2 Modal transect construction for silvicultural design

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Summary

Modal transects are scale-drawings of a forest ecosystem sample, that can be used to answer silvicultural questions with a previously determined degree of accuracy. They need to contain the necessary information in a directly visible or measurable form, that can be used either to insert more information or to abstract the information as necessary and within falsifiable limits. Contrary to a 'real' transect, where a narrow strip in a forest stand is drawn by ground-plan and profile diagram, a modal transect comprises information about the whole stand in a more or less abstracted profile diagram, but always representing the real stem number and canopy density. Simple examples are worked out, to explain the use of modal transects of different abstraction levels, for specified purposes.

2.1 Introduction and problem

The management requirements for forests, or forest stands, are usually described in terms of the silvicultural qualities of the mature growth.

In 1984, the Dutch State Forest Service formulated requirements for 'target forests', as the standard for the future. This long-term national plan was approved by parliament in 1986 (Anonymus, 1984, 1986).

On a well-defined site, the possible target forest area depends upon:

- the suitability of the site for tree species forming the skeleton of such projected stands;
- the management objectives.

Site factors can be classified into primary factors and secondary factors (Fanta, 1985). The primary factors, climate, topography, orography, geological material, ground and surface water, determine certain ecological properties of ecosystems but are themselves not a part of the ecosystem as are the secondary site factors. The secondary factors, forest climate, micro-relief, soil, humus and hydrology, arise from interaction between biotic and abiotic components of the ecosystem. Secondary site factors, lacking in young forest ecosystems, are very important in mature ones. Other factors, related to site factors and influencing growth, are pests and diseases, fire, fertilization practices and other stressors or facilitators.

To select the required possible forest target types and also to determine the most effective course from an existing to a target forest, presents the problem of going from the present status to the intended one, requiring a silvicultural system to be chosen. In addition to site factors, the dynamics of tree species on different sites must be understood to approach the problems. There are different courses leading to the goal as Leibundgut (1966) points out in a simple

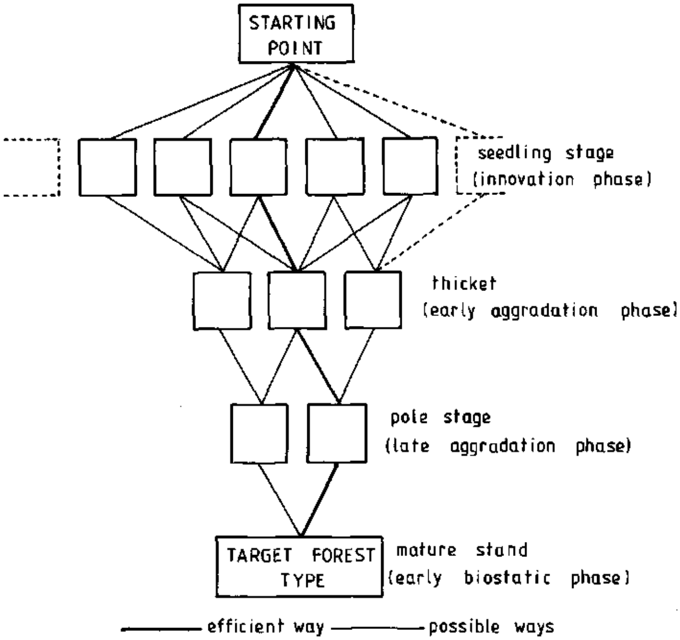

Fig. 2.1. Diagram to determine the intended forest management type and the most efficient silvicultural system, also indicating the crucial intermediate stages (Leibundgut, 1966; terms see Oldeman, 1983).

scheme (Fig. 2.1). Finding the best course is an optimalization problem involving all forestry disciplines. The potential consequences of different silvicultural interventions for the next development phase and for the mature stand on the site must be projected. In the case of deviations from the original program, the question arises whether it is still possible to implement the intended target or not and, if needed, how to alter the process from there on.

This paper intends to define a quantitative method to graphically represent important qualities of the different development stages and the changes, expected, or found to occur, due to growth and development of a stand as regulated by silvicultural interventions, with a previously determined degree of accuracy. With the method one should be able of anticipating on and checking of the consequences of a silvicultural system, to obtain and to pass on insight in the system, and have an aid in management.

2.2 Tree component dynamics

2.2.1 Analysis of tree dynamics

To study growth characters of tree species, the Department of Silviculture and Forest Ecology uses transect analyses (e.g. Oldeman & al., 1983). A transect represents a narrow sample, selected within a forested area. There are different ways to draw a transect. For example, species, biomass or soil-profiles can be assessed along a line or strip through the landscape to inventory species or biomass-graphs or soil differences set out against one (length) coordinate. With a second coordinate one gets a surface and draws the results:

- height against length to give a profile diagram,
- width against length to give a ground-plan (Oldeman & al., 1983).

Transect drawings of forests usually are a combination of ground-plan and profile diagram. Examples of such transects, visualizing the actual situation as real as possible, can be found in Winckel (1980), Koop (1981) and in Greeven & Harmsel (1983) (Fig. 2.2).

By including dead trees, fallen trees, and tree stumps, it is possible to learn about the history of the stand structure. The architecture of trees can also contribute to historical diagnosis, such as diseases and crown development. To trace the contiguing development of trees, a new transect must be drawn after a number of years.

Because of the diversity of information that can be included, a transect drawing means to learn about relationships between forest components (Oldeman, this volume). Studying a transect is an unbiased, verifiable and repeatable way to get information about different aspects of a stand. The method has some pitfalls to be avoided:

A

B

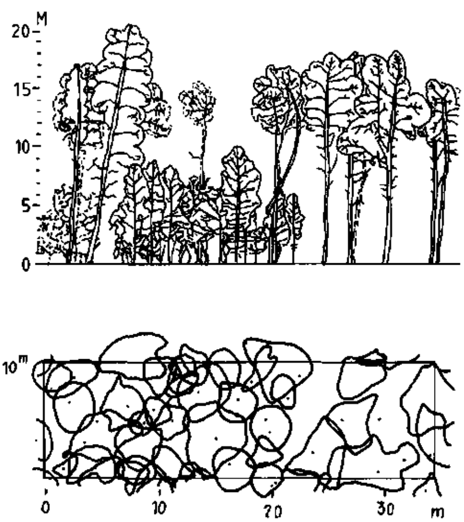

Fig. 2.2. Real transect of a representative part of a stand in the 'Zeisterbos' in Utrecht, The Netherlands (e.g. Greeven & Harmsel, 1983): A: profile diagram; upper storey existing of *Pinus sylvestris* L.; under storey existing of *Betula pubescens* Ehrh. and *Quercus* spp.
B: ground-plan.

- All the work of gathering and processing data is done between the start of the field work and the finishing of the scale-drawing. No time should be spent in later calculations. If no selection is made of the number and nature of data to be included, this method may become time-consuming.
- A choice has to be made, whether to gather many data per m^2 on a small surface, or few data per m^2 on a large surface. Architectural analysis can provide a high density of information. If one takes small samples in a stand, representativity for that stand should always be considered.
- If the information density is too high, the resulting scale-drawings become cluttered because in a two-dimensional projection, all measured features become superposed. The separation in a side-view and a ground-plan is prefered above the complications of a projection of one stand picture in three-dimensional perspective. If the sample area chosen is too large for the information density, and too much data are gathered, unreadable and useless documents can result.

2.2.2 Dynamics of representative trees on representative sites

Dynamics of tree species and provenances are related to site factors. However, exact prediction of these dynamics on a given site is impossible because of unknown and unpredictable factors, such as fluctuating weather conditions or attacks by pests and diseases. In older forests the secondary site factors, varying over short distances can be very important and also change with time. They are dynamic, compared to the more static primary site factors.

To establish patterns in dynamics of tree species and provenances, as related to the site, one has to find representative trees on well defined, representative sites in different developmental stages. The dynamics of these trees are used to model the dynamics of similar trees in the target stand. On extreme sites with regard to properties such as soil chemistry, hydrology, climate and forest history, one should look for special stand and tree qualities such as stand structure in relation to dimensions of mean and crop trees, plustrees, border trees and trees with undesirable characters. Such stand and tree qualities should be known in all developmental stages of a stand (Fig. 2.1).

Within certain limits, as explained above, the understanding of tree response makes it possible to foresee developments in a stand on a specific site. An efficient silvicultural system can be chosen to convert the present stand into one of the target stands and designing a development course with economically and ecologically acceptable phases.

2.2.3 Silvicultural design

Long-term national Dutch aims in forestry require a multiple-use silviculture. Therefore silvicultural systems cannot be built exclusively around the production of wood crops. The study of the dynamics of representative trees on representative sites may be narrowed down to few relevant criteria as long as the management aims are limited. The implementation of the new plans requires in many cases the conversion of present-day stands to very different future stands. First it is necessary to define the parameters for designing conversions, and to gather information needed for implementation, in close connection with teaching these principles to future foresters who will have to deal with the national plan and its implementation. The Dutch Forest Service has coined the word 'forest image' (bosbeeld) to indicate the observed or depicted image of an existing or planned forest, in every development phase (Fig. 2.1). Most often, a forest image concerns a stand (eco-unit level, Oldeman, 1983, this vol.) or sometimes a mosaic of stands (silvatic mosaic level). In this chapter, only the stand-level will be considered.

A population of stands with the same architecture, species composition and production characteristics, but in all development phases (age classes) could be exemplified by pine stands with normal age class distribution. They are all of the same 'kind' but differ in maturity, whereas stands of the same kind can also be found elsewhere. Such a population was termed a 'bossoort' by Westra (1983), a Dutch term that litterally means 'species of forest', in analogy to a population of organisms of the same kind, a species. Oldeman (pers. comm.) proposes to use the term 'sylvon' to denote such populations of stands, and to define it as follows: A sylvon is a population of eco-units with the same architecture, species composition and production processes, in all their possible development phases. For a definition of an eco-unit, see Oldeman (1983).

In the following section, the foreseen development of a member of a simple sylvon (Fig. 2.3), with or without silvicultural intervention, and on the basis of knowledge of the main components, will be examined. It is thought, that a simple start is more suitable to establish methods, and test principles, than a more complicated one that might introduce problems difficult to solve prior to establishment of basic approaches.

2.3 Construction and use of modal transects

2.3.1 Representation of forest images by modal transects

According to the Oxford Dictionary, 'modal', means 'involving affirmation of possibility, necessity, or contingency'. Transects that are used in silvicultural design should be just that. They must contain information for a precise aim, and have the ability to answer questions by including or excluding extra information. Definition: a modal transect is a scale-drawing of a forest ecosystem sample that can be used to answer silvicultural questions with a previously determined degree of accuracy. It needs to contain the necessary information in a directly visible or measurable form, that can be used either to insert more information or to abstract its information as necessary within falsifiable limits.

Generally the modal transect as used here, will consist of a profile diagram, representing the real number of trees per ha, compared to the profile diagram from 'real' transect drawings, described in chapter 2.2.1.

The modal transect can be at any point between an extreme with a very low degree of abstraction with very high information density, and an extreme with a very high degree of abstraction. The highest degree of information density is reached when a three- or four-level model is made (Oldeman, this vol., his Fig. 1.1). The last ones include data at the level of organs, organisms and ecosystem(s). For instance it can include:

- number of trees per ha and tree species
- canopy density per ha and tree species
- variation in crown width and depth per tree species
- variation in tree height per tree species
- variation in tree architecture per tree species with detailed tree drawings and data about diameters and quality aspects.
- distribution of dead wood on the forest floor
- distribution, height and density of shrubs and herbaceous plants
- soil data.

The following aspects of modal transects must be considered:

- The need for a ground-plan depends upon the questions asked. Abstraction can often include this ground-plan.
- The dilemma of dense information on a small surface against sparse information on a large area, given the same investment of time, manpower and means, must be resolved at all intermediate points.
- A well-chosen modal transect should be adapted to show clear relationships between site qualities and tree development.
- Finally silvicultural interventions and their results should be shown with great simplicity in modal transects. This is only possible if reactions of tree species and other forest components on the sites are understood.
  Leaving out unknown facts is not abstraction in the constructive sense, and may lead to lack of relation to the real forest situation, as well as make the model unfalsifiable.

2.3.2 Modal transects: construction and abstraction

The construction of modal transects at different abstraction levels is demonstrated here for an existing 35-year-old forest stand in which a real transect with ground-plan and profile diagram has been drawn (Fig. 2.3-A). The forest stand is situated near Wageningen, Gelderland, The Netherlands.

The tree component population contains 420 trees/ha, with a mean tree distance of 5.24 m, consisting of 90% Scots pine (*Pinus sylvestris* L.), 5% oak (*Quercus robur* L.), 5% birch (*Betula pendula* Roth.) and Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco). Canopy closure is about 65%.

a. First abstraction level (Fig. 2.3-B).
   This level is close to the real transect. On a line transect of 90 m long, 17 trees $(90^*(5.24)^{-1})$ have to be drawn. In this case there are 16 pines (90%) and 1 oak (5%) and no birch and Douglas fir. In addition to tree number and tree species, variation in tree height, stem form, crown width, depth, architecture and variation in stem distances remain. This level is very well suited to foresee the consequences of silvicultural interventions in detail.

b. Second abstraction level (Fig. 2.3-C).
This level resembles the first one, but for the crown characters: only crown width, depth and (a)symmetry, i.e. Koop's 'crown coordinates' have been precisely indicated (cf. Koop's computer model, 1987). Crown form and architecture are only roughly shown, but the contents of crown volumes are left out.
This level can be used if only crown coordinates are available without complete tree drawings. Stand structure can be shown, but not tree architecture. In the two-level model (Oldeman, this vol., his Fig. 1.1), only the volumes or spatial niches of the tree components are introduced as subsystems at the eco-unit level (also cf. Kuiper & Schoenmakers, this vol.).

c. Third abstraction level (Fig. 2.3-D).
This level gives tree species distribution, stem number per ha, mean tree height, mean crown depth and width. It can be used to indicate the development of these features and may be considered to visualize some aspects of stand yield tables.

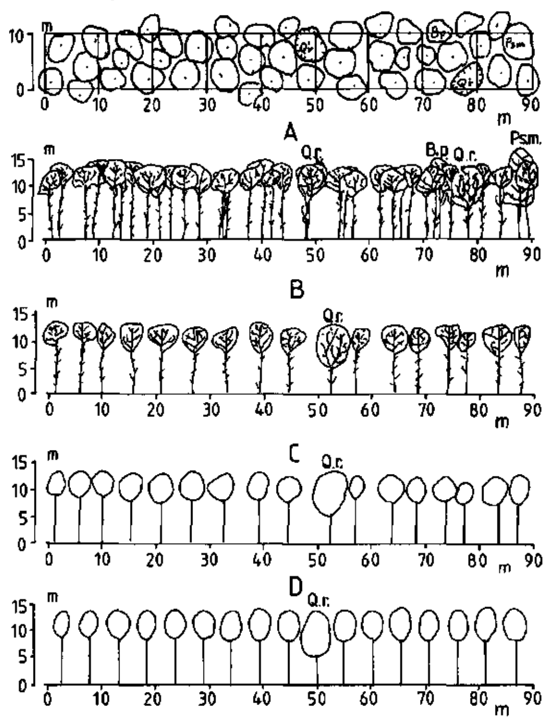

Fig. 2.3. Four examples of different abstraction levels for the respresentation of a forest image of Scots pine (*Pinus sylvestris* L.) with some oak (Q.r.: *Quercus robur* L.), birch (B.p.: *Betula pendula* Roth.) and Douglas fir (Ps.m.: *Pseudotsuga menziesii* (Mirbel) Franco). Canopy closure is ca 65%. A: ground-plan and profile diagram of the 'real' transect; B: modal transect with a low abstraction level (level 1); C: modal transect with an intermediate abstraction level (level 2); D: modal transect with a high abstraction level (level 3).

More abstraction levels can be used. To follow the development of other forest components, for example, the shrub and herb compartments (for definition of compartment, see Oldeman, this vol.), the scale of the transect has to be adapted to the dimensions of the components. For a good architectural drawing of shrubs, a scale of about 1:50 will be needed, whereas for the above third abstraction level a scale of 1:500 will serve. Generally speaking, the less interest there is in individual tree characteristics, the higher the degree of abstraction of the modal transect can be.

2.3.3 Examples and use of modal transects of different abstraction levels

To construct a modal transect one has to know the intended purpose in order to include necessary data. From there, the most useful scale and the length of the transect can be defined.

Example 1 (Fig. 2.4a).

Use: prediction of stand structure and of tree architecture of a stand after a 30-year-management period according a yield table. Scale: 1:500 (1:200 might be better). Length: 90 m.

– Present situation (Fig. 2.4a-A; compare the transect in Fig. 2.3B):

Tree sp.	Age (Years)	Stemnumber/ha =420	Canopy closure 65%	Crown width (m)	Crown depth (m)	Tree height (m)
Pinus sylvestris;	35	376	53.5	3-6	3-6	12-15
Quercus robur;	35	23	6.5	± 6	± 8	± 13
Pseudotsuga menziesii;	35	11	3.0	± 6	± 11	± 17
Betula pendula;	35	10	2.0	± 4	± 6	± 16

As already mentioned in 2.3.2, a stem number of 420/ha results in a mean distance between trees of 5.24 m. In a transect of 90 m long, a total of 17 trees have to be drawn. The tree canopy closure of 65% (ground-plan) has to be transformed for the profile-diagram into a canopy closure of about 80% ($\sqrt{0.65}$ * 100%) and this leads to a mean distance between crowns of 1.05m (0.2 * 5.24m).

Attention: The trees theoretically have a triangular espacement. This means that crowns have a sixangular surface. The crown of one tree therefore has a surface of $0.5 * a^2 \sqrt{3}$ and not $0.25 * \Pi a^2$ (Fig. 2.4b). Variation in tree architecture and relative distance between the trees can be read from the 'real' transect.

– Situation after 10 years (age 45; Fig. 2.4a-B): Because of the very low stem number at age 35, the next 10 years no thinnings are to be performed. Height growth of Scots pine in this period would be about 3 m (according to the yield table of Grandjean & Stoffels, 1955, site index II). The mean canopy

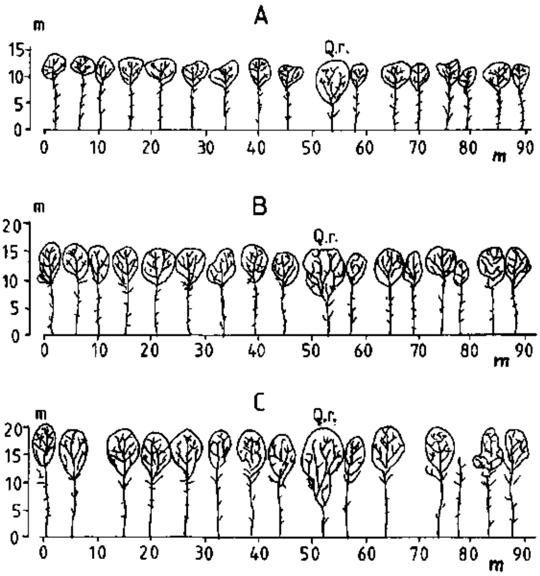

Fig. 2.4a. Prediction of growth of trees in a stand, under conditions defined in the text, with the help of a modal transect of abstraction level 1. A: 35 years old (compare Fig. 2.3-B); B: 10 years later (45 years old); the arrows show the trees removed; C: 30 years later (65 years old). Height development from yield table (Grandjean & Stoffels, 1955).

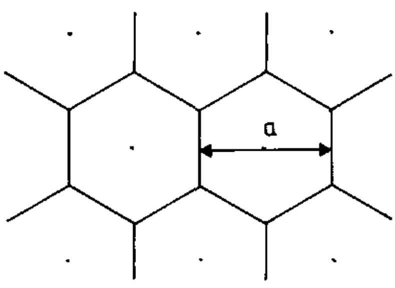

Fig. 2.4b. Tree in a triangular espacement and their theoretically crown $0.5a^2\sqrt{}/3$. In a profile diagram in principle crown diameter a will be drawn.

closure would increase to 80%. Tree architecture at age 35 can still be recognized at age 45. Supposing that during the next 20 years about 25% of the stem number will be removed, 320 trees/ha remain, with a mean stem distance of about 6 m. In a transect of 90 m, 15 trees will have to be drawn. Assuming a selective thinning procedure in the upper story favouring oaks, the trees to be removed can be indicated (see arrows Fig. 2.4a-B). After thinning the canopy closure is about 65%.

- Situation after 30 years (age 65; Fig. 2.4a-C): The mean tree height is 19 m

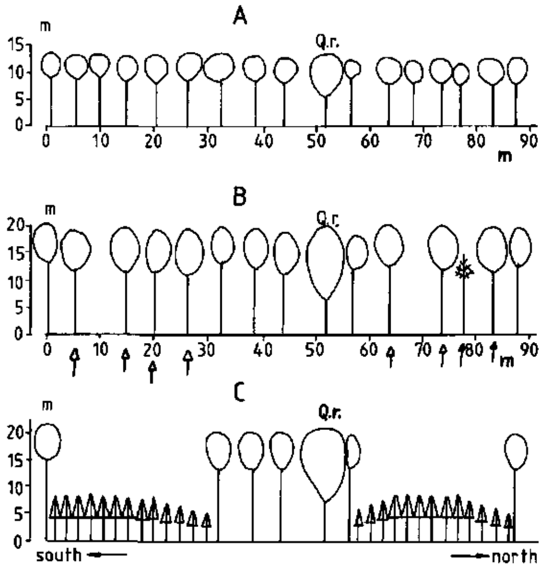

Fig. 2.5. Prediction of tree behaviour in a stand, under conditions indicated in the text, with the help of a modal transect of abstraction level 2. A: 35 years old (compare Fig. 2.3-C); B: after 30 years (compare Fig. 2.4-C). The arrows show the trees removed; C: after 45 years (Scots pine 80 years old and Douglas fir 15 years old).

and crown closure is about 70% (Grandjean & Stoffels, 1955; Schütz & Tol, 1982). In this case 40 trees are presumed to have died due to lack of vitality, leaving a stem count of 280 trees/ha.

Example 2 (Fig. 2.5).
Use: design of stand structure after multiple strip felling in a 65 year old Scots pine stand to establish Douglas fir, a current Dutch silvicultural system ('coulissenkap'). Scale: 1:500 (1:200 might be better). Length: 90 m.

- Present situation (Fig. 2.5-A): as in example 1, but instead of 'real'-trees, model trees are used, indicating crowns only by crown volumes as defined by coordinates (Fig. 2.3-C).
- Situation after 30 year (age Scots pine stand 65; Fig. 2.5-B): Silvicultural interventions and stand development were exactly as in example 1. Now 30 m wide strips are cleared with 30 m wide intervals between them. Cleared strips are planted with Douglas fir, 4.000 plants per ha, with a mean stem distance of 1.70 m.
- Situation after 45 year (age Scots pine 80, age Douglas fir 15, Fig. 2.5-C): The Scots pine stand has not been thinned in the past periode. In the Douglas fir stand, one release cutting has been performed. The stem number is now 2.200/ha (mean stem distance 2.29 m). Northern border trees have a growth

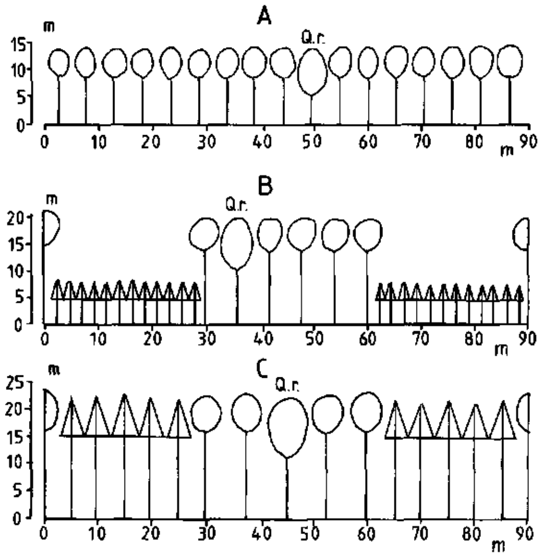

Fig. 2.6. Prediction of growth of trees in a stand, under conditions indicated in the text, with the help of a modal transect of abstraction level 3, containing less information, but in another hierarchy (Oldeman, this vol.), than yield tables. A: 35 years old (compare Fig. 2.3-D); B: Scots pine 80 years old and Douglas fir 15 years old (compare Fig. 2.5-C); C: Scots pine 110 years old and Douglas fir 45 years old. Note the variable position of the oak in this modal transect, indicating that its exact position is unimportant for this abstraction level.

delay due to exposition (cf. Koks & Leersnijder, 1984). Border trees can have a growth delay due to competition. In this case we presume some competition with oak.
Probably there is no competition with old Scots pine (van Goor, pers. comm.; Sevenster, pers. comm.).

Example 3 (Fig. 2.6).
Use: design of progressive conversion of a Scots pine stand into a Douglas fir stand (within about 50 years). Scale: 1:500. Length: 90 m.
- Present situation (Fig. 2.6-A): as in example 1. Known data are only tree number/ha and therefore the mean stem distance, mean canopy closure, mean tree height and crown depth (compare Fig. 2.3-D) can only be presumed.
- Situation after 45 years (age Scots pine 80, age Douglas fir 15; Fig. 2.6-B): as in example 2.
- Situation after 75 years (age Scots pine 110, age Douglas fir 45; Fig. 2.6-C): Number of trees in the Scots pine strips has decreased to 210/ha with a mean stem distance of 7.5 m. The number of trees in the Douglas fir strips has decreased to 460/ha with a mean stem distance of ca. 5 m. The site index for the Douglas fir stand is about IV (yield tabel of Bastide & Faber, 1972).

2.4 Preliminary conclusions

Models (cf. Oldeman, this vol., his Fig. 1.2) are tools to arrange information, to get new information and /or insight in processes. With the construction of modal transects the optimal input of information, the information density for a given forest area, depends upon the complexity of the forest cover, and the specific purpose of the model. Examples of different aims of modal transects, requiring different input of information, are given in paragraph 2.3. The information density is unfluenced both by the number of hierarchical levels involved and the quality of the information included: population data, architectural data and/or production data. A conscious choice of the model criteria as linked to other models and in view of furthering the understanding of specific problems, is necessary if the method will be used for designing future forests. For example, the forests with far-reaching multiple-use principles as stated in the national forest plan. The method requires an investment in research and testing in many different forest situations of increasing complexity before it can be fully operational in silviculture.

The testing in simple situations presented here, allows the following preliminary conclusions to be drawn:

1. Production parameters, such as diameter, heigth/diameter ratio or basal area cannot be included in architectural, graphical models. They are part of an indispensable model along another line (biomass accumulation, cf. Bormann & Likens, 1979) that has to be represented by another area of research.
2. If the abstraction level is well-chosen, modal transects are a powerful tool for the delimitation of functional compartments. They also can be used in population and production research, as illustrated by the borderzone aspects between eco-units on Fig. 2.5-C. This requires more special compartmentalisation if eco-units become smaller and the relative weight of borders become more important in a target forest. The modal transect gives a quantitative, geometrical criterium for delimitation.
3. Leaving out component architecture, as was gradually done (Fig. 2.3), makes the model more abstract to show more clearly some aspects of the stand, but less about stand dynamics. This is acceptable only in global planning. As soon as special aims are to be implemented, and the silvicultural methods are designed to produce them, component architecture and build-up become more important. Examples are nesting space for birds (Komdeur & Vestjens, 1982), establishemt of special plants in target stands with nature conservation aims, crooked trees may be of interest for recreation stands, or minor forest products linked to components such as fungi (cf. Keizer & Arnolds, this vol.) or blueberries (*Vaccinium myrtillus*, Ericaceae).
4. A modal transect can be influenced vertically, considering the number of hierarchical system levels to be included, or horizontally, considering the number of data per system level. It seems prudent to limit most modal transects to two levels, as illustrated by Fig. 2.3-A (component architecture/mosaic architecture), respectively corresponding to stand management questions and conversion questions.

5. Contrarily to a weighted choice of the distribution of needed data over the different hierarchical system levels chosen, the reduction of the number of data makes the whole model weaker in information, especially about relationships in and between different components and about dynamics of components. Fig. 2.6 is at the limit of this case, the situation depicted seeming self-evident to all involved and the model only depicting properties of systems and components that can be arguably represented better by tabulated numerical data concerning population or production ecology.
6. Relations have been principally established in this paper between architectural and production criteria, but links at the stand level could be sought with population criteria. These links may be found by using the microcoenon concept of Barkman (1970), as exemplified in Koop (1981).
7. The concept of modal transect as developed in these pages is to serve as a tool for architectural model optimalization in silviculture and forest ecology.

Acknowledgments

We wish to thank P. de T. Alvim, A. Krochmal, R.A. Leary and R.A.A. Oldeman for their constructive criticisms and useful suggestions.

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