APPLICATION OF STEREO AERIAL PHOTOGRAPHS TO STUDY NATURAL GAP DYNAMICS IN A BEECH FOREST

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ABSTRACT

We used remote sensing methods to reconstruct natural stand dynamics of a semi-natural beech forest (Őserdő Forest Reserve, Bükk Mountains, Northern Hungary). We mapped canopy gaps using aerial photographs taken in 1975, 1980, 1993 and 2000, then we built a GIS database containing the geocoded photographs, the digitised gap contours for each time step, and digital elevation model. The purposes of our analyses were *i)* to test the applicability of this method; *ii)* to define descriptive gap characteristics; *iii)* to analyse gap dynamics of 25 years by following the fate of individual gaps.

Our results show that remote sensing is an important tool for studying the above phenomena. The observed canopy gaps covered 2.3–4.2% of the total area in the different years. Gap creation did not show any preference for special altitude, aspect, or slope steepness within this small study area. Average gap size increased from 39.4 m^2 to 61.3 m^2 during the 25 years study period. The number of gaps varied between 125 and 151. On average, slightly more new gaps were created than old ones closed each year (1.75–9.3%, and 3.21–7.89% of original number, respectively). The annual change of gap-area was 0.14–0.53%.

In addition to the information we gained from the stand dynamics of our study site, we also concluded, that the applicability of time series of aerial photographs (limited by differences in tilt and shadow in each photograph) could be greatly enhanced by applying 3D stereo images for delineating gaps.

Keywords: aerial photograph, GIS, beech, semi-natural, gap dynamics

1 INTRODUCTION

Gap formation – driven by the death of one or a few old trees – has an important role in the natural stand dynamics of temperate deciduous forests (Runkle 1985, White & Pickett 1985, Peterken 1996). In moist humid temperate regions this dynamics results in forests characterized by fine-scale mosaic of patches in different phase of forest development, by heterogeneous stand structure and by high diversity of habitats suitable for specialized forest-dwelling species (Standovár & Kenderes 2003). A clear understanding of natural stand dynamics is a prerequisite of developing nature-based management techniques for such forests.

Remote sensing techniques can help us understanding this process as these methods extend our observation both in space and back in time. With the ever increasing resolution of available techniques, nowadays remote sensing can be used in forest studies both at the landscape and the stand scales.

The purposes of our analyses were *i)* to test the applicability aerial photographs in retrospective analysis of stand dynamics; *ii)* to define descriptive gap characteristics (size, number, area, and spatial distribution among patches with different topographic characteristics, such as altitude, aspect, slope steepness) at each time step; *iii)* to analyze gap dynamics of 25 years by following the fate of individual gaps, i.e., to quantify the speed and importance of creation of new gaps, closure of gaps by lateral expansion versus by infilling of young undergrowth.

2 METHODS

The study area (Őserdő Forest Reserve) is a small (25 ha) beech-dominated stand situated on the plateau of the Bükk Mountains (48° 03'N, 20° 27'E), in Northern Hungary. Elevation ranges from 830 to 900 m. Mean annual temperature is 6.1 °C (January: -4.1 °C, July: 15.5 °C), the annual precipitation is 896 mm. The age of dominant beech trees varies between 150-200 years. It was managed and cut in the past, but it has been developed freely during the last 60 years. Stand structure is heterogeneous with trees of different sizes, canopy gaps and regeneration patches.

We used aerial photographs of two origin: *i*) Hungarian State Forest Service takes photos every ten years for forest management planning; *ii*) Photos have been taken for military and general land survey purposes by responsible institutes. We could use only those photos that were taken during the growing season. Most photos are black and white and we used the scanned images of the films. Canopy gaps were mapped using photographs taken in 1975, 1980, 1993 and 2000. First, we built a GIS database that contains the geocoded photographs, and the digital elevation model of the area. Then we digitised the contour lines of the gaps for each study year using two different working environments. For each time step we drew the contour lines into a polygon layer of our GIS database in ArcView 3.3 environment. To resolve ambiguities and uncertainties caused by differences in shade and tilt in each photograph, we also used 3D images generated from pairs of photographs by using the stereo analyst module of ERDAS IMAGINE.

An ArcView extension (Patch Structure) was developed, which not only calculates gap characteristics for each time step, but also follows the fate of individual gaps. This provided us with data to quantify the speed and importance of certain dynamical processes: creation of new gaps, closure, dissection of gaps, merger of neighbouring gaps.

3 RESULTS

Figure 1 contains the four maps showing the distribution of canopy gaps in the four study years.

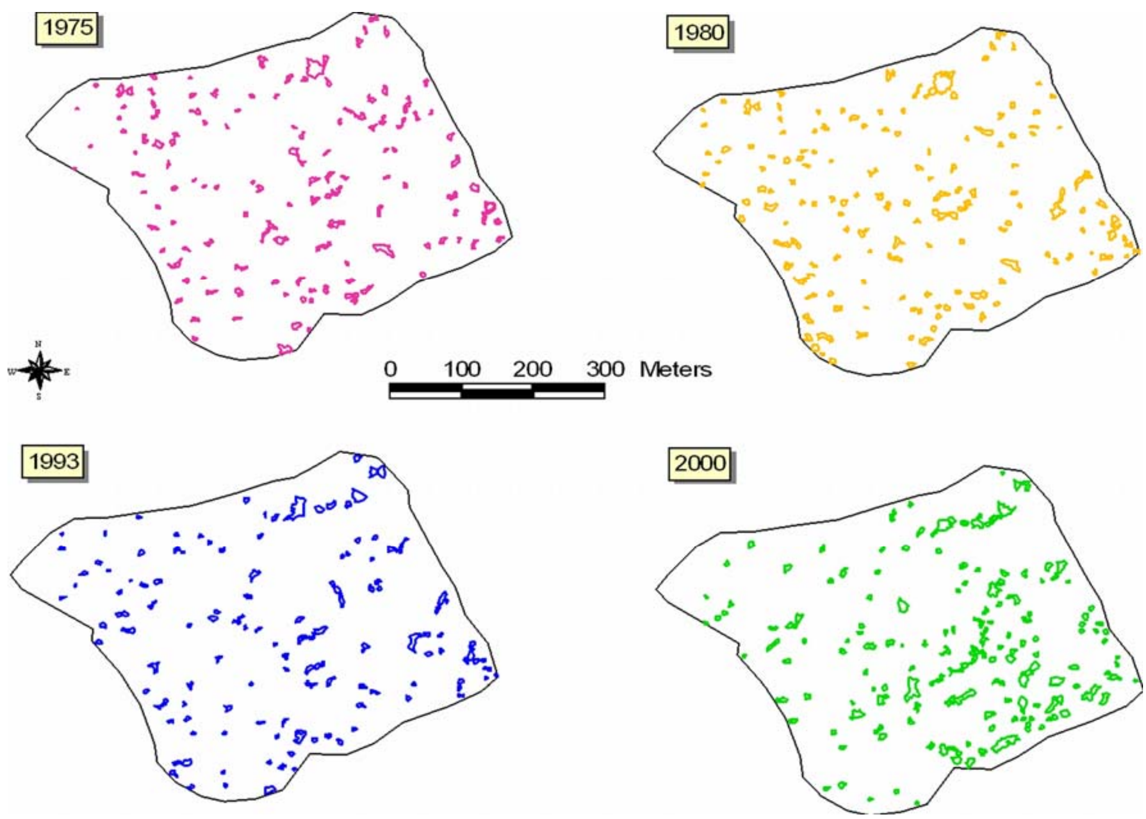

Figure 1: Distribution of canopy gaps in the Őserdő Forest Reserve in 1975, 1980, 1993 and in 2000 as they were delineated using aerial photographs taken in respective years.

Table 1 shows descriptive statistics of canopy gaps in the four study years. The number of gaps varied between 125 and 151 in the different years. The observed canopy gaps covered 2.3–4.2% of the total area. Both mean gap size and total gap area increased during the 25 years study period (from 39.4 m² to 61.3 m² and from 4928.22 m² to 8954.55 m², respectively). The most significant change took place between 1993 and 2000, especially in the south-eastern part of the area (cf. Fig. 1).

Table 1: Descriptive statistics of canopy gaps in the four study years.

	1975	**1980**	**1993**	**2000**
Number of gaps	125	151	114	146
Total gap area (m²)	4928.22	6592.12	5223.82	8954.55
Percent of total area covered by gaps (%)	2.31	3.09	2.45	4.20
Mean gap size (m²)	39.43	43.66	45.82	61.33
Standard deviation of gap size	52.76	67.34	58.24	71.02
Maximum gap size (m²)	487.36	731.05	454.55	377.61
Minimum gap size (m²)	3.25	5.60	4.08	4.36

Maximum gap size decreased during the study period. Determination of minimum gap size is a matter of a rather subjective decision that – among others – depends on the aim of the study. However, it is not reasonable the distinguish gaps smaller than 3 m² in size. Gaps occupied similar topographic positions at each occasion, i.e., gap creation did not show any preference for special altitude, aspect, or slope steepness within the study area.

As Tab. 2 shows, except for the period from 1980 to 1993, slightly more new gaps were created than old ones closed each year. The annual change of gap-area was 0.14–0.53%.

Figure 2 shows examples of all possible events: There are gaps that were closed during the study period (e.g., gaps No. 1, 2 or 10 in the line of the year 1975); there are newly created gaps (e.g., gaps 1, 2 and 3 in the line of the year 1980), there are about the same number of gaps that were merged (gaps No. 11 and 12), as gaps (e.g., No. 6, 7, 14, 16) that were dissected by infilling trees into several sister gaps.

Table 2: Characteristics describing different aspects of gap dynamics occurred during the three periods covered by our study.

	1975-1980	**1980-1993**	**1993-2000**
Number of new gaps	44	26	95
Proportion of new gaps (%)	29.14	22.81	65.07
Proportion of gaps opened annually (%)	5.83	1.75	9.30
Area of newly created gaps (m²)	1549.06	1294.95	4941.09
Percent of total area covered by new gaps (%)	0.73	0.61	2.31
Number of closed gaps	23	63	63
Proportion of closed gaps (%)	18.40	41.72	55.26
Proportion of gaps closed annually (%)	*3.68*	*3.21*	*7.89*
Area of closed gaps (m²)	565.58	1795.78	2067.51
Percent of total area covered by closed gaps (%)	0.00	0.01	0.01
Change of gaps surviving the period (m²)	680.42	-867.47	857.15
Change of total gap area (m²)	1663.90	-1368.30	3730.73
Change of total gap area (%)	0.78	-0.64	1.75
Annual change of gap area (%)	0.16	-0.05	0.25
Area where gap creation or closure occurred (m²)	2795.06	3958.20	7865.75
Proportion of area where gap creation or closure occurred (%)	1.31	1.85	3.69
Annual proportion of area where gap creation or closure occurred (%)	0.26	0.14	0.53

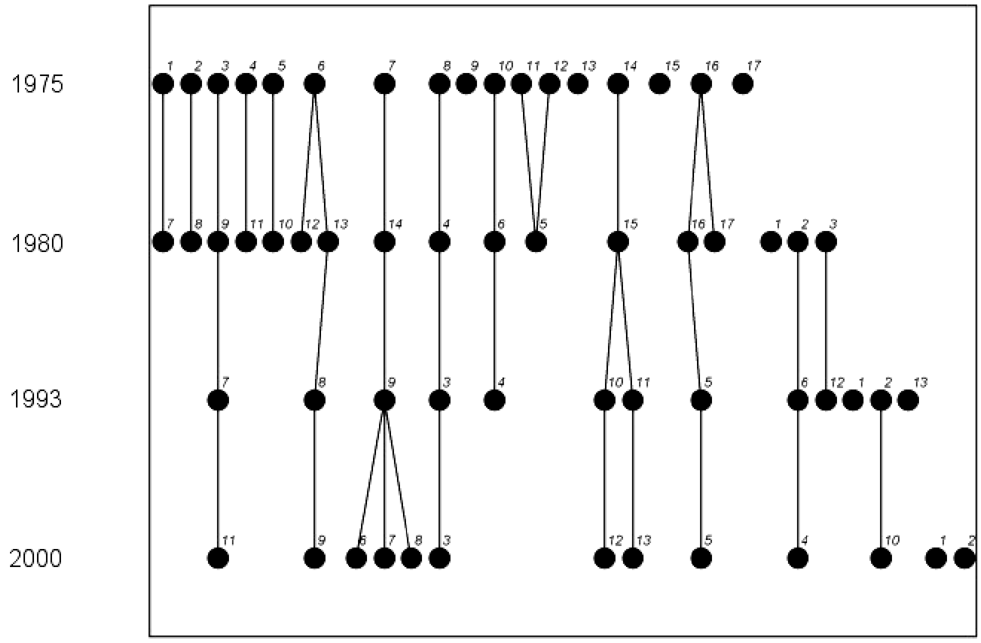

Figure 2: A small part of the large figure showing the fate of each gap: closure, creation, dissection and merger of neighbouring gaps. Numbers at the beginning of each line indicate the study year. Black dots indicate individual gaps, connecting lines indicate relationships (e.g., gap 7 in 1980 overlaps with gap 1 in 1975). Gaps can be traced back in the map by their identification numbers.

4 DISCUSSION

In answering our first question, we can state that our results show that application of aerial photographs is an important tool in studying gap dynamics. When applying this simple method – airborne photography –, the photos themselves set the limit of applicability. For our purposes the two major weaknesses of the photos we used were: *i)* the position of our stand in the photo was different in each time step; *ii)* the spatial resolution of the photos. The effects and limits set by the resolution are straightforward. However, the fact that our forest stand was viewed from different angles in the different photos, caused several difficulties. Not only the position of gaps "moved around" in time, but also the size and shape of gaps changed. The first problem was treated by the ArcView extension we developed while digitising the gap polygons. The effects of different viewing angles could be moderated by the stereo analysis, however not properly. In the photographs taken in 1993 our study site has extremely marginal position, for this reason, data collected from these images should be treated with caution. We assume that several small gaps could not be recognized, and also data on gap area might be underestimated. In addition to real dynamical processes, these effects might play a role in breaking the trend of increasing total gap area from 1975 to 2000 (cf. data in Tabs. 1 and 2).

We aimed at defining descriptive gap statistics of this semi-natural beech stand for several reasons. It has both theoretical and practical implications. Our results show that both total gap area, and average gap size in the Őserdő Forest Reserve are similar to those found in different temperate and tropical forests (Runkle 1982, Lorimer 1989). From a practical viewpoint we think our results have importance in demonstrating that natural processes usually create rather small gaps for regeneration, which is not in harmony with contemporary forestry practices. We did not find evidence of preferential gap formation at certain altitudes, slope steepness or aspects. However, as Figure 1 shows, by 2000 relatively large new gaps had been created in the south-eastern part of the reserve. This part is characterized by the best site conditions. The deep soil has always enabled large annual increment for the trees that had been freed up by regular tending cuts before the reserve was designated. As a result, the beech trees in this part of the reserve are spaced quite far from each other, could develop large canopies, and were not suppressed during their life. Consequently these large, old individuals are rather susceptible to different disturbance agents (e.g., fungi, wind). Even the death of single trees creates relatively large gaps.

With the help of the ArcView extension we could follow the fate of individual gaps throughout the 25 year study period. The average percentage of canopy that was converted to gaps in the Őserdő Forest Reserve is in harmony with literature data (e.g. Sousa 1984). We showed that in each period two to four times larger area was affected by dynamical processes than simple change of total gap area would indicate (cf. Tab. 2). This means that intensive gap creation and closure took place simultaneously. We have to emphasize that our estimates on gap number, gap size and on the importance of different dynamical processes (creation closure, merger, dissection) depend on the conventions we applied in drawing the gaps.

Finally, we want to stress, that the size of the study area in itself set limits to drawing general conclusions about the dynamics of this beech forest, since it was definitely smaller than the minimum dynamic area (sensu White and Pickett 1985). However, we – as many other colleagues in Europe – had to live together with constraints set by the long and intensive land use history of our forest that has left very little near natural forests for such studies.

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