Silvicultural tools to develop irregular and diverse forest structures

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Summary

This paper discusses the dynamic definition of irregularity; it looks at conditions of sustainability and considers under which conditions irregularity could be promoted efficiently. Irregularity is not usually innate in natural forest ecosystems, the exception being in certain developmental stages of old or over-mature stands. Because of these natural tendencies, it is necessary to differentiate between temporary stand structures and sustainable irregular systems. Therefore, any assessment of irregularity needs to take the rules of demographic regulation into account. Different kinds of irregularity are discussed, as is the reference scale for implementation. This makes it possible to distinguish between genuine irregularity within the crown layer, full (vertical) irregularity on stand level (plenter system) and horizontal irregularity (for greater reference scales), by creating irregular patches (as under the irregular shelterwood system). The paper presents the differences between broadleaved species and conifers in a full irregular plenter system with a developed vertical structure. These differences are due to the degree to which tree species can support shade, without losing the ability to recover qualitative capacity and, for older stages, to use crown space efficiently. Other factors are also important: the reaction of tree species to openings, the production of epicormic branches, topology and crown expansion. Therefore, broadleaved plenter forests need much lower equilibrium standing volumes than classical conifer plenter forests and there are also losses in volume increment and stem quality. The silvicultural results produced by the different models for differentiating stands and promoting irregularity are also discussed. It is assumed that for broadleaved species, the compromise between the necessary educative steps (shaping of the stem form within tree populations) and closure control function are better in small populations (openings) than in stands with a single tree structure. Because the ultimate aim is to create not one, but several, co-existing forms of heterogeneity, in the sense of creating varied habitats, modern silviculture should make use of all silvicultural tools. This is a significant challenge for silvicultural expertise.

Introduction

From the classical plenter system to other forms of structural diversity

The case for heterogeneous or so-called 'structured' forests has been the subject of fierce controversy ever since the philosophical movement of the Physiocrats and the debate on 'close-to-nature' forest systems in the nineteenth century (Schütz, 1999a). It is interesting to examine the reasons behind this interest. It is obviously linked to current concepts such as diversity, not only of species but also of habitats. Apart from ecologically based arguments in this debate, some values are also added in favour of or against developing heterogeneous forest stands. These values may have their roots in ethics, aesthetics or emotions.

Heterogeneity seldom occurs spontaneously in forests. Natural forests tend towards evenness, at least in a large part of the central temperate belt in Europe (i.e. in the beech, spruce and oak vegetation belt), and therefore tend towards homogeneity. On the one hand, this is due to natural developmental processes within the forest, that is, the ability of trees to accumulate biomass, which finally leads to canopy closure. On the other hand, it is due to the dominance of a few particularly competitive species such as beech or spruce. This tendency towards stand homogeneity becomes even more significant as site conditions become more favourable. Because of the limited number of species in the temperate climate of central Europe, those tendencies are much more pronounced in European forests than in American or tropical ones. For example, geobotanists have estimated that in Germany 66 per cent of the forest area would be stocked with beech forests, and in Switzerland at an average elevation it would be 79 per cent (Spellmann, 1999).

The key question here is, therefore: how can we create heterogeneous forests, or under which circumstances will they establish naturally? It is too easy to assume that such heterogeneity occurs automatically. A sufficiently critical analysis of beech or oak virgin forest development indicates that during long periods of their life cycle (or silvigenesis), a great accumulation of biomass leads to cathedral-like structured forests. The study of development cycles in central European virgin beech forests shows that temporal imbrication of cohorts of different ages growing into each other, leads to a certain constancy of standing volume. Korpel (1995) showed that the standing volume of pure beech virgin forests never falls below 400 m^3/ha.

If heterogeneity could be expected, it would occur, for example, in naturally mixed forests such as montane fir–beech forests. This is due to the differing growth of partially intimate mixed tree species; in particular, it is due to the varied duration of growth cycles (ontogenesis) of the species involved, which creates natural conditions for heterogeneity. However, the tendency to accumulate biomass dominates, and formations such as plenter-like structures are only found occasionally, amounting to between 0 and 15 per cent of the forest area (according to various authors, for example Pintarić, 1978; Mayer *et al*., 1980; Schrempf, 1986). In these mixed forests, evenly formed stand structures with high standing volume dominate more frequently. Natural irregularity, however, occurs spontaneously in forests at subalpine elevations, where recurrent disturbances through snow, frost and other climatic factors lead to the creation of a group-based structure.

The first conclusion of these observations is that the complexity of a stand is the outcome of natural processes, which (at least in central European forests) tend towards simplicity and homogeneity, of disturbances, which create local heterogeneity, and of human influence, where both homogeneous systems (regular stands) and heterogeneous systems (plenter system) can be favoured.

Consequences of creating structured forests

The forests of central Europe once displayed much more heterogeneity than they do today. Until the eighteenth century, multiple uses such as pasture, fuel timber production and domestic use led to severe over-use and many forests became extremely impoverished. Forests were so overused at that time, and the pressure was so great, that the forest had a sparse stocking and was open in structure. The forest management system of coppice-with-standards, which at that time was the usual method of forest management in central Europe, had standing volumes of less than 100 m^3/ha. As a result, the forests were fairly mixed and stratified. However, the coppice-with-standards system is not only an unstable working method; seen from an economic standpoint, it is also an undesirable system (Dubourdieu, 1991). Nevertheless, the wide-ranging and well documented experience gained from this system can be useful when discussing the structuring issue, especially as it used to be applied mainly to broadleaved species.

So far, the only silvicultural method known that has led to permanent irregular structures is the plentering method (or selection forest system), which has been applied successfully in montane fir-dominated forests in central Europe for 120 years. The plentering model is based on perfect vertical structuring and on yield individualization. However, a plenter forest can only be achieved by means of intensive and recurring silvicultural interventions. This results in man-made structures heavily dependent on human interference. Plenter forests that lie unexploited over a long period evolve slowly towards uniformity, with trees growing up into the upper storey, canopy closure and a lack of young growth (or recruitment).

Most attempts to apply this silvicultural model in broadleaved stands have failed. During the heyday of plentering (from 1880 to 1950), most Swiss forests were managed in this way for 50–70 years. In broadleaved forests the results, however, were extremely poor, which led to a return to other methods of forest management, focusing on regeneration of small groups. There are very few examples of plentering functioning with broadleaved trees – even shade-tolerant species such as beech. Plenter forests with beech that have been managed in a sustainable way are 100 times less likely to occur than plenter forests without beech dominance; and the former also only occur under special site and ancillary conditions. There must be reasons to explain the lack of structured broadleaved forests.

The concept of structure, and why it is important

Terms such as uneven-sized, heterogeneity, structuring and stratification are somewhat ambiguous. Depending on the perspective, such words can evoke very different meanings. As already mentioned, an interest in heterogeneity can be linked to society's ethical, aesthetic and emotional aspirations. Similarly, these terms cannot always be associated with a clearly defined intention. In general, the interest in heterogeneity may be interpreted as 'the living space demands of humans, as habitat conditions of plants and animals'.

Because of their personal cognitive experience, foresters often have a different interpretation of these terms than game biologists, nature conservationists or other forest users. As a rule, foresters usually relate to a stand, because it is the basic entity of forest treatment. Most other individuals concerned with forest issues relate to substantially larger scales, that is, a whole forest, a habitat, the landscape. There is a risk of misunderstanding due to this variety of scales.

Careful consideration of these levels of scale, both temporal and spatial, is crucial if issues such as biodiversity are to be tackled coherently (Bunnell and Huggard, 1999; Kerr, 1999). Furthermore, ecosystems do not function according to the principle of segregation, but according to the principle of multiple use, as forests simultaneously shelter versatile plant and animal communities. Therefore, covering temporal and spatial scales is a crucial aspect of ecosystem management, especially when devising concepts.

Different forms of structuring: horizontal versus vertical structures

In order to further clarify heterogeneity as a term, it is necessary to distinguish between natural variability and genuine structuring, as well as between temporal and permanent structures. Within a stand, tree dimensions vary naturally. This is the result of natural genetic diversity, which brings about natural stand differentiation. In each stand, the struggle for resources leads to a distinct formation of social classes. Those trees with the most powerful vitality tend to dominate and suppress the others. The presence of a certain diameter variation is, therefore, not a valid indicator of age variation or structuring. This is one of the reasons why it is advisable when analysing forest irregularity to use the term uneven-aged rather than uneven-sized.

There are significant tree height and crown dimension variations within the crown layer of an even-aged stand. Silvicultural measures such as thinning can enhance these differences and, therefore, lead to a degree of structuring (Figure 1). This variation in the crown dimension may meet certain ecological demands, for example those of crown-dwelling bird species. Therefore, the crown layer structure is a significant biological indicator for some types of fauna. However, this kind of structuring within the crown layer is significantly different from ensuring permanent

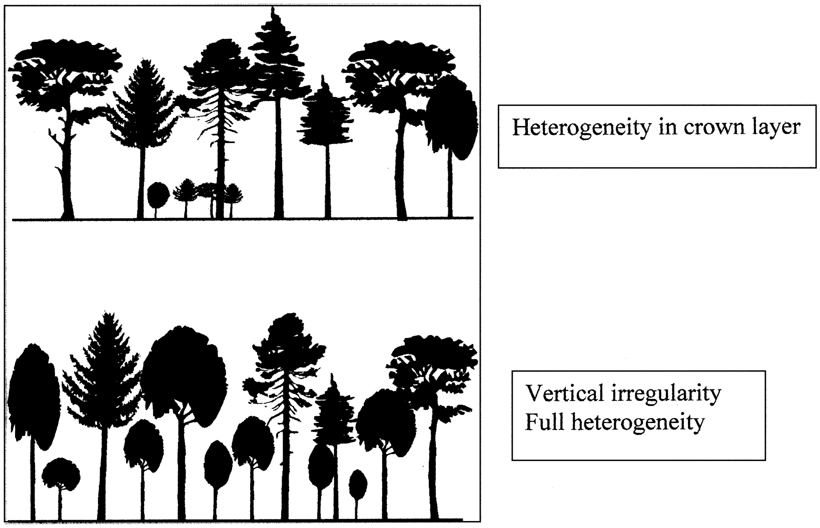

Figure 1. Schematic differences between crown layer structuring and full vertical structuring.

vertical structuring throughout the whole stand. So-called stratification, brought about by promoting different layers resulting from regular openings in the upper crown storeys, can be seen as an intermediate method.

If the structure is to be maintained over time, one has to consider demographic rules. To maintain the equilibrium of the growing stock, a certain amount of young growth needs to be promoted, either permanently (if the plentering system is applied), or in cohorts (if using the coppice-with-standards system). In contrast to the temporary structuring of shelterwood openings, it requires stronger interventions in the upper storey and a considerable reduction of crown closure. The reason for this is simple: to promote regeneration and young growth, sufficient light must reach all the way down to the base of the stand. The principles of renewal sustainability can be formulated using simple demographic rules (Schütz, 1975, 1999b, 2001). Thus indicators of sustainability are: a demographically balanced stem-number distribution (curve of equilibrium) and the standing-volume equilibrium, which is an important determining factor in the treatment of young growth.

If structuring is to occur at a level other than the stand, other methods may be considered, such as horizontal structuring, creating so-called 'patchiness'. This is important for the great majority of habitat demands of large animals. The creation of gaps within the stand, regardless of dimension, distribution and arrangement, is a relatively efficient silvicultural method of allowing light to reach the floor of the stand (Schütz, 1998). In this way, the dynamics of regeneration within irregularly distributed gaps staggered in time and space can be favourably influenced, allowing structuring to be achieved over time. Silvicultural systems based on this technique are efficient. This applies in particular to light-demanding species as well as to broadleaved trees in general. Whether the gaps need to be enlarged or not is related to the shade tolerance of the trees, as well as to additional desirable criteria, such as the establishment of inner edge-lines, which have important ecological properties for game management (Scherzinger, 1996). These inner edge-lines are, in fact, just as important when it comes to shaping habitats as the permanent ecotones along the forest edge. The gradual enlargement and joining of gaps, as in the irregular shelterwood system, allows a favourable management of such border lines.

Problems in relation to management of forest irregularity

The most important questions concerning structuring can be summarized as follows:

On what scale do we need heterogeneity?

On a large or small scale? Modern concepts of ecosystem management such as polyvalent silviculture seek to use a combination of all methods because the associated organisms in ecosystems have very different requirements (Schütz, 2001).

Over what period of time is heterogeneity to be achieved?

Temporary or permanent heterogeneity? This issue should be combined with management concepts of controlling sustainability.

At what cost?

As nature tends towards homogeneity, drastic interventions are required to counter this effect. So the likelihood for implementation structuring depends on the efficiency of the silvicultural measures and, in turn, on the necessary recurrence of interventions. This in turn determines the costs, and risks.

This last question is of great importance: are some stand treatment methods more efficient than others? This raises the question of the degree of stand self-realization or, in other words, of minimal human interference to the system. These days, this is described using the term ‘hemeroby’ (Jalas, 1955). The aim is to achieve hemerobic systems that still bring about the best possible structuring.

Findings from the plenter forest concerning structuring

If the canopy of plenter stands closes as a result of accumulating standing volume, the extinction of diffuse light will be more acute. The recruitment of young growth and its height increment will be slow. In the plenter forest, trees in the understorey are most vulnerable to shading. This is not only restricted to the sapling stage of regeneration, during which some conifers can endure long periods in the shade without losing any development potential. Fir and spruce can in fact remain in the shade for decades, sometimes for even over a century, in a quasi-stationary state (Schütz, 1969). The pole stage seems to be much more sensitive to shading, as shade influences stem slenderness, and excessive slenderness occurs particularly in the pole stage, this in turn makes the trees more vulnerable to snow pressure.

In the classic plenter forest, the *point of no return* for recruitment, as far as shelterwood is concerned (and therefore standing volume conservation), can be illustrated by the graph of the diameter increment of the different tree categories within a classical plenter forest in equilibrium (see full line in Figure 2) considering their position within the stand. The diameter increment decreases significantly for the categories that are more overshaded (overshading measured by the basal area of covering trees; G_{cum}). A dramatic decrease is seen when tree categories are overshaded more than 27–33 m^2 basal area. If stand density exceeds this critical limit, the growth of recruitment trees is reduced to such an extent that recruitment conditions are endangered. In classical fir–spruce plenter forest, the standing-volume equilibrium can be calculated as being between 350 and 500 m^3/ha, depending on the site’s growing potential and on regeneration capacity (Schütz, 1997, 2001).

It is interesting to compare broadleaved tree species with conifers, to see how, for instance, beech reacts to stand closure. From the perspective of shade tolerance, beech should not present any problems, at least theoretically. In reality, however, beech, unlike conifers, shows significant behavioural differences in a plenter structure as regards stem form and space utilization capacity.

The first disadvantage of beech, and other broadleaved tree species with sympodic crown architecture, is that the shade tolerance of beech is distinctly lower than that of conifers. If beech remains in the shade for too long, it loses the capacity to grow upright (acrotony) and shows tilted (plagiotropic) growth. Plagiotropic beech, or oaks which have been suppressed for too long, never recover sufficiently to produce a upright stem axis.

The second disadvantage is that when beech

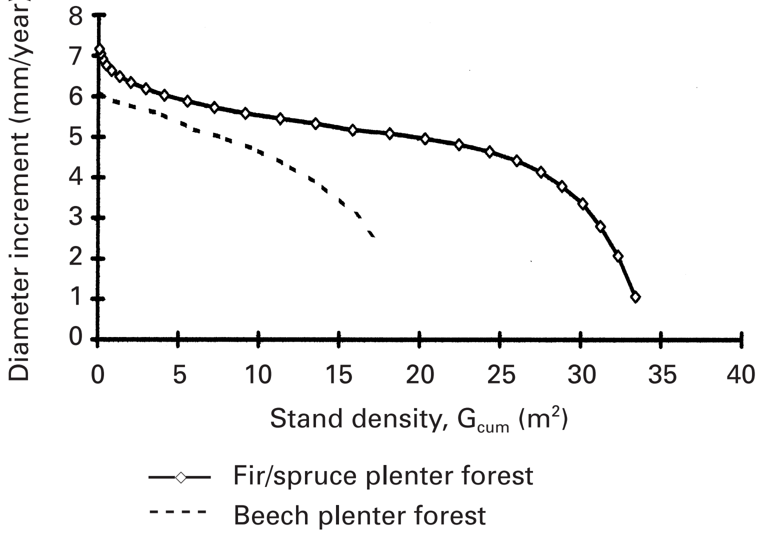

Figure 2. Increment of the tree categories within plenter forests as function of shading. Overshading (G_{cum}) is measured with the basal area of trees larger than the considered diameter category. Full line: classical fir–spruce plenter forest type Emmental (Schallenberg/Rauchgrat); dotted line: pure beech plenter forest (Langula, Thuringia).

obtains crown freedom, it reacts with very rapid lateral expansion. In beech, this regeneration capacity can be attributed to the favourable inherent strategy of spatial occupation; that is, growing both short and long shoots (Thiébaut *et al.*, 1990). This crown expansion capacity prevails until an advanced age. If beech is liberated in a plenter stand, it fills the crown space in an undesirable way, unlike spruce, which keeps its conical-shaped crown. Moreover, beech crown liberation can also lead to the disintegration of the stem axis (forking), which further enhances the phenomenon of lateral expansion. When investigating the spatial crown efficiency of spruce, fir and beech in Swiss plenter forests, Badoux (1949) proved that to achieve a similar volume increment, beech requires four to five times as much crown space as spruce or fir. As far as the efficiency of space utilization in regard to value increment is concerned, beech is 10 times less efficient than spruce and fir (Schütz, 1997).

Finally, the negative sheltering influence of beech combines an unfavourable, rounded crown shape (as a matter of topology) with a powerful light impermeability of the beech crown. According to Horn (1971), beech crown foliage belongs to the type that retains light very effectively. This results in a higher light extinction than in stands dominated by spruce or fir. Further observations of the effect of diameter increment on stand density were carried out in a plenter beech forest in Thuringia (eastern Germany). These show a pronounced decrease in diameter increment due to shading, at a considerably lower basal area level (see dotted line in Figure 2). Where the basal area rises above 15 m^2, the increment of young beech growth at pole stage is drastically reduced; it stops completely at a basal area of 27 m^2. At this density, the growth of recruitment trees of pole size ceases. There are therefore considerable differences between spruce/fir plenter forests and beech plenter forests. The calculated plentering equilibrium of pure beech plenter forests leads to standing volumes of 250 m^3/ha as opposed to spruce/fir plenter forests: 400 m^3/ha in the Swiss Jura and as much as 500 m^3/ha in the area of Emmental, Switzerland (Schütz, 1997).

From these observations, we can conclude that even beech, which is considered to be a shade-tolerant species, has more difficulty in coping with light extinction than the slender shaped crowns of conifers. These differences explain why beech plenter forests are rare, and they also prove that there is a risk of structural disintegration at a considerably lower standing volume. They also indicate that this model is rather unfavourable as far as yield processes are concerned, as the limit level of growing stock conservation (the point of no return) is at such a low level that it leads to overall increment reduction. In beech plenter forests, the risk of structural disintegration can only be countered by frequent and heavy interventions. Moreover, a low standing volume entails quality reductions because of the development of epicormic branches. These negative effects should not be underestimated.

The light high forest: a model taken from the system of coppice-with-standards

Experience gained from the system of coppice-with-standards has produced interesting findings regarding the structuring of broadleaved species. In theory, when considering sustainability, the system of coppice-with-standards functions similarly to the plenter forest, except for the process of restocking, which occurs about every 25 years, by means of drastic interventions in the upper canopy and the coppice. However, as the coppice-with-standards system is aimed at optimizing fuel timber production, these findings are not directly transferable to today's interests. Around 1870, Gurnaud suggested an analogous form of treatment for light-demanding trees – without coppice yield – called *light high forest* (French: *futaie claire*). The aim was to obtain a stand of standards without stump sprouting, but only enough young growth for sustainable recruitment of the upper canopy. Indisputably it was a system of high forest, and intrinsically some kind of plenter forest. Experiments with this treatment in the research forest of the Forestry School near Nancy (France) failed, mainly because the young growth from regeneration could not establish itself, having to compete with bramble and stump sprouts. From experience gained in Denmark (Sabroe, 1959), we know that plenter forests of maple and ash operate at even lower equilibrium standing volumes (~150–170 m^3/ha), with lower stand density, than is the case with beech. Therefore the disadvantages of a (necessarily) very low standing volume cited above for beech plenter forest are magnified for light-demanding tree species.

Conclusions

This example of the plenter beech forest shows that permanent single-stem structuring of broadleaved forests poses severe silvicultural problems and entails considerable disadvantages. It requires interventions of a kind that question its feasibility. It is therefore reasonable to ask whether or not temporary structuring of just the canopy, obtained by means of crown thinning, and possibly combined with the promotion of multiple layers, would be sufficient to meet ecological and aesthetic requirements.

This idea is supported by the classical silvicultural model of quality oak forest management: optimally mixed oak forests produce top-quality trees (Schütz, 1993). This occurs with double-storeyed stands, due to a well-developed understorey that shades the stems of the target trees. Moreover, if the mixture of species is promoted at the time of stand establishment, the effect of diversification is multiplied, even though absolute vertical heterogeneity is not achieved. We tend to opt for that model, in particular for noble broadleaved tree species such as oak, cherry, etc., which have a high value-adding capacity.

In order to counter the disadvantages caused by individualization in single-stem plentering for broadleaved species, it is possible to propose a compromise of full irregular models based on the steering of beech in small clusters (three to five stems). These are not only limited to the sapling stage, as in the classical plenter forest, but achieve individualization as soon as they reach the upper storey.

Another method deserves attention: the system of horizontal unevenness or patchiness; that is, the promotion of small, co-existing groups. This can be achieved by means of the classical technique of irregular group shelterwood felling, where one begins with small gaps that are gradually expanded or united. A similar extended method is to work with different size groups, arranged irregularly in time and space, without further expansion, which means that the entire development cycle takes place within the opening. The dimensions of the openings can vary considerably depending on the light requirements of the target tree species. This corresponds to the multi-cohort stands concept of Oliver and Larson (1996).

As regards silvicultural efficiency (from the perspective of optimal hemeroby), the classical irregular group shelterwood system is probably the most efficient system because it is based on the effective control of light for the regeneration process (Schütz, 1998). In the gap, it is possible to focus distinct light efficiently and, with that, to beneficially manage regeneration, combined with the favourable educational effect of competition in groups. In the case of mosaic gaps without enlargement, the main problem lies in defining the different gap sizes. As far as light incidence is concerned, small gaps have a similar effect to a shelterwood. A pronounced increase in light availability on the floor occurs if the gaps are equivalent to one or two tree lengths. Problems arise if the gaps are not expanded at the pole stage, because it is at this stage that slenderness of tree shape becomes decisive, when considering vulnerability to snow pressure.

Last, but not least, the combination of shelterwood and gaps should be mentioned as an interesting compromise. This is possibly one of the most favourable discussion models. The difficulties experienced by small gaps, which have been mentioned above, can be overcome if the gap edges are not too dense, but instead are opened up irregularly. Perrin (1954), an expert in oak coppice-with-standards, has stated that spatial utilization could be improved by 35 per cent if regular openings in coppice-with-standards were combined with gaps of ~0.3 ha.

It is clear that silviculturists have a considerable choice of methods for promoting heterogeneity. These depend on the species, on site conditions and also on the method chosen for creating heterogeneity. One method may have more advantages than another. Because our ultimate aim is to create not only one, but several, co-existing forms of heterogeneity, in the sense of creating varied habitats, modern silviculture should make use of all these silvicultural tools. This is a significant challenge for silvicultural expertise.

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