Starr, M. 1999. WATBAL: A model for estimating monthly water balance components, including soil water fluxes. In: Kleemola S., Forsius M. (Eds.), 8th Annual Report 1999, UN ECE ICP Integrated Monitoring. The Finnish Environment 325: 31-35. Finnish Environment Institute, Helsinki, Finland.

Topp, G. C., Davis, J. L., Annan, A. P. 1980. Electromagnetic determinatin of soil water content: measurements in coaxial transmission lines. Water Resour. Res. 16: 574-582.

von Wilpert, K., Mies, E. 1995. The influence of stand structure and tree species on mineral cycling. In: Nutrient uptake and cycling in forest ecosystems. European Commission. Luxembourg. Viii, 276 pp.

Wieder, R. K., Lang, G. E. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. Ecology 63: 1636-1642.

Wright, E. F., Coates, K. D., Bartemucci, P. 1998. Regeneration from seed of six tree species in the interior cedar-hemlock forests of British Columbia as affected by substrate and canopy gap position. Canadian Journal of Forest Research 28: 1352-1364.

9. GAP DYNAMICS AND DISTURBANCES IN FORESTED ECOSYSTEMS

Floor Vodde
Forest Ecology and Forest Management Group, Wageningen University, the Netherlands, E-mail: floor.vodde@wur.nl

Abstract
The components of gap dynamics, consisting of spatial and temporal factors and of magnitude, are also applicable to disturbance dynamics. Comparing research results in gap and disturbance dynamics on different geographical locations is a useful tool for the investigation, prediction and implementation of the impact of different disturbance types in several forest ecosystems. The exact description of key terms, concepts and methodologies of research are very important for these comparisons. A digital database, containing details on research parameters like location, plot size and disturbance frequency, could form an interesting guide for future research.

Keywords: gap dynamics, natural disturbances, disturbance regimes, ecosystem management

Introduction

This article is based on the theoretical framework for a study of the importance of windthrow in a pine forest ecosystem in Estonia.

In this research, as in many studies of disturbance mosaics, an attempt was made to relate the gap patterns in the plots with forest disturbances. Understanding of gap dynamics and disturbances is of importance for various reasons. Risk management in silviculture is often mentioned in ecosystems experiencing frequent disastrous disturbance events. Also for the implementation -or even imitation- of disturbance dynamics in sustainable ecosystem management improved insights in the driving forces of these processes are required (e.g. Johnson et al. 1999, Payette et al. 1990). As a starting point, this article will distinguish the components of both gap and disturbance dynamics, based on theories in available literature.

Components

The **spatial component** of gap dynamics consists of the size and the patterns of gaps. Often the gaps appearing in a forest stand are not of equal size nor is there any regular pattern present. However, areas often show a tendency to a certain gap size or regularity. Relating this phenomenon to the disturbance types addressing the area, the characteristics of the disturbance agents could explain the spatial distribution of the gaps present (Armstrong 1999, Quine 1999).

Closely related to the patterns in the spatial component is the **temporal component** of gap dynamics. This component is usually expressed as the frequency of the occurrence of gaps in time. Frequency can be considerably varying: even within stands gaps can appear with intervals of decades to millennia. However, when the cause of gap formation can not be determined, the frequency signature can seem rather chaotic. According to Seymour et al. (2002), size of gaps caused by disturbances and frequency of occurrence are related. More catastrophic disturbances, causing large sized gaps, in general occur with large intervals, while small-scale disturbances have a higher frequency (e.g. Lorimer et al. 1988, Rogers 1996).

The **component of magnitude** is composed of intensity, being the physical forces to which the forest stand is subject, and severity, which is the actual damage done, often expressed as the loss of biomass. Each species and site reacts differently to a certain disturbance intensity, which could explain some of the differences in severity. Therefore, gap size, recovery rate and patterns are depending on the disturbance types, but also on surrounding parameters like the horizontal and vertical stand structure and the site conditions (Blackburn et al. 1988, Canham et al. 2001).

Distinguishing and studying different biotic and a-biotic disturbance types separately could help to understand the interaction of disturbances and complex patterns of gaps existing in forest stands. For example, small-scale disturbances by storms, addressing an area regularly, can cause an accumulation of woody debris. This can be the fuel wood for large-scale forest fires occurring on an infrequent basis.

Comparing the results of disturbance research in different geographical sites is an important tool to quantify the effects of disturbance types to different forest ecosystems. A comparable research approach, including definition formulation and a close description of the site conditions will facilitate the interpretation considerably.

Of course one should realise that not each gap is caused by disturbances. More gradual processes, like senescence and global climate change, are also influencing gap formation and gap closure or expansion (Ban et al. 1998, Bergeron and Leduc 1998). Furthermore, natural and human disturbances often interfere, complicating the picture increasingly.

Research and analysis
When considering research approach and definition formulation in gap dynamics research, it is important to define the scale of the research, the study plots and the boundaries set to gap size. Reporting the shape of the gap, in terms of minimum width and the way of assessment of gap shape, is essential when studying the gap overlays of several disturbance types or in case of a specific disturbance type like windthrow (Quine 2003). Furthermore, meth-

ods to report gap boundaries should be described accurately as these are not univocal between studies (e.g. Runkle 1985, Brokaw 1982, Brandani et al. 1988). While studying gap occurrence frequency, the methods applied to date gaps and to determine the gap formation agent are varying (Lorimer and Frelich 1989, Lorimer et al. 1988). Additionally, in long-term research it is important to set the monitoring frequency. Investigating magnitude, the severity and intensity of disturbance types should not be related without considering and describing the biotic and abiotic site characteristics. The implementation of natural disturbances in ecosystem management also means that the impacts of human disturbances, especially in terms of silvicultural activities, are adequately clear.

In conclusion, for the comparison of research results in gap and disturbance dynamics, it is very important to describe key terms, concepts and methodologies as exact as possible.

Suggestions for the SNS network 'Natural disturbances dynamics as component of ecosystem management'

The SNS Network resources are obviously aimed at the exchange of ideas and research experiences. During the Hiiumaa and Geysir meetings, in 2002 and 2003 respectively, suggestions were made to extend the results and effects of this scientific network. Subjects for research were highlighted for co-operation in projects. Furthermore, analogue to the existing Database on Forest Disturbances in Europe (DFDE, see for more information *http://www.efi.fi/projects/dfde*), a disturbance dynamics research database could be developed. Besides results, investigated parameters like gap size, perimeter, pattern, disturbance frequency and intensity, size of the area researched *etc.* could be included in this digital database. In this way, existing literature can be categorised and form a guide for future research in forest disturbance dynamics.

Eventually, experiments with management schemes in ecosystem management can be adapted to the frequency, patterns and severity of the natural disturbance regime in an area. The availability of data and information on sites with corresponding characteristics is relevant in case existing data resources are insufficient. However, we should beware of the risk of simplifying reality. Researching different separate disturbance types is just a first step in understanding the complex synergism of natural processes and human activities in forested ecosystems.

References

Armstrong G. W. 1999. A stochastic characterisation of the natural disturbance regime of the boreal mixed-wood forest with implications for sustainable forest management. Canadian Journal for Forest Research, 29: 424-433.

Ban Y., Huacheng X., Bergeron Y. and Kneeshaw D. D. 1998. Gap regeneration of shade-intolerant *Larix gmelini* in old-growth boreal forests of north eastern China. Journal of Vegetation Science 9. Special features in vegetation science 15: 529-536.

Bergeron Y. and Leduc A. 1998. Relationships between the change in fire frequency and mortality due to spruce budworm outbreak in the south eastern Canadian boreal forest. Journal of Vegetation Science 9. Special features in vegetation science 15: 493-500.

Blackburn P., Petty J. A. and Miller K. F. 1988. An assessment of the static and dynamic factors involved in windthrow. Forestry, 61: 29-43.

Brandani A., Hartshorn G. S. and Orians G. H. 1988. Internal heterogeneity of gaps and species richness in Costa Rican tropical wet forest. Journal of Tropical Ecology, 4: 99-119.

Brokaw N. V. L. 1982. The definition of treefall gaps and its effects on measures of forest dynamics. Biotropica 14, 2: 158-160.

Canham C. D., Papaik M. J. and Latty E. F. 2001. Interspecific variation in susceptibility to windthrow as a function of tree size and storm severity for northern temperate tree species. Canadian Journal for Forest Research, 31: 1-10.

Johnson N. C., Malk A. J., Szaro R. C. and Sexton W. T. 1999. Ecological Stewardship - A Common Reference for Ecosystem Management. Vol. I. Elsevier Science Ltd.

Lorimer C. G. and Frelich L. E. 1989. A methodology for estimating canopy disturbance frequency and intensity in dense temperate forests. Canadian Journal for Forest Research, 19: 651-663.

Lorimer C. G., Frelich L. E. and Nordheim E. V. 1988. Estimating gap origin probabilities for canopy trees. Ecology, 69: 778-785.

Payette S., Filion L. and Delwaide A. 1990. Disturbance regime of a cold temperate forest as deduced from tree-ring patterns: the Tantaré Ecological Reserve, Quebec. Canadian Journal for Forest Research, 20: 1228-1241.

Quine C. P., Humphrey J. W. and Ferris R. 1999. Should the wind disturbance patterns observed in natural forests be mimicked in planted forests in the British Uplands?. Forestry, 72: 337-358.

Quine C. P. 2003. Wind-driven gap formation and gap expansion in spruce forests of upland Britain. Proceedings of International Conference 'Wind Effects on Trees'. September 16-18. University of Karlsruhe. Germany.

Rogers P. 1996. Disturbance ecology and forest management: a Review of the Literature. US Department of Agriculture. Forest Service. Intermountain Research Station. 16 p.

Runkle J. R. 1985. Disturbance regimes in temperate forests. In: Pickett S. T. A. and White P. S. (eds.). The ecology of natural disturbance and patch dynamics. Academic Press. New York. 17-33.

Seymour R. S., White A. S. and deMaynadier P. G. 2002. Natural disturbance regimes in north eastern North America - evaluating silvicultural systems using natural scales and frequencies. Forest Ecology and Management, 155: 257-267.

Ulanova N. G. 2000. The effects of windthrow on forests at different spatial scales: a review. Forest Ecology and Management, 135: 155-167.