SPATIAL DISTRIBUTION OF TREES ON LIGHT TAIGA PLOTS BEFORE SELECTIVE THINNING

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ABSTRACT

Since 2009 the School of Agroecology and Business, Institute of Plant and Agricultural Sciences of the Mongolian University of Life Sciences in Darkhan has established research plots in two research areas in the Selenge aimag. The establishment was conducted in close cooperation with development organisations (FAO, GIZ) and the University of Goettingen. The purpose of the research initiative is to combine capacity development and monitoring of forest structure in the mountain forest steppe zone and taiga zone. Here we report results on the horizontal spatial structure of forest stands. We analysed the spatial distribution of trees on birch and larch plots of the research area «Altansumber» before a selective thinning took place on some plots in 2009. The research area is situated in the mountain forest steppe zone. The forests belong to the light taiga. The selected stands approach a chronosequence. The results showed that the tree distributions were mainly irregular («clumped»). Random spatial tree distribution occurred especially in the medium-aged birch stand. We found no indication of regular tree distributions in any of the plots. We assume that the disturbance regime and successional processes are the driving factors leading to the specific tree distribution pattern on the plots. Due to different regeneration strategies and life span of the dominating species the birch stands and the larch stands seem to differ slightly concerning the chronological occurrence of clumped and random spatial tree distribution. We finally conclude that a better control of the disturbance regime would not only support an undisturbed forest succession to riper forest stands but also result in less forest stands with irregular spatial distribution. This may also have implications on forest productivity.

KEY WORDS: *spatial forest structure, mountain forest steppe, light taiga, disturbance regime*

INTRODUCTION

Forest structure is considered as being an indicator of stand development phase, biodiversity, ecological stability, competition processes and overall functioning of forest ecosystems (Korpel 1995, Naumburg & De Wald, 1999; Zirlewagen & Wilpert, 2001; Bobiec, 2002). Moreover, measures of forest structure are useful indicators of naturalness (Winter 2012, Winter et al. 2015) and management impact (Schall & Ammer 2013). Forest structure can be divided into non-spatial and spatial structure. Non-spatial structure refers to common measures like stem number, basal area or the relative frequencies of species. Horizontal spatial structure refers to the spatial distribution of tree attributes and can be divided into dominance (in relation to neighboring trees) and species mingling. Finally, the spatial distribution (synonymous with spatial positioning) of trees may be irregular (also referred to as «clumped»), random or regular (Gadow & Hui 2002; Gradel & Muehlenberg 2011).

There are only few studies that deal with spatial forest structure in near-natural boreal forests. Only recently research on spatial forest structure has been started in Mongolia. The forests of northern Mongolia largely belong to the mountain forest steppe zone and taiga zone (Dulamsuren 2004). Most forests are dominated by the so-called light taiga (Muehlenberg et al. 2012): *Betula platyphylla*, *Pinus sylvestris, Larix sp.* Many accessible forest stands close to settlements have recently become degraded in terms of age structure and species composition. For example, the relative fraction of birch, which is an indicator of recent disturbances, increased around settlements, like the wood logger village Tunkhel. Because of forest loss and degradation different monitoring approaches are necessary in Mongolia. Permanent research plots are one component of a comprehensive forest monitoring. Repeated inventories in such plots allow the detailed monitoring and evaluation of the effects of a certain treatment, as for example thinnings.

In 2009, the School of Agroecology and Business, Institute of Plant and Agricultural Sciences of the Mongolian University of Life Sciences (MUL) in Darkhan established in close cooperation with international partners (FAO, University of Goettingen) research plots in the research area of Altansumber (Градел и др. 2015; Gradel et al. 2015[2]). The area represents typical mountain forest steppe of the western Selenge aimag. In our study the horizontal spatial structure, specifically the spatial distribution of trees on the plots before a thinning in 2009 were analyzed. Based on a pilot study in the eastern part of the Selenge aimag around the research station Khonin Nuga (see Muehlenberg et al. 2004), we assume that the original spatial distribution of the trees in the research area of Altansumber is predominantly irregular (Gradel & Muehlenberg 2011).

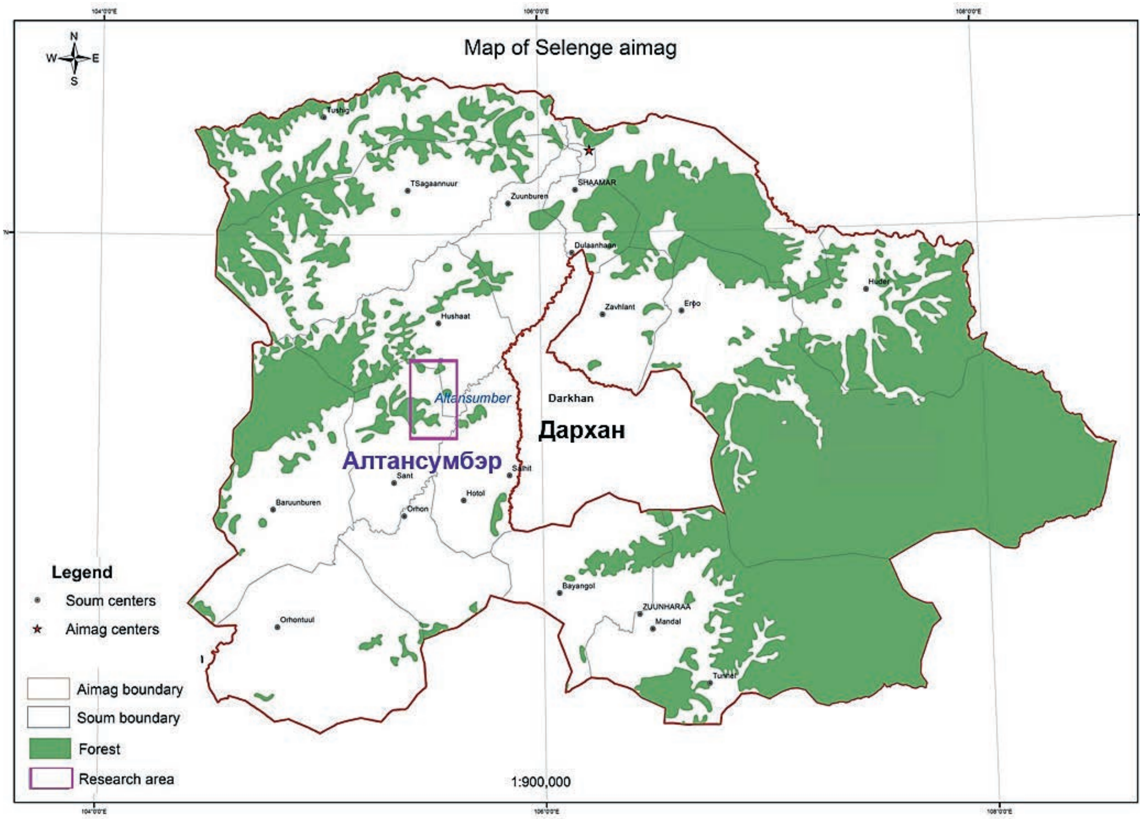


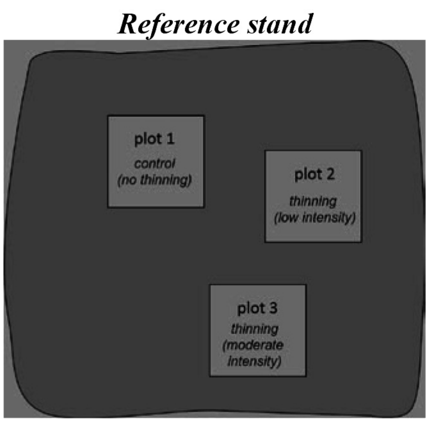
Figure 1. The research area (RA) Altansumber (mountain forest steppe zone) about 32 km areal distance to the west of Darkhan and 30 km to the north of Sant (soum center).

MATERIALS AND METHODS

Plot establishment in the research area Altansumber

In 2009 research plots were established in the framework of international cooperation (FAO-project: GCP/MON/002/NET). According to the focus and guidelines of the FAO-project (Output No. 5) the plot establishment was concentrated on the area of one forest user group (FUG Altansumber)) and involved different stakeholders and players: FUG-members, students of the MUL Darkhan, FAO-office Darkhan and staff of the responsible environmental office (Gradel 2010).

The research area Altansumber is situated about 32 km to the west of the town Darkhan (figure 1; N: 49°29’07.29’’; E: 105°31’30.36’’). The northern slopes of the mountain forest steppe are dominated by birch (*Betula platyphylla*) and larch (*Larix sibirica*). All forest stands are affected by fire and most of them also by small scale logging activities. The area is inhabited by traditional Mongolian nomads that largely rely on livestock raising. They have recently united to the forest user group (FUG) Altansumber (Gradel 2010, FAO 2014, Gradel & Petrov 2014). The plot establishment was based on the concept of reference stand and reference plot (Petri & Michel 1959; Gadow et al. 2000). The concept of reference stands with a core area (reference plot) that is representative for common stands is especially applicable for regions that aim at continuous cover forestry management. The monitoring aspect is a main benefit of this concept. The reference stand should have a minimum size of 2 hectares (Gadow et al. 2000). The reference plot should have a rectangular shape. The common shape is 2500 m² (Gradel & Muehlenberg 2011). The stand selection was based on the following criteria: typical for the region, accessibility and intended utilization. The selected stands approach chronosequences (young to medium aged). All stands are classified as *Larix sibirica-Betula platyphylla* forest (Muehlenberg et al. 2004), which means that the selected stands in the RA Altansumber are either dominated by birch or larch trees. In every selected stand three plots were established on representative sites based on expert judgement. The plot design is in accordance with Pretzsch (2002), Андреева et al. (2002), Gradel & Muehlenberg (2011) which means that standard stand attributes can be calculated from the plots. The following data has been collected: species, diameter size and stem coordinates (x and y within the plot) of every living tree with a minimum diameter at breast height (DBH) of 7cm. A sufficient number of tree heights of the main tree species was measured in each stand. After the first assessment some plots in the stands BI, BII, LI and LII became subject to selective thinning. See figure 2 for the theoretical design of the concept of reference stand and reference plots (including thinning trials) in the RA Altansumber. For our analysis only living trees at the time before the thinning activities were considered. See table 1 for an overview of the selected reference stands. For details of each plot see Градел и др. (2015) and Gradel et al. (2015)².



	Purpose	Assessment
Reference plot	- orientation for impacts - utilisation planning - detailed monitoring of forest dynamics	- tree species - tree positions - DBH, height - regeneration inventory
Reference stand	- education - view object - silvicultural concepts (e.g. evaluation of thinning impact)	(an inventory of the reference stand is not necessary)

Figure 2. Theoretical design, purpose and assessment of the reference plots in the RA Altansumber (Gradel 2010 based on Gadow et al. 2000). Detailed forest structure was only assessed in the reference plots (species, tree positions, DBH, height)..

Table 1

Background information of the selected light taiga stands in the mountain forest steppe of Altansumber (Градел и др. 2015, Gradel et al. 2015[2]). The plots in the stand BIII exhibit the highest DBH standard deviations, because very large and small diameters occur (Gradel et al. 2015[2]).

reference stand	height above sealevel	exposition	N (plots)	plot size (m^2) 2009	indication of disturbances	year of assessment	N (stems/ha)	basal area/ha	diameter (Ш)
BI*	934	N	3	2500 (1550)	s.f.	2009	1144-1174	8.70-14.66	9.4-11.8
BII	966	N	3	2500	s.f.	2009	984-1188	17.29-17.90	13.3-14.0
BIII	1118	NE	3	2500	s.f., s.p.l.	2012	324-612	22.12-29.78	20.6-26.9
LI	911	NW	3	2500	s.f.	2009	1136-1528	13.51-16.71	10.2-12.0
LII	976	NW	3	2500	s.f., s.p.l.	2009	416-656	21.64-24.88	20.8-24.9
LIII	913	N	3	2500	s.f., s.p.l.	2009	188-268	16.91-17.96	28.4-33.3

*The plots BI2 and BI3 were enlarged to 2500 m² only in 2013. Here the original plot data from 2009 is analyzed.

Abbreviations table 2. L: larch stands (LI.LII:LIII: 85-100%); B: birch stands (BI, BII: 92.5-100% birch, BIII: a mixed birch stand) ; I: forest stand with relatively small diameters (young stand); II: forest stand with relatively medium diameters (young-medium aged stand); III: forest stand with relatively large diameters (medium-aged (LIII), medium-aged - old (BIII)); s.f.: signs of fire impact; s.p.l.: signs of previous logging (stumps).

Characterization of the spatial tree distribution on the plots via L-functions

Rrecorded tree positions on a plot can be considered as point process. A common tool for analysing such point processes is Ripley's K-function $K_{(r)}$. The cumulative K-function $K_{(r)}$ is defined as the expected number of points within a given distance r of an arbitrary point of the pattern, divided by the intensity λ of points of the pattern (Wiegand 2004). The K-function allows to determine if the trees in the study area appear to be regular, irregular, or randomly distributed. The characterization of the spatial tree distribution pattern is based on testing the hypothesis of complete spatial randomness (CSR). The CSR assumes that the tree distribution follows a homogenous Poisson process across the whole distance (Stoyan & Stoyan, 1994; Corral Rivas et al., 2006). It can be difficult to interpret $K_{(r)}$ visually (Wiegand 2004). We therefore used the square-root transformation of the univariate K-function, the univariate L-function $L_{(r)}$, also referred to as L_{11} (Besag 1977; Ripley 1981, Pretzsch 2002; Wiegand 2004; Wiegand & Moloney 2004) that makes the $K_{(r)}$ linear and stabilizes its variance (Moeur 1993, Lingua et al. 2008). See formula 1.

$$L_{(r)} = \sqrt{\frac{K(r)}{\pi}} - r \quad (1)$$

The pattern is defined as irregular («clumped») if the values of the original function at the distance r are greater than the values of the confidence envelope. The pattern is defined as regular if the values of the original function at the distance r are lower than the values of the confidence envelope. A random pattern is indicated if the values of the original function are located within the range of the confidence envelope. The 95% confidence envelope was constructed using the Monte Carlo method (see Stoyan & Stoyan, 1994). 999 simulations have been computed for deriving critical values for alpha=0.05 for each data set.

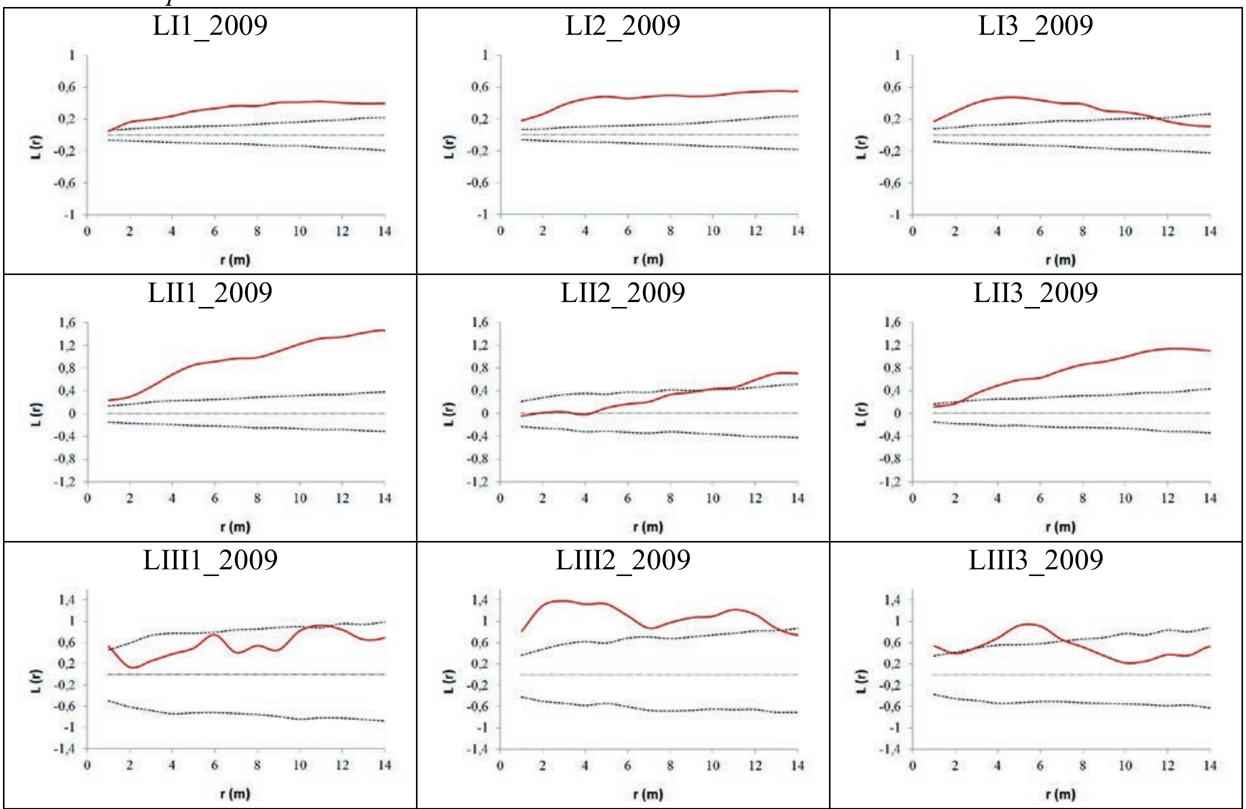
Based on a previous study of light taiga stands in the western Khentey Mountains (Gradel & Muehlenberg 2011) we assume that the original spatial tree positioning of the plots is predominantly irregular («clumped») with *r.max.* = 14 m. The analyses were conducted using Excel 2007 (Microsoft Corp.) and the Programita software (Wiegand 2004; Wiegand & Moloney 2004).

RESULTS

The L_{11}-functions for the reference plots in the selected larch stands are presented in figure 3. Apart from LII2 and LIII1 all larch plots exhibited a predominantly irregular («clumped») tree distribution pattern until r=7 m and in most cases even up to r=14 m.

The results of the birch plots are presented in figure 4. In the birch stand which was characterised by lower tree diameters (BI) the tree distribution of two of the three plots was predominantly irregular. In contrast, on the plots with a higher mean diameter (BII) the tree distribution was random until r=7m. The tree distribution of the birch stand BIII was predominantly irregular.

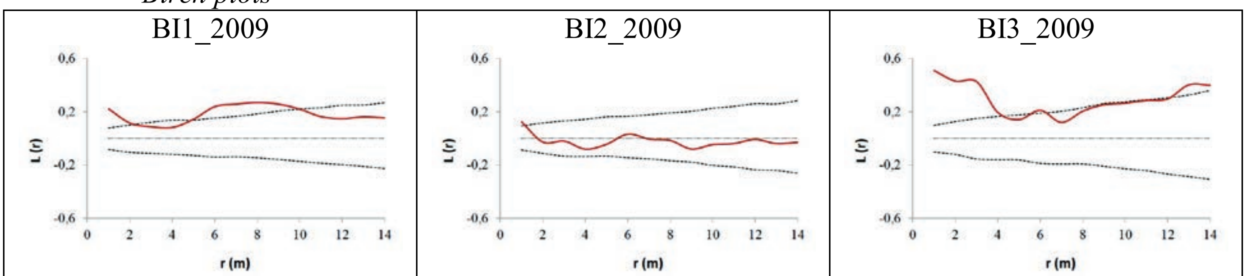
Larch plots



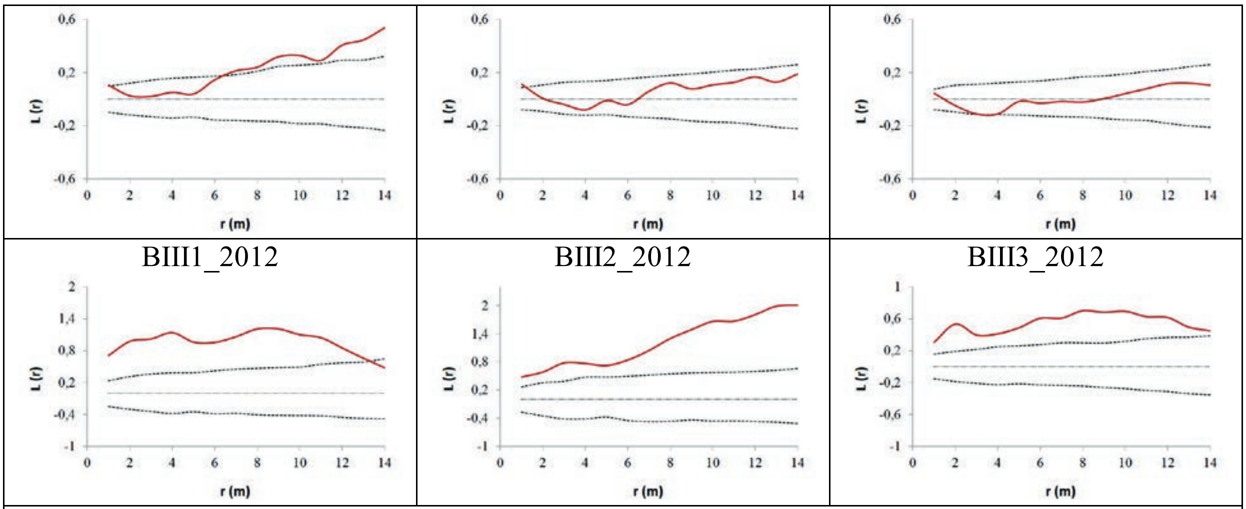
continuing line: original L-function of the respective plot; upper and lower dashed lines: confidence envelopes; dotted line: 0-line

Figure 3. *L_{11}-functions of the reference plots in the selected larch reference stands (research area Altansumber).*

Birch plots



BII1_2009	BII2_2009	BII2_2009



continuing line: original L-function of the respective plot; upper and lower dashed lines: confidence envelopes; dotted line: 0-line

Figure 4: *L_{11}-functions of the reference plots in the selected birch reference stands (research area Altansumber).*

DISCUSSION

It was shown that the spatial distribution of trees was, as expected, predominantly irregular. This is especially true for the forest stand LI and partly also the stand BI, which consist almost completely of trees with small diameters. These stands are very young. Regeneration often occurs clumped because of ground layer structure (Zagidullina & Tikhodeyeva 2006). This explains the clumped distribution pattern of young tree stands. Density and distribution of trees change during the process of forest succession (Бузыкии и др. 1985). Random tree distribution appeared more often in forest stands with medium diameter (especially BII). It seems as if with continuing succession the competition processes increasingly control growth and tree survival and thus tree distribution. Single trees are outcompeted by neighbouring trees and die, the horizontal structure becomes less clumped. If these processes continue tree distribution evolves towards a more random pattern. Consistently random tree distributions can be found in gap-driven forest ecosystems; in Mongolia for example in the dark taiga old growth forests of the Khentey Mountains (Gradel & Muehlenberg 2011). Several studies also showed predominantly random tree distributions in near-natural European mountain spruce forests, e.g. in a study of the Orlickй hory in the Czech Republic (Hofmeister et al. 2008). Depending on site conditions and development phase, the spatial positioning of near-natural spruce forests was often found to be random or clumped (Gradel et al. 2014). Forest dynamics of the mountain forest steppe, however, is driven by another disturbance regime. Frequent anthropogenic, abiotic and biotic desynchronising disturbances (Бузыкии и др. 1985), more specifically repeated interruptions by irregular disturbance events (especially fire and unplanned selective logging) influence the remaining forest structure and sometimes stimulate forest succession. This may be a reason, why in the RA Altansumber the spatial tree distribution on the plots of the birch stand with the highest average diameter (BIII) and also highest diameter variability (Градел и др. 2015, Gradel et al. 2015²) was found to be predominantly clumped as well. The high diameter variability indicates that this forest stand is already in a regeneration phase. The root stock sprouting of birch and aspen after disturbances can be a cause for clumped tree positioning. After disturbance events riper birch forests will, due to their specific regeneration capacities and intensive succession response, faster exhibit clumped tree distribution compared to larch forests. One factor is also the different life span of the two species (birch, short-lived, larch: long-lived), which influences the succession-cycle of the respective forest stands. Because of this the stand BIII is already in a relatively later development phase (regeneration of the next generation) than the stand LIII for example. The ground vegetation of many light taiga stands (e.g. LIII) consists of a dense grass layer, which also influences tree positioning during the process of forest succession. The larch stand LIII showed a relatively less clumped horizontal structure when compared with the stand LI, but here also only one of three plots (LIII1) exhibited a predominantly random distribution. The diameter variability in the stand LIII is relatively low (Градел и др. 2015; Gradel et al. 2015[2]), as this stand is rather even aged. In such larch stands the forest succession is especially facilitated by releasing disturbances (e.g. intensive fires). Of unknown importance are the small scale site conditions. For example, within a sub-alpine altitudinal gradient in the Italian Alps of near-natural forests the spatial positioning was found to be predominantly clumped, especially the tree groups close to the tree line showed more often aggregation when compared to forest sites at lower elevations (Lingua et al. 2008). However, repeated disturbances, which prohibit an undisturbed stand development are the main reason why many light taiga stands are thrown back to an initial stage and exhibit irregular distribution of trees.

The reference stands are situated on the territory of the FUG Altansumber. Improved forest protection against fire and illegal logging is the main aim of the Mongolian FUG-concept. Different management impacts can be monitored in the reference stands of the RA Altansumber (e.g. control plot versus thinned plots).

Forest structure directly affects competition processes and growth (Gadow et al. 2012). This means it also has influence on stand stability and growth. The individual growth of trees in a stand also depends on the stand density. A clumped tree distribution may not provide optimal conditions for maximal growth, but may be effective in terms of stand stability. Tactical managed stands often exhibit a regular tree distribution (optimized competition). So far studies of mixed stands show that the optimal structure in terms of growth especially depends on the tree species mixture (Pretzsch et al. 2013).

CONCLUSION

Our study indicates that the spatial distribution of trees in light taiga stands of the Mongolian mountain forest steppe is predominantly irregular («clumped»). We found no indication of regular tree distributions in any of the plots. Due to different regeneration capacities and life span of the dominating species birch and larch stands seem to differ slightly in the expression and chronological occurrence of clumped and random spatial tree distribution. Random spatial tree distribution occurred especially in the medium-aged birch stand BII. In the mountain forest steppe the disturbance regime (e.g. fire, logging activities etc.) directly influences the forest structure, releases succession processes and drives forest dynamics. We conclude that a better control of the disturbance regime would not only support the succession to riper forest stands but also result in less irregular distributed forest stands which may offer the option to more effective wood production.

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