest edge (n = 6)					Total			
I	6.6± 1.4	10.6± 2.5	70.0± 35.3 (31 - 121)	2.5± 0.3	2.8± 0.2	3.2± 2.3	25.1± 15.1	27.3± 23.5
				Stem area index			Mean stem angle	
II	38.2± 5.8	60.3± 6.5	42.9± 26.2 (11 - 91)	0.8± 0.2	1.0± 0.2	1.0± 0.2	80.7± 5.0	62.9± 15.5
			LAI	1.7	1.8	2.2		

1)area basis 2)uniform overcast sky 3) I fully leafed period:Jun 22,Jul 8 and 23,Aug 8;II leafless period:Dec 22,Jan 6 and 21,Feb 4 4)authors of canopy models 5)degrees above horizon 6)standard deviation 7)range

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Landscape and crown pattern of an alluvial forest along the Rhine, Île de Rhineau, Alsace. Photo: J.-M. N. Walter. June 1976.

GROWTH AND DEVELOPMENT OF SCOTS PINE IN THE NETHERLANDS

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Summary

By means of multiple correlation growth formulas are derived and a growth simulation programm has been written in "C-language". With this programm growth of individual trees can be simulated based on planting distance, site-index value (= S-value) per tree, age and thinning regime. The output results in a yield table per tree and a picture of the stand.
Keywords: growth model, structure, stand picture, modal transect, thinning regime, Scots pine.

Prologue

With the introduction of a long term forestry plan in the Netherlands as a result of a 1986 government decision, suitable conversion methods from an existing forest type to a chosen forest utilisation type received more attention. The incomplete and often inaccessible knowledge about tree behaviour in specific circumstances impede the development of such methods. Stand growth and development often are described by yield tables, which give an idea about mean wood production, mean diameter and mean height of a closed stand at certain age. But yield tables neither give information about competition factors between trees, nor about forest structure, nor about yield data of open or mixed stands.

To get more insight in these matters parameters probably defining growth and dynamics of individual trees are investigated. These parameters are quantified with collected field data to construct a computer programm simulating growth of individual trees in modal transects (Leersnijder & Boeijink, 1987). Preliminary results for even aged *Pinus sylvestris* stands are shown.

Field experiment

Growth and dynamics of individual Scots pine trees are studied in several stands of different ages representing different growth stadia. As production stands of Scots pine in the Netherlands will mainly be planted on humic podzols, all test plots are situated on this soil type.

In each stand four median basal area trees, four "future trees" and two till four less common trees are sampled.

Parameters of standing trees

Collected data per tree are height, diameter at 1.3m (dbh), crown length, crown projection, stem distance to relevant neighbor trees, height of neighbor trees, dbh of neighbor trees, points of crown contact of neighbor trees with the sample tree and a picture.

Parameters of felled trees

From some felled trees volume and branch diameters at different places in the crown have been measured.

Formulas

For the weighted value of half a stem distance (a) in the direction of the neighbor tree applies:

$$a_i = \frac{h_o^c}{h_o^c + h_i^c} * A_i$$

h = height,
o = sample tree.
i = neighbor tree.
A = stem distance between sample tree and neighbor tree.
c = a constant.

The corresponding growth area is $\frac{1}{2} a_o^2 \sqrt{3}$.

Height growth is described by the Chapman-Richards formula:

$$hdom = S(1-e^{-c1t})^{c2}$$

hdom = top height.
S = site-index.
t = age,
c1, c2 are constants.

By means of multiple correlation formulas have been derived for diameter (d), crown length (cl) and crown width (cw).

$$d = t^{p1}.h^{q1}.(2a)^{r1}.s1$$

$$cl = t^{p2}.h^{q2}.(2a)^{r2}.s2$$

$$cw = t^{p3}.h^{q3}.(2a)^{r3}.s3$$

p1, q2, r3, s2 etc. are constants,
2a = weighted stem distance.

Translating these formulas to growth formulas results in:

$$de = db.(te/tb)^{p1}.(he/hb)^{q1}.awe/awb)^{r1}$$

$$cle = clb.(te/tb)^{p2}.(he/hb)^{q2}.(awe/awb)^{r2}$$

$$cwe = cwb.(te/tb)^{p3}.(he/hb)^{q3}.(awe/awb)^{r3}$$

$$he = hb.[(1-e^{-c1te})/(1-e^{-c1tb})]^{c2}$$

de = diameter at the end of a period,
db = diameter at the beginning of a period.

In these growth formulas the weighted value of half a stem distance at the end of a period (awe) is:

$$awe_o = minimum(ae_o+ae_i-amaxe_i, amaxe_o)$$

$$amaxe = ab * [(clb+he+hb)/clb]^{1/r} * (te/tb)^{-p/r} * (he/hb)^{-q/r}$$

The Growth Simulation Programm

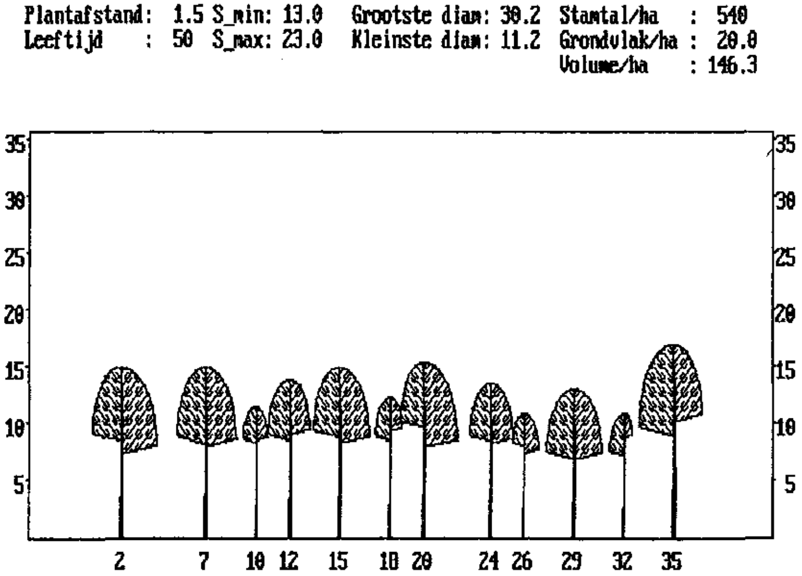
With the above growth formulas a growth simulation programm has been written in "C-language". This programm asks the user the following questions:

- which is the original planting distance?
- which is the maximum and minimum height a tree can reach? (The programm calculates a random site-index value per tree following a normal distribution and at a confidence level of 95%),

* (First picture is shown on the screen. The stand is 2 years old)

- at which age do you want to see the stand?
- how many trees do you want to cut?
- which trees do you want to cut?
- do you want to simulate natural dying or not?

An example is given here for a stand with a minimum site-index value (S_min) of 12 and a maximum site-index value (S-max) of 21 meter. The original planting distance is 1.2 meter.



```
Plantafstand: 1.5 S_min: 13.0  Grootste diam: 30.2 Stamtal/ha   :  540
Leeftijd    :  50 S_max: 23.0  Kleinste diam: 11.2 Grondvlak/ha :  20.0
                                                   Volume/ha    : 146.3
```

Sample of a picture constructed by the computer programm.

Three thinning methods are presented, crown thinning, low thinning and no thinning. Natural dying occurs when tree height divided by crown width is more than six.

Conclusion

The derived growth formulas are well suited to construct a growth model. With this model growth of individual trees can be simulated based on planting distance, site-index value (= S-value) per tree, age and thinning regime. Growth performance according the formulas (used in the model) results in a mean growth under given circumstances. The model gives a good idea of the forest structure. When more is known about growth parameters and their influence on other tree species simulating growth of mixed stands will probably be possible. With such a model any pattern can be simulated.

The given growth formulas can not simply be used for real trees. Namely when we measure parameters like crown length, crown width and diameter beside height and stem distances, it is unknown what part of the growth area the individual tree is really using. In some cases diameter, crown width and crown length can be larger than statistically possible. This results from the measuring and calculating method, assuming all trees having the same growth rhythm depending upon the S-value. In my opinion it is impossible to derive growth formulas that return the exact growth of individual trees of unknown history.

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GRIDS AND NATURAL LIMITS IN FOREST ECOSYSTEM RESEARCH

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Facts established

1. On a single image, pixel size is not variable and quite often is not in accordance object size, which indeed is variable. Besides, the object will only become "really" visible on the map when more than one pixel covers it. See fig. 1.
2. Pixels crossing borderlines are counted as an "average" of both sites. These hybrid pixels veil information, particularly along these most interesting lines (limits). See fig. 1.
3. Blending small pixels into larger ones leads to pattern-information loss due to averaging. See fig. 1.
4. Scaling down of profile drawings leads to loss of detail, but the borderlines between architecturally defined units remain clear. See fig. 2.
5. Special qualities can be segregated and depicted separately, either by reduction or -if necessary- by averages over pixel surface. See fig. 2.
6. It is not possible to solve the riddle of either the planting design or the grid with a variable pixel size coming first [chicken or egg?]. See fig. 3.
7. In this case the variability of the pixel size has a meaning only for two dimensions [length and depth] but not for the third [heigth]. See fig. 3, profile diagram.

General conclusion

The temporal and spatial delimitations of system architecture and of its architecturally defined subsystems on a map can be done meaningfully only by defining pixel size in regard to

1) the system's architecture to be assessed;
2) the subsystems to be used for explanation of the system;
3) the scientific questions to be solved.

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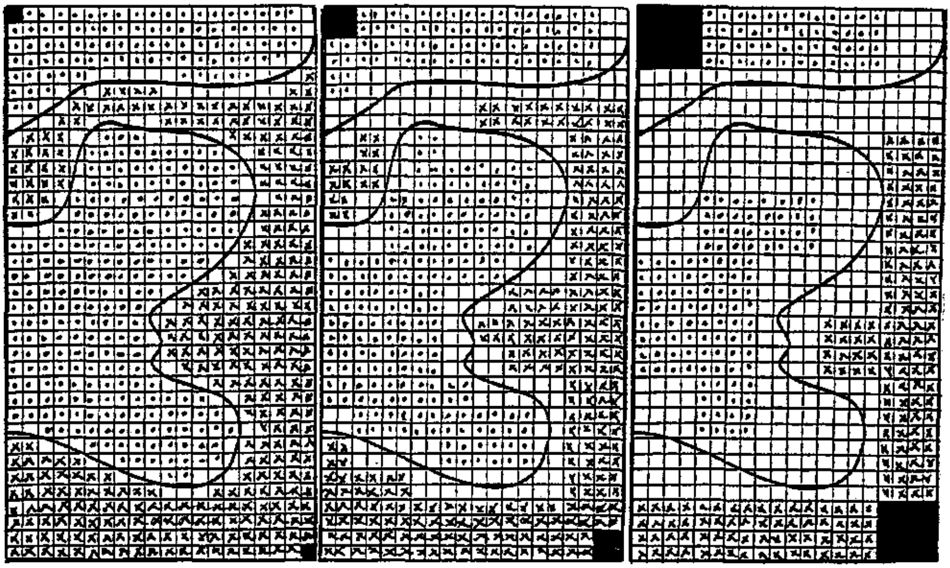

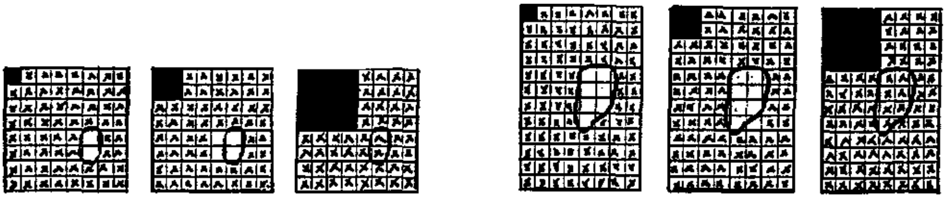

Fig. 1, above : Diagram of pattern-information loss along borderlines (limits) due to blending small pixels into larger ones. Flowing line indicate limit as may be seen by the human eye. Pixels marked by a full stop : left of borderline; pixels marked by a cross : right of borderline; white pixels on borderline. Pixel size enlarged from one to four to sixteen squares, see black squares.

Fig. 1, below : Diagram on changes in pattern-information on small objects due to blending small pixels into larger ones. Flowing line : object. Pixels marked by cross : more than half of the pixel surface is outside the object; white pixels : more than half of the pixel surface is inside the object. Pixel size enlarged from one to four to sixteen squares, see black squares.

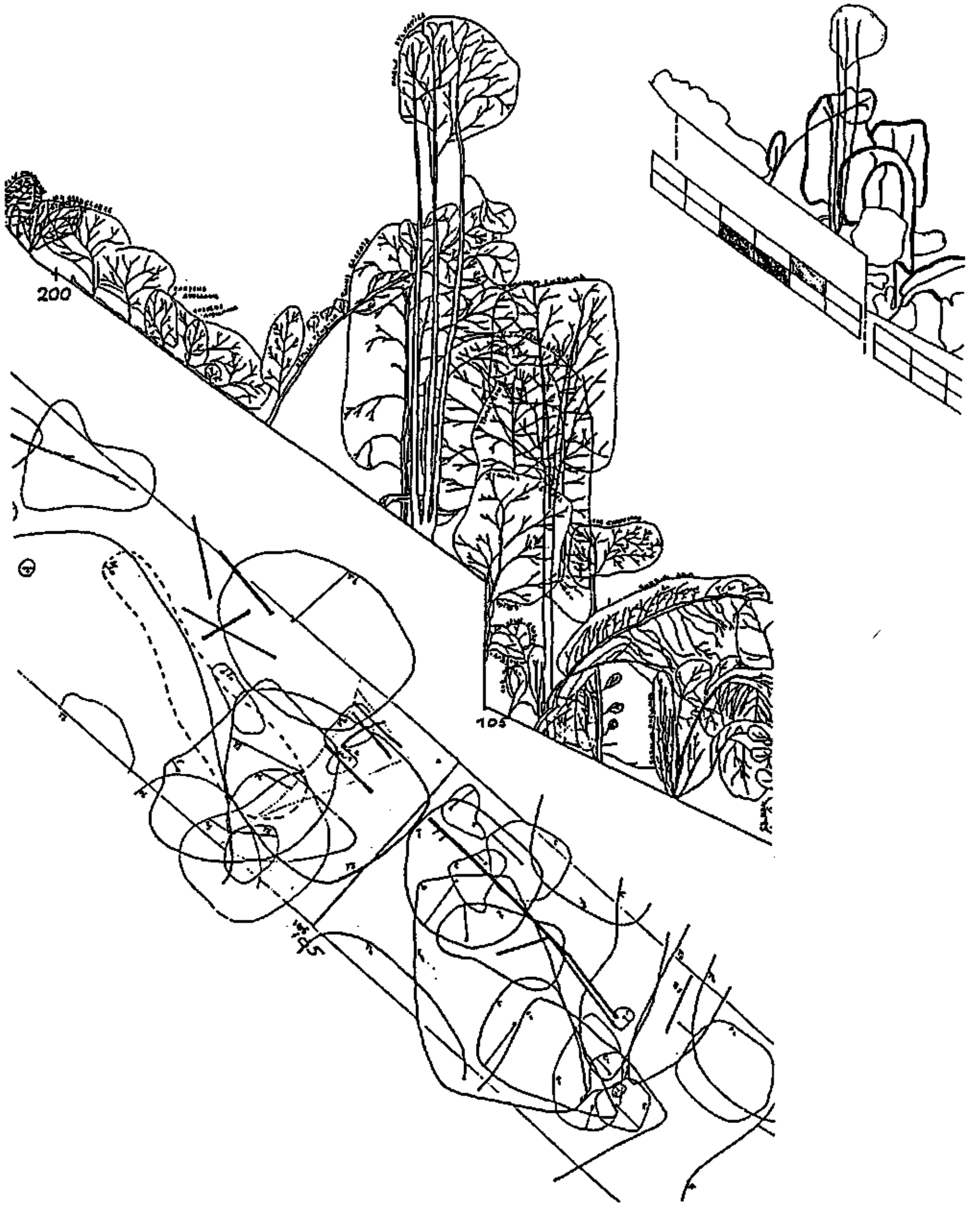

Fig. 2. Lady Park Wood, United Kingdom.

Profile diagram and crown projection map [original scale 1 : 200] as drawn for transect analysis and (top right) version reduced in the laboratory [originally to scale 1 : 450] with below an indication of the occurrence of natural regeneration of tree species (pattern in the bars). Source : Bartelink et al., 1987

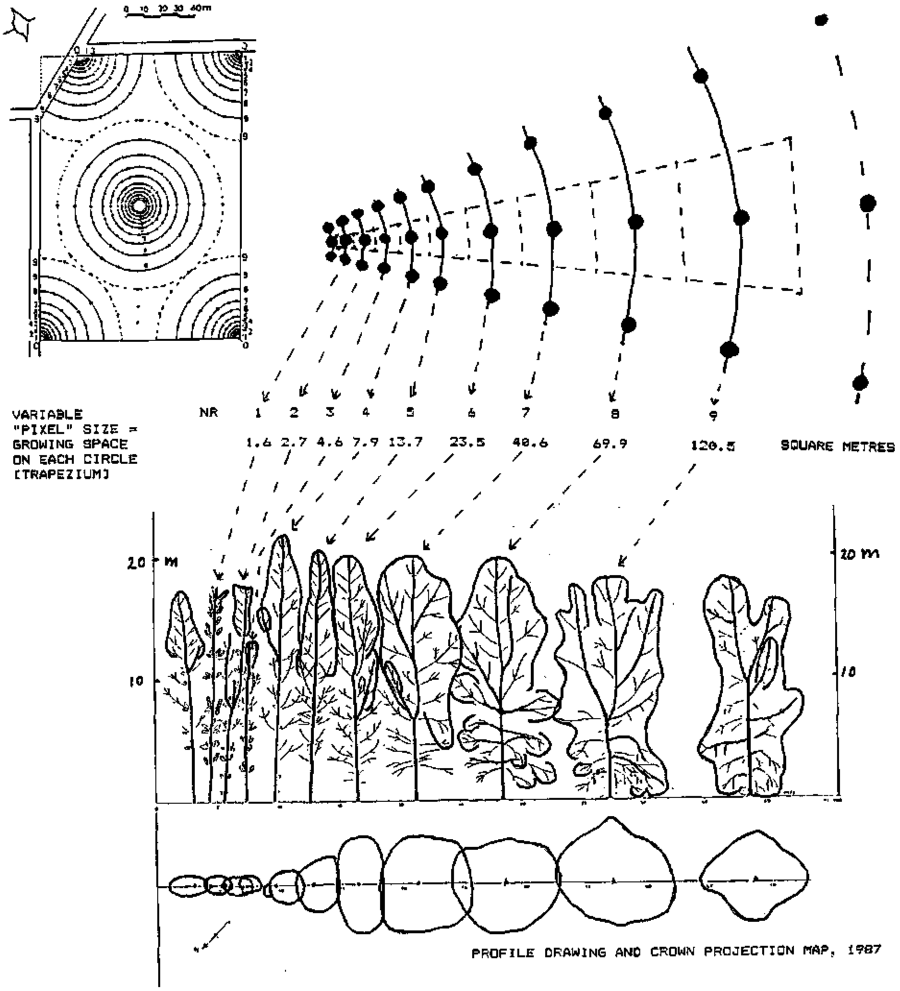

Fig. 3 : Nelder spacing trial with *Populus x euramericana* cv Rap, the Netherlands

Planting design (top left), growing space (trapezoid, striated lines; area in m2) on each planting circle (top center) and profile diagram and crown projection map (original scale about 1 : 300) (bottom) at age 13.

Source : Faber, 1985 & Schmidt, 1989
Courtesy : H. Ruissen & S. Habic.

STRUCTURAL ANALYSES OF SCOTS PINE STAND FOR PROCESS BASED STAND GROWTH MODELS

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Summary

Structural analyses can provide information on the light interception properties of trees and on the regularities in tree form. For such purposes a tree should be divided into functionally different biomass compartments. The dimensional properties of such compartments and regularities of the the dimensions between compartments should be analysed. The experimental design should be hierarchical consisting of different levels from stand level to needle level. The sampling should be performed so that generalizations from higher lever of hierarchy to lower one would be possible.
Keywords: structural analises, light interception, structural regularities, biomass compartments, hierarchical sampling

Introduction

It has been shown for many agricultural plant species that the total annual biomass production is linearly proportional to the amount of light intercepted (Monteith 1977, Legg et al. 1979). Similar determinations for forests are still lacking (Linder 1987). Especially the carbon consumed on the below ground parts of trees is problematic to measure (Santantonio and Grace 1986). However, Kellomaki et al. (1979) have observed a linear relationship between photosynthesis as estimated from light measurements and above ground growth of individual trees, which would suggest a similar relation to exist for woody plants as for agricultural species.

Several environmental factors affect the total biomass production of a stand. The length of the growing season and temperature, water and nutrient availability being the most important together with the light climate. Factors such as drought and nutrient deficiencies can cause substancial differences in the momentaneous rates of photosynthesis (eg. Korpilahti 1988, Linder and Axelsson 1982). However, several studies would suggest that substantial changes in the total productivity are caused by the changes in the stand leaf area (eg. Lassoie et al. 1987, Linder and Axelsson 1982, Linder 1985, Linder et al. 1985). As shown in the Swecon studies in Sweden, the irrigation and fertilization treatments have considerably changed the carbohydrate partitioning in trees (Linder and Axelsson 1982, Linder 1987). However, the mechanisms bringing about the partitioning are still somewhat poorly understood.

One possibility to derive information on the carbohydrate partitioning is to examine the structural regularities of trees and investigate which implications these have on the carbohydrate partitioning. The regular structure of trees have received attention of investigators for a long time and different theories on the form of trees have evolved (Assman 1970, Zimmermann 1983). Most attention have received the mechanical stress explaining the stem form (eg. Metzger 1893, (according to Assman 1970), Ylinen 1952) and the pipe model theory (Shinozaki et al. 1964) which focuses mostly on the water transport requirement. The latter has been more recently modified by Tyree et al. (1985) to correspond better the detailed observations of hydraulic architecture of trees (Zimmermann 1983, Ewers and Zimmermann 1984, Tyree et al. 1985).

Valentine (1985), Hari et al. (1985) and Makela (1986) have examined the implications of pipe model theory on the carbon partitioning. The results of such practises in providing to some degree functionally based description of carbohydrate partitioning are promising. The simulated dynamics of partitioning in trees growing in stands resemble those few observations made (Hari et al. 1985, Albrektsson and Valinger 1985, Mohren 1987, Nikinmaa and Hari (manuscript)). On the other hand Albrektsson and Valinger (1985) concluded that the changes in the observed growth are a response to mechanical stress.

Long et al. (1981) observed that assumptions of the pipe model theory are sufficient to explain the mechanical support requirement in small trees. In large trees they, however, observed that additional growth of stem takes place to satisfy the mechanical support requirement. More recent studies would suggest that there is variation in the leaf area:sapwood area ratio between stands on different site conditions or growing densities (Espinosa et al. 1987, Keane and Weetman 1987, Long and Smith 1987), which can be explained by the increase of the total sapwood area (Long and Smith 1987).

Structural analyses can provide information on both the amount of leaf area and its distribution within a crown and canopy and on the regularities of tree form and their variation in different growing conditions. Combining these observations with process determinations of photosynthesis and respiration and meteorological data on light, temperature and vapour pressure deficit, the minimum information needed for process based stand growth model can be adquired.

Structural analyses

The structural analyses can be seen to have two main objectives: 1) The description of light climate at various levels within the stand and 2) The description of the structural regularities of trees. For these purposes it is convenient to divide the study objects into different compartments. In Scots pine these compartments could be a) needles, b) new shoots, c) branches, stem and transport roots and d) fine roots.

The needle level measurements would consist of needle area and needle biomass determinations of needles grown in different environmental conditions (within a stand in different light conditions).

The shoot level measurements would be mainly to determine the light capturing properties of shoots, but also to investigate the carbohydrate consumption on formation of the structure. The measurements would include determinations of average needle length and needle angle, number of needles per shoot and the total needle biomass of the shoot, the shoot lenght and the average shoot diameter or cross-sectional area and the shoot wood density. The shoot level information would also need to include the number of new shoots in a branch and their forking pattern.

At the transport structure level the main intrest is on the structural regularities between foliage and sapwood at different points in the transport path from shoots to fine root and on the other hand on the amount of hartwood and how this depends on the position in the transport path and the senescence of needles. The measurements involved are determinations of cross-sectional areas at different branching levels in branches and at different heights along the stem and foliage biomass and area measurements above the points of the cross-sectional area measurements.

The measurements should be both total sapwood area needle biomass or area determinations as well as measurements on needle biomass changes and sapwood area changes. The latter would provide us with information on the senescence of sapwood into heartwood together with lenght and whorl number determinations of non-needle bearing parts of the trees. Combined with these analysis the average density of wood should be measured at different heights along the transport path. At the same time a more detailed analyses on average tracheid size could be performed.

The measurements at fine root level are the most difficult and cannot be made for individual trees but they have to involve the whole stand. However, the compartment flow model suggested by Santantonio and Grace (1987) offers a possibility to estimate the fine root production and mortality at the stand level. The actual measurements consist of biomass determinations of living and death fine root fractions from repeated soil core sampling in the experiental stand.

The measurements made at different levels from sample trees should be generalized over the stand, and a possibility to generalize over a wide range of stands in different conditions should be attempted to. In choosing the stand the generalizing aspect should be considered to guarantee wide enough variation in the environmental conditions, especially concerning the soil properties.

The experimental design

The experimental stands should be of the similar stage of development in each climatic region to be able to observe the effects of changing environment. Preferably there should be stands in different soil conditions and at least at two developmental stage in each country or climatic region; a stand with a recent canopy closure and another more mature stand.

The experimental design is presented graphically in the annex. From experimental stands a representative area should be limited and mapped. The diameter, height, height and diameter of the pruning limit and the biggest crown radius together with three other radius measurements at 90 degree angle to each other and the corresponding directions from each tree should be measured. According to the dbh measurements the stand should be divided into two strata, from each of which n sample trees should be selected randomly. Also a sufficiently large number of soil core sampling points should be chosen as well as the points for taking the hemispherical photographs.

The crowns of each sample tree should be stratified to two strata: The crown above the widest crown diameter and that part below it. From each strata the sample branches should be selected so that their probability entering the sample is proportional to their size. The number of sample branches above the widest point in the crown should be higher than below. From each sample branch the oldest needle bearing shoots would be marked with coloured tape.

For the grude determination of the light climate of the stand a systematic net of sample points should be determined for the measurement of the light climate of the stand. From each point four hemispherical photographs should be taken at the heights of 75, 50, 25 and 0 % of the maximum canopy length. These photographs should be taken before and after the growing season.

After the growing season the sample trees should be felled. From a subsample of sample branches a sample of shoots should be taken for a more detailed analyses. The branches should be stratified into three strata; from the tip to the quarter-most living whorl, from this to the mid-most living whorl and from this to the lowest living whorl. The shoots should be clasified according to their age and branching order (two classes for the latter) and the length of 5 to 10 shoots selected systematically from each class would be measured. The length measurements would be divided into two strata of equal length sum and from each strata a random sample of shoots would be taken for shoot level measurements.

In addition, from each sample branch needles should be removed and dried by age classes according to the same stratification as mentioned above. The branch diameters in two directions at 90 degree angle to each other should be measured beyond each whorl of sub-branches above which the needle biomasses were determined. From the same points 4 radial growths would be measured. In addition from each sample branch the diameter at the base of the last living whorl of sub-branches should be measured as well as the diameter at the base of the branch, together with the width of the heartwood if present.

The total length of each branch and the lengths along the main branch to the points of diameter measurements on the main branch should be measured, together with the branch angles between the stem and the diameter measuring point. Finally the number of tree rings at the base and beyond the first living whorl of sub-branches should be counted and noted the number of sapwood and heartwood rings.

From the stem the diameter of each branch above the base swelling and stem diameters between each living whorl and below the last living whorl should be measured. Below the crown at least four diameter measurements should be made at the heights of the stump, 1.3m, 0.2 h and in the middle of the living crown and 0.2 h. From the same points the radial growth and earlywood/latewood determinations should be made.

From each tree, three disks should be removed from the stem at the heights of 0.2 h, pruning limit and the mid-most living whorl and three disks from the mid-most sample branch. These disks would be used for the wood density and tracheid size analyses.

From a subsample of sample trees, the stumps should be digged up and the ratio between the stump cross-sectional area and the sum of transport root cross-sectional areas below the basal swelling should be determined.

For the fine root determination a similar methodology as explained by Santantonio and Santantonio (1987) is suggested.

To be able to determine the magnitude of the stored carbohydrates from the total needle weight , it is suggested that the needle density is followed during the growing period.

Concluding remarks

The measurements suggested involve a great deal of work and the actual process determinations and how these depend on the environmental conditions are not included. Therefore it may be that some of the measurements suggested here have to be dropped. Similarily there are some aspects which are not included in the suggestion which would be wise to include in the studies. The most important of these is the following of the nutritional status of the trees and soil. In addition, the measuring requirements of different existing models may differ from those proposed and would therefore have to be included so that the data collected would serve as many people as possible. However, I wish that the suggested hierarchical structure of measurements can serve as a starting point for discussion which would hopefully lead to an operational and comparable measuring method in different countries.

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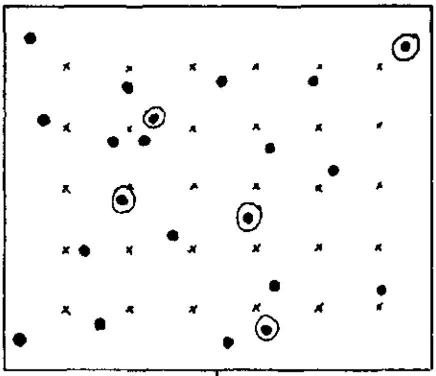
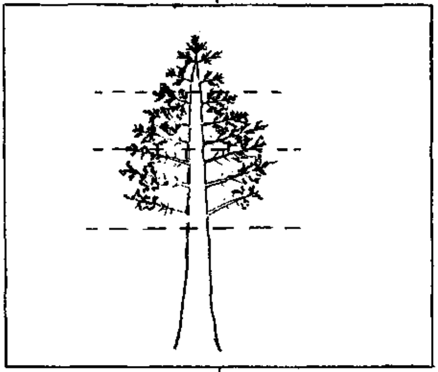


A Stand

- height
- diameter at 1.3 m
- diameter and height of the pruning limit
- mapping (+crown diam.)
- hemispherical photos
- soil core sampling

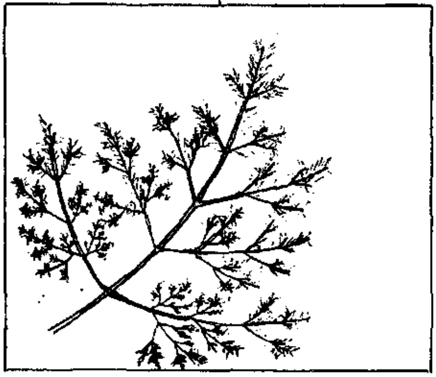
(- env. monitoring)



B Sample Tree

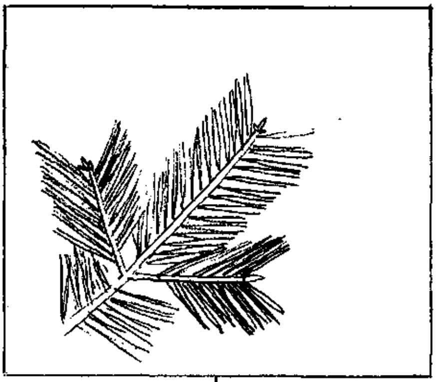
- sample branches
- d below living whorls + stump, 1.3m, 0.2·h
- radial growth, same heights
- transp. root cross-sectional area below basal swelling
- wood density (3+3)

(- tracheid size)



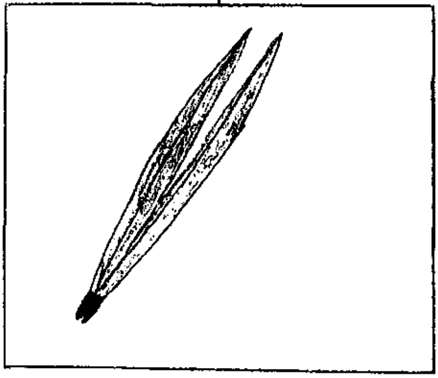
C Sample branch

- hemis. photog. above the tip
- senesc. sample shoots
- sample shoots
- needle masses (by age classes) above specif. points
- diameters, diam. growth at specif. points
- branch lengths, angles from stem to specif. point
- number of whorls of the newest shoots, forking pattern



D Sample shoots

- av. needle length
- av. needle angle
- needle number
- sample needles
- shoot length
- shoot diameters
- shoot wood density



E Sample needles

- needle weight
- needle area

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