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Uneved-aged Silvicultural systems of Scots Pine in the Czech Republic and in the Community of Madrid, Spain: experience, application and suggestions

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Abstract

The master's thesis was aimed on close-to-nature Silviculture in Scots pine stands and focused on comparison of structural diversity on plots with even-aged and uneven-aged management on different sites in the Czech Republic and in Spain.

Four permanent research plots were established in Scots pine-dominated forest stands, of which two were placed in Western Bohemia, the Czech Republic (plots CZ-1 and CZ-2), and two were placed in Community of Madrid, Spain (plots ES-1 and ES-2). The plots were located in forest example-locations that together practically show the stages of transition from regular to irregular management – CZ-1: stand with regular DBH structure and lower stand complexity as a result of less intensive harvest treatments in the past; CZ-2: stand in transition from even-aged to uneven-aged stand, recent selection harvest and very complex stand structure; ES-1: regular stand with low intensity intervention in the past and low stand complexity; ES-2: irregular stand with high intensity intervention and high stand complexity.

On those plots, growth parameters, horizontal and vertical structure were described. Unconstrained principal component analysis (PCA) was used to analyse relationships among plots attributes, stand parameters, climate data, and diversity of *Pinus sylvestris* and similarity of 4 research plots. Core increment samples were extracted to investigate the core annual increment pattern, particularly for recent years in relation to silvicultural measures.

The results showed the state of the forest stands and differences of characteristics between individual plots. All plots had similar density characteristics, but different DBH structure, reached by different intensity of silvicultural interventions. Trees on ES plots showed lower H: DBH ratio. On even-aged plots (CZ-1, ES-1), the spatial distribution of trees was predominantly random (CZ-1), or random bound to regular (ES-1), while it was aggregated on the more irregular plots (CZ-2, ES-2) according to *L*-function.

In PCA analysis, the first ordination axis explained 55.8%, the first two axes together 93.5% and the first three axes together explained all 100.0% of the variability in the data. Altitude was positively correlated with precipitation and gradient, while these parameters were negatively correlated with temperature, stand age and total diversity index. Stand volume, mean height and DBH positively correlated to each other, while these parameters were negatively correlated with canopy (crown closure, crown projection area), stand density and structural differentiation indices. Plots generally inclined to variability of different parameters, especially for plots ES-1 and ES 2.

Mean core increment in recent years was highest on the most intensively managed plot, as a result of selection cutting. The important increment reaction was apparent across a number of DBH classes (14, 18, 22, and 46).

Keywords: Selection silvicultural systems, Scots pine, stand structure, increment cores, Monte de Cabeza de Hierro, Plasy

Abstrakt

Diplomová práce se zabývá problematikou přírodě blízkého pěstování borových porostů. Zaměřuje se na porovnání převodů stejnověkých porostů na porosty nestejnověké na různých plochách v České republice a ve Španělsku.

Byly založeny čtyři trvalé výzkumné plochy v porostech s dominantním zastoupením borovice lesní: dvě v západních Čechách (plochy CZ-1 a CZ-2), a dvě v Madridu v centrální oblasti Španělska (ES-1 a ES-2). Plochy byly umístěny v příkladových lokalitách v přestavbě na nestejnověké porosty, které ilustrují přechod z normálního na nepasečné hospodaření – CZ-1: porost s pravidelnou tloušťkovou strukturou a menší diverzifikací v důsledku málo intenzivních těžebních zásahů; CZ-2: porost v procesu přestavby na nestejnověký les s výrazně rozrůzněnou strukturou; ES-1: porost s pravidelnou tloušťkovou strukturou, s málo intenzivními minulými těžebními zásahy a malou diverzifikací; ES: porost s výběrnou strukturou, vysokou diverzifikací a intenzivními zásahy.

Na těchto plochách byly změřeny růstové parametry, a byla popsána horizontální a vertikální struktura. Analýza hlavních komponent (PCA) byl použita pro analýzu vztahů mezi vlastnostmi ploch, porostními parametry, klimatickými daty a diverzitou borovice lesní a podobností daných čtyř ploch. Dále byly odebrány vzorky letokruhů pro zjištění dynamiky přírůstu, zejména v posledních letech jako reakce na konkrétní pěstební opatření.

Výsledky znázorňují rozdíly ve stavu borových porostů. Všechny plochy vykazovaly podobné charakteristiky hustoty, ale rozdílnou tloušťkovou strukturu, která byla dosažena různými pěstebními zásahy. Stromy na španělských plochách měly nižší poměr H: DBH. Na stejnověkých plochách (CZ-1, ES-1) bylo rozmístění stromů náhodné (CZ-1), anebo náhodné částečně směřující k pravidelnému (ES-1), zatímco na nestejnověkých plochách bylo, podle *L*-funkce, uspořádání shlukovité (CZ-2, ES-2).

Při analýze hlavních komponent první osa vysvětlila 55.8% variability dat, první dvě osy dohromady 93.8% a první tři dohromady 100%. Nadmořská výška byla pozitivně korelována se srážkami a sklonem, a tyto parametry byly negativně korelovány k teplotě, věku porostu a indexu celkové diverzity. Porostní zásoba, porostní výška a tloušťka pozitivně korelovaly k sobě navzájem, zatímco tyto parametry vykázaly negativní korelaci k charakteristikám korunového patra lesního porostu (korunovému zápoji, projekci korun), hustotě porostu a k indexům strukturní diferenciace. Plochy byly charakteristické variabilitou různých parametrů, rozdíl byl patrný zejména mezi ES-1 a ES-2.

Průměrný přírůst na letokruhu v posledních letech byl nejvyšší na ploše s intenzivními těžebními zásahy jako důsledek výběrné těžby. Výrazná reakce přírůstu byla patrná napříč tloušťkovými stupni (14, 18, 22 a 46).

Klíčová slova: výběrný hospodářský způsob, borovice lesní, struktura porostu, přírůst na letokruhu, Monte de Cabeza de Hierro, Plasy

Resumen

El trabajo fin de máster se centra en el estudio de diferentes regímenes selvícolas de pino silvestre; compara la diversidad estructural en parcelas con gestión de masas regulares e irregulares en diferentes estaciones forestales en la República Checa y en España.

Se establecieron cuatro parcelas permanentes en pinares de silvestre, de las cuales dos se situaron en el oeste de Bohemia, República Checa (parcelas CZ-1 y CZ-2), y dos se situaron en la Comunidad de Madrid, España (parcelas ES-1 y ES-2). Las parcelas se localizaron en masas forestales que muestran ejemplos de la transformación de masas regulares a irregulares – CZ-1: masa con estructura regular de DBH y baja complejidad de la masa como resultado de gestión y cortas simples menos intensiva en el pasado; CZ-2: masa en la transición de masa regular a irregular, con cortas por entresaca y estructura compleja del rodal; ES-1: masa regular de baja intensidad de intervención en pasado y con baja complejidad; ES-2: masa irregular de alta intensidad de intervención y con alta complejidad.

En estas parcelas, se midieron los parámetros de crecimiento, se describió la estructura forestal horizontal y vertical. Se usó un análisis de componentes principales sin restricciones para analizar las relaciones entre los atributos de las parcelas, parámetros estructurales, datos climáticos, y diversidad de las masas de pino silvestre y la afinidad de las 4 parcelas. Se barrenaron varios árboles y se estudiaron las muestras de barrena para analizar el esquema del crecimiento anual.

Los resultados muestran el estado de los rodales y las diferencias en las características dasométricas entre parcelas individuales. Todas las parcelas tuvieron parecidas características de densidad, pero diferente estructura del DBH, como consecuencia de la diferente intensidad y tipo de los regímenes selvícolas. Las parcelas ES indicaron el ratio H: DBH más bajo en el arbolado. En las parcelas regulares (CZ-1, ES-1), la distribución espacial de los arboles fue, sobre todo, aleatorio (CZ-1), o aleatorio con tendencia orientada a regular (ES-1), mientras esta misma fue más agregada en las parcelas irregulares (CZ-2, ES-2) según la *L*-función.

En el análisis PCA, el primer eje explicó 55,8% de la variabilidad, los primeros dos ejes en conjunto, el 93,5% y los primeros tres ejes explicaron el 100,0% de la variabilidad de los datos. La altitud tuvo una correlación positiva con precipitaciones y pendiente, mientras que estos parámetros fueron negativamente correlacionados con la temperatura, edad del rodal y con el índice de la diversidad total. Las variables de volumen en pie, altura media y DBH se correlacionaron entre sí, mientras que estos parámetros se relacionaron negativamente con la superficie de copas (espesura del dosel, fracción de cabida cubierta), densidad del rodal y con los índices de diferenciación estructural. Las parcelas se inclinaron a la variabilidad de distintos parámetros, particularmente entre las parcelas ES-1 y ES-2.

El crecimiento promedio de los anillos en los últimos años fue más elevado en las parcelas tratadas con una gestión intensa por entresaca. El incremento en el ritmo de crecimiento en diámetro fue patente en varias clases de DBH (14, 18, 22 y 46).

Palabras clave: entresaca, pino silvestre, estructura de masa forestal, anillos de crecimiento, Monte de Cabeza de Hierro, Plasy.

Contents

1 Introduction

Silviculture is the art of cultivating forests for the needs of people. It is not just a coincidence that the term “sustainability” was defined in this field of human activity: the needs of sustained yield were described in the work of Carl von Carlowitz more than 300 years ago (PODRÁZSKÝ 2013; SCHMIDT 2013) before the industrial revolution, when wood was the main energy source and construction material, and forests all over Europe suffered over-exploitation.

The final thesis is derived from the works carried out by Department of Silviculture in Prague. The general aim of the research project is to increase the adaptability of pine silviculture in the conditions of the Czech Republic. The task is to elaborate new approaches and systems of regeneration in pine dominated stands, differentiated according to management intensity, to support biodiversity of species composition and the resistance to extreme climatic effects and changes, and for the support of retention capability of forest ecosystems.

Foresters pointed out the need of reduction of large-scale monocultures already in the first half of the 19th Century (SOUČEK 2006). That was the time when many different management systems started to evolve: oriented to single tree selection and natural regeneration of site appropriate species (SCHMIDT 2009). The aims were to reach stabilized forest ecosystems with balanced wood production on small forest arrangement units (REMEŠ 2008). The silvicultural systems based on this principle are variable and can be grouped under a common term ‘close-to-nature silviculture’ (HAVERAAEN 1995).

2 Aim of the study

The objective of the master’s thesis was to evaluate the structure and growth characteristics of forest stands with natural dominance of Scots pine in the conditions of Western Bohemia (the Czech Republic) and Community of Madrid (Spain). The selection of locations was deliberately done so that it would characterize small-scale silvicultural practices that are rather exceptional in pine as a light-demanding tree species. Yet, in each (environmentally distinct) locality always two plots with higher and lower degree of differentiation were selected, in order to cover broader spectrum of stand structural characteristics. The broader aim of the work was to investigate, whether the diversification of Scots pine forest stands could be viable in terms of wood production, stand stability and diversity.

3 Literature review

3.1 The environment of Scots pine

3.1.1 Scots pine range

The investigation was conducted at sites with natural occurrence of Scots pine (*Pinus sylvestris* L.). Scots pine is distributed across Europe and Russia to far Siberia, occupying largest area of all pine species (Ešnerová & Kuneš 2014). The distribution in Spain makes its south-western limit (Fig. 1).

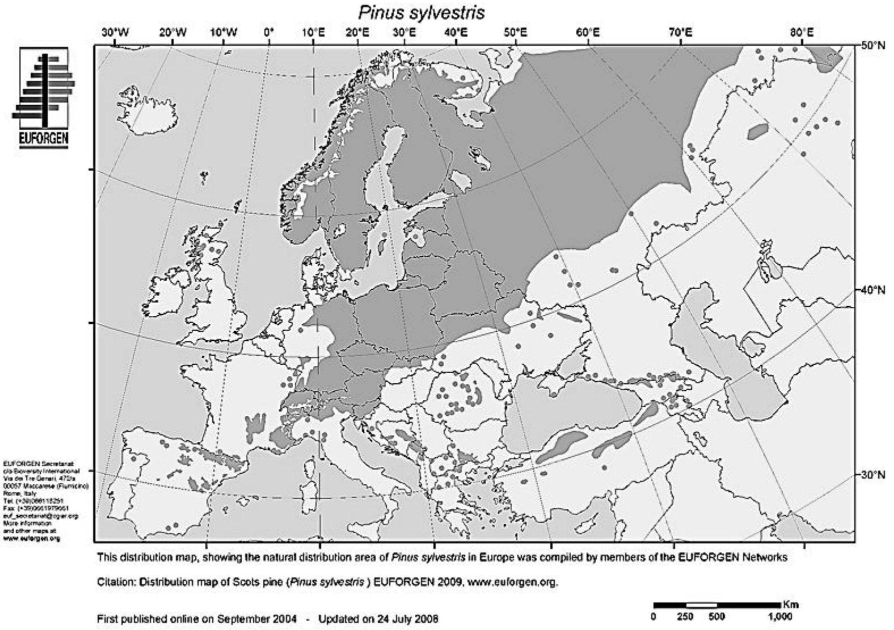


Fig. 1. Natural distribution of Scots pine (source: EUFORGEN)

3.1.2 Ecological characteristics of Scots pine

Scots pine is a generally known tree species. Its silvics has been described thoroughly in forestry handbooks (Savill 1991). It can reach 40 m of height and live over 300 years. On extreme sites, the species forms shrubby habitus. In the upper part of stem the colour is cinnamon and small branches can be yellow, therefore is easily distinguishable from relative pines. In the lower part, the bark forms large smooth scales.

Although the indigenous stands of Scots pine in the Czech Republic are scarce: the autochthonous pine is rather individually distributed at extreme and relict sites (Musil & Hamerník 2007), it is the second commercially most important forest tree species (Ministry

OF AGRICULTURE 2014), after Norway spruce (*Picea abies* [L.] Karst.). As a woody plant that is adapted to a wide range of climatic conditions, having particularly high tolerance to soil moisture, from drying-up sites to waterlogged sites, it has a prerequisite for resisting climatic extremes. Therefore, Scots pine could serve as a stabilizing part of forest ecosystem, on both silicate and sandy sites. Historically, pine had been planted on extensive areas on poor, sandy sites, where often the removal of litterfall for the purpose of collecting bedding material, resulted in occurrence of non-productive forest cultures; as it is known from the region of Pilsen (*Czech*: Plzeň), around the municipality Plasy, Western Bohemia (MIKESKA et al. 2008). At many sites, wrong provenience had a negative impact on the quality of the cultures; at other sites, on the contrary, many valuable local cultural types were exerted (MUSIL & HAMERNÍK 2007).

In Spain, Scots pine is forming mountain stands between 800–2000 m AMSL, the optimum is between 1600 – 1700 m (SERRADA HIERRO et al 2008). In the Central system of Spain, *Pinus sylvestris* var. *iberica* (Svoboda) is distinguished (AMARAL FRANCO 2015; SERRADA HIERRO 2008; SERRADA HIERRO et al. 2011; LÓPEZ-SÁEZ et al. 2013) from all other populations, and also all the Spanish populations are genetically significantly different from other European populations (PRUS-GLOWACKI & STEPHAN 1994; ALÍA et al. 2001). Apart from *iberica* variety of Scots pine, Pravdomil Svoboda, a Czech dendrologist and a long-time director of Forestry Faculty in Prague in the 1960's, also determined *pyrenaica* variety of the same species and *Abies alba* var. *pyrenaica* Svoboda (according to floraiberica.es). Also many cultivars are bred for ornamental use and arboriculture. Therefore, it could be difficult to precisely establish the area of origin and distribution.

3.2 Silviculture of Scots pine

The utterly dominating silvicultural system in pine woods is the management of even-aged stands, particularly with the use of clear-felling. In the Czech Forest Act, there is exception from rule of maximum clear-cut of area 1 ha for pine silviculture, where clear-cut of 2 ha is acceptable, which speaks for itself. In Sierra de Guadarrama, there is various experience of Scots pine management of both natural and artificial origin. Public property Navafría is managed under large-scale shelterwood system – again even-aged large scale management.

Only a very limited attention has been paid to the possibility of small-scale procedures of regeneration, and from Europe there are only a few examples of an intentional and continuous shift from clear-cutting to small-scale regeneration techniques derived from the principles of close-to-nature silviculture. The Möller's forest on Bärnethoren property served as an example of pine silviculture for the forestry community and was well accepted. Far more often, the softer approaches are used in connection with shade-tolerating species, such as silver fir or Norway spruce. Different situation is in the south-eastern USA, where there is various experience with shelterwood and selection system of *Pinus taeda* and *Pinus echinata*. Several examples were derived there from experiments on balanced selection silviculture lasting over 70 years (GULDIN 2011).

In general, the essential prerequisite for the success of selection system is much greater decrease in standing volume, but nevertheless, even here the positive effects that are generally connected with close-to-nature forestry can be expected. Among these effects are biological automatization, lower inputs, and therefore higher economical effectivity of management, improved stability of stands with lower risk of large-scale calamity disintegration and reinforcement of non-wood-producing roles of forest including aesthetics, increase of biodiversity and the standpoint of structural diversification.

Up to now knowledge about stand mixtures with Scots pine show that there is a strong potential of wood production increase, and potential for establishing more favourable stand structure in comparison with pine monoculture, with the maintenance of stand stability (PRETZSCH 2013). The findings differ from one stand to another, according to stand and site conditions. In the Czech conditions, the focus was particularly on the mixtures spruce-pine (POLENO 1975). There is a lack of knowledge about the characteristics of mixtures pine-broadleaves. In spite of the fact that Scots pine contributes on poor soils to the nutrition cycle (TERAUDA & NIKODEMUS 2006), the litter is acidic and favours the acidification of soil. In case of stand mixtures, with the dominance of Scots pine, the mixed litter of different species can positively affect the decomposition process, nutrition loss by leaching, and the activity of microorganisms (BERGKVIST 1987, BORKEN & BEESE 2005). There is some knowledge about the influence of individual species' litterfall, but the influence of stand mixtures is little known.

The problems with artificial regeneration of Scots pine are often related to human factor during planting (delayed budflush, bad growth and high mortality after planting resulting from insufficient morphological and physiological quality of planting stock), as well as to environmental conditions, which in case of Scots pine are relatively high temperatures and low precipitation in lowland regions of Central Europe – with a precondition to short-term drought (MARTINCOVÁ 1998). Similarly, in European forests there are documented changes leading to subsequent dying of light-demanding (and relatively drought-tolerant) pines and oaks (*Pinus sylvestris* and *Quercus pubescens*) (MORÁN-LÓPEZ et al. 2014), probably because of ever dryer and warmer climate in the late decades. Therefore, the possibility of natural regeneration of pine, particularly in lower and warmer sites, deserves an increased focus.

Scots pine can regenerate in moderate shade, but reacts strongly to a different availability of light within gaps particularly by total height increment, above-ground biomass and leaf area. The species also has, in comparison to spruce, higher flexibility in relation to a lower availability of light (DE CHANTAL et al. 2003); e.g. in needle morphology (elongation with higher light intensity) and in enlarged leaf area that enables a better competition in a gap. Similar changes can be related to assimilation apparatus and its further characteristics (NIINEMETS et al. 2002). On the other hand, seedlings cultivated under the canopy can show higher stress and humidity deficit, which can at the same time decrease the tolerance to shade. The production of assimilates can also change, as well as the proportion of above and below-ground biomass of young plants (RODRIGUEZ-CALCERRADA et al. 2008). The nutrition status on site can play a role in adapting to the availability of light (NIINEMETS et al. 2002). Drought stress commonly leads to decrease in increment, total seedling size, and also to decrease in root biomass volume (PEARSON et al. 2013).

CREGG & ZHANG (2001) and MATÍAS et al. (2014) confirmed that more drought-tolerant provenances (from Central Asia or from southern parts of the area of distribution in Southern Europe) differ by lower increment, more significant transfer of biomass into the below-ground part, and a higher effectivity of water use. This way, those provenances decrease their drought stress and have relatively higher probability of survival and higher increment in dry period than provenances less drought-tolerant, which on the contrary have higher increment in optimal periods.

3.3 Close-to-nature silviculture of Scots pine stands

For this chapter and the next, the book by KORPEĽ & SANIGA (1993) was used as the primary reference. The basic unit of a selection forest is a clump (group), made up by trees of different age, diameter and height, which is connected by growth bonds and life relations. On the area of a clump, all growth phases of forest are represented horizontally and vertically. The crowns fill all the available space given by the height of highest trees, without being a hindrance to each other. Such constitution of stand is permanent with respect to growth processes, the stocking is stabilized. The aim of harvest is to cut the current periodical volume increment accumulated after a certain period of time (interval of return). Natural regeneration is irregular and continual.

Selection cutting depends on perfect spatial arrangement and a dense net of skidding lines. Attention should be paid to balanced timber extraction and skidding on all sub-compartments: the directional felling and assortment method should be used (TRUHLÁŘ 1997). Forest depletion by extracting the most valuable assortments of highest dimensions, as the selective felling, is not in accordance with the selection principles. KORPEĽ & SANIGA (1993) further suggest that the principles of selection silvicultural system, and therefore selection forests, have general relevance. They could be applied in all original (natural) European forests, without any restriction of tree species composition and site conditions.

Selection forest is a model of biological automatization and autoregulation of forest ecosystem, regulated by forester (SCHÜTZ 1989). Independent growth from the thicket stage leads to strong positive selection with an important value increment. The principles were theoretically elaborated by LIOCOURT (1898) and verified in practice by Swiss forester Henry Biolley. Biolley was convinced of the selection idea from the point of view of forest management planning and regulation of harvest. In Switzerland (Neuenburg canton), he was the first who was realizing continuous control of volume increment and created optimal stand volume according to DBH classes, unlike previous forest management plans, where the basic factor was time, rotation and regeneration period, and the production process depended on those. Biolley created a control method for the regulation of selection structure and he reached to the systematic requirement of continuous selection cutting in all stand layers.

The function of selection forest, as described by LIOCOURT (1898) is:

$$N_i = A * q^{-(i-1)}$$

Where: N_i – number of trees in respective diameter class, A – number of trees in the first registered diameter class, q – quotient of geometric order, i – diameter class.

The same year as LIOCOURT presented his work, the forestry reformer K. Geyer said: “If we want to find the way back to nature without prejudices, then we should, on the way back, reach the selection forest” (in KORPEĽ & SANIGA 1993). KERR (2013) states that the original findings of Liocourt’s “seminal study on uneven-aged forests” were widely misunderstood:

With respect to site conditions, it is stated that on rich sites selection system can be used for its production advantages, while on poor sites, it should be used as a matter of priority, or even obligatory (AMMON 1946). Higher tree species diversity allows easier application of the conception related to uneven-aged character and vertical diversity and vice-versa, in unmixed stands this is more difficult or can be economically ineffective. The independent growth from thicket stage leads to increased value production, in the meaning of positive selection (KORPEĽ & SANIGA 1993). Selection forest produces significantly less trees of smaller dimensions in comparison to regulated forest. An important characteristic is height increment of trees, which is influenced and regulated by sunlight gain. This increment has an ascending trend from advance regeneration stage to upper storey stage (in comparison to regulated forest)

In terms of stability, KERN (1966) found out that the slenderness coefficient was significantly lower, and the mechanical stability higher in selection forest in comparison to regulated forest. The crucial interval is in DBH dimensions 12–20 cm, i.e. trees of medium layer, where the acceleration of growth is expected. It is the differentiated structure and relations of small groups that creates the conditions of stability.

The selection silvicultural system involves the four main intentions: tending, structure formation, regeneration and harvesting (LEIBUNDGUT 1951). The sustainability and continuity of regeneration processes in selection forest was initially considered as matter of course, but in many cases this assumption was not fulfilled. In ideal state, selection forest perfectly uses not only the production capability and ecological conditions of environment, but also growth characteristics of tree species and individual trees by differentiated vertical structure and radial system. Even though selection forest is considered as close-to-nature forest ecosystem and selection system as the conception of forest management closest to nature, the balanced and convenient structure from the production point of view is not dependent on natural processes, but is result of an intentional activity of forest manager. Without continual interventions, the forest loses its structural characteristics: already after 15–20 years without active intervention, it leads to subsequent equalization of layers. It is documented especially in forests with protective functions, where the demand on vertical differentiation is pronounced, but silvicultural measures are not carried out during several decades. The so called purpose cut does not represent any concrete meaning, is often limited to salvage (hygienic) cutting and cannot serve as an effective tool for the achieve or maintenance of forest stability and function.

As for the selection cut, the interventions are inseparable in terms of time period, they continuously overlap and integrate. The necessity of better use of production space does not allow for stronger stand release, not even for regeneration benefit of sun-demanding species.

If the space completion of at least medium layer in close future is not expected, the harvest of mature trees needs to be postponed. Positive as well as negative selection should be applied according to the current needs. Despite the emphasized time inseparability of individual parts of selection cut, the cut should be planned in phases. Trees of main canopy damage smaller trees when harvested and extracted, and therefore the intervention into main canopy should be performed first. Silvicultural measures aimed on adjustments of low layer are performed consequently. Where the juvenile layer is insufficient, or where the quality of harvesting process is lower, the return period has to be shortened.

The emphasis is put on the control of value culmination of individual trees, which particularly distinguishes selection system from even-aged systems. The value depends on diameter, morphology of stem and inner features of wood such as annual rings, proportion of core wood etc. The closer the structure is to optimal structure, the lesser negative phenotype selection is used, and positive selection is preferred.

There are more criteria in terms of sanitary cutting in selection forest compared to clear-cutting. Some components are left for the purpose of positive influence on the surrounding value holding trees, soil shading, and litterfall, which prevents soil deprivation.

Crown height and shape are particularly important traits in selection forests of coniferous trees, of their development and growth potential, and therefore their suitability as component for balanced selection structure. In stands without selection cut for longer period of time, there is excessive number of trees in upper canopy or medium layer and the crowns are being shortened rapidly, the stability and vitality of trees both decrease.

Artificial regeneration should be applied only in case of reintroduction of previously lost species that was excluded from the ecosystem by wrong harvesting measures, and its reintroduction signifies the production or functional effect, and the increase of ecological stability and improvement of regenerative processes.

3.4 Transformation to close-to-nature silviculture of Scots pine

Forests are considered for the transformation (rebuilding) to selection forest for functional reasons: stands with diverse structure, numerous transitions from one-layer even-aged forest, through moderately vertically differentiated stands, to highly differentiated all-aged forests, which already resemble selection stand (KORPEĽ & SANIGA 1993). The transition is the more difficult and prolonged, the more equalized the vertical structure is. According to the state of the forest, different methods of transition are used (Fig. 2)

LEIBUNDGUT (1949) characterized so called transition thinning for the quality increase and transition to other silvicultural system and other forest management type. Under selection thinning is understood such tending measures into relatively young stands, by which the low vertically differentiated stand far from selection structure is intended to be transformed into balanced state. Therefore, as opposed to selection cut, selection thinning is performed in stands, where the biological automatization has not yet reached the sustainable and balanced production of large-diameter stand. The particular feature of this thinning is an adequate force of intervention and the foreseeing of growth reaction of given trees and of closest components. Even though it is more adequate to work with lower stocking in this phase (in comparison to balanced stocking), it is desirable to exclude an excessive force of intervention. Softer measures can better ensure the fluent transition and the manager can adapt to expressed growth reaction and to the need of the commencement of natural regeneration. Selection thinning can be successful in stands of low level of development, with enough individuals that are flexible and capable of strong reaction after the increase of sun-light availability, capable to increase and form their crowns. There have to be enough vital trees capable to remain in existence and in a good health status for a relatively long time during the transition. The aim of the thinning is time-limited. When the structure closes to balanced structure of selection forest, the interventions start to have character of selection cutting.

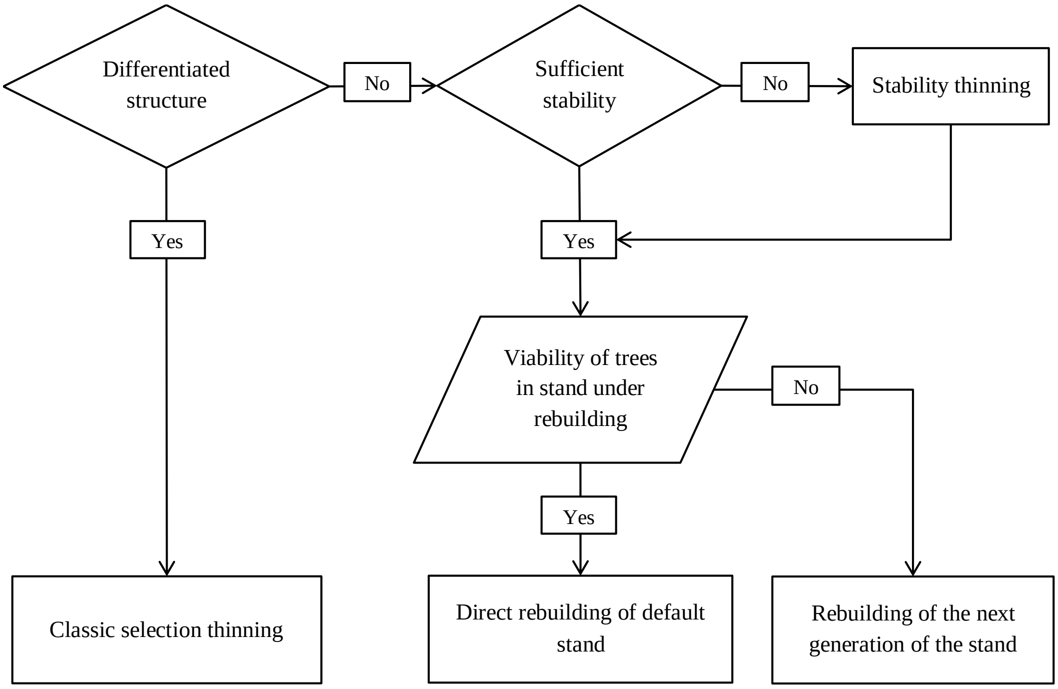


Fig. 2. Stand rebuilding decision scheme (according to Schütz 2002)

There is not much information so far available on the topic of rebuilding pine stands into selection system. In Spain, there are several examples of pinewood with relatively complicated vertical structure. Pinar de Lillo in northern Castilla-León region is considered as natural forest of differentiated structure (GARCÍA ABRIL et al. 2005). The situation in Spain is, however, very different, especially in ecological terms: first, *Pinus sylvestris* is a mountain species (on its south-western limits of distribution); and second, it naturally forms unified, nearly monospecific stands.

3.5 Natural conditions and history of the study areas

Forest Administration Plasy is situated in the western part of Bohemia, the Czech Republic. Its area stretches over the Berounka river watershed, in natural forest zone 6 - hilly region of Pilsen (Fig. 3). River Střela, as a tributary of river Berounka, passes the whole Forest Administration area and forms a canyon that that is one of the most precious natural monuments in the region. The monastery of Plasy was built in 1144 and is important part of regional cultural heritage.

Forest district Špankov is one of the 10 forest districts under the Forest Administration. It covers an area of 1.596 ha and is within Natural Park Manětínská. Regional bedrock is predominantly of Proterozoic origin, but locally prevail Carbonic sediments (ÚHÚL 2000).

The experimental forest of Scots pine silviculture on poor soils (absolute site quality index of 16–20 m) is maintained within the district. The objective is to transform the uniform Scots pine stands into more differentiated uneven-aged stand and diversify the species structure (ČERVENÝ 2012).

From other tree species, European beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* Carst.), sessile oak (*Quercus petraea* Matt.), and Silver fir (*Abies alba* Mill.) are commonly represented. The stands are complemented by individual trees of silver birch (*Betula alba* Roth), black alder (*Alnus glutinosa* (L.) Gaertn.), and European larch (*Larix decidua* Mill.). The principal problem for forest regeneration is posed by overpopulated introduced Sika deer (*Cervus nippon*).

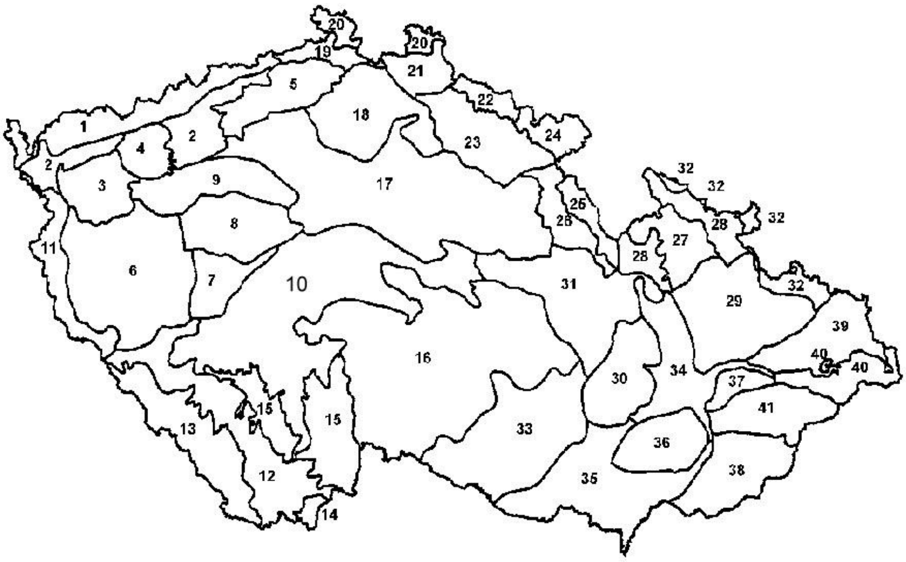


Fig. 3. Natural forest zones in the Czech Republic (there are 41 forest zones according to 83/1996 directive).

The Monte de Cabeza de Hierro Forest is situated in Spanish Central System, in the north-west of the Community of Madrid. The forest covers the initial, most elevated part of Lozoya river watershed (southbound part of Guadarrama watershed and part of Tajo river catchment) in altitudes of 1.260 – 2000 m AMSL. The bedrock is composed of metamorphic glandular gneiss. The most common tree species is Scots pine, accompanied by Pyrenean oak (*Quercus pyrenaica* Willd.) in lower parts. Other tree species are represented by common holly (*Ilex aquifolium* L.), individually dispersed trees of silver birch (*Betula alba* Roth), rowan (*Sorbus aucuparia* L.), yew (*Taxus baccata* L.), poplar (*Populus tremula* L.), half a dozen of sessile oak trees (*Quercus petraea* Matt.), and two specimen of Spanish juniper (*Juniperus thurifera* L.)

Understorey of shrubs and subshrubs is formed by *Genista florida*, *Genista cinerea*, *Sarothamnus scoparius*, *Cytisus oromediterraneus*, *Adenocarpus hispanicus*, *Erica arborea*, *Pteridium aquilinum*, *Juniperus communis* and various species of the genus *Rosa*. Scarcely present is *Vaccinium myrtillus*. The main potential biotic diseases for *Pinus sylvestris* are *Cronartium flaccidum* var. *corticola* and *Phelinus pini*.

It is a privately owned woodland, managed since 1840 by Sociedad Belga de los Pinares de El Paular Company, therefore the forest is commonly called Monte de los Belgas [The forest of the Belgians]. The history of the forest is well documented from the 15th Century (BRAVO FERNÁNDEZ & SERRADA 2007). Apart from 2050 ha of forest land, the Company also manages timber yard with sawmill for subsequent processing of wood.

The forest is divided into six compartments, from which five are managed under shelterwood system and one under selection system. The rotation period is 150 years and regeneration period is 25 years. In the third revision of management, it was first proposed to manage all compartments as irregular stands (BRAVO FERNÁNDEZ, SERRADA 2007). The first management plan was conducted in 1957. A new inventory was carried out in 1967, and later in 1977. The first revision was delivered in 1987, followed by the second in 1999, and the third, latest, in 2007.

The woodland is the home and one of important refuges of the cinereous vulture (*Aegypius monachus* L.). The number of nesting pairs has been continuously growing, despite active forest management. The trees with nests are protected and no management is performed within 100 m perimeter. The cutting operations predominantly take place outside nesting and breeding period (November – January). Nowadays, the Monte de Cabeza de Hierro forms peripheral protection zone of the Sierra de Guadarrama National Park.

4 Materials and methods

4.1 Data collection

Four squared permanent sample plots (50x50 m) were established; two in Western Bohemia, the Czech Republic (CZ-1, CZ-2), and two in the Community of Madrid, Spain (ES-1, ES-2) (Fig. 4).

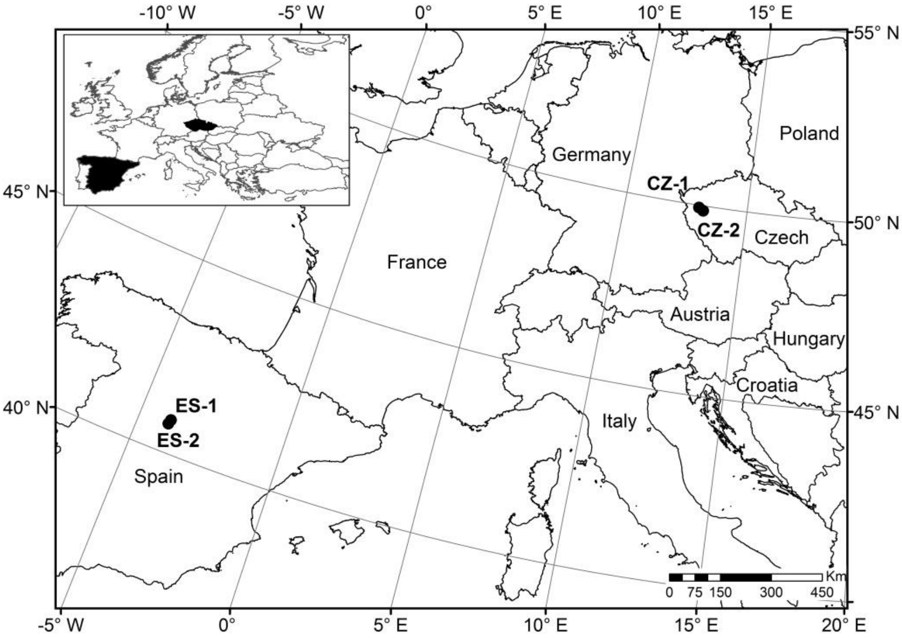


Fig. 4. Localization of permanent research plots.

Plots CZ-1 and CZ-2 are located in Plasy Forest Administration (Forests of the Czech Republic, state enterprise), in Špankov Forest district, Western Bohemia. The geological and soil conditions are characterized as kaolinite-clayed Carboniferous sandstone with acidic soils heavily compacted, sand-clay to clay-sand and poor to very poor (ČERVENÝ 2012). Plots ES-1, ES-2 were located in Monte de Cabeza de Hierro, Central System of Spain. The geological and soil conditions were poor acidic gneiss with silicate-clayed soil. Climatic conditions according to nearest meteorological stations are characterized by mean annual temperature of 7.4°C and precipitation of 500–550 mm for CZ (Plzeň); and 6.5°C and 1150 mm for ES plots (Puerto de Navacerrada). General description of the plots is summarized in Table 1.

Table 1. General characteristics of investigated forests included in the study (data from forest management plans).

Parameter	*Plots*			
	CZ-1	CZ-2	ES-1	ES-2
Longitude	49.9099036N	49.9055694N	40.8229028N	40.8224694N
Latitude	13.1998936E	13.2062422E	3.9202889W	3.9206583W
Elevation [m]	600	590	1710	1710
Mean height [m]	17	20	17	17
Mean DBH [cm]	27	32	35.5*	35.5*
Stock [m^3]	211	162	222*	222*
Age	142	145	140	140
Exposure	-	E	N	N
Gradient [%]	0	5	30	30
Average precipitation (mm)	550	550	1300	1300
Average temperature (°C)	7.4	7.4	6.5	6.5

*data is from forest management revision, referring to whole sub-compartment (52)

The two adjacent CZ plots were only several hundred meters from each other, and in the same sub-compartment in case of ES plots. The plots were chosen in natural (autochthonous) Scots pine-dominated forest stands of following characteristics: CZ-1: unmanaged for at least 30 years with regular structure, lower stand complexity as a result of less intensive harvest treatments in the past; CZ-2: managed stand in transition from even-aged to uneven-aged stand, recent selection harvest and very complex stand structure; ES-1: regular stand with low intensity intervention; ES-2: irregular stand with low intensity intervention. All plots are regenerated by natural regeneration under the shelter of mature parental stand. CZ-1 and CZ-2 were Scots pine dominated stands with admixture of Norway spruce (CZ-1, CZ-2) and silver birch (CZ-1), ES-1 and ES-2 were pure Scots pine stands without admixture. Cutting frequency on the three managed plots was 5–10 years. Photos of plots are included in Appendices.

4.1.1 Stand structural characteristics

Data was collected from four 0.25 ha study plots. Within each study plot, all woody trees of DBH ≥ 4 cm were measured. For each stem, the diameter in mm at 1.3 m above ground, the total height and the crown height (hypsometer Vertex, accuracy 0.1 m) were measured. For selected trees in particular diameter class, increment cores were sampled.

Field-Map technology (IFER-Monitoring and Mapping Solutions Ltd.) was used for the setup and field inventory of investigated plots. It is a software and hardware solution fort computer-aided field data collection and processing. It combines a flexible real-time GIS software Field-Map with electronic equipment for mapping and dendrometric measurements.

Its use starts from the level of single tree measurement, through the level of research or inventory plot, up to the landscape level. Field-Map has been designed primarily for the purposes of forest inventory, but it is also suitable for a number of different field data collection tasks like forestry mapping, attributing forest stands for forest management planning, carbon offset monitoring, landscape mapping, standing volume assessment, measurement of research plots, inventory and monitoring of nature reserves, etc.

The hardware of Field-Map (Appendix: photo) is composed of a stand of various types (in this case monopod) and a board computer. It enables high-precision measurements of horizontal angles on plots. The software combines flexible real-time GIS software with electronic equipment for mapping and dendrometric measurement. The powerful tool allows mapping and visualization, calculations and analyses, validity checking, processing etc. Comfortable use of Field-Map is in a couple, but the complete inventory is most commonly performed in group of three.

The position of all trees with DBH above 4 cm was localized. Tree heights, heights of the live crown base and crown perimeter were measured, at least at 4 directions perpendicular to each other. DBH were measured with a metal calliper to the nearest 1 mm. Heights and heights of the live crown base were recorded with Vertex III hypsometer to the nearest 0.1 m. Trees of DBH under 4 cm, but height > 150 cm, were considered as regeneration.

4.1.2 Sampling increment cores

The core increments were sampled by Pressler’s increment borer at 1.3 m above ground. When possible, 3–5 trees per DBH class were sampled. However, not always was the number of trees within DBH class available (Table 2).

Table 2. Number of sampled trees for core increments in each DBH class on plots

Diameter class	CZ-1	CZ-2	ES-1	ES-2
0-4 (2)	/	/	/	/
4-8 (6)	2			3
8-12 (10)	3	5		3
12-16 (14)	4	5		3
16-20 (18)	4	3		3
20-24 (22)	6	1		3
24-28 (26)	4	4		3
28-32 (30)	4	5		3
32-36 (34)	4	5	3	3
36-40 (38)	4	4	4	3
40-44 (42)	2	1	3	3
44-48 (46)	2	1	3	3
48-52 (50)			3	2
52-56 (54)			3	3
56-60 (58)			3	2
60-64 (62)				1
64-68 (66)				0

The reaction of trees with DBH > 20 cm (in CZ-1 were 100 trees with DBH > 20, sampled: 38; in CZ-2):

4.2 Data analysis

4.2.1 Stand structural characteristics

The general statistics was done in MS Excel. Based on DBH classes and number of trees in each DBH class, figures comparing DBH forest structure were created. Structural and growth parameters, quantity and quality of production, horizontal and vertical structure and biodiversity were evaluated on each plot. Structural characteristics were computed using the Sibyla growth simulator (FABRIKA, ĎURSKÝ 2005). In the growth simulator SIBYLA, production characteristics are calculated separately for individual stand components. In addition, they are calculated separately for individual tree species and for all tree species together (http://etools.tuzvo.sk/sibyla/english/model.htm).

The number of trees per hectare was calculated as the ratio of the total number of trees of a particular stand component in a simulation plot (n) to its area (p):

$$N = n : p$$

Tree volume was calculated using the volume equations published by PETRÁŠ, PAJTÍK (1991). Tree diameter (*d*) and tree height (*h*) were the inputs to the equations. The equations differ by species, for Scots pine it was:

$$v = a_1.(d+1)^{a_2 - a_3.\log(d+1)}.h^{a_4} - a_5.(d+1)^{a_6}.h^{a_7}$$

The equations were also derived for other tree species, and also for the volume of the timber to the top of 7 cm outside bark. By default, in the growth simulator SIBYLA production was evaluated by the volume of the timber to the top of 7 cm inside bark, while the volume of the timber to the top of 7 cm outside bark was applied only in the case of biomass estimation.

Mean age is calculated as weighted arithmetic mean of ages of the trees forming the particular stand component, while their tree volumes are taken as weights:

$$\bar{t} = \frac{\sum_{i=1}^{n} v_i . t_i}{\sum_{i=1}^{n} v_i}$$

Mean diameter is obtained as a quadratic mean of diameters of all trees forming the stand component:

$$d_g = \sqrt{\frac{\sum_{i=1}^{n} {d_i}^2}{n}}$$

Diameter variability is calculated as a standard deviation of diameters of all trees forming the stand component:

$$s_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \bar{d})^2}{n}}$$

Mean height is calculated in two ways. In order to follow the temporal development and temporal height changes, an arithmetical mean of all tree heights in the particular stand component is used:

$$h_s = \frac{\sum_{i=1}^{n} h_i}{n}$$

In order to assign the forest stand to a site class of yield tables, mean height derived from top height using the regression model below is used:

$$h_s = a_0 + a_1 \,.\, h_{95\%} + a_2 \,.\, h_{95\%}^{\;2}$$

Stand volume per hectare is obtained as a sum of volumes of all trees in the stand component:

$$V = \frac{\sum_{i=1}^{n} v_i}{p}$$

Basal area per hectare is calculated as a sum of basal areas of all trees forming the particular stand component:

$$G = \frac{\sum_{i=1}^{n} \frac{\pi}{4} . d_i^{\,2}}{p}$$

Mean stem volume is obtained when stand volume is divided by the number of trees of the particular stand component:

$$\bar{v} = \frac{V}{N}$$

A form factor is the ratio of tree volume to the volume of a cyclinder having the same basal area ($g_{1.3}$) and height (h). The form factor is determined from the mean tree which is characterised by mean quadratic diameter (d_g) and mean arithmetic height (h_s) :

$$f = \frac{\bar{v}}{\frac{\pi}{4} . d_g^{\,2} . h_s}$$

The crown projection area per hectare is calculated using the crown diameters of trees forming the stand component and the size of the simulation plot (p) according to the formula:

$$PCA = \frac{\sum_{i=1}^{n} \frac{\pi}{4} . b_i^2}{p}$$

Crown closure expressed in per cents is derived from the tree crown projection area of the stand component according to CROOKSTON, STAGE (1999):

$CC = 100 . (1 - e^{-1.PCA})$

Stand density index is calculated from the number of trees per hectare and mean quadratic diameter of trees forming the particular stand component using the formula of REINEKE (1933):

$$SDI = N.\left(\frac{25}{d_g}\right)^{-1.6}$$

It represents the theoretical number of trees per hectare, if the mean quadratic diameter of the stand component were equal to 25 cm.

Situational maps were created in the ArcGIS programme (Copyright 1995-2010 Esri). H: DBH relation was expressed according to NÄSLUND (1936).

In the framework of biodiversity evaluation, these indices were computed: diameter differentiation index (TM_d), height differentiation index (TM_h, values of indices 0–1) (FÜLDNER 1995), species diversity index (SHANNON 1948), species evenness index (PIELOU 1975), Arten Profil index (A, values of indices 0–1) (PRETZSCH 2006) and overall diversity index ($B < 4$ – monotonous structure and $B \geq 9$ – highly structured stands) (Jaehne and Dohrenbusch 1997). Index D (Mi) and index G (Gi) (Gini 1921; Sterba 2008) were also calculated.

Indices

Index R (C&Ei) was calculated according to CLARK AND EVANS (1954):

$$R = \frac{\frac{1}{N} . \sum_{i=1}^{N} r_i}{0{,}5.\sqrt{\frac{p}{N}} + 0{,}0514.\frac{u}{N} + 0{,}041.\left(\frac{u}{N}\right)^{\frac{3}{2}}}$$

Where: r_i – distance between two nearest neighbours, N – number of trees in the plot, p – plot area, u – perimeter of the plot

The value of the index is from 0 to 2.15. The value 0 indicates an aggregated structure, i.e. the trees are aggregated in clusters. The value 1 represents a complete random distribution of trees in the plot area (so called *Poisson* distribution), while the value 2.15 stands for the regular tree distribution in the plot (in hexagonal spacing) (FABRIKA 2005).

Arten Profil index A (Pi): is calculated using the basal area of i^{th} tree species in j^{th} stand layer (p_{ij}) according to PRETZSCH (1992):

$$APi = \frac{-\sum_{i=1}^{m}\sum_{j=1}^{3}\left(p_{ij}.\ln(p_{ij})\right)}{\ln(3.m)}$$

Where: i – i^{th} tree species, j – j^{th} stand layer, p_{ij} – basal area

The first layer in the stand is composed of the trees with the height above 80% of the maximum height in the stand; the second layer consists of the trees with the height lower than 80% and higher than 50% of the maximum height. The index fluctuates between 0 and 1. Higher index values indicate more diverse vertical structures. If the index exceeds the value 0.9, the stand can be considered to have the structure of the selection forest (FABRIKA 2005).

Total diversity index according to Jaehne and Dohrenbusch (1997):

$$\alpha = \log(m).(1,5 - Z_{\max} - Z_{\min})$$

$$\beta = 1 - \frac{h_{\min}}{h_{\max}}$$

$$\chi = \left(1 - \frac{r_{\min}}{r_{\max}}\right)$$

$$\delta = \left[1 - \log(KA_{\min})\right] + \left(1 - \frac{KD_{\min}}{KD_{\max}}\right)$$

$$\varepsilon = 4.\alpha + 3.\beta + \chi + \delta$$

Total diversity (*epsilon*) is the aggregation of partial components of diversity: tree species diversity (*alfa*), diversity of vertical structure (*beta*), diversity of tree spatial distribution (*chí*), and diversity of crown differentiation (*delta*). The input variables are: number of tree species (*m*), maximum and minimum tree species proportion (Z_{max} and Z_{min}), maximum and minimum tree height in the stand (h_{max} and h_{min}), maximum and minimum tree spacing (r_{max} and r_{min}), minimum height to crown base (KA_{min}), and minimum and maximum crown diameter (KD_{min} and KD_{max}). If the final value is equal to or higher than 9, stand structure is very diverse, the values from 8 to 8.9 indicate a diverse structure, index values in the range from 6 to 7.9 mean an uneven structure, an even structure is indicated by the values between 4 and 5.9, and the values below 4 represent a monotonous structure.

Diameter differentiation TMd is related to the ratio between the larger and the smaller diameter of all nearest neighbouring trees in the plot (rd_{ij}) as defined by Füldner (1995):

$$TM_d = \frac{1}{n}.\sum_{i=1}^{n}\left(1 - rd_{ij}\right)$$

Height differentiation $\mathbf{TM_h}$ is related to the ratio between the larger and the smaller height of all nearest neighbouring trees in the plot (rd_{ij}) as defined by Füldner (1995):

$$TM_h = \frac{1}{n}.\sum_{i=1}^{n}\left(1 - rh_{ij}\right)$$

The index can obtain values from 0 to 1. The values below 0.3, between 0.3 and 0.5, between 0.5 and 0.7, and above 0.7 indicate small, medium, high, and very high differentiation, respectively.

Diversity of crown differentiation was part of the total diversity index, calculated separately.

Tree species heterogeneity H´ (Si):

$$\lambda = 1 - \sum_{i=1}^{m} w_i^{\,2}$$

Tree species evenness E ($\mathbf{P_{ii}}$):

$$E1 = \frac{H'.\ln(10)}{\ln(m)}$$

To determine the spatial distribution Hopkins-Skellam index (Hopkins & Skellam 1954), Pielou-Mountford index (PIELOU 1959; MOUNTFORD 1961), Clark-Evans index (CLARK & EVANS 1954) and Ripley’s *L*-function (RIPLEY 1981) were computed. The David-Moore index (DAVID & MOORE 1954) was used as a distribution index based on tree frequency in the particular quadrats. The size of quadrats on PRP was 10 × 10 m. The PointPro 2.1 (ZAHRADNÍK & PUŠ, Prague, Czech Republic) was used to calculate these characteristics describing the horizontal structure of individuals across the plot. The test of significance of the deviations from the values expected for random distribution of points was done using

Monte Carlo simulations. The mean values of *L*-function were estimated as arithmetical means from *L*-functions calculated for 1999 randomly generated point structures. The respective expected values of these indices were computed by means of numerical simulations for each particular case separately. In results statistically significant values (exceeding the confidence interval) were marked by asterisk.

PCA Analysis

Unconstrained principal component analysis (PCA) in the CANOCO for Windows 4.5 program (TER BRAAK,ŠMILAUER 2002) was used to analyse relationships among plots attributes, stand parameters, climate data, and diversity of *Pinus sylvestris* and similarity of 4 research plots. Data were centred and standardized during the analysis. The results of the PCA analysis were visualized in the form of an ordination diagram constructed by the CanoDraw program (TER BRAAK, ŠMILAUER 2002).

4.2.2 Increment cores

The samples from plots CZ-1 and CZ-2 were measured manually with an accuracy of 0.01 mm, using Olympus SZ51 microscope on a sliding table TimeTable - TT85 that through subtraction module subtracts the width of the rings.

The software PAST4 (KNIBB 2007) measurements were taken. Based on similarity of optical curves were chosen to create the standard chronologies. The degree of similarity between ring series was verified by the correlation coefficient and a coefficient of agreement (GI). The samples from plots ES-1 and ES-2 were measured automatically by Cybis software (CDendro and CooRecorder). The subsequent operations were the same.

4.2.3 Statistical analyses of increment cores

STATGRAPHICS Centurion XVII (Statpoint Technologies, Inc.) software was used for statistical analyses. For comparison among plots, ANOVA was performed to verify the statistical differences between means. The analysis of variance (ANOVA) decomposes the variance of dependent variable into two components: a between-group component and a within-group component.

Subsequently, multiple-range test was used, if possible with respect to the character of data. The test applies a multiple comparison procedure to determine which means are significantly different from which others. The method used to discriminate among the means was Fisher's least significant difference (LSD) procedure. With this method, there is a 5.0% risk of calling each pair of means significantly different when the actual difference equals 0.

Kruskall-Wallis non-parametric test was performed when the data didn’t follow normal distribution. The Kruskal-Wallis test tests the null hypothesis that the medians of increment within each of the plot are the same. The data from all the levels is first combined and ranked from smallest to largest. The average rank is then computed for the data at each level.

Analysis of means (ANOM) was performed for comparison of DBH classes within one plot. This plot constructs a chart similar to a standard control chart, where each sample mean is plotted together with a centerline and upper and lower decision limits. The centerline is located at the grand average of all of the observations $\bar{Y}$.

$$\bar{Y} \pm h_{n-q,1-\alpha}\sqrt{\frac{MS_{within}}{n_j}\left(\frac{q-1}{q}\right)}$$

Where: h – a critical value obtained from a table of the multivariate t distribution.

The chart tests the null hypothesis that all of the sample means are equal to the grand mean. Any means that fall outside the decision limits indicate that the corresponding sample differs significantly from that overall mean (StatPoint Technologies 2013).

5 Results

5.1 Stand structure

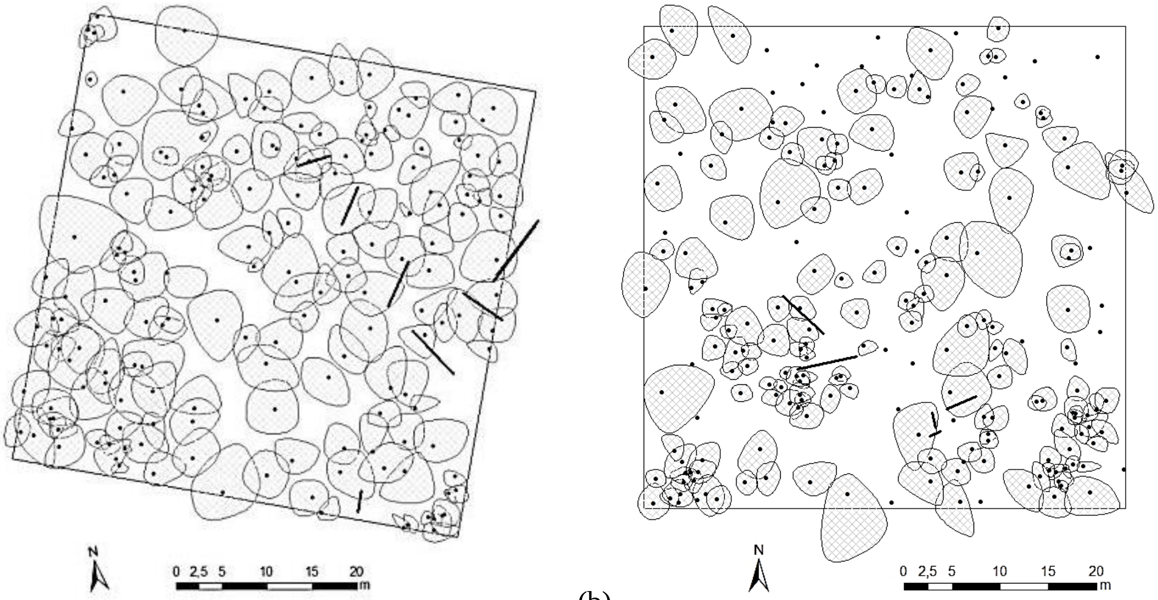
Dendrometric characteristics are shown in Table 3. Mean DBH is relatively equal on CZ-1 and CZ-2. The ES-1 plot was a mature compartment of regular forest, and therefore features the supreme DBH of all plots. ES-2, on the hand, represents an example of fully functional basic unit of selection forest and features all DBH classes, which reduces the mean DBH. These arrangements have consequences also in differences in mean height, form of tree, mean tree volume, number of trees per hectare, basal area, stand volume and h: DBH ratio. The absolute site quality is lower on the CZ plots in comparison to ES, as can be seen on the mean height (it was estimated to 17–20 m on CZ plots by ČERVENÝ (2012) and according to management plan).

Table 3. Stand parameters of the investigated plots

Plot	*Main stand*							
	DBH ± SD [cm]	h [m]	f [-]	v [m^3]	N [ind./ha]	G [m^2*ha^{-1}]	V [m^3*ha^{-1}]	h:DBH
CZ-1	24.0 ± 10.0	15.50	0.534	0.374	688	31.3	260	64.6
CZ-2	22.9 ± 11.1	13.12	0.720	0.389	820	33.8	319	57.3
ES-1	45.9 ± 8.0	20.08	0.480	1.596	276	45.7	441	43.7
ES-2	20.7 ± 12.6	9.05	0.761	0.232	996	33.4	231	43.7

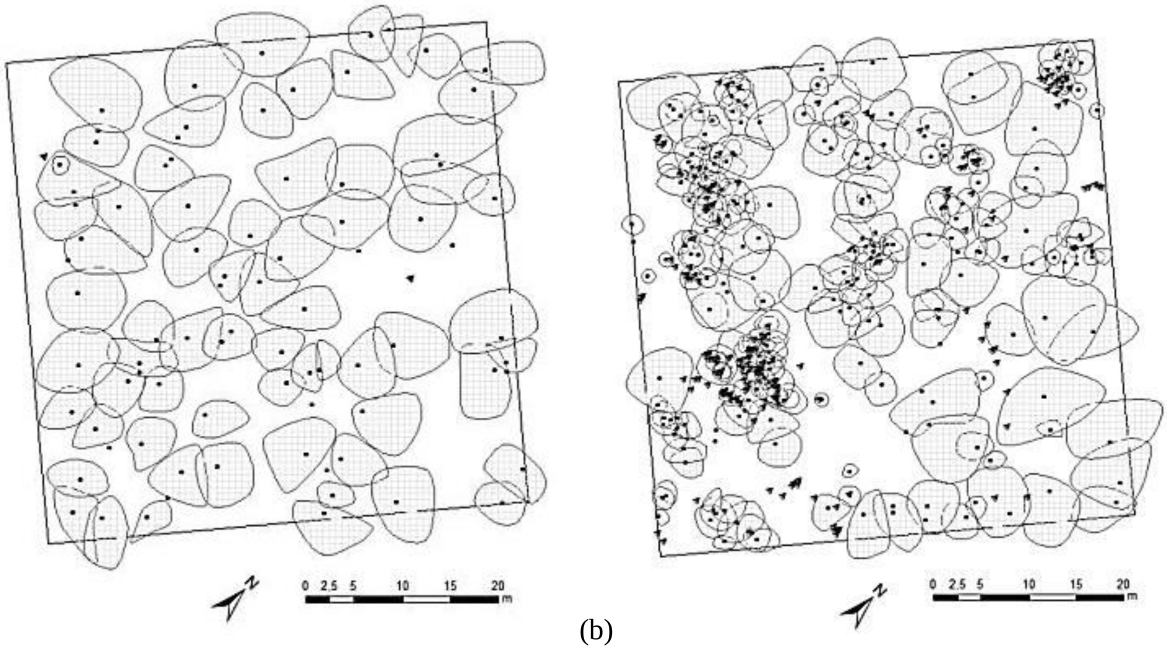
DBH – mean quadratic breast height diameter, SD – standard deviation, F – form factor, v – mean tree volume, N – number of trees, G – basal area, V – stand volume, h: DBH – slenderness ratio

The horizontal structure of the four stands is on Figures 5–8. Harvested stems were marked as black sticks: they were present on CZ-1 and CZ-2, not on ES-1 neither on ES-2. Regeneration cluster was marked as black triangle: it is missing on both CZ-1 and CZ-2 (Fig. 5), scarcely present on ES-1, and most abundant on ES-2 (Fig. 6).



(a) (b)

Fig. 5. Horizontal structure of plots CZ-1 (a) and CZ-2 (b)



(a) (b)

Fig. 6. Horizontal structure of plots ES-1 (a) and ES-2 (b)

Table 4 shows the density characteristics. Canopy closure was highest on ES-2, stand with most irregular structure, followed by ES-1. CZ-1 – stand with lower intensity management showed higher CC compared to CZ-2 with high intensity selection harvest. Canopy closure followed the same trend on all plots. Stand density index was comparable within the individual forest areas.

Table 4. Density characteristics on the investigated plots

Plot	*Density*		
	CC [%]	CP [ha]	SDI
CZ-1	77,3	1.48	0,64
CZ-2	76.3	1.44	0,72
ES-1	70.9	1.23	0,74
ES-2	79.6	1.59	0,74

CC – canopy closure, CP – crown projection area, SDI – stand density index

The distribution of trees in DBH classes on all plots is shown in Figures 7–8. CZ-1 can be considered as relatively close to regular structure, however, with elevated number of trees in thin DBH class. In CZ-2, continual measures were applied for the transition to irregular stand, which is illustrated by most trees of small dimensions and decreasing trend of abundance, however, with some major problems in following DBH classes, which have insufficient numbers of individuals. ES-1 had relatively regular DBH structure, shifted in favour of larger dimensions, typical for mature compartment. ES-2, on the contrary, had selection (irregular) structure of distribution of trees among DBH classes.

Plots under intensive selection cutting were compared to ideal selection forest model by LIOCOURT (1898). Target diameter was set to 66 cm and number of trees in target diameter was 4/ha (Fig. 9). From this target, the number of trees in first registered class resulted in A = 136 (DBH class 6). Quotient of decreasing geometric series (coefficient q) was 1.265.

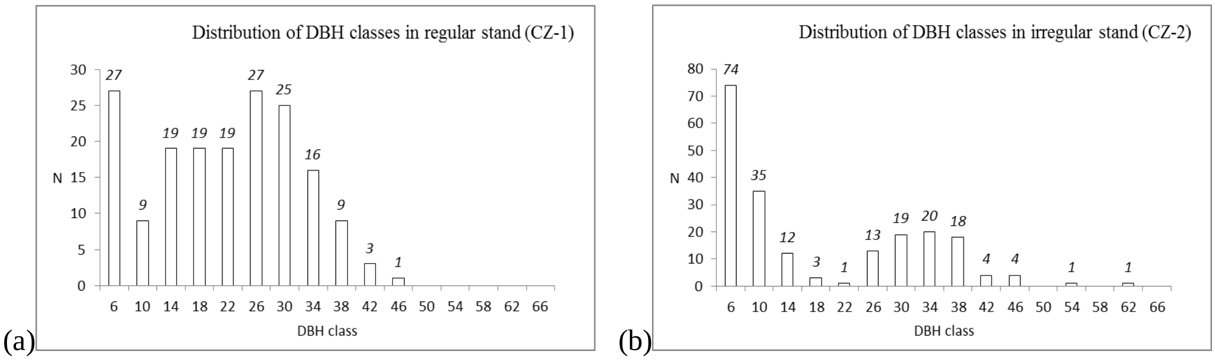


Fig. 7. Distribution of trees in DBH classes on CZ-1 (a) and CZ-2 (b)

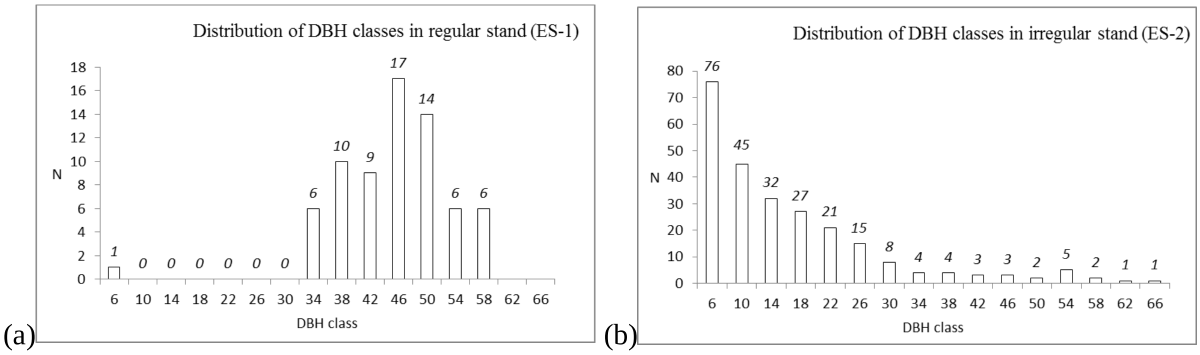


Fig. 8. Distribution of trees in DBH classes on ES-1 (a) and ES-2 (b)

Fig. 10 depicts comparison of the relation between height and DBH class on all plots using Näslund function. From the lowest DBH classes, CZ-1 and CZ-2 had higher value of the h: DBH ratio. The comparison could not be fully demonstrated in case of ES-1, because of its shift to higher DBH classes.

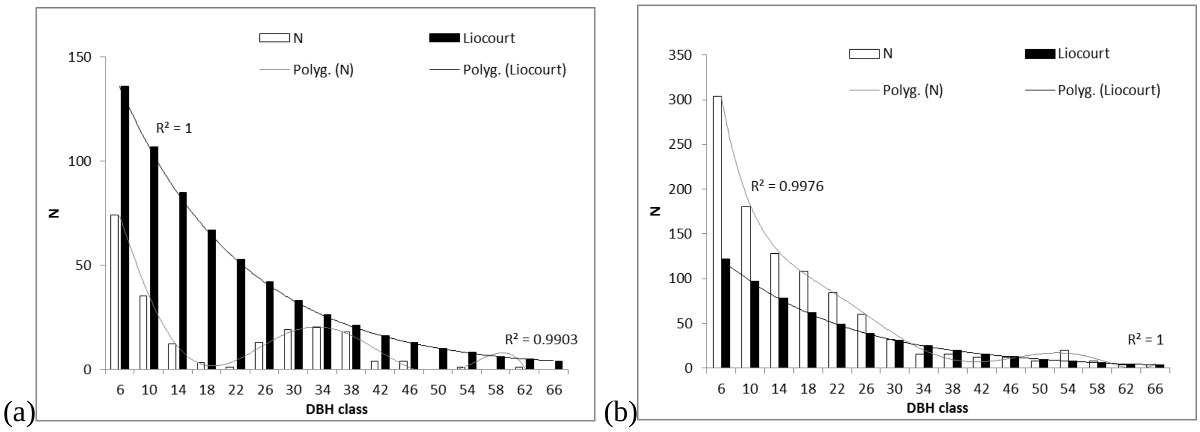


Fig. 9. Comparison of plots CZ-2 (a) and ES-2 (b) to LIOCOURT ideal selection forest (A = 136, q = 1.265)

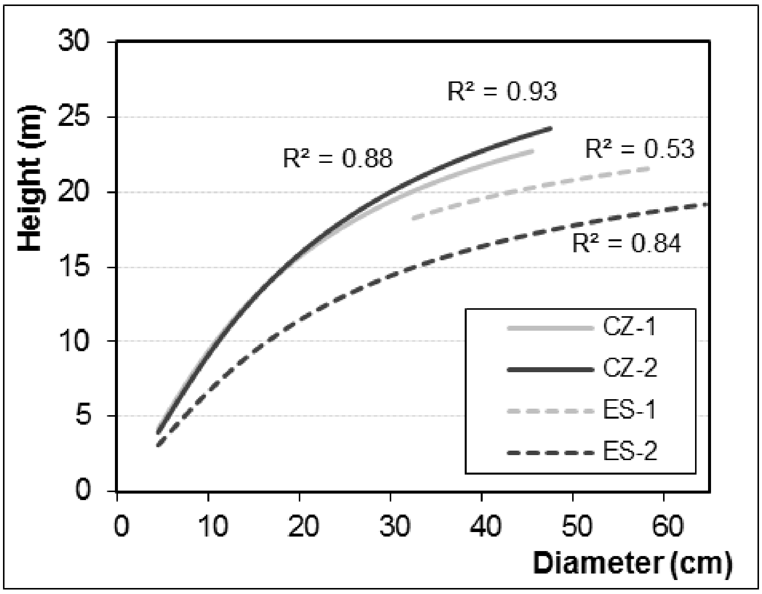


Fig. 10: Relation between diameter and tree height (NÄSLUND 1936).

5.2 Diversity of tree layer

Table 5: Indices of horizontal structure and diversity of tree layer on investigated plots.

Plot	*Indices*						
	R (C&Ei)	A (Pi)	B (J&Di)	TM_d (Fi)	TM_h (Fi)	H´ (Si)	E (Pii)
CZ-1	1.044	0.364	7.919	0.368	0.287	0.184	0.222
CZ-2	1.072	0.218	6.618	0.408	0.334	0.005	0.010
ES-1	1.041	0.415	5.846	0.166	0.083	0.000	0.000
ES-2	0.790	0.981	6.287	0.405	0.323	0.000	0.000

R – Clark and Evans aggregation index, A – Arten Profil index, B – total diversity index, TM_d – diameter differentiation index, TM_h – height differentiation index, H´ - index of species heterogeneity, E – index of species evenness

Table 5 shows the indices of horizontal structure and diversity of tree layer. Since the R (C&Ei) index, describing the distribution of individuals, can reach values from 0 to 2.15, the most aggregated structure was found in irregular forest (ES-2). ES-1 was very close to value 1 (fully random distribution) and the two Bohemian plots were slightly more of a regular distribution, although still far from fully regular.

The Arten Profil Index of vertical structure A (Pi) reaches values from 0 to 1; when more than 0.9, the stand is considered as selection forest. Therefore, the plot ES-2 is an adequate example of selection forest. It can be noted, that the continuing transition of structure form regular to irregular at plot CZ-2 has not yet secured the vertical differentiation form regular plot CZ-1.

Total diversity index B (J&Di) is an aggregation of partial diversity components: the highest value was found in unmanaged regular forest CZ-1. The second highest value was in selection forest ES-2. CZ-2 and ES-1 had similar values.

Diameter differentiation TMd (Fi) and height differentiation TMh (Fi) were medium on ES-2, and low on all the other plots.

Because of the admixture of spruce and birch, the plot CZ-1 had elevated value of tree species richness index, which was negligible on the other plots of pure pine stands. Same pattern was obtained for tree species evenness E (Pii). Indices of horizontal structure showed are summarized in Table 6. On even-aged plots (CZ-1, ES-1), the spatial distribution of trees was predominantly random (CZ-1), or random bound to regular (ES-1), while it was aggregated on the more irregular plots (CZ-2, ES-2) according to *L*-function (Fig. 11 and 12).

Table 6. Indices of horizontal stand structure

Index	Obtained values	Expected values	Lower limit	Upper limit	Obtained values	Expected values	Lower limit	Upper limit
	CZ 1				*CZ 2*			
Hopkins–Skellam	0.450	0.499	0.431	0.577	0.460	0.501	0.439	0.575
Pielou–Mountford	1.000	1.081	0.885	1.342	1.123	1.075	0.898	1.341
Clark–Evans	1.104	1.033	0.954	1.117	1.127*	1.026	0.949	1.100
David–Moore	-0.110	0.001	-0.261	0.308	0.521*	0.002	-0.228	0.275
	ES 1				*ES 2*			
Hopkins–Skellam	0.466	0.495	0.385	0.622	0.658*	0.500	0.443	0.559
Pielou–Mountford	1.048	1.116	0.808	1.579	1.758*	1.070	0.897	1.282
Clark–Evans	1.163	1.055	0.909	1.191	0.826*	1.027	0.962	1.097
David–Moore	-0.013	-0.002	-0.248	0.309	2.866*	0.012	-0.258	0.351

*statistically significant

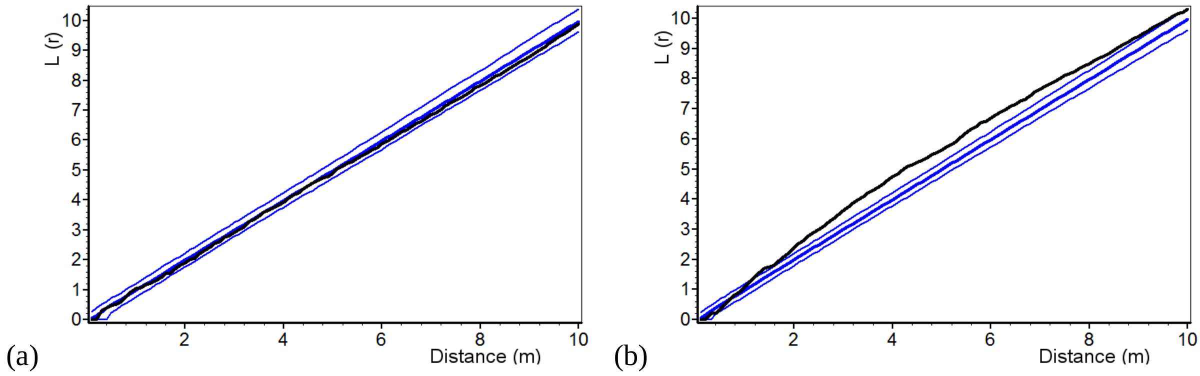


Fig. 11: L-function of CZ-1 (a) CZ-2 (b)

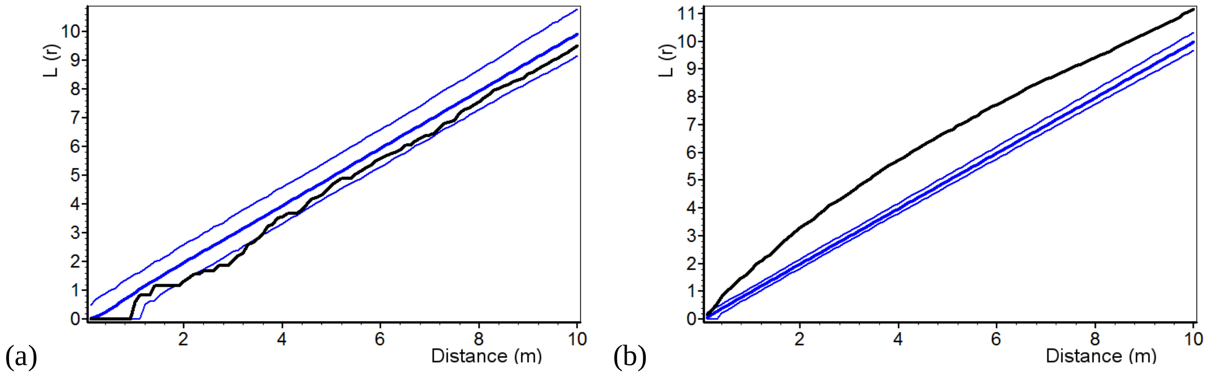


Fig. 12. L-function of ES-1

5.3 Relationships among plot attributes, stand parameters and diversity

Results of the PCA analysis are presented in the form of the ordination diagram in Fig. 18. The first ordination axis explained 55.8%, the first two axes together 93.5% and the first three axes together explained all 100.0% of the variability in the data. The first axis x represented diameter and height differentiation, number of trees with DBH. The second axis y represented Arten-profile index with aggregation index. Altitude was positively correlated with precipitation and gradient, while these parameters were negatively correlated with temperature, stand age and total diversity index. Stand volume, mean height and DBH positively correlated to each other, while these parameters were negatively correlated with canopy (crown closure, crown projection area), stand density and structural differentiation indexes. The contribution of stand age was the smallest. Plots were different amongst one another, especially for plots ES-1 and ES 2, as marks of each record are relatively distant from one another whereas marks for PRP CZ-1 and CZ-2 were fairly close together in the diagram. Czech plots with higher age, mean temperature and total diversity occupied the bottom left part of the diagram, while higher altitude, gradient and sum of precipitation were typical for Spanish plots (top right).

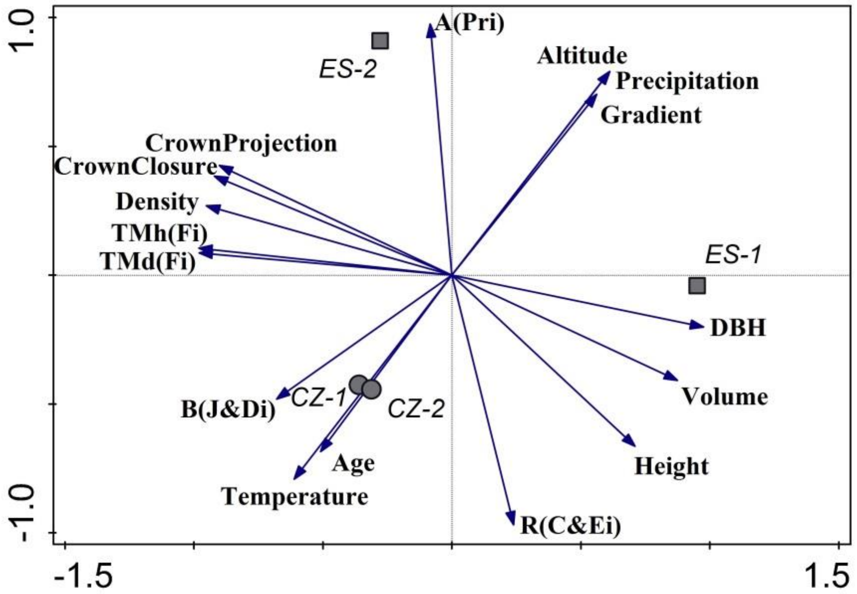


Fig 13. Ordination diagram showing results of PCA analysis of relationships among plot attributes (*Altitude*, *Gradient*), climatic data (*Temperature*, *Participation*), stand parameters (*Age* mean stand age, *DBH* quadratic breast diameter, *Height* mean stand height, *Volume* of stand, *Density* number of trees, *Crown closure*, *Crown projection* area) and diversity indices (*R/C&Ei/* aggregation index, *A/Pri/* Arten-profil index, *TM/Fi/* structural differentiation indexes, *B/J*&Di/ total diversity index); Codes: ●,■ indicate country with plot number

5.4 Increment cores

5.4.1 General overview

The course of mean annual core increment is shown in Fig. 14. The mean annual core increment (also mean periodical increment) in the period of 150 years (1865–2015) was 0.92 mm on plot CZ-1, 1.11 mm on CZ-2, 1.44 and 1.43 on ES-1 and ES-2, respectively. The development roughly resemble U letter – after initial (relatively) rapid growth, mean annual increment decreased, and again rose in the last decades.

In the last 10 years (2006–2015) it was 1.12 and 1.72 for CZ-1 and CZ-2, respectively, and the mean of the last 30 years reached 1.05 and 1.27 for CZ-1 and CZ-2, respectively. The mean increment therefore differed by 0.20 mm, 0.22 mm, and 0.60 mm for those 150, 30, and 10 year periods.

For the last 10 years, the mean annual increment was 0.88 on ES-1 and 1.84 on ES-2, and it accounted for 0.90 and 2.04 on ES-1 and ES-2, respectively, in the period 1986 – 2015 (last 30 years).

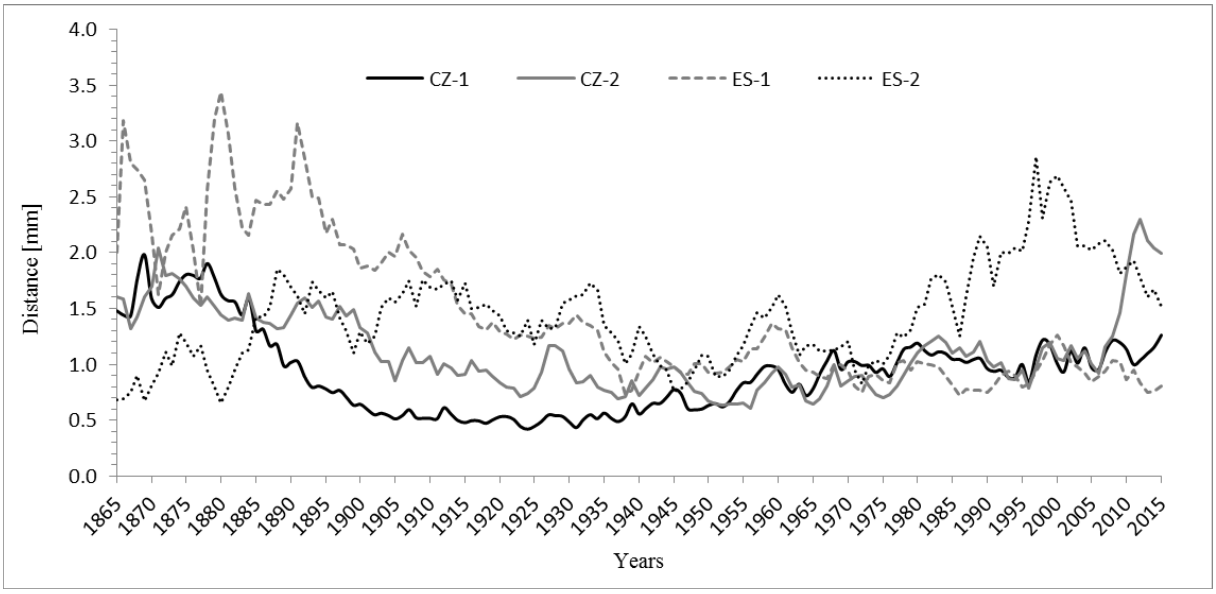


Fig. 14. Mean annual core increment of all sampled trees on CZ-1 and CZ-2 (1860–2015)

The mean annual core increment of trees above 20 cm of DBH showed similar general dynamics as when all trees were considered (Fig. 15). The previously faster-growing CZ-1 was outperformed by CZ-2 from 2010 on (Fig. 16).

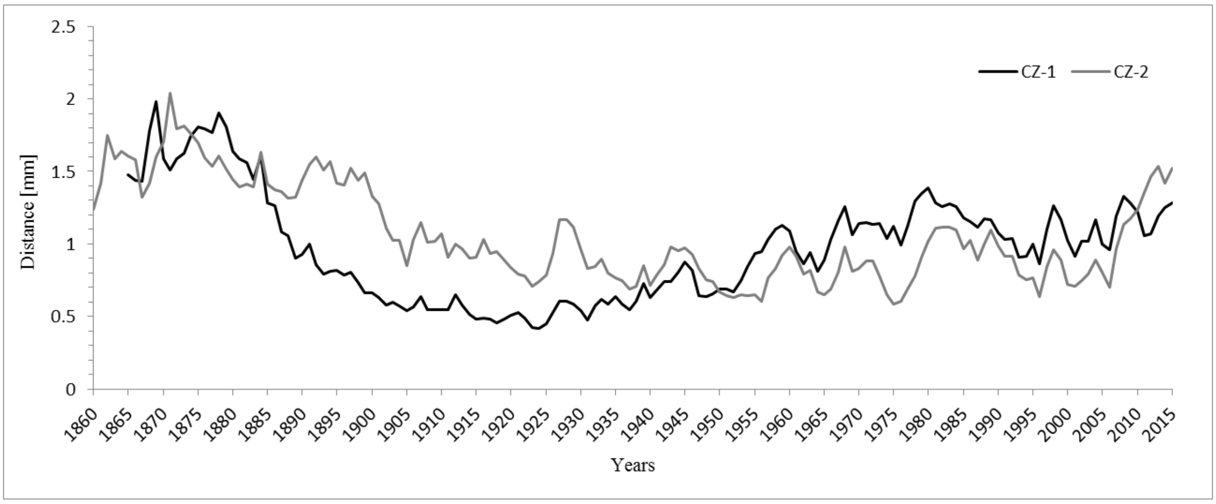


Fig. 15. Increment of trees with DBH >20 cm in sample plots CZ-1 and CZ-2 (1860–2015)

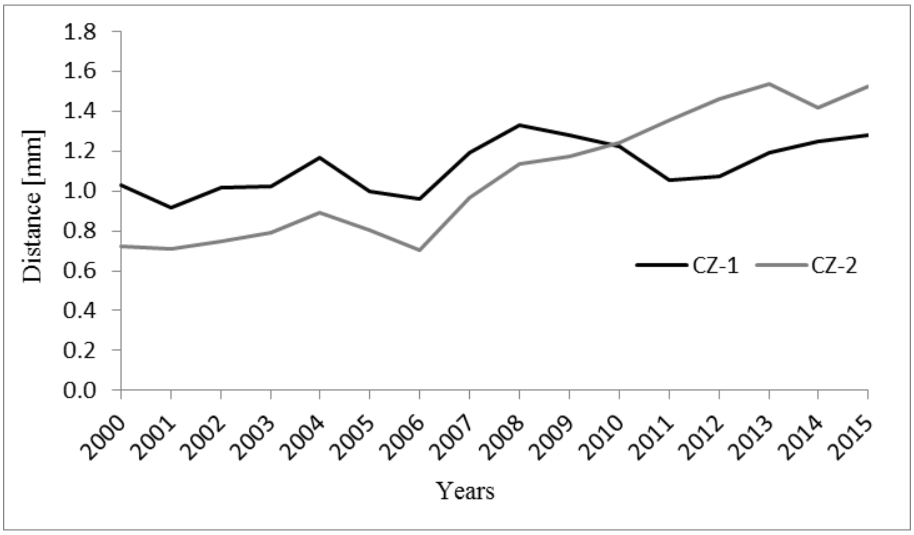


Fig. 16. Mean core increment of trees with DBH >20 on sample plots CZ-1 and CZ-2 in 2000–2015

On ES-1, all trees were DBH >20 cm, however, comparison of all trees of DBH >20 cm from plot ES-2 with all trees from ES-1 and also ES-2 was done for the last 30 years (1985–2015). No unprecedented difference in performance was registered in recent period (Fig. 17), i.e. all trees as well as group of only mature trees on ES-2 both showed higher mean annual core increment in comparison to all trees on ES-1.

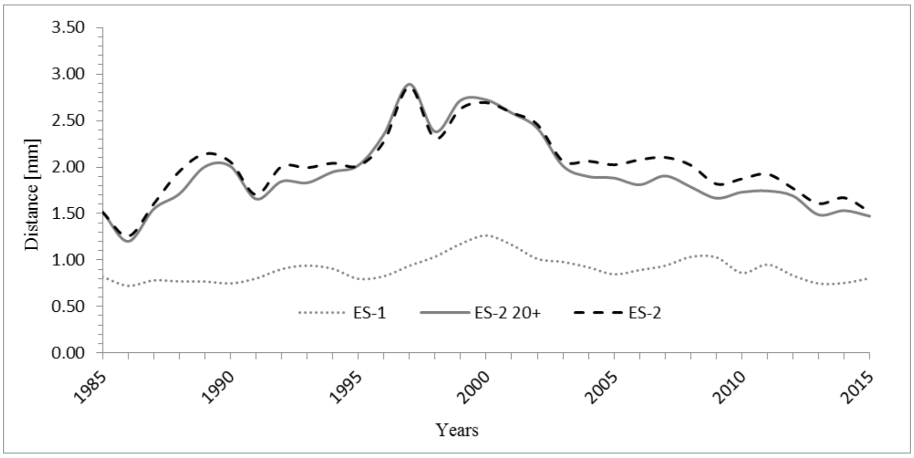
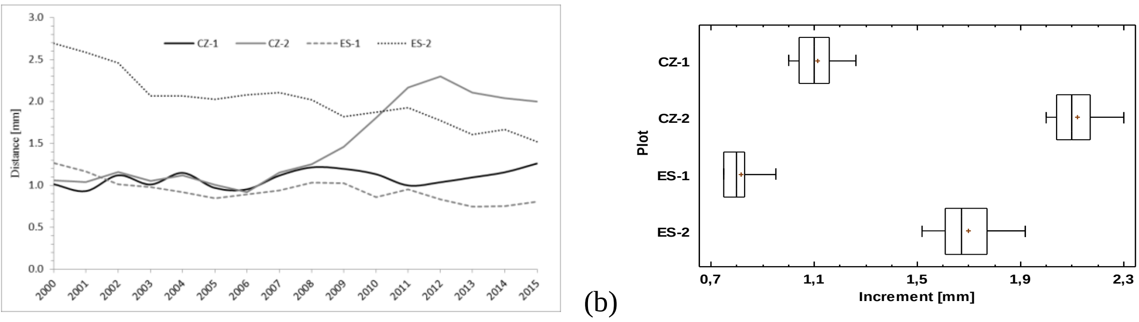


Fig. 17. Comparison of mean core increment of trees with DBH >20 cm on plot ES-2 with all sampled trees on ES-1 and ES-2 in the last 30 years (1985–2015)

5.4.2 Comparison of all plots



(a) (b)

Fig. 18. Comparison of mean core increment in 2000–2015 (a); Box-and-Whisker plot comparison of mean core increment on all plots in 2011–2015

Fig. 18 (a) shows the course of mean annual increment on plots CZ-1 and CZ-2 in the last 15 years. The increment on both CZ plots was almost equal until 2008, then on CZ-1 continued with similar dynamics and on CZ-2 started to increase, and the increase was more pronounced since 2009. In 2011 and 2012 the mean annual increment on CZ-1 was doubled by the CZ-2. By contrast, the trend of ES-1 and ES-2 followed each other, but ES-2 showed constantly higher increment.

The Box-and-Whisker plot for comparison between plots in 2011 – 2015 is in Fig. 18 (b). Analysis of means (ANOVA) showed statistically significant differences among plots (*F* = 124.7, *P* = 0.0000). Differences in all six pairs were statistically significant according to multiple-range test.

5.4.3 Core increment according to DBH class

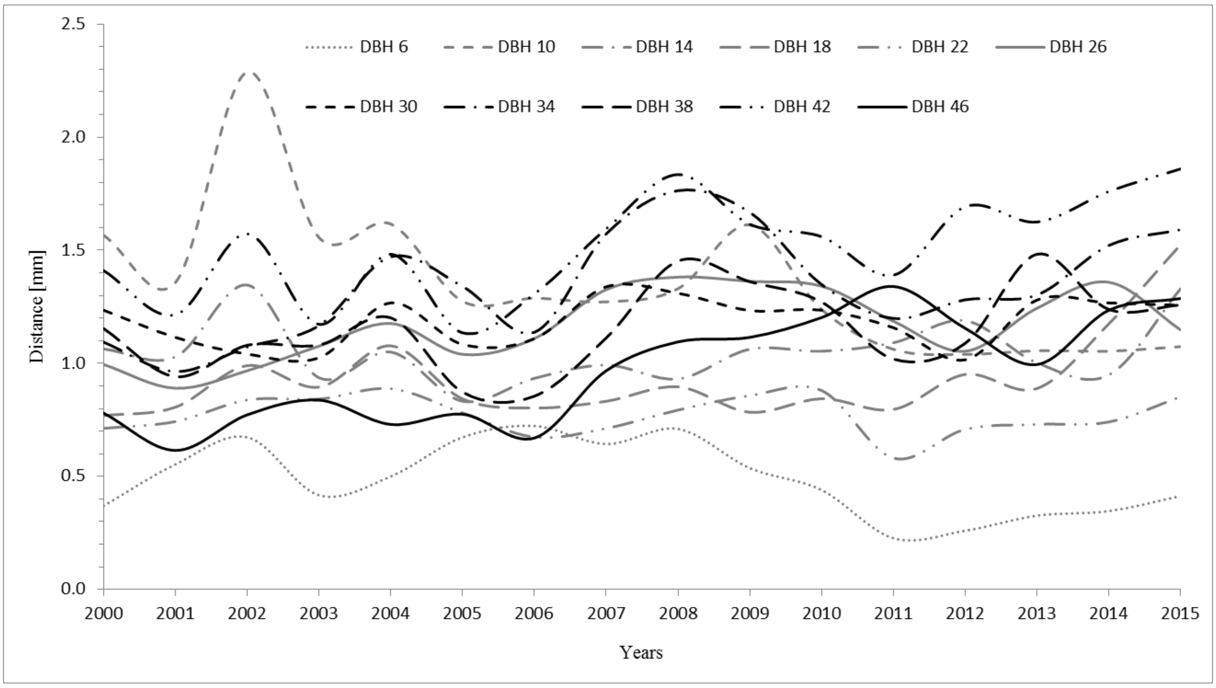
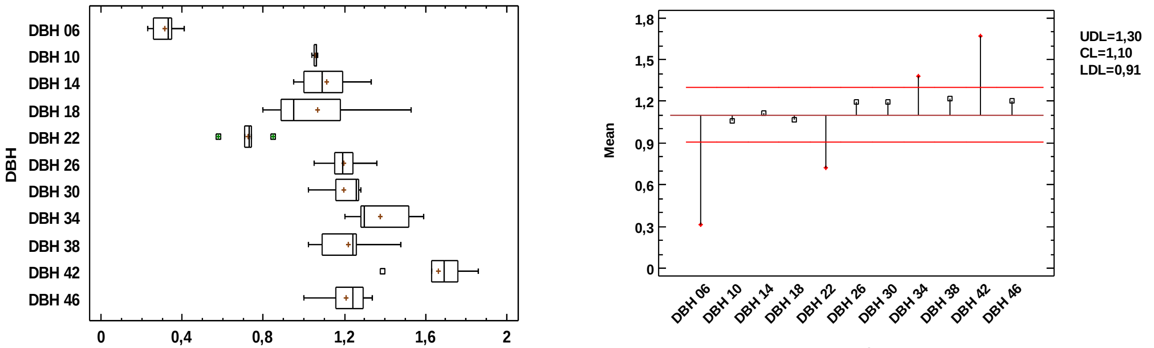


Fig. 19. Comparison of core increment in each DBH class on CZ-1 plot 2000–2015



(a) (b)

Fig. 20. Box-and-Whisker plot comparison of core increment in each DBH class on CZ-1 in 2011–2015 (a); ANOM comparison of core increment in each DBH class on CZ-1 in 2011–2015 (b)

Comparison of core increment in each DBH class was performed to verify the within-plot mean increment dynamics. Various types of lines were used to depict the core increment in each DBH class within individual plots. Grey colour was used for DBH classes 6–26, lines in black are for DBH classes 30–46, similarly on the next plots first half of the lines representing DBH classes was grey and the upper half black.

On CZ-1, the increment in most of the DBH was balanced, although some statistical differences in pairs occurred, especially for DBH class 6 and 22, which showed lower increment than all the other classes.

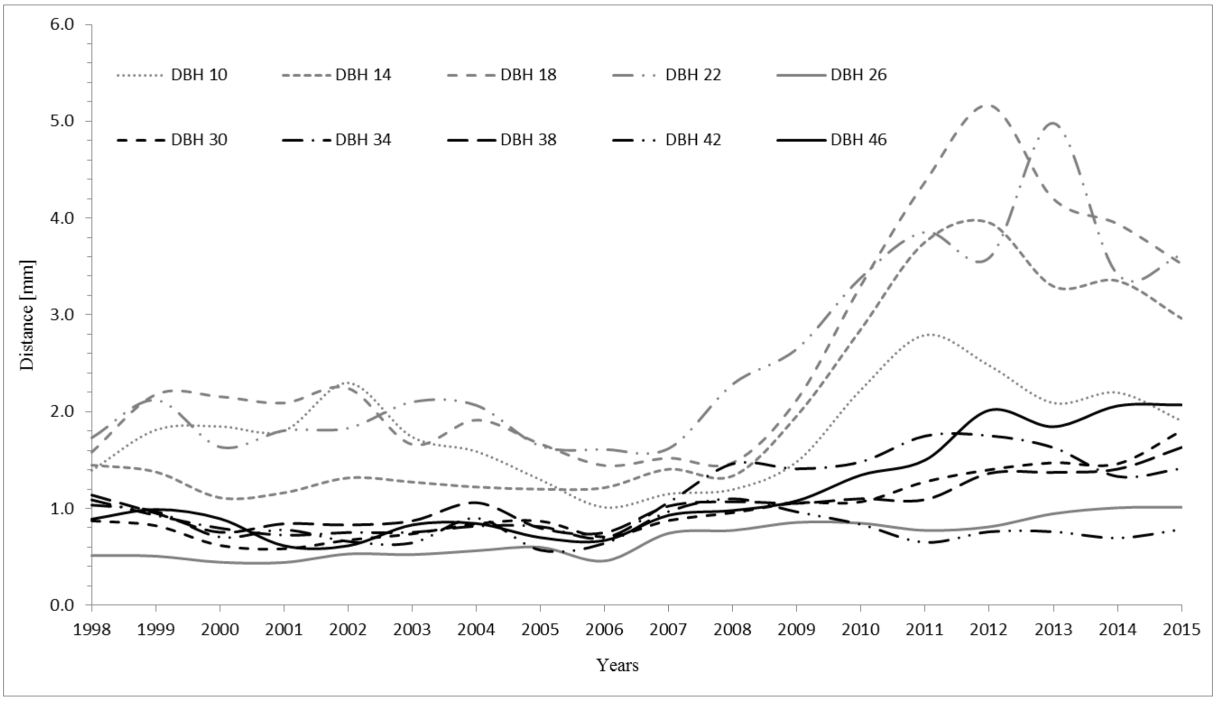
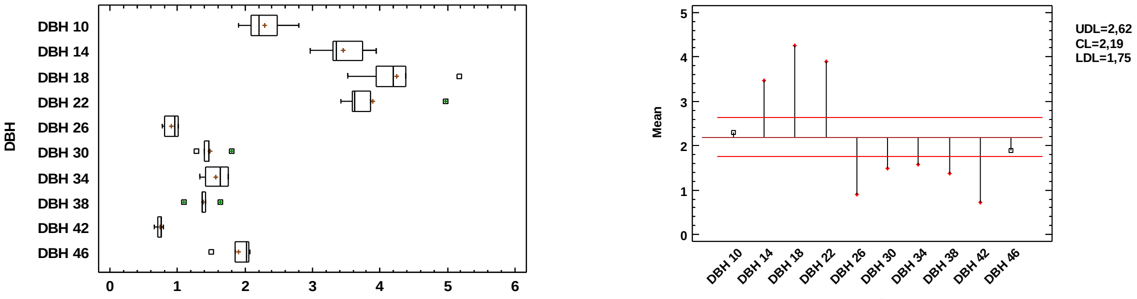


Fig. 21. Comparison of core increment in each DBH class on CZ-2 plot



(a) (b)

Fig. 22. Box-and-Whisker plot comparison of core increment in each DBH class on CZ-2 in 2011–2015 (a); ANOM comparison of core increment in each DBH class on CZ-2 in 2011–2015 (b)

By contrast to CZ-1, on CZ-2 the minor DBH classes clearly showed increased mean annual increment in comparison with higher classes in recent years (Fig. 21). DBH classes 10, 14, 18, and 22 showed higher increment than classes 26, 30, 34, 38, 42, 46 according to Box-and-Whisker plot comparison and ANOM (Fig. 22). Kruskal-Wallis with 95.0% Bonferoni intervals showed following pairs as significantly different: 14–26, 14–42, 18–26, 18–42, 22–26, and 22–42.

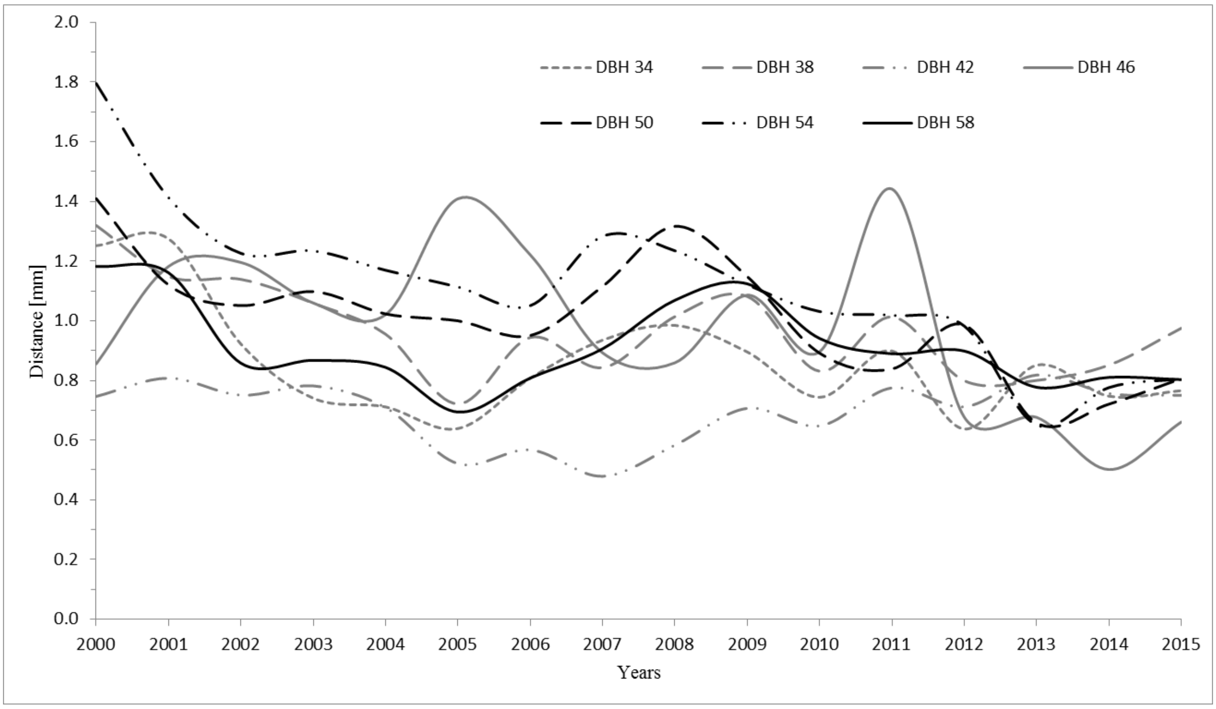


Fig. 23. Comparison of core increment in each DBH class on ES-1 plot

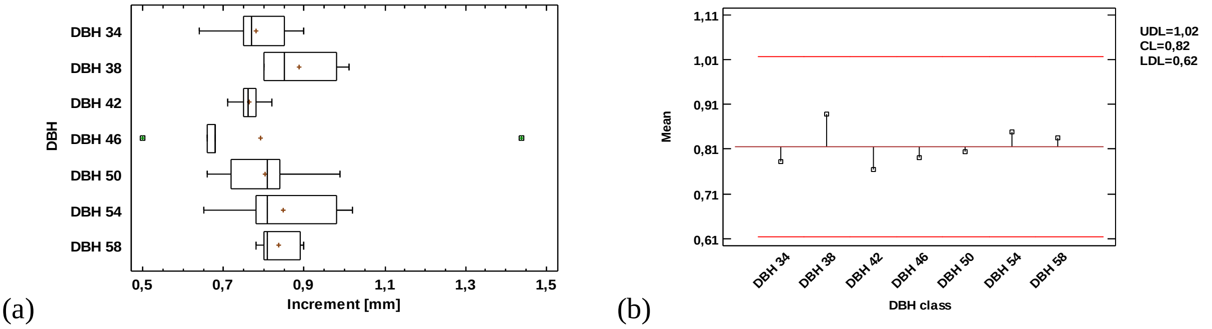


Fig. 24. Box-and-Whisker plot comparison of core increment in each DBH class on ES-1 in 2011–2015 (a); ANOM comparison of core increment in each DBH class on ES-1 in 2011–2015 (b)

On ES-1, the differences between increments of DBH classes from previous years were rather brought together in recent years (Fig. 23). Importantly, the range of DBH classes was on this plot the smallest from all plots. Box-and-Whisker plot comparison as well as ANOM showed relatively unified structure. ANOVA showed insignificant results (F = 0.33, P = 0.9181), similarly Kruskal-Wallis test of medians didn't reveal any statistical significance.

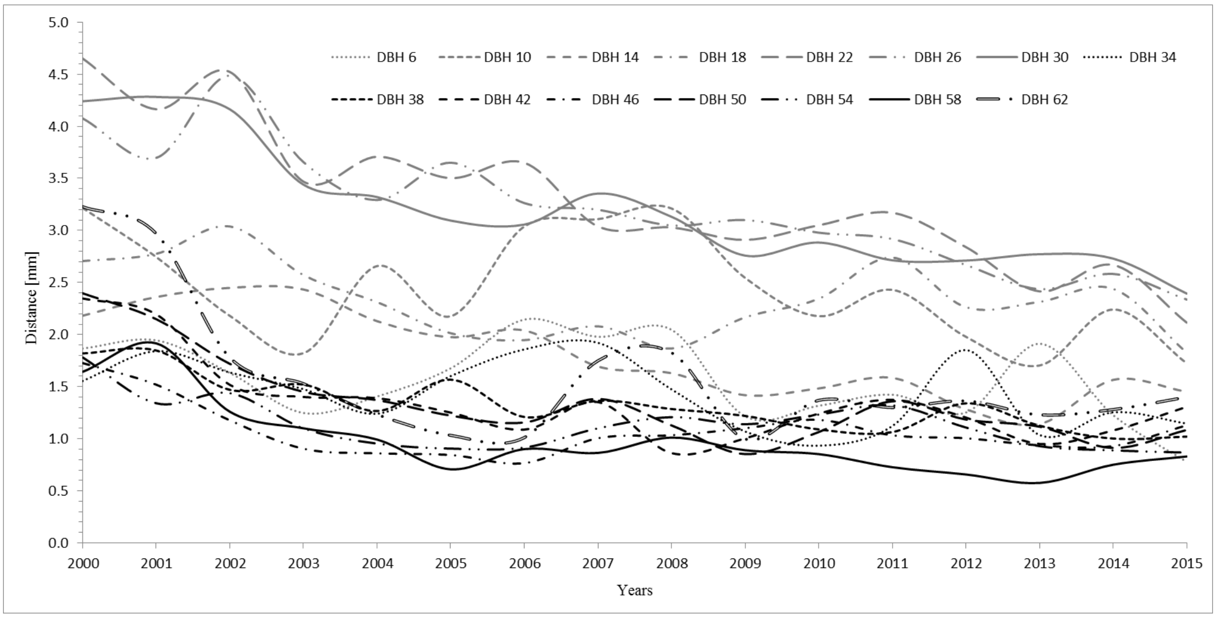
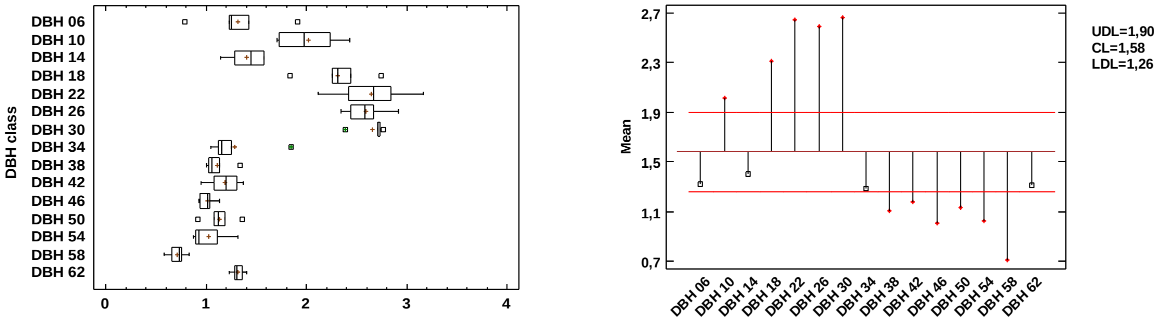


Fig. 25. Comparison of core increment in each DBH class on ES-2 plot



(a) (b)

Fig. 26. Box-and-Whisker plot comparison of core increment in each DBH class on ES-2 in 2011–2015 (a); ANOM comparison of core increment in each DBH class on ES-2 in 2011–2015 (b)

Smaller DBH classes relatively dominate the zone of higher increment during the last 15 years on ES-2 plot (Fig. 26) with the exception of DBH class 6. The contribution of each DBH class to the overall increment on the plot in 2011–2015 and the variability of data are in the Box-and-Whisker plot (Fig. 26a). DBH classes 10, 14, 18, 22 and 26 showed higher mean increment than the grand mean on the plot according to ANOM (Fig. 26b). Following pairs were showed statistically significant difference according to Kruskal-Wallis: 10–58, 18–58, 22–46, 22–54, 22–58, 26–46, 26–54, 26–58, 30–46, 30–54, and 30–58.

5.4.4 DBH amongst plots

In this section, the results of comparing each DBH class between the plots are presented. This allows to exactly see in which stage of development are the plots most different. Not all DBH classes were represented on all plots, especially ES-1 only started to be represented by DBH class 34 (see Table 2).

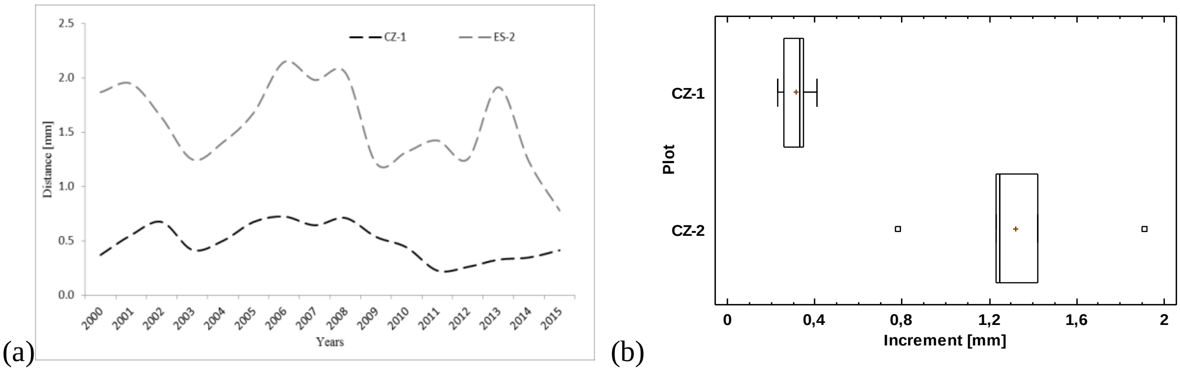


Fig. 27. Core increment of trees in DBH class 6 in 2011–2015

DBH class 6 showed significantly higher median of increment on CZ-2 in comparison with CZ-1 (Fig. 27).

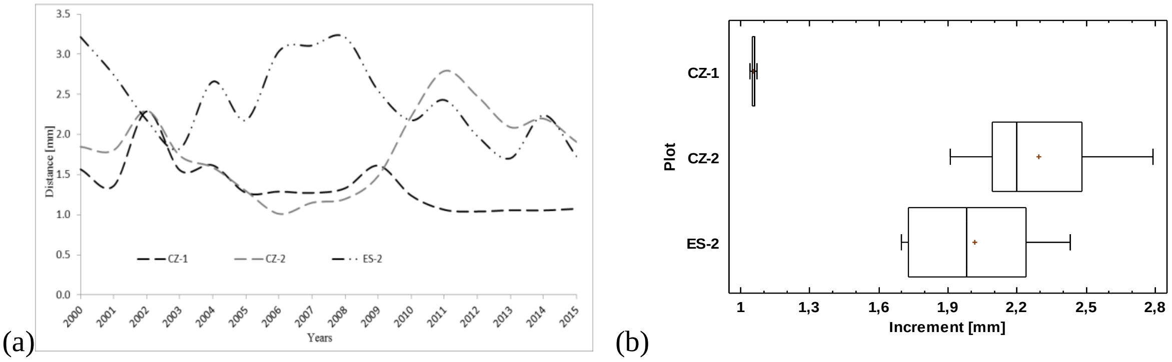


Fig. 28. Core increment of trees in DBH class 10 in 2011–2015

Regarding diameter class 10, both uneven-aged plots showed increased increment in comparison to CZ-1 (Fig. 28). In DBH 14, the pronounced increment was registered on CZ-2 (Fig. 29).

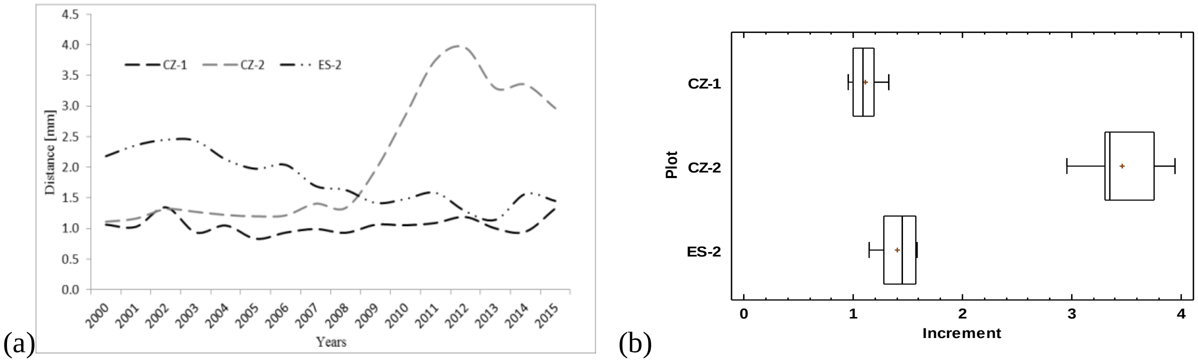


Fig. 29: Core increment of trees in DBH class 14 in 2011–2015.

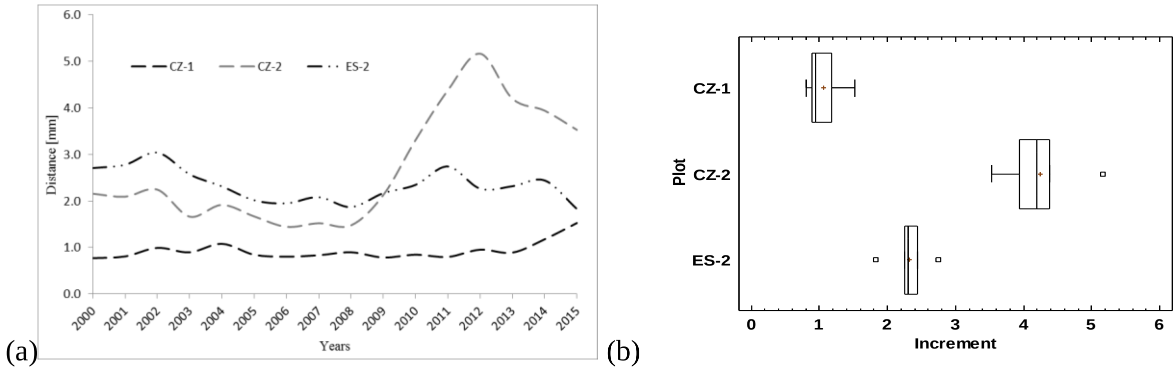


Fig. 30. Core increment of trees in DBH class 18 in 2011–2015

DBH classes 18 and 22 followed the same pattern, i.e. the highest mean increment on CZ-2, followed by ES-2 and CZ-1 (Fig. 30 and 31). In the next class, 26, CZ-1 outperformed CZ-2 (Fig. 32), however, not significantly according to Kruskal-Wallis test. Statistically significant difference was registered between CZ-2 and ES-2.

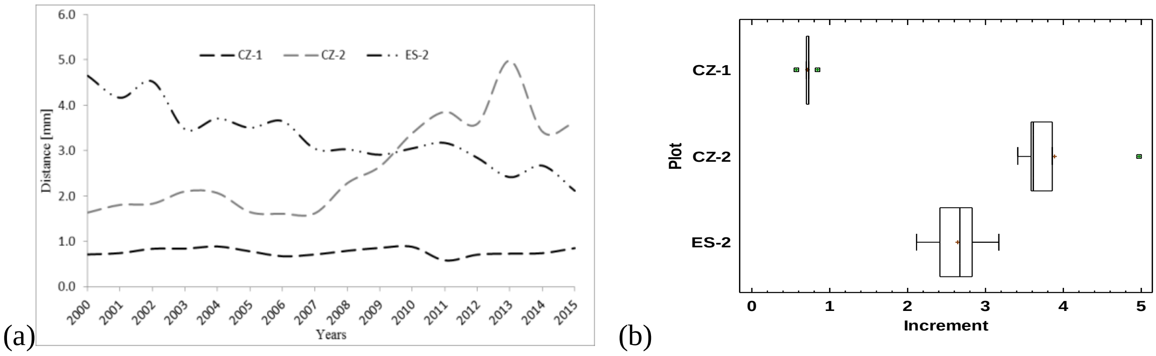


Fig. 31: Core increment of trees in DBH class 22 in 2011–2015.

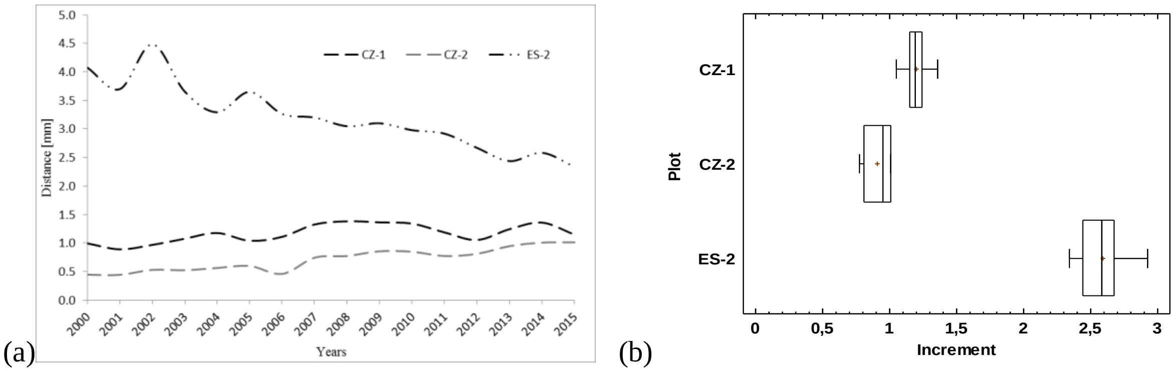


Fig. 32: Core increment of trees in DBH class 26 in 2011–2015.

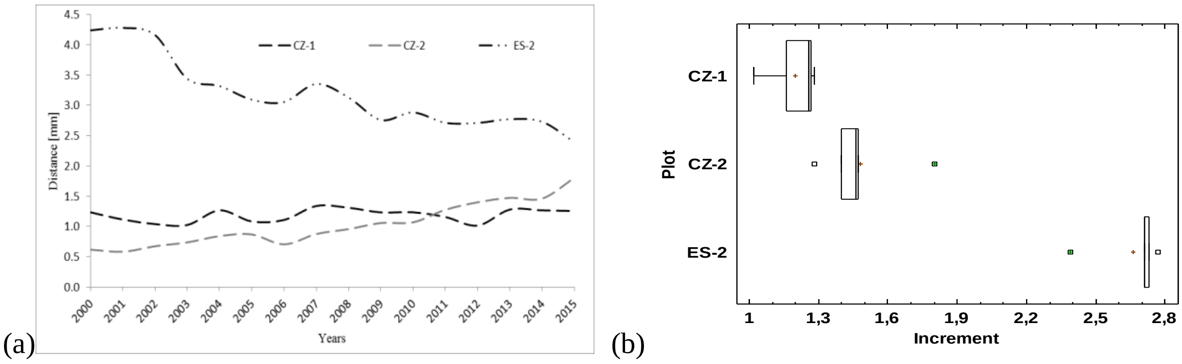


Fig. 33: Core increment of trees in DBH class 30 in 2011–2015.

Mean annual core increment in DBH classes 30 and 34 is on Fig. 33 and 34, respectively. Regarding DBH 30, there was statistically significant difference of medians between CZ-1 and ES-2. Kruskal-Wallis test applied on the comparison of medians within DBH class 34 showed statistically significant difference between CZ-2 and ES-1.

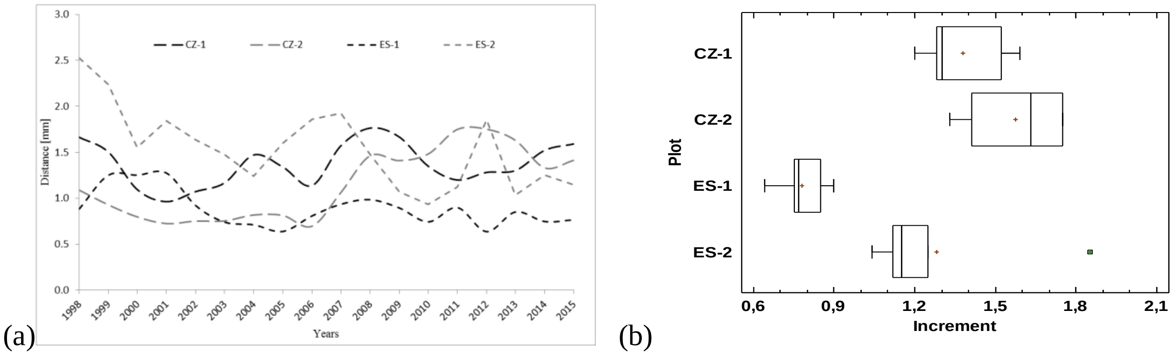


Fig. 34: Core increment of trees in DBH class 34 in 2011–2015.

DBH class 38 (Fig. 35) followed similar dynamics of increment as 34, CZ-2 and ES-1 showed statistically significant difference of means.

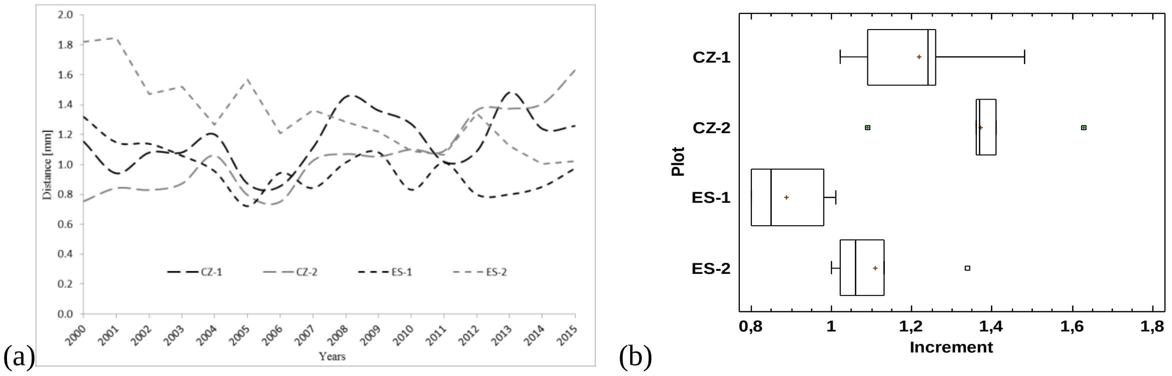


Fig. 35: Core increment of trees in DBH class 38 in 2011–2015.

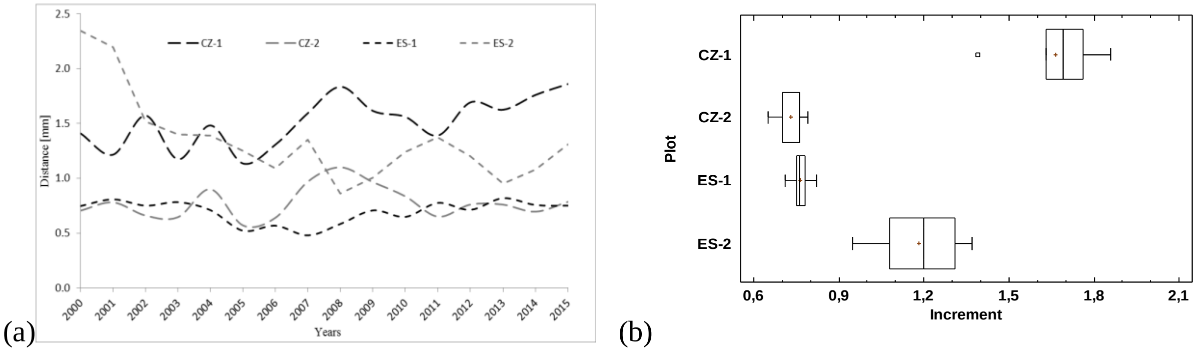


Fig. 36: Core increment of trees in DBH class 42 in 2011–2015.

Statistical significances of medians within the DBH classes were found as follows: between CZ-1 and CZ-2, CZ-1 and ES-1 within DBH class 42. In DBH class 46 it was: CZ-2 and ES-1, CZ-2 and ES-2. It is evident that in DBH class 42, CZ-1 clearly outperformed CZ-2 (Fig. 36). This pattern was not confirmed in geometrically neighbouring DBH classes, as in case of DBH class 46 (Fig. 37).

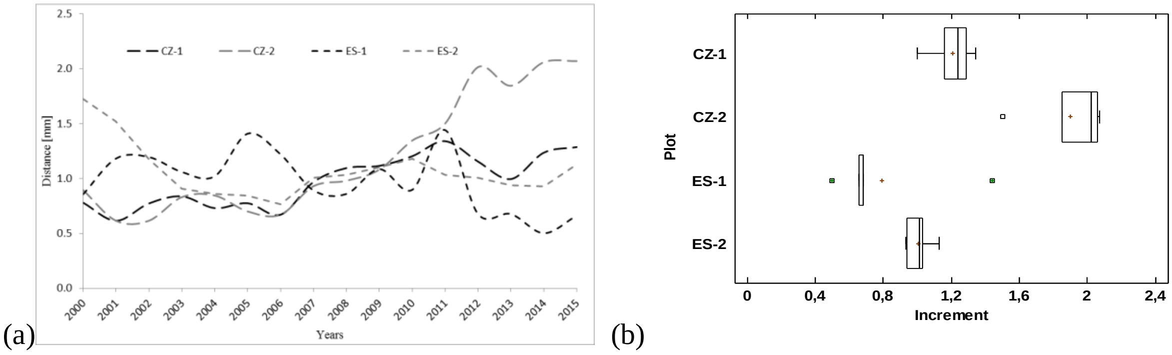


Fig. 37: Core increment of trees in DBH class 46 in 2011–2015.

From DBH class 50 on, only ES plots were represented. The Box-and-Whisker plots showed better performance on ES-2 for DBH classes 50 and 54 (Fig. 38 and 39), and the contrary for DBH 58 (Fig 40).

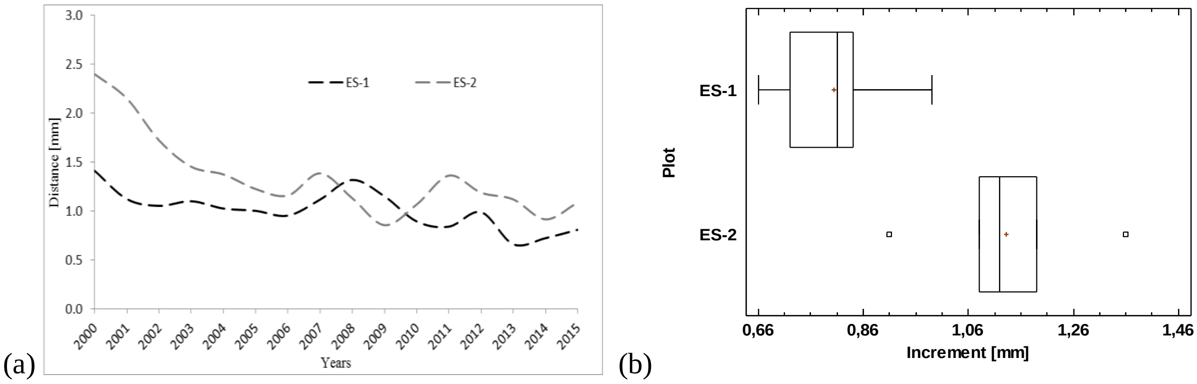


Fig. 38. Core increment of trees in DBH class 50 in 2011–2015

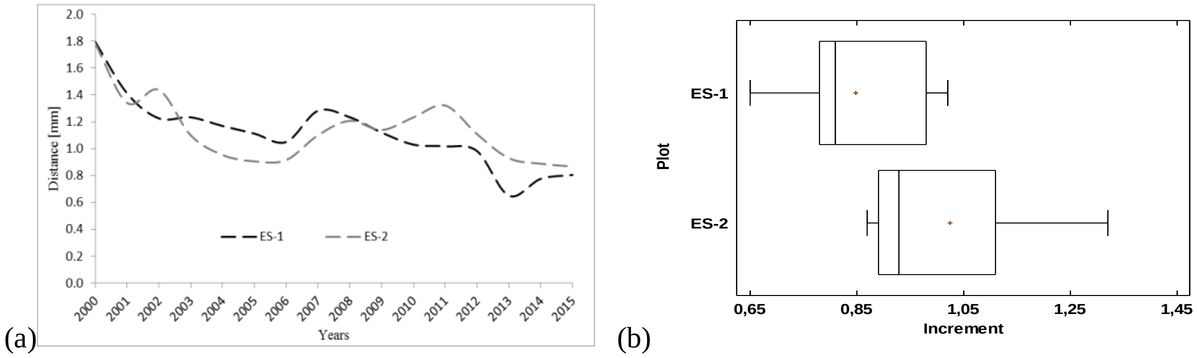


Fig. 39. Core increment of trees in DBH class 54 in 2011–2015

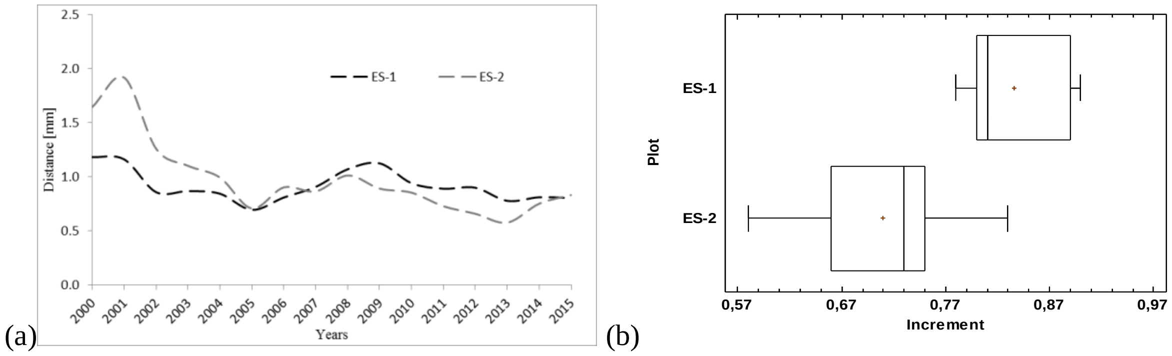


Fig. 40. Core increment of trees in DBH class 58 in 2011–2015

5.4.5 Current annual increment amongst plots

In this section, mean increment for plot was compared in a single year. The pattern was the same in all of the recent years with uneven-aged plots relatively outperforming the even-aged plots.

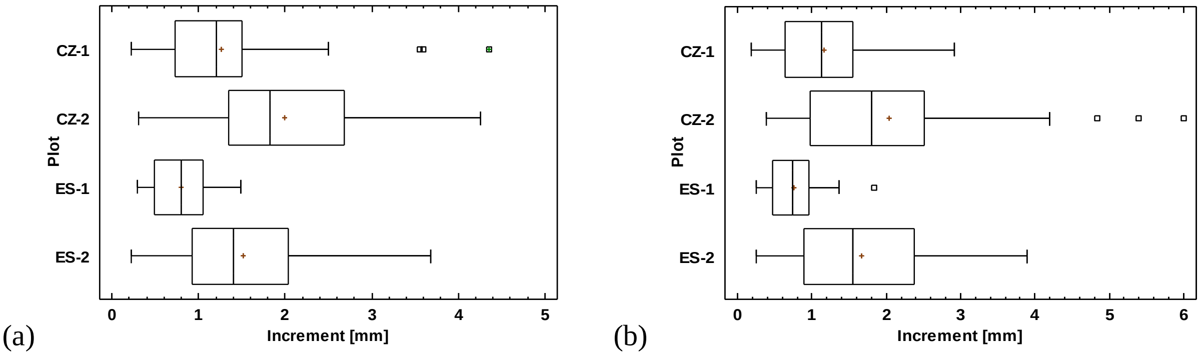


Fig. 41. Current annual increment in 2015 (a) and 2014 (b), all plots

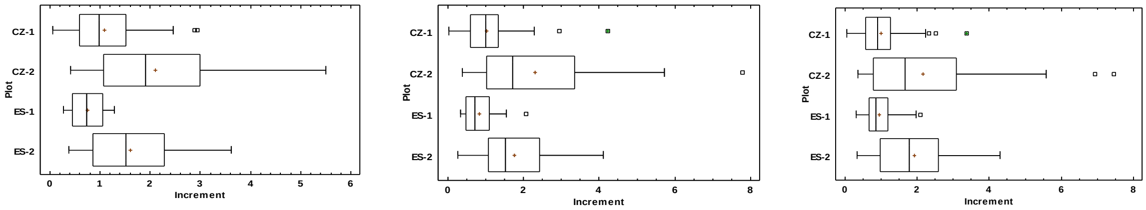


Fig. 42. Current annual increment in 2013 (left), 2012 (centre), and 2011 (right)

5.4.6 Increment of aggregated DBH classes

To verify the importance of obtained patterns, DBH classes were aggregated to four groups and tested for differences in annual mean increment. In group of DBH classes 10–18, the selection plots outperformed the only represented regular plot (Fig. 43), CZ-1. Statistical differences were found between CZ-1 and CZ-2; CZ-1 and ES-2. Within DBH classes 22–30, the statistically different pairs of medians were CZ-1 and ES-2, CZ-2 and ES-2 with ES-2 showing the highest mean increment (Fig. 44).

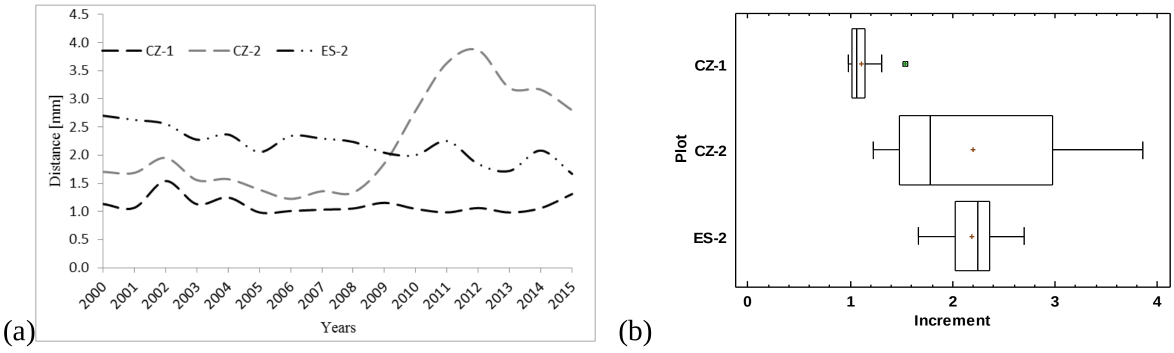


Fig.43. Increment in DBH classes 10–18 (a); boxplot for period 2000–2015 (b).

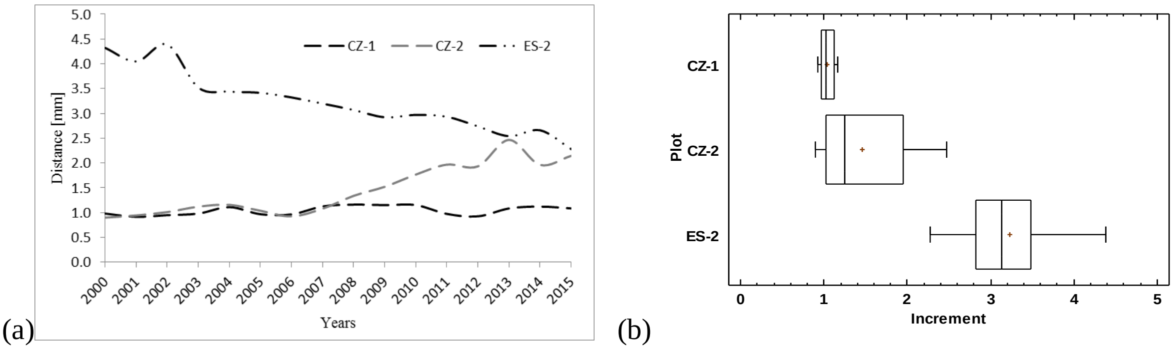


Fig.44. Increment in DBH classes 22–30 (a); boxplot for period 2000–2015 (b).

In DBH classes 34–46 (Fig. 45), Kruskal-Wallis test showed statistically significant differences between CZ-1 and ES-1, as well as between ES-1 and ES-2. In the last registered group of classes 50–58, represented only by ES plots (Fig. 46), there was no statistical significance registered.

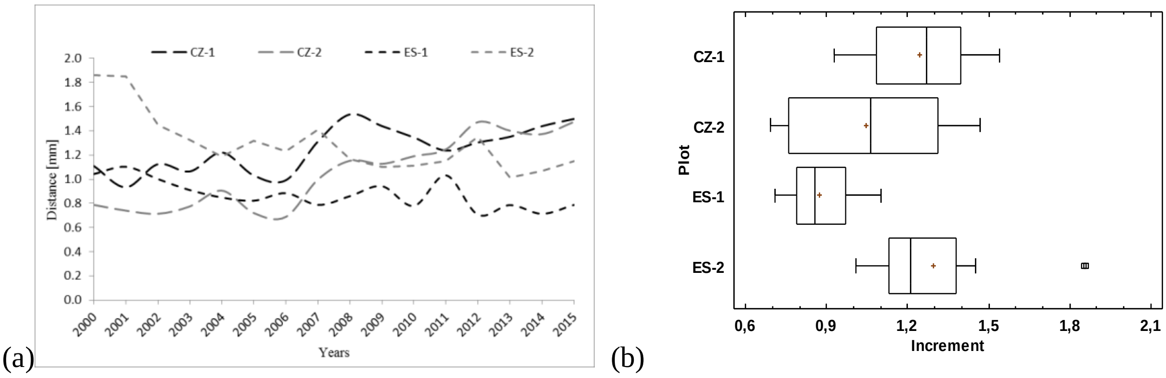


Fig.45. Increment in DBH classes 34–46 (a); boxplot for period 2000–2015 (b).

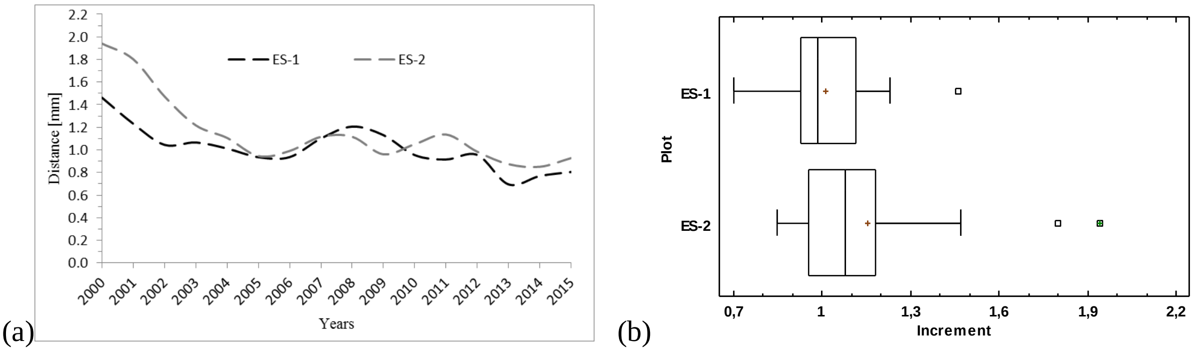


Fig.46. Increment in DBH classes 50–58 (a); boxplot for period 2000–2015 (b).

5.4.7 *Current periodical increment*

The current periodical increment was, in this case, calculated for the last 5 years as: sum of mean annual increments for DBH class. The sums for each DBH were compared with each other i.e. the current periodical increment was the dependent variable (Fig. 47). Plots under transformation and selection system, respectively, showed higher variability of the data during the last 5 years and outperformed the regular plots as well.

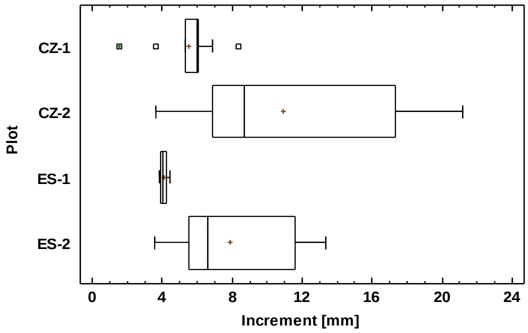


Fig.47: Box-and-Whisker plot comparison of current periodical increment for the last 5 years

6 Discussion

The trees had lower h: DBH ratio on ES plots compared to CZ plots, i.e. Spanish pines were thicker. This is an important trait of increased stand stability (KORPEĽ & SANIGA 1993, SCHÜTZ 1999). On even-aged plots (CZ-1, ES-1), the spatial distribution of trees was predominantly random (CZ-1), or random bound to regular (ES-1), while it was aggregated on the more irregular plots (CZ-2, ES-2) according to *L*-function.

In regard to mean core increments, it was examined, whether different silvicultural measures caused a reaction in growth performance. CZ-1 was a regular forest plot with low intensity management, while CZ-2 was in the process of transition into uneven-aged stand with high intensity interventions in recent years. Since the dynamics when comparing "all sampled trees" and "trees above 20 cm of DBH" of mean annual core increment on plots CZ-1 and CZ-2 resulted similar, it can be assumed that mature trees positively reacted to release cutting. That contradicts the traditional view on Scots pine as exclusively pioneer species and suggests its possible use in uneven-aged silvicultural systems.

Such difference in growth performance-reaction could not be expected on ES-1/ES-2. Even though the silvicultural systems used are different, the practical intervention resulted in similar cutting intensity in recent periods: individual tree cutting, which made up the preliminary cutting (as part of small-scale shelterwood silvicultural system) on ES-1, and individual mature trees harvest on ES-2, as practical implementation of the four united intentions in single tree selection silvicultural system (harvesting and regeneration in the first place, followed by structure formation and stand tending).

As outlined in the literature review and results, in the practical application of selection management no separated interventions are considered. They can be partially delimited as for time, but are always done with reflection to all common interests.

Generally, advantages of uneven-aged, and particularly selection silviculture systems are the attainment of elevated number of large diameter stems for veneer processing, continuous cover forestry with no temporal loss of forest environment, which subsequently leads to balanced diversity and stand structure.

Uneven-aged forest stands require consistent silvicultural interventions every 5–10 years. Longer pause of intervention causes the loss of stratification and 2-etage stand begins to form.

However, the model of can be applied also in Scots pine, where differentiated structure is desirable as an alternative (BÍLEK et al. 2016).

Sufficient quantity of natural regeneration is of essential importance. This can be limiting in forests, where forest pasture takes place (common in Spain), and also in forest heavily browsed by deer (problem in the Czech Republic). On the other hand, selection forest is not necessarily the only scheme of uneven-aged stand, as documents Moser et al. 2002.

There are long-term examples of uneven-aged silviculture of coniferous and coniferous-broadleaved mixtures (Switzerland, France). Mixed forests are commonly recommended as more stable, diverse, and natural. Nevertheless, we present an example of Scots pine selection forest that fulfil protection, as well as production function. The advantage of producing larger diameter assortments is documented.

In regard to the investigated plots, some principal suggestions could be derived. In the conditions of Plasy, the forest ecosystems are close to its existential limits. A transition to more close-to-nature uneven-aged forest is favourable for the decrease of inputs and for the increase of overall stand stability. It is necessary to mention the problems with regeneration caused by browsing pressure that could be partially solved by gradual change of tree species composition together with transition to irregular stand.

Similar problem is described for the conditions of mountain Scots pine forests in Spanish Central system, however, caused by traditional forest pasture. But it didn’t seem to be of such crucial importance as it was in case of Sika deer browsing in the Bohemian forests.

In the Guadarrama Mountain range of Central Spain, Scots pine forests are traditionally managed as even-aged by shelterwood silvicultural system. This can be viewed as relatively drastic by the public, especially on steep slopes where protection functions are a priority, depending on the intensity of opening thinning. On the other hand, leaving the forests unmanaged for ‘conservation’ purposes leads to accumulation of standing volume, lack of natural regeneration and ultimately increases the potential of large-scale forest fires. Eventually the contrary is achieved: more threats to endangered species like cinereous vulture, soil erosion, loss of retention function etc.

In this context, the suggestion of uneven-aged silviculture serves as an alternative, proportionally fulfilling all the desired services.

7 Conclusion

In this work I cooperated on project that focuses on investigating the transition of classical even-aged pine silviculture management to close-to-nature pine silviculture. The reasons are various: sustained yield in a limited area of forest, saving the economical and physical inputs, biodiversity protection, as well as social and visual benefits. From my point of view, and according to previous general knowledge, the aim of management on large scale should be a landscape mosaic composed of various structures, which necessarily requires diversified approaches of foresters-silviculturalists by using various silvicultural systems that are already known.

The work, however, verifies such measures in Scots pine, a species which is traditionally considered as pioneer and light demanding. And so, it could be viewed as a challenge to introduce (generally) uneven-aged or even single selection silvicultural systems. Nevertheless, it was possible to find examples of such Silviculture in both Bohemia and Community of Madrid. Both forests are examples of multifunctional silviculture and a result of high-qualified management. The Plasy area in Bohemia is an example where woodland is on its limits because of poor soils, and relatively low precipitation.

El Monte de Cabeza de Hierro, on the other hand, is an example of long-term sustainable management, important from the point of view of nature conservation, where one compartment of the property is managed under selection silvicultural system. By doing so, the forest continuity is secured by definition (continuous cover forestry, CCF). How close to natural pine forest the selection forest is, should be further studied. From some results, including this study, the conditions and structures are supposed to be similar. That should be the main advantage of such management: producing forest goods, and protecting nature at the same time.

Conservation, on the other hand, with the exclusion of management, could be rather problematic, leading to an accumulation of biomass and subsequent loss of structural and species diversity in unnatural conditions. Close-to-nature silvicultural procedures in pine forests and their reasonable use should thus be seen in the broader context of sustainable natural resources management.

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9 The plan of the project

9.1 Specific technical conditions of the project

The Spanish part of investigation was carried out in the complicated mountain terrain. Four-wheeled drive vehicle was used to enter the site. This was provided by the staff of Sociedad Belga de los Pinares de El Paular. Personal vehicles were used in the Czech part of the project, where the plots where in reach of paved roads. Special hardware and software was also used on the sites, which made the logistics more difficult.

9.2 Phases of the project realization

First was the selection of topic, which was realized in accordance with the international character of the study programme and considering existing investigation projects. The project was derived from current project of the Department of Silviculture in Prague, which is aimed on the development of close-to-nature pine Silviculture. This arrangement facilitated the elaboration of the project and also helped the investigation itself.

The fieldwork consisted of data collection – first part in the Czech Republic, and later in Spain. The fieldwork was followed by data classification and analysis. The analysis and interpretation were already combined with the elaboration of this final text.

9.3 Description of tasks realized by the student

The student actively participated in all activities related to the investigation - from preparation of material, data collection, to analyses and interpretation of results. The student elaborated the final text independently, with the guidance of the Spanish director of the master thesis and the Czech consultant.

9.4 Time plan of the project

The master thesis elaboration was intended for the second year of study in Madrid, i.e. third year of master study. The phases of project elaboration are summarized in Fig.48.

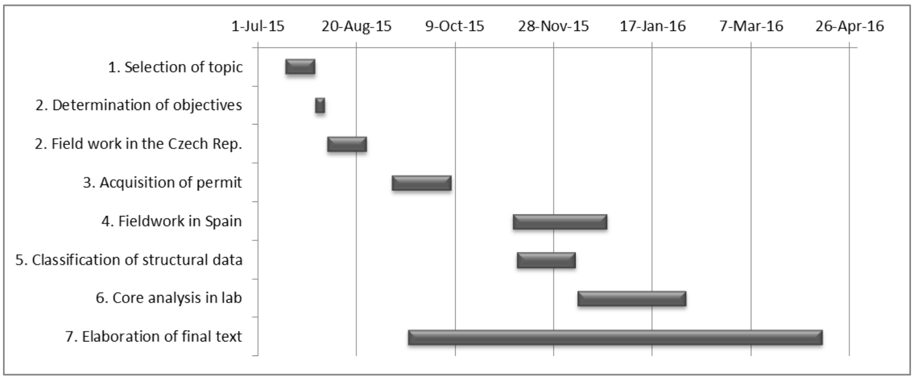

Fig.48 Gantt chart for phases of project elaboration

9.5 Estimation of costs of the project

The analysis of costs is divided into two main points:

- Costs of human resources
- Costs of material

The estimation of costs is summarized in Table 7.

Table 7. Estimation of costs of the project

	total (hours)	Cost/h (€)	Total (€)
Material, hardware and software	128	5	640
Fieldwork in Czech Republic	120	8	960
Fieldwork in Spain	136	11	1496
Classification of structural data	45	8	360
Core analyses and results	90	8	720
Final text	100	8	800
Total costs of the project			**4976 €**

Total costs of the project could be estimated to 4976 €.

10 Executive summary

The study compared two geographically and environmentally different sites of Scots pine forest, represented by two plots on each location. Two plots on each location represented natural Scots pine forest managed under regular even-aged system and irregular uneven-aged silvicultural system, respectively. The study was conducted to verify the effects of different types of management and to compare the structure of stands under different intensity of silvicultural measures. The social demands are increasing at present, forests are supposed to fulfil multiple functions at the same time. After obtaining the knowledge of structure, the right decisions for transformations of forest stands could be suggested. The distinction characteristics of sites in the Czech Republic and in Spain were described. Three different scenarios for stand transformations were suggested according to previous literature.

With the use of Field-Map hardware and software and standard forestry tools, horizontal and vertical structure data, as well as the diameter structure data were obtained. Tree core samples were extracted to understand the dynamics of annual increment.

General stand structure was described using the obtained data. DBH structure of uneven-aged plots was compared with LIOCOURT ideal selection forest. Structural indices and diversity of tree layer was calculated using Sibyla growth simulator. Ratio between height and diameter on all plots was calculated to obtain information about stand stability. Unconstrained principal component analysis (PCA) was used to analyse relationships among plots attributes, stand parameters, climate data, and diversity of *Pinus sylvestris* and similarity of 4 research plots. Core samples were analysed in lab and statistically evaluated by STATGRAPHICS Centurion software.

The results allowed seeing the state of the forest and differences of characteristics between individual plots. All plots had similar density characteristics, but different DBH structure, reached by different intensity of silvicultural interventions. Trees on ES plots showed lower H: DBH ratio. On even-aged plots (CZ-1, ES-1), the spatial distribution of trees was predominantly random (CZ-1), or random bound to regular (ES-1), while it was aggregated on the more irregular plots (CZ-2, ES-2) according to *L*-function.

In PCA analysis, altitude was positively correlated with precipitation and gradient, while these parameters were negatively correlated with temperature, stand age and total diversity index. Stand volume, mean height and DBH positively correlated to each other, while these parameters were negatively correlated with canopy (crown closure, crown projection area), stand density and structural differentiation indices. Plots generally inclined to variability of different parameters, especially for plots ES-1 and ES 2.

Increment cores showed significantly increased growth on intensively managed plots in recent years. This increase was predominantly due to release and selection interventions and was driven by rapid increment in smaller diameter classes on those plots.

Where required, close-to-nature silviculture is a viable model for creating more complex forest structure in stands naturally dominated by Scots pine. The reasons are various: sustained yield in a limited area of forest, saving the economical and physical inputs, biodiversity protection, as well as social and visual benefits.

11 Appendices

Work with Field-Map

Photo of ES-1 (regular structure) plot, from NW

Photo of ES-2 (irregular structure) plot, from NE

Photo of CZ-1 (regular structure) plot, from NE

Photo of CZ-2 (under rebuilding) plot, from NE