Forest structures

English: forest structures; *Welsh*: strwythurau coedwigol; *German*: Waldstrukturen; *Russian*: лесные структуры; *Spanish*: estructura forestal; *French*: structures forestières.

Structure is an important characteristic of forests. Typical of biological structures are repetitive patterns which are the result of complex interactions. They can be comparatively simple such as the structure of honeycombs or more complex. There are three important concepts in biological structures, *self-organisation*, *structure/property relations* and *pattern recognition*.

Trees fill spatial niches and their morphology reflects the geometry of the niche. The morphology of open-grown trees is very different to the morphology of forest trees. This is a result of a range of complex interactions, one of which is competition. Trees compete for light, water and nutrients. Competition pressure caused by surrounding trees influences the growth of a tree. Too much competition pressure can be lethal and can cause what is referred to as natural mortality or self-thinning. In managed forests one of the most important tasks of foresters is the management of competition: Through selective thinning and harvesting more resources are given to some trees. Thinnings modify growing space and soon after release a tree puts energy into occupying the newly available space (see Figure 1). Competition and other interaction processes can be understood as self-organisation. Forest structure is modified by interactions between individual trees, which to a large degree are influenced by the initial structure.

Self-organisation: Irreversible processes in non-linear systems, which create complex structures of the total system as a result of interactions between parts of the system (complex interacting systems).

Structure/property relations: The effective properties of a heterogeneous material depend on the properties of its components (phases) and microstructural information.

Torquato (2002)

Pattern recognition plays an important role in biology, i.e. immune systems and information technology. The basic principle of pattern recognition is to reduce raw data to a useful summary form.

Wolfram (2002); Deutsch (1994)

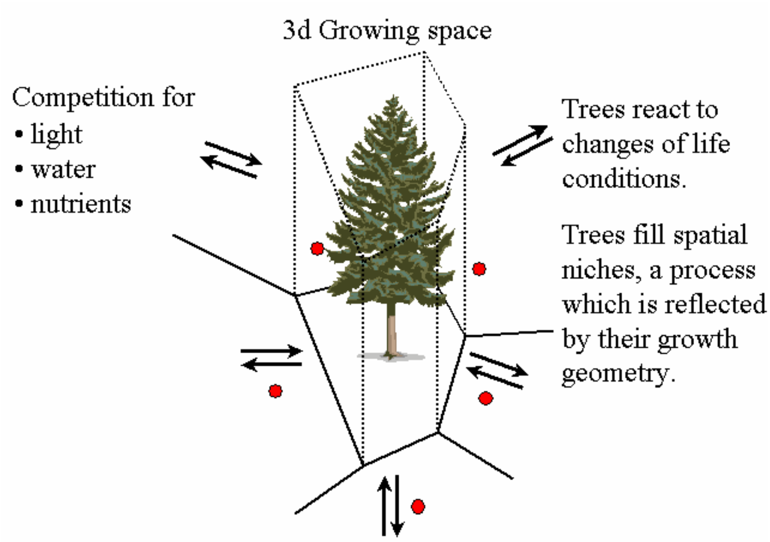

Figure 1. Tree reactions to changing growing space. The red dots symbolise the locations of surrounding trees in a forest.

There is a close relationship between structure and property, which is well known in material science, physics and geology (Torquato, 2002). The individual components of a material or the tree species or tree sizes of a forest arranged in different ways may result in very different properties for the material or forest as a whole. This suggests that the complex interactions between the components result in a dependence of the effective properties on nontrivial details of the microstructure. Properties can be habitat functions, biodiversity or biomass production. As an example the left hand graph in Figure 2 shows how basal area increment of a mixed beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* (L.), silver fir (*Abies alba* MILL.) stand relates to the way the individual trees are spatially arranged.

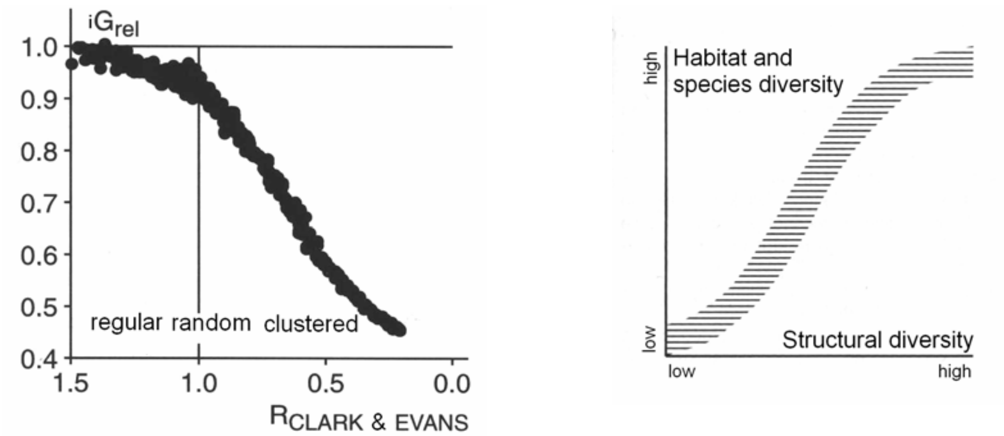

Figure 2. Relative basal area increment (iG_{rel}) as a reaction to different patterns of tree positions (left). The correlation between habitat & species diversity and structural diversity (right). After Pretzsch (2002).

The corresponding simulation study was based on real initial tree data but the tree positions were modified with a structure generator and then growth was simulated. The correponding basal area increment of the forest stand was divided by that obtained from simulations of the same trees of the stand but with regular tree positions. The pattern of tree positions is measured with the aggregation index *R* by Clark and Evans (1954). Maximum basal area increment occurs with regular distributions of tree positions. 95% of the maximum increment is realised with random distributions of tree positions. From $R = 0.9$ downwards the basal area increment decreases in an almost linear way (Pretzsch, 2002).

While stand increment was the property of the first example of Figure 2, habitat and species diversity is the property of the second one. It demonstrates that habitat and species diversity generally increases with increasing structural diversity. With increasing woodland structure the resulting properties change. Landscape and forest structure determines the occurrence and population dynamics of brown bears, owls and woodpeckers to such a degree that direct conclusions concerning habitat and population development can be made from spatial structure (Letcher et al., 1998; McKelvey et al., 1993; Wiegand, 1998). Similar results have been found for birds, beetles, spiders and other animals living on and in forest trees. Pattern recognition helps to identify distinctive spatial patterns and to link them with the corresponding properties. In neuropsychological studies patients with and without brain damage were requested to draw trees.

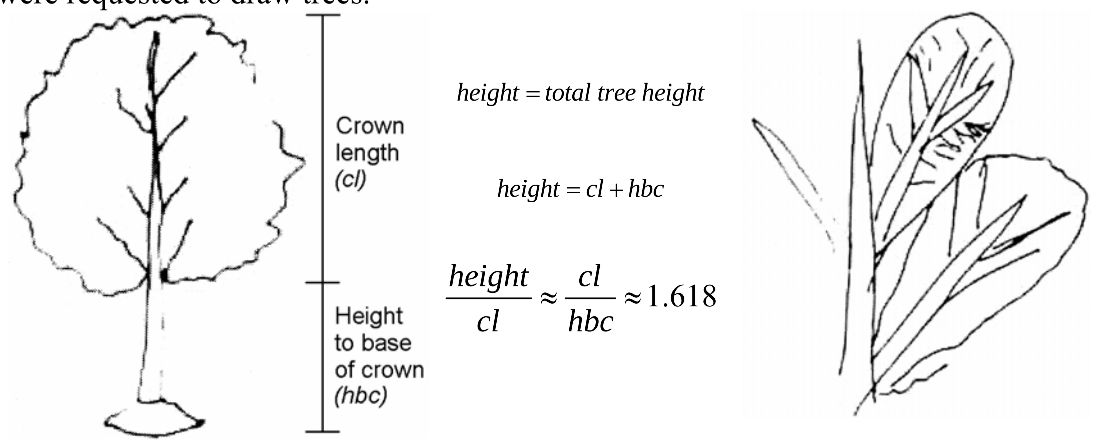

Figure 3. Pictures of trees drawn by a patient in normal state (left) and by a patient with depression in the right brain hemisphere (right) (Anonymous, 2003).

In pictures of trees drawn by the patients in their normal state (see Figure 3), the part-to-the-whole proportion most closely approached the *golden section*[1]. This constancy

[1] A line segment is divided in *golden section* if the ratio of the whole length to the larger part is equal to the ratio of the larger part to the smaller part. This definition implies that, if the smaller part has unit length and the larger part has length τ, then $(\tau + 1)/\tau = \tau/1$. It follows that $\tau^2 - \tau - 1 = 0$, which gives $\tau =$

in the relation between the whole and its parts makes the image recognisable (Anonymous, 2003).

Another example of pattern recognition in forestry is the analysis and interpretation of diameter distributions. Tree diameters and heights are the most important dimensional variables in silviculture. Diameter distributions often assume very characteristic shapes, which reflect stand type and silvicultural treatment and can be uni- or multimodal. Because of this diameter distributions are often used to reduce raw diameter data to a useful summary form. In order to construct diameter distributions the diameters, either of all trees or of a sample of a forest stand, usually measured at 1.3*m* above ground level, are measured. The measurements can be put into broad classes and frequency distributions (histogram) can then be computed.

Figure 4 shows six different diameter distributions.

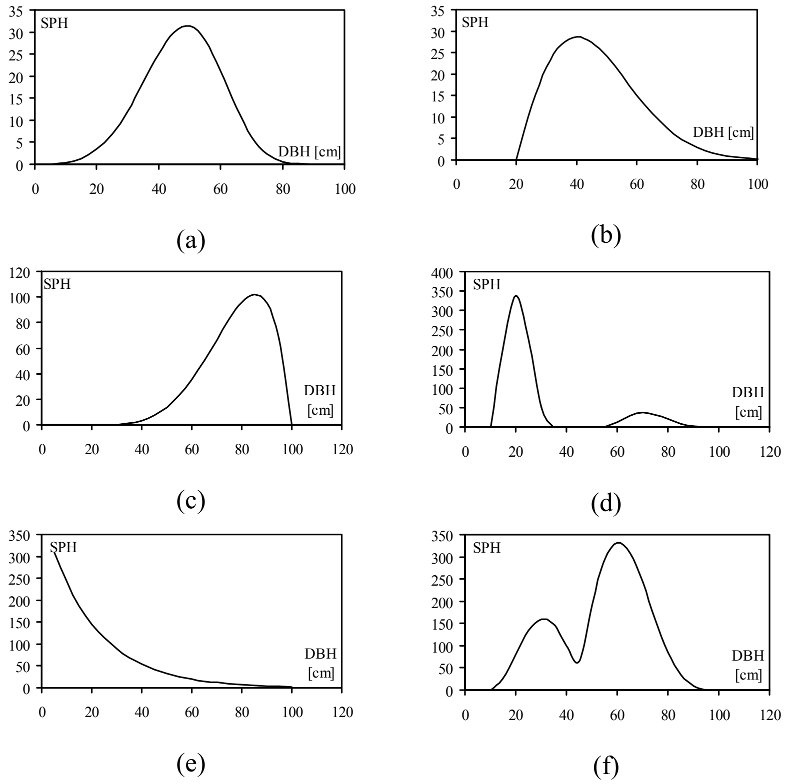

Figure 4. Typical frequency distributions of diameters at breast height (DBH) of (a) an even-aged pure species stand (plantation), (b) an even-aged pure species stand (right skewed due to a few exceptionally big trees), (c) an even-aged pure species stand (left skewed due to a few exceptionally small trees), (d) a young (regenerated) stand with a few standards/seed trees, (e) an uneven-aged selection forest (negative exponential) and (f) a two-storied mixed forest. SPH is stems ***p****er* ***h****ectare.*

$\frac{1}{2}(1 + \sqrt{5}) = 1.6180$, to 4 decimal places. This number τ is the golden ratio (Clapham and Nicholson, 2005). It arises in a wide range of mathematical and biological contexts.

Because structure/property relations are particularly strong between diameter distributions and growth a considerable effort has been put into modelling diameter distributions (Pretzsch, 2002; Siipilehto and Siitonen, 2004). Structure determines processes (e.g. growth) on a short- term basis (quick response). A good example of this is competition as a result of forest structure and its influence on a tree's diameter increment. Processes modify structure on a long-term basis (slow response). While trees grow they constantly change the structure of the forest surrounding them. This happens through primary allocation processes such as diameter and height increment. A secondary process is mortality which is the result of complex interactions of which growth is a part. A full understanding of processes is only possible if structural patterns are known. This is why in tree growth models diameter increment is estimated from so-called competition indices, which provide information about the immediate forest structure surrounding a tree. Sequences of changing structural patterns can help to interpret the underlying processes (Pretzsch, 2002). Again patterns are recognised and linked with the corresponding properties. The crown morphology of trees and the relationship between total tree height and diameter can for example help to make judgements about past management and land use.

Because of the benefits of structural diversity in terms of habitat functions, forest growth and stability it has become an important objective of modern silviculture (see also next section).

Forest structure and α-diversity is often subdivided into three different aspects, the diversity of tree positions, tree species diversity and the diversity of tree dimensions (see Figure 5).

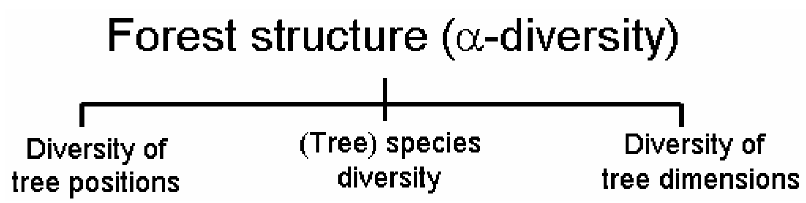

Figure 5. The three major characteristics of forest structure and α-diversity (modified from Pommerening [2002], Aguirre et al. [2003]).

Tree species diversity and the diversity of tree dimensions can be quantified non-spatially explicit or spatially explicit. The diversity of tree positions is by definition always spatially explicit. Tree dimensions can be diameters, heights, volume/biomass, crown measures etc. Another way of subdividing aspects of forest structure is to distinguish between horizontal and vertical elements. A sufficient degree of vertical forest structure is an important habitat requirement for many animal species such as the red squirrel (Spiecker *et al.*, 2004). Vertical structure is also an important part of the definition of selection forests (Schütz, 2001).

Structure like biodiversity can be expressed in numbers (Krebs, 1999; Pommerening, 2002; Pommerening, 2006). Some of the concepts available will be demonstrated in subsequent parts of this course.

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