Influence of climate and mixture effect on radial increment of European beech (*Fagus sylvatica*) in pure and mixed stands with Scots pine (*Pinus sylvestris*)

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Master Thesis no. 245

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MSc Thesis in Forest Management – Euroforester Master Program SM001
Advanced level (A2E), SLU course code EX0630, 30 ECTS

Abstract

The main aim of this study was to investigate the trends of radial increment of European Beech (*Fagus sylvatica* L.) in pure stands and mixed stands with Scots pine (*Pinus sylvestris* L.). The study plots were located in Kivik and Tyringe in Skåne which is the southernmost region of Sweden. Applied methods were based on analyze of tree ring widths in cores extracted from trees. The factor mostly influencing the radial increment turned out to be trees' age ($p<0{,}001$). Stands were losing their growth potential with growing age, however the pattern differed between the stands. Precipitation had also statistically significant ($p<0{,}001$) but minor impact on increment of beech in June and July. Temperature and mixture effect were found to have no effect on radial increment ($p>0{,}05$). Further analysis showed that the investigated period (1961-2013) can be divided into three minor periods which are characterized by specific relations between beech and pine. On the basis of mentioned results multiple regression model was created, to predict radial increment with varying input values of age, precipitation, temperature and mixture. The number of plots in this study was found to be insufficient to give certain results on radial increment trends of beech but it is a part of European EuMixFor transect study on beech and pine which may bring significant input to knowledge on mixed forests in the future.

Key words: European beech, Scots pine, radial increment, climate, mixed forest, stands age, dendrochronology, tree ring width

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1. Introduction

Many studies have shown an influence of mixture on stand growth and stability (ASSMANN 1970). In the case of overyielding, a complementary use of resources available in the stand is used as explanation (Forrester 2014). Usually, trees of different species with diverse biological features fill the available space with canopy and roots in different ways (PRETZSCH 2014). The same is happening with water and nutrient management of trees (BINKLEY 1986). These varying strategies would lead to maximized benefits and increased productivity when different tree species are growing together (MORIN ET AL. 2011). A mixture effect should be visible more easily when individuals of different tree species are distributed evenly in the stand and are occupying multiple canopy layers (CAVARD ET AL. 2011). However, increased productivity can occur more likely when mixture is using more effectively the resource which is a limiting factor (KELTY 1992). Therefore, no growth advantage may be observed in a stand consisting of light-demanding overstory species and shade-tolerant understory tree species which are using fully the available light, when the limiting factor is water (VILÀ ET AL. 2013). Mixed forests were constantly attracting attention of researchers and foresters for several decades. Today, it is driven by raising social awareness on biodiversity and stability of ecosystems but also constant willingness to increase stands productivity. Several papers are stressing the role of tree species mixtures which have been published in recent years, especially investigating complementary interactions between species (FORRESTER 2014). Numerous positive effects of species diversity like reduction of damage (JACTEL ET AL. 2009) or better nutrition (ROTHE AND BINKLEY 2001) were reported. Many studies found somewhat increased productivity in specific mixed forest types (LINDEN 2003; JONSSON 2001, PRETZSCH ET AL. 2010; MASON AND CONOLLY 2014), comparing the relative yield or the periodic annual increment (PAI) of the mixture to the two monocultures on a similar site according to Kelty (1992) or Pretzsch (2009).

The tree species European beech and Scots pine were chosen as study object. The reason for this choice was a transect study of this particular species mixture along a gradient from Spain to Sweden within a European network study (EuMixFor). The two Swedish study sites were the base for this master thesis. They were the northernmost located sites in the network. European beech and Scots pine are very suitable candidates to investigate tree species interactions due to their different demands and patterns of growth (ØYEN ET AL. 2006; PRETZSCH 2009; FORRESTER 2014). In addition, European beech is one of most dominating and competitive tree species of potential natural vegetation in Central Europe (ELLENBERG 1996) while Scots pine is frequent more north or in limited growth conditions (BIAŁOBOKA ET AL. 1993). Combination of these species may play significant role in transforming monocultures of pine that are located on potentially rich habitats which can be suitable for mixed or deciduous forest. Such situation is common for instance in eastern Germany and Poland where large areas have been afforestated in years 1946-1970 almost entirely with pine, without complete consideration on site conditions and possibilities (SOBCZAK 1996).

The initial goal set in this thesis was to discover the relations between pure and mixed stands of beech and pine and their impact on radial increment of trees. Nevertheless, age differences between pine trees turned out to be much bigger than previously expected on the basis of field survey and therefore were excluded in further analysis. To get deeper insight also climate was decided to be taken into consideration.
Climate and especially its changes over time can be another important factor influencing the growth of trees (BONAN 2008, BERGH ET AL. 2010). Some researchers showed that varying

precipitation and temperature can have significant impact on radial tree growth in Europe (MÄKINEN ET AL. 2003). Therefore it was tested in this work. Following hypotheses were formulated according to the goals:

1. The radial increment of European beech is more stable over time in mixture with Scots pine than in monoculture.
2. The radial increment of European beech is decreasing with ageing of stands.
3. Climate has the largest influence on the growth of the sampled trees of European beech

Annual radial increment was used to define the mixture effect of trees as it gives a detailed insight into growth pattern. Second part of this study was a climatic analysis of the acquired tree-ring data set. Average annual temperature and sum of precipitation were paired with this data to analyze the impact of the past climate on tree growth over time.

2. Materials and Methods

2.1. Study area

The measurements for this study were conducted in six stands near Tyringe and Kivik located in Skåne region (Fig. 1.) which is the most southwestern part of Sweden. Cambisoil was the dominating soil type on both sites. The climate conditions are typical for northern nemoral zone (AHTI ET AL. 1968). In Kivik, mean annual temperature for the period 1961-2013 was 7,9°C and annual precipitation was 670 mm. Respectively these values in Tyringe were 7,2°C and 840 mm (SMHI 2015). The forest data collection was done in June and October 2014 in Tyringe. Forest data from Kivik was collected in November and December 2014.

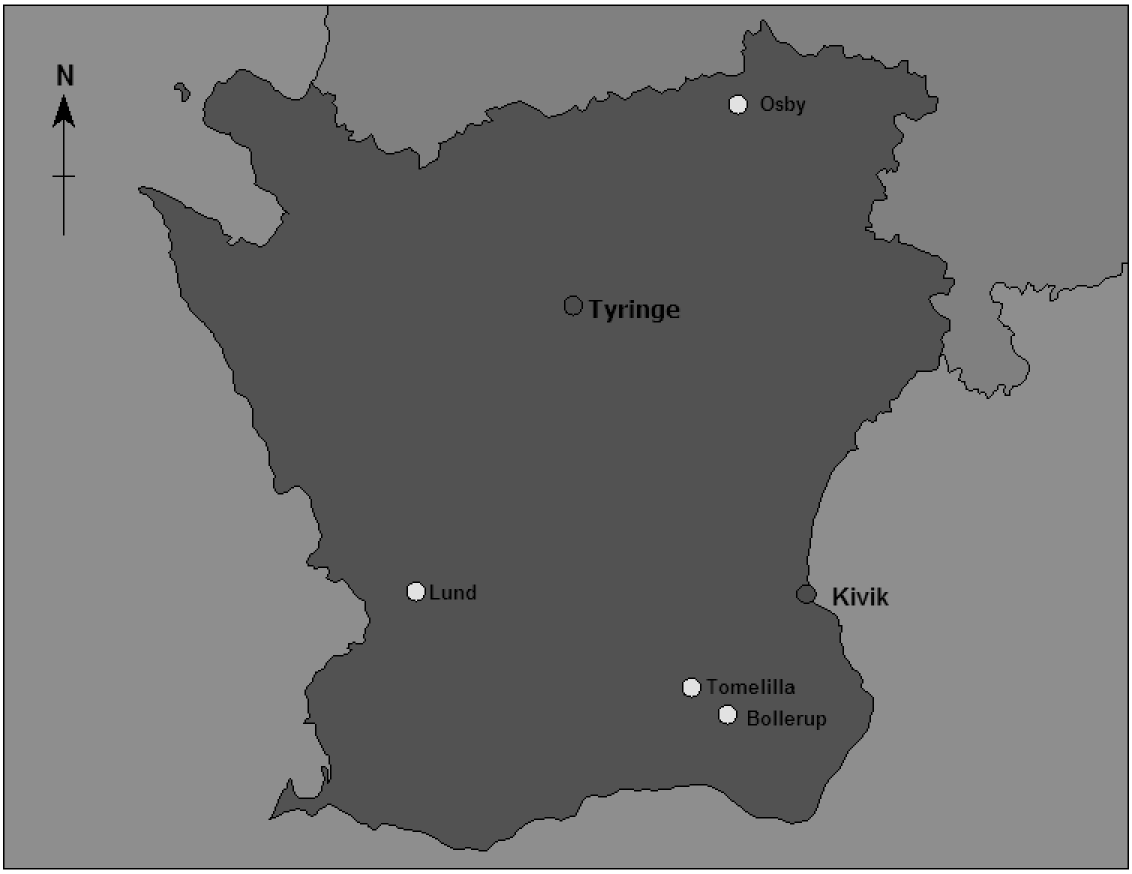


Fig. 1 Location of the two study triplets in the Skåne region. Red – study plots, Yellow – nearest climate stations with continuous observations since 1961.

2.2. Description of study stands

In total, six study stands were established on the two sites (two triplets) in Kivik and Tyringe. On each site, the stands were located close to each other (Fig. 2. and 3.) and consisted of pure pine, pure beech and a mixture of those species. In the further text, such an experimental design is called a triplet according to Pretzsch et al. (2010). Selected stands were mono-layered and species were mixed evenly by single trees or in small groups. Table 1., 2. and 3. provide more information about the study stands. The selection process was carried out according to the instructions given for a European transect study covering pine and beech forests from Spain to Sweden (PRETZSCH, personal communication):

1. A triplet contains a pure stand of Scots pine, a pure stand of European beech and a stand with the mixture of these two species.
2. Each plot contains 20 dominant trees in pure stands and 40 dominant trees in the mixed stand of which at least 20 trees belong to a single species (beech and pine).
3. All stands should not be thinned for more than 10 years to minimize the effects of management. All six stands in Sweden were characterized by very dense and closed canopy and remnants of at least one dead large tree.
4. According to the instructions, all stands should be of similar age ranging from 50-80 years. However, age estimates based on extracted cores later during this study indicate stand ages described in Table 3. The stand structure should be even-aged and mono-layered.
5. Plots within one triplet should be located directly next to each other or represent the same site conditions.
6. The type of mixture in the selected mixed stands should be individual tree- or small group-mixture to observe a maximal impact of mixture.

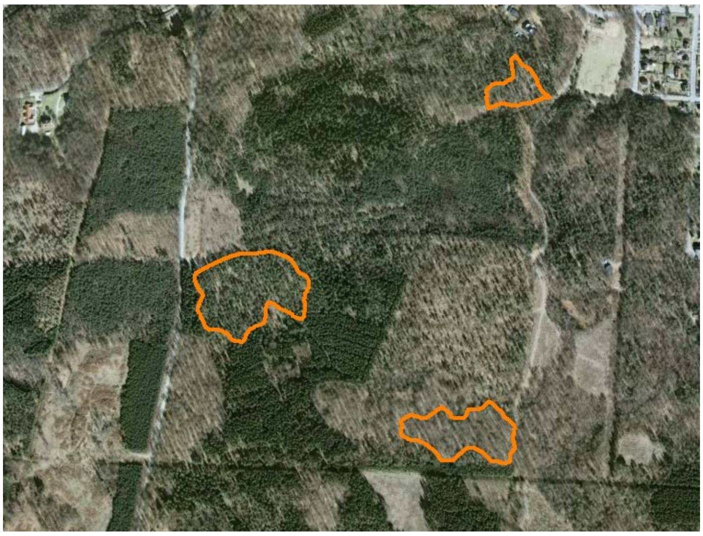


Fig. 2. Spatial distribution of study stands in Tyringe.

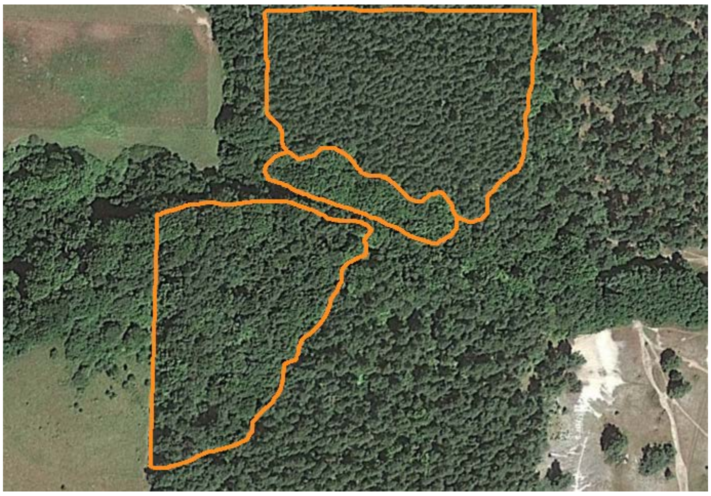


Fig. 3. Spatial distribution of study stands in Kivik.

Fot. 1. Pine stand in Kivik (author: M. Löf)

Fot. 2. Pine stand in Tyringe (author: M. Löf)

Fot. 3. Beech stand in Kivik (author: M. Löf)

Fot. 4. Beech stand in Tyringe (author: M. Löf)


Fot. 5. Mixed stand in Kivik (author: M. Löf)


Fot. 6. Mixed stand in Tyringe (author: M. Löf)

2.3. Stand data collection

A standard stand data collection has been conducted to characterize the study stands. Every dominant tree included in the investigation was measured with diameter at breast height (DBH), height, height of lowest living branch (crown base) and basal area (Tab. 1). Vertex ultra sonic device was used for remote measurement of all heights. Every tree was marked with unique code and its position defined with reference to center of the plot with known absolute geographical coordinates (Tab. 2).

Tab. 1. Basic stand data of measured plots

Site	DBH (cm)				Height (m)				Average crown base height (m)	Basal area (m^2)
	Average	Variation	Min	Max	Average	Variation	Min	Max		
Kivik Pure Pine	34,8	19,7	27,0	41,0	25,5	1,5	22,6	27,1	15,8	31,6
Kivik Pure Beech	42,1	144,4	27,6	69,4	27,1	10,0	20,9	35,0	10,0	31,1
Kivik Mixed Pine	57,9	113,1	38,5	75,1	24,7	4,8	21,0	28,2	15,0	37,9
Kivik Mixed Beech	37,8	131,3	22,5	60,5	26,1	37,3	15,1	40,5	8,7	
Tyringe Pure Pine	31,4	21,0	21,3	39,6	22,3	2,9	19,7	25,3	13,1	26,0
Tyringe Pure Beech	45,2	130,6	27,7	68,4	23,5	4,5	19,5	28,1	5,5	19,3
Tyringe Mixed Pine	42,1	56,9	28,0	52,5	23,2	6,0	18,3	26,7	13,3	27,1
Tyringe Mixed Beech	36,2	73,1	26,4	59,5	21,1	9,2	16,3	27,7	3,6	

Tab. 2. Geographical coordinates of measured plots

Site	Longitude	Latitude
Kivik Pure Pine	14°11'51" E	55°42'42" N
Kivik Pure Beech	14°11'49" E	55°42'41" N
Kivik Mixed	14°11'46" E	55°42'33" N
Tyringe Pure Pine	13°35'11" E	56°8'59" N
Tyringe Pure Beech	13°35'29" E	56°08'50" N
Tyringe Mixed	13°35'35" E	56°9'12" N

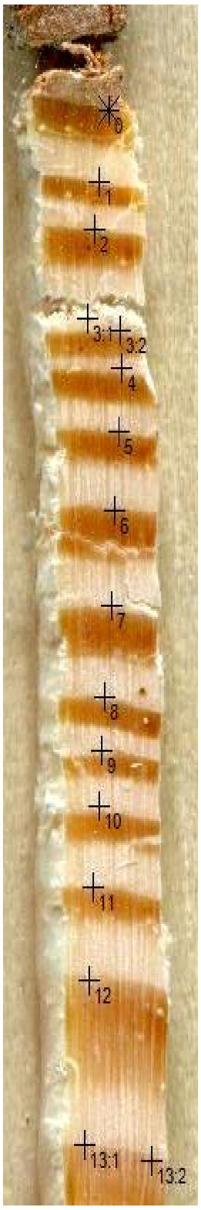
Tab. 3. Age of trees in study stands

Site	Age
Kivik Pure Pine	61
Kivik Pure Beech	76
Kivik Mixed Pine	124
Kivik Mixed Beech	65
Tyringe Pure Pine	58
Tyringe Pure Beech	89
Tyringe Mixed Pine	125
Tyringe Mixed Beech	105

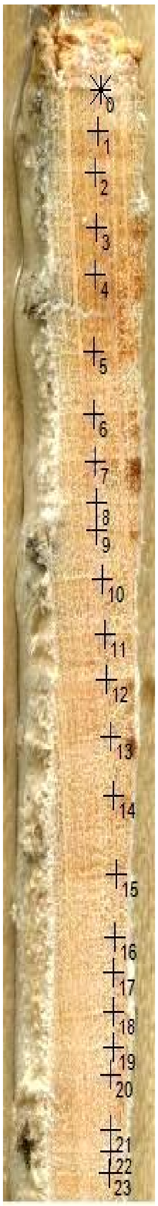
2.4. Tree core sampling

To analyze the pattern in radial increment 320 cores were extracted from 160 trees. All trees included in this study were cored with increment borer (GRISSNO–MAYER H. 2003). In every case coring was conducted at height of 130 cm from northern and eastern direction. After that, acquired core was immediately mounted on wooden stick (Fig. 10.) and tied with the tape to avoid bending caused by changing moisture conditions in sampled wood. All collected samples were sanded gradually from 80 grit sanding paper down to 400 and later scanned with resolution of 2400 dpi (Fig. 11.). Widths of tree rings were measured with CooRecorder 7.7 and then cross-dated with CDendro 7.7 software. To provide good data quality tree ring widths were marked in parallel to wood rays (Fig. 12.). As reference to cross-date beech cores we used a master file created by Igor Drobyshev on the basis of beech trees from Skabersjö with clear growth response to mast years. (DROBYSHEV, personal communication) In the case of pine, master file was created from samples with the least influence of compression wood and relatively wide rings to avoid missing rings (YAMAGUCHI 1999).

Fig. 10. Pine core mounted on wooden stick and sanded



Figur 11 Core extraacted from pine



Figur 12 Core extracted from beech

2.5. Data analysis

Standard deviation was used as an indicator of variation existing in collected data. The analyses included univariate linear and non-linear multiple regressions. Linear regression models were developed as ratio between observed and calculated growth which was designated from the trend line equation. The Pearson´s correlation coefficient was used to study the influence of a single factor on mean annual radial increment. Values from the t-test table based on the normal distribution were used to determine statistically significant differences in two-tailed test (WINER ET AL. 1971). The confidence interval was 95%.

3. Results

3.1 Impact of mixture effect on radial increment of European beech.

3.1.1 Tyringe

Beech trees in the pure beech stand in Tyringe (TPB) were found to be similar in radial increment pattern compared to beech trees in the mixed pine-beech stand (TMB) during the investigated period (Fig. 4.). Standard deviation (SD) in the data was almost the same in pure (SD=0,38) and mixed (SD=0,44) stand. There was a weak and statistically not significant advantage of growth detected in pure stand (Fig. 5.). Three minor periods can be distinguished (Tab. 4.). The first one (1961-1972) was characterized by almost random growth relation between the stands (Corr=0,07). Differences in average increment (AI) were small (AI_{TPB}=2,43; AI_{TMB}=2,29) as well as standard deviation (SD_{TPB}=0,27; SD_{TMB}=0,25). In the second period (1973-1992) correlation was high (Corr=0,76) while disparity of average increment (AI_{TPB}=1,97; AI_{TMB}=1,94) reached lowest value and standard deviation remained similar (SD_{TPB}=0,31; SD_{TMB}=0,24). Correlation became the highest (Corr=0,78) in the last period (1993-2013), the same as standard deviation (SD_{TPB}=0,35; SD_{TMB}=0,23). In last 20 years, decline of growth in mixed stand was observed (AI_{TPB}=1,89; AI_{TMB}=1,38).

Tab. 4. Radial increment of Tyringe stands in given periods.

Period		Pure beech	Mixed beech
1961 - 1972	Average increment	2,43	2,29
	Standard deviation	0,27	0,25
	Correlation	0,07	
1973 - 1992	Average increment	1,97	1,94
	Standard deviation	0,31	0,24
	Correlation	0,76	
1993 - 2013	Average increment	1,89	1,38
	Standard deviation	0,35	0,23
	Correlation	0,78	

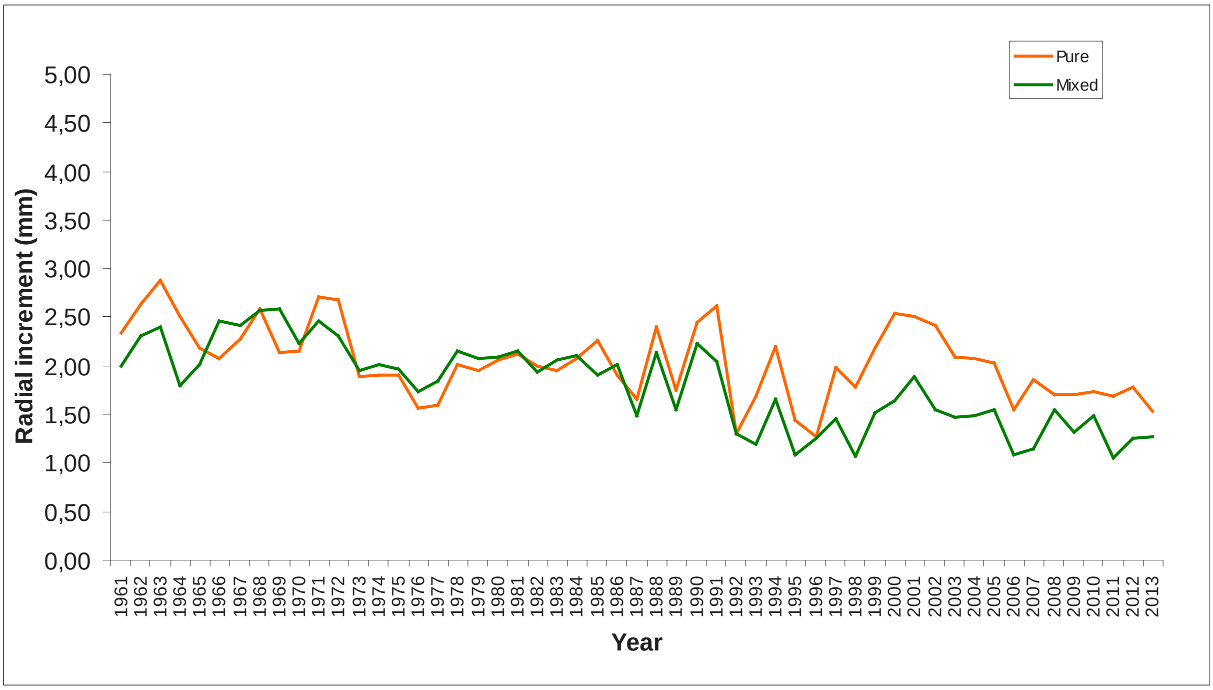


Fig. 4. Annual radial increment in pure and mixed stands in Tyringe.

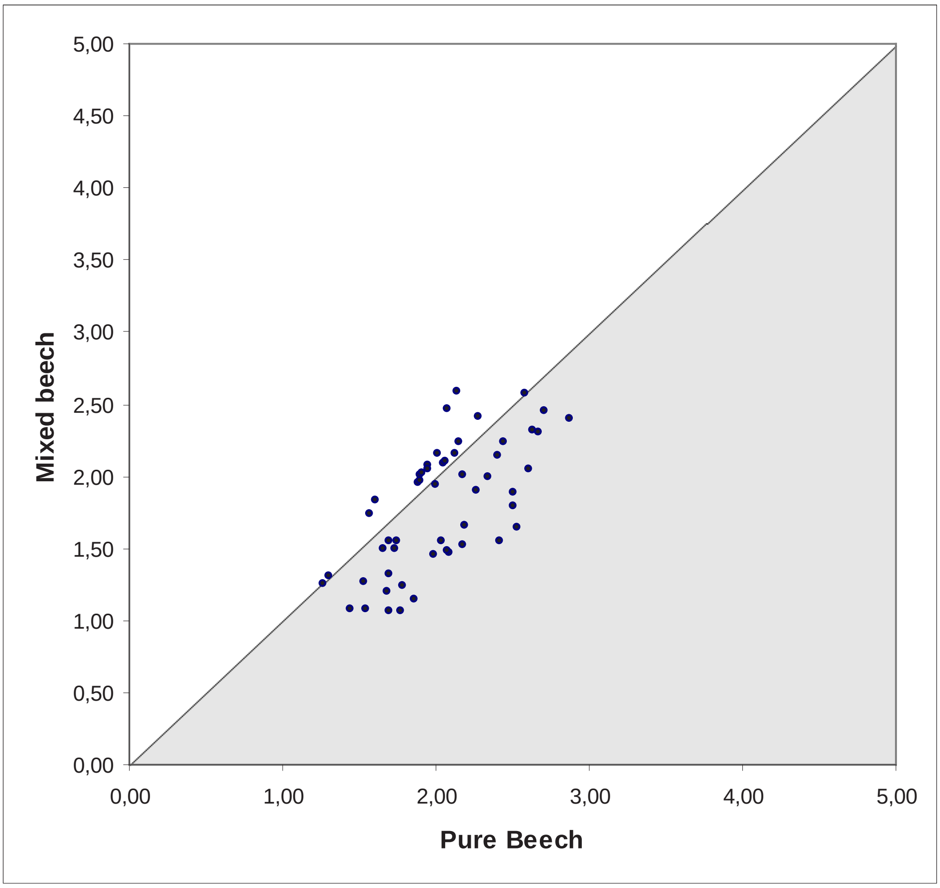


Fig. 5. Radial increment (mm) ratio of Tyringe stands. Each point represents increment ratio in single year, what allows to access which stand had bigger increment for most of studied period.

3.1.2 Kivik

In Kivik radial increment patterns between pure (KPB) and mixed stand (KMB) were clearly different. It was more steady in mixed stand (SD=0,40) while the pure stand had biggest standard deviation (SD=0,97) among studied plots with visibly decreasing increment with growing age of the trees (Fig. 6.). In this case growth was slightly better in mixed stand (Fig. 7.), especially during the last 20 years. Again, three minor periods with various features can be separated (Tab. 5.). In the first period (1961-1974) increment was higher in pure stand (AI_{KPB}=3,52) than in mixed stand (AI_{KMB}=2,93) and correlation between them was the lowest (Corr=0,40). Values for standard deviation were SD_{KPB}=0,48 and SD_{KMB}=0,37. Middle period (1975-1991) was characterized by the smallest difference in increment (AI_{KPB}=2,60; AI_{KMB}=2,73) like also standard deviation (SD_{KPB}=0,33; SD_{KMB}=0,31) and highest correlation (Corr=0,79). In the latest period (1992-2013) the highest difference of increments (AI_{KPB}=1,35; AI_{KMB}=2,41) was observed with decrease of correlation (Corr=0,63). Standard deviation for stands was respectively SD_{KPB}=0,28 and SD_{KMB}=0,35.

Tab. 5. Radial increment of Kivik stands in given periods.

Period		Pure beech	Mixed beech
1961 - 1974	Average increment	3,52	2,93
	Standard deviation	0,48	0,37
	Correlation	0,40	
1975 - 1991	Average increment	2,60	2,73
	Standard deviation	0,33	0,31
	Correlation	0,79	
1992 - 2013	Average increment	1,35	2,41
	Standard deviation	0,28	0,35
	Correlation	0,63	

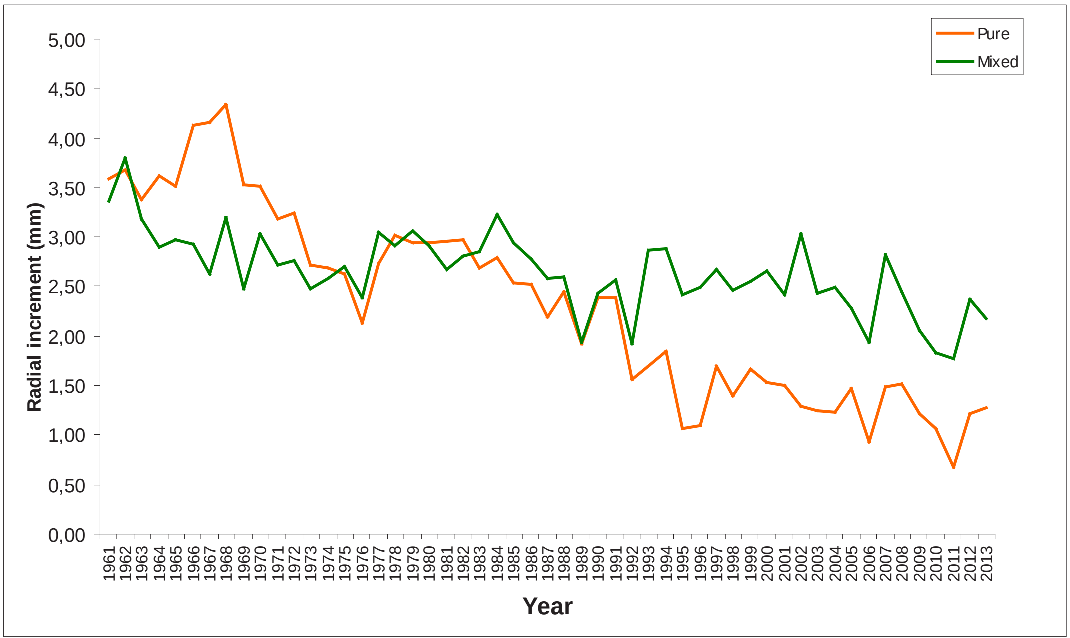


Fig. 6. Annual radial increment in pure and mixed stands in Kivik.

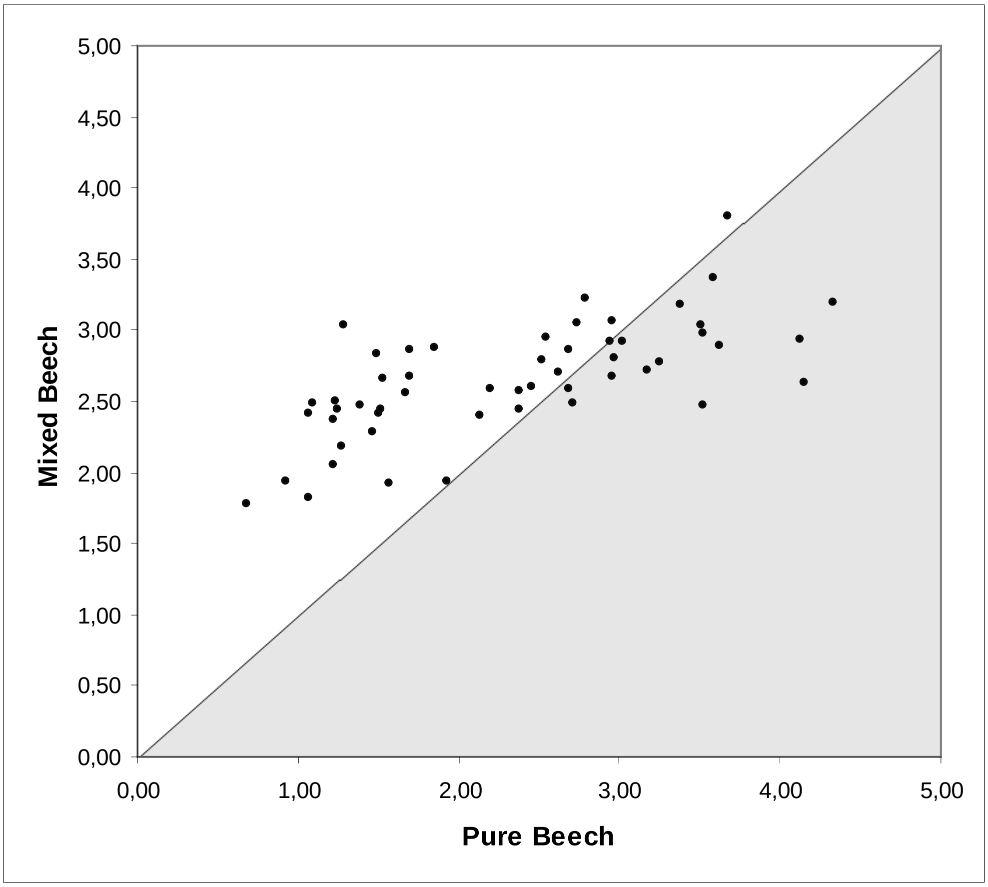


Fig. 7. Radial increment (mm) ratio of Kivik stands. Each point represents increment ratio in single year, what allows to access which stand had bigger increment for most of studied period.

3.2 *Impact of stand age on radial increment of European beech.*

Based on univariate, linear regressions, age is the factor that influenced radial increment of beech the most. The results in section 3.2-3.4 showed that it has larger impact on increment than climate or species composition. Almost the same values were detected for diameter at breast height (DBH) and basal area of trees. The growth decreased while the trees became older. However, the pattern differs between Kivik and Tyringe and mixed and pure stand. In Tyringe, mixed stand is losing its growth potential faster than the pure one, while in Kivik situation is opposite. According to the analysis, stands with faster decreasing annual increment have higher correlation coefficiency. (Fig. 8.)

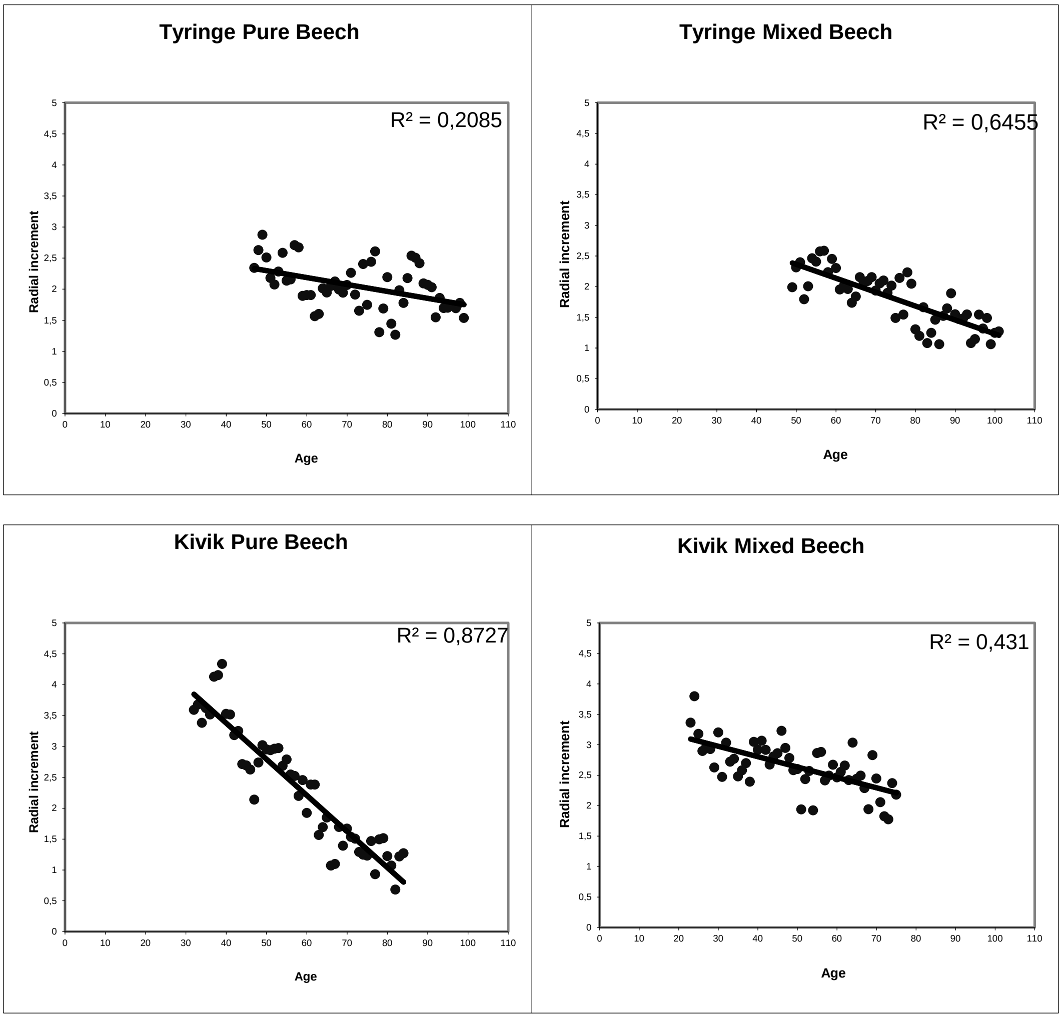


Fig. 8. Relation between stand age and annual radial increment in studied beech stands.

Nevertheless, another observation is that beech in the pure stand in Kivik behaves differently than beech in the other stands shown in Figure 8. It is characterized by much bigger standard deviation which is 0,97, while in other cases this value is relatively equal and varies between 0,38 and 0,44.

3.3 Impact of temperature on radial increment of beech

No important correlation were noticed between mean annual radial increment of beech stands and average temperature in given months (Tab. 6). There is only one statistically significant positive observation in the mixed stand in Kivik for August ($p<0,05$).

Tab. 6. Correlation of mean annual radial increment and monthly average temperature. Statistically significant values are marked.

Month	Tyringe		Kivik	
	Pure	Mixed	Pure	Mixed
Jan	0,08	0,03	0,02	0,00
Feb	0,05	-0,14	-0,12	0,02
Mar	0,12	0,04	0,09	-0,10
Apr	0,24	-0,10	-0,02	-0,05
May	0,13	0,06	0,14	-0,13
Jun	-0,18	-0,09	-0,11	0,03
Jul	0,09	0,19	0,02	0,21
Aug	0,10	0,13	-0,05	0,29
Sep	0,14	-0,03	-0,02	0,00
Oct	0,05	0,08	0,05	0,04
Nov	0,11	0,18	0,17	0,02
Dec	0,06	-0,06	0,04	-0,12

3.4 Impact of precipitation on radial increment of beech

More significant correlation values have been observed for all beech trees during June or July (Tab. 7). The monthly sum of precipitation had a positive impact on pure stands in June (Tyringe Corr= 0,46; $p<0,001$; Kivik Corr= 0,29, $p<0,05$), what means that radial increment was increasing with raising amount of precipitation. However, negative correlation was observed in June for mixed stands in both locations (Tyringe Corr= -0,28, $p<0,05$; Kivik Corr= -0,32, $p<0,05$). Another negative value was shown for mixed stand in Kivik in December ($p<0,05$).

Tab. 7. Correlation of mean annual radial increment and montly sum of precipitation. Statistically significant values are marked.

Month	Tyringe		Kivik	
	Pure	Mixed	Pure	Mixed
Jan	0,15	0,18	0,23	-0,07
Feb	0,17	0,02	-0,01	0,17
Mar	-0,06	0,11	0,04	0,01
Apr	-0,03	-0,10	-0,11	0,03
May	-0,02	0,01	-0,19	0,18
Jun	0,46	0,18	0,29	-0,17
Jul	0,02	-0,28	0,05	-0,32
Aug	0,09	0,00	-0,03	0,10
Sep	0,02	0,03	-0,15	0,17
Oct	0,02	0,05	0,05	-0,12
Nov	-0,11	0,19	0,07	0,07
Dec	-0,10	-0,12	0,10	-0,30

3.5 Multiple regression model of impact of stand age, mixture effect and climate on radial increment of beech.

No statistically significant impact was detected in the case of mixture effect (p= 0,30) and temperature (p= 0,63). Precipitation had minor but significant (p<0,001) effect on beech growth. The greatest influence on radial increment of studied trees is connected with stand age effect (p<0,001). (Tab. 8.)

Tab. 8. Summary of multiple regression analysis. Mixture effect was treated as dummy variable. Sum of precipitation and average temperature were calculated for vegetation period.

	Value	Standard Error	Degrees of freedom	t-value	p-value
Intercept	3,3007	0,3233	4343	10,2102	0,0000
Mixture	0,1300	0,0658	1	1,9763	0,2982
Age	-0,0281	0,0012	4343	-22,5604	0,0000
Precipitation	0,0011	0,0002	4343	5,2383	0,0000
Temperature	0,0133	0,0277	4343	0,4818	0,6299

4. Discussion

The first hypothesis in this study assumed that radial increment of beech is more stable over time in mixed stands with pine than in pure stands. However, the acquired results did not confirm that as they did not show a clear answer. In Tyringe, the increments of stands were closely correlated to each other with little less stability in the mixed one. On the contrary, the Kivik stands differed significantly. Growth rate in the pure stand was declining much faster and standard deviation of data is much higher than for mixed stand. A possible explanation for that can be that beech is growing slower in the beginning because of the shading by older pine (NEWBOLD AND GOLDSMITH 1990; KINT ET AL. 2006). Then, more openings in upper canopy are likely to occur over time as the pines are dying or being removed. Then, beech can increase growth and benefit from partial shading (JAWORSKI 1995). However, the results in this study are not so conclusive due to the different patterns observed on both sites. Therefore, the first hypothesis cannot be confirmed. Generally, basing on increment pattern it is possible to distinguish three periods in the studied time interval. In the first period, the stands within each triplet showed random or weak relationships. In the second period, the growth pattern was highly correlated and trees had similar rates of increment. However, the variation increased in the last period and the younger stands took advantage of their higher productivity potential compared to the older stands (EKÖ 1985; PRETZSCH 2009).

During the last century, the average annual temperature in Europe increased for about 0,8ºC (SOU 2007, IPCC 2001) what could lead to more frequent occurrence of severe effects like droughts but also to growth benefits of trees because of longer vegetation periods (WALTHER ET AL. 2002, BERGH ET AL. 2010). Also in this study temperature increases have been observed. It was 1,1ºC, both in Kivik (Fig. 9.) and Tyringe (Fig. 10.) comparing average temperature of first half of investigated period to value of the second one. Such phenomena may have crucial impact on trees distributed on the edge of their natural range (FRITTS 1976). Some of the species can react with increased variation of growth between the stands located in the same region (HICKLER ET AL. 2012). One of investigated beech stands was characterized by bigger variation of increment. However, while this stand may support the findings by Andreau et al, the other stands did not. Other factors were not included here like soil, provenance or management which could have substantial impact too.

Second hypothesis was stated as complementation of general overlook of factors determining the increment of trees. Growth potential is deteriorating in all stands with their ageing. This statement was proved by this work and found to be statistically significant factor ($p<0,001$). Moreover, it was considered as the most important and describing majority of variation in collected data set, according to developed multiple regression model.

The last hypothesis was formulated with caution for the above mentioned climatic issues. In fact, it turned out that precipitation had minor but statistically significant impact on radial increment of beech. Nevertheless, the last hypothesis was rejected. In the light of the applied analysis the greatest influence on radial increment was the age of trees. According to the constructed multivariate model, age is explaining the majority of the variability that existed in collected data set. In line with many other studies, it has a negative effect on tree growth which is decreasing with ageing of stands in maturing phase (RYAN ET AL. 1997, PRETZSCH 2009) Due to the requested stand selection criteria, stands within one triplet should have been located in possibly close neighborhood to limit number of factors influencing site conditions. However, the mixture of pine and beech is not very frequent in Skåne. Therefore, substantial age differences between stands existed in this study. Because of this large age difference, pine was totally excluded from analysis. The age of beech trees in the stands in Kivik was characterized by a difference of 9 years and in Tyringe 16 years. This leads to the conclusion that the mixing effects were heavily affected by age. Within each triplet, older beech stands lost their growth potential faster according to Figure 4. and 6. - what is especially visible in the last 20 years of the investigated period. The investigated stands had only one clearly formed layer consisting of dominant and co-dominant trees, thus no clear outcome based on multi-layered stand construction should be expected and in fact was not observed.

5. Literature

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Acknowledgements

Most of all I would like to thank Lars Drössler for patient supervision, like also for help in data collection and advices how to become a better scientist.

I would like to thank Mateusz Liziniewicz for significant input to this work which improved its quality very much.

Big thanks to Magnus Löf for help with field work, supervision and sharing materials I needed.

In the end I would like to thank Igor Drobyshev for guidance in the first steps with dendrochronology and Eric Agestam for examining and accurate remarks.

Appendices

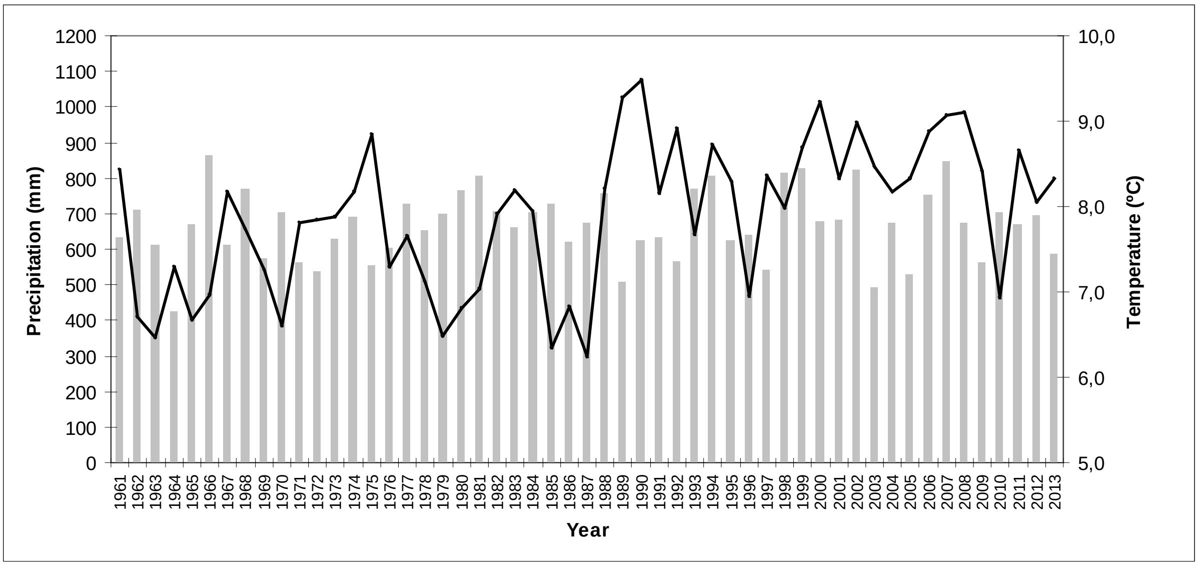

Fig. 9. Average annual temperature and annual sum of precipitation in Kivik.

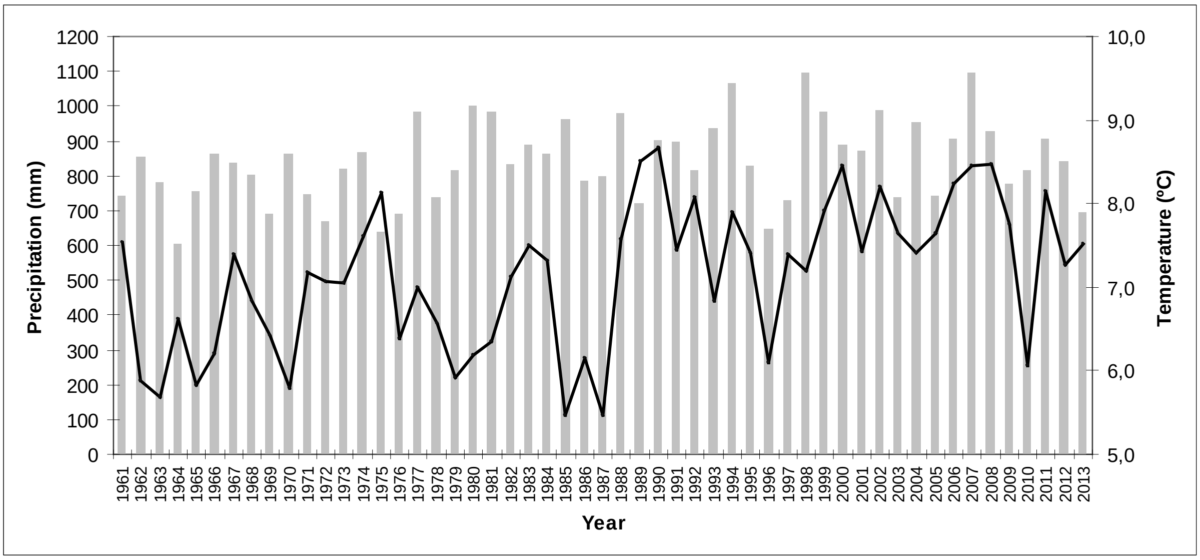

Fig. 10. Average annual temperature and annual sum of precipitation in Tyringe.

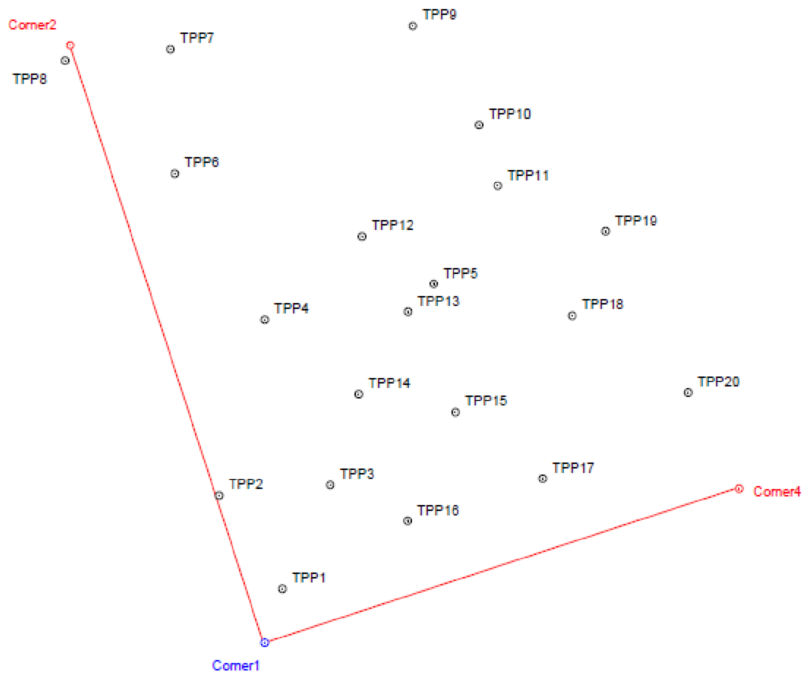

Fig. 11. Map of pine sample plot in Tyringe.

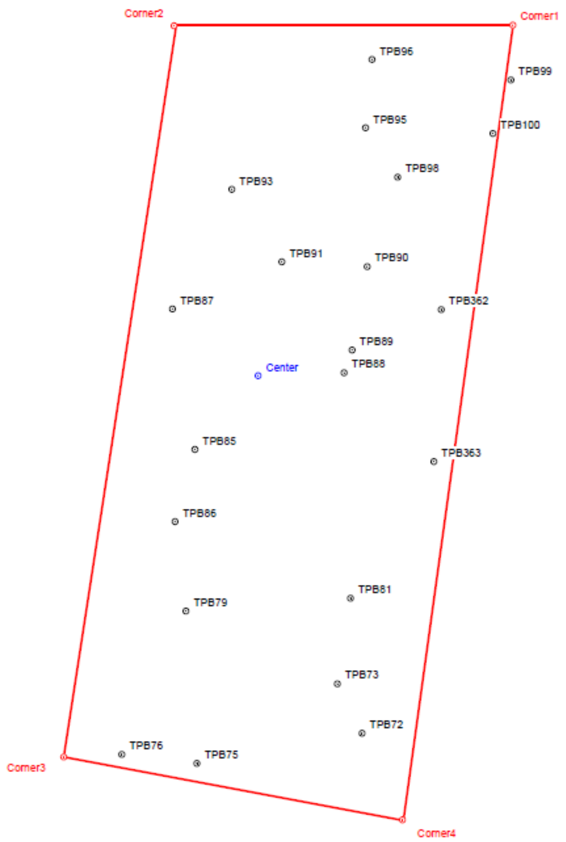

Fig. 12 Map of beech sample plot in Tyringe.

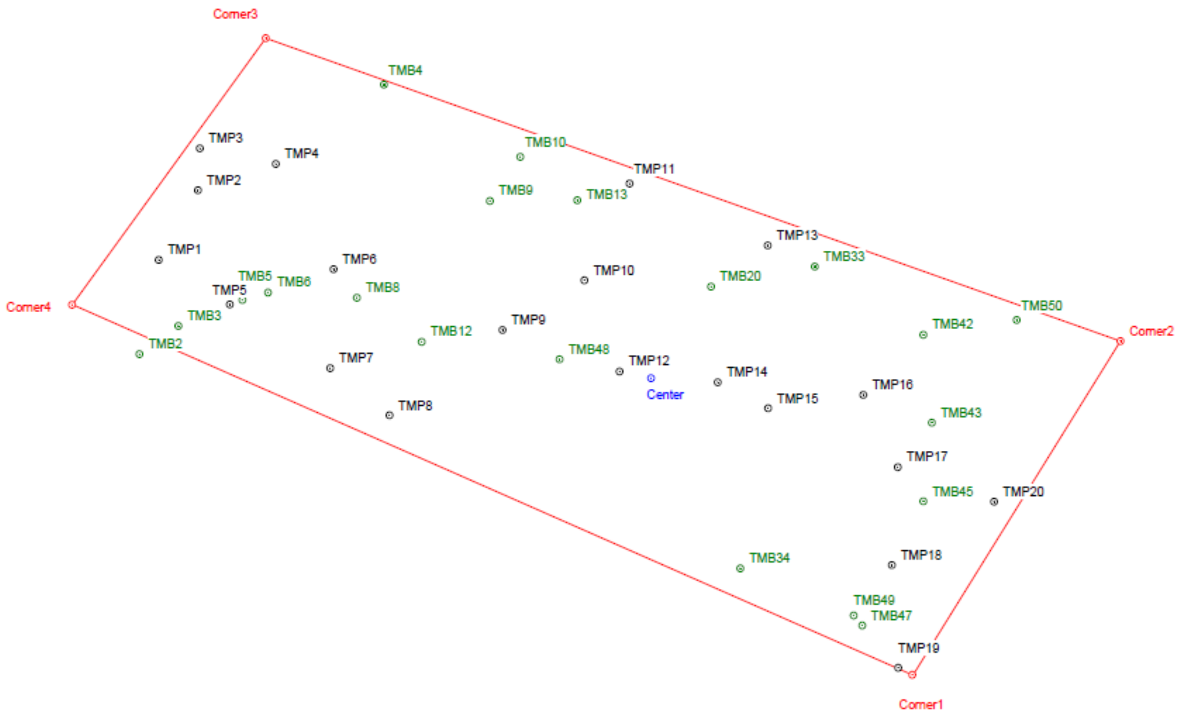

Fig. 13. Map of mixed sample plot in Tyringe

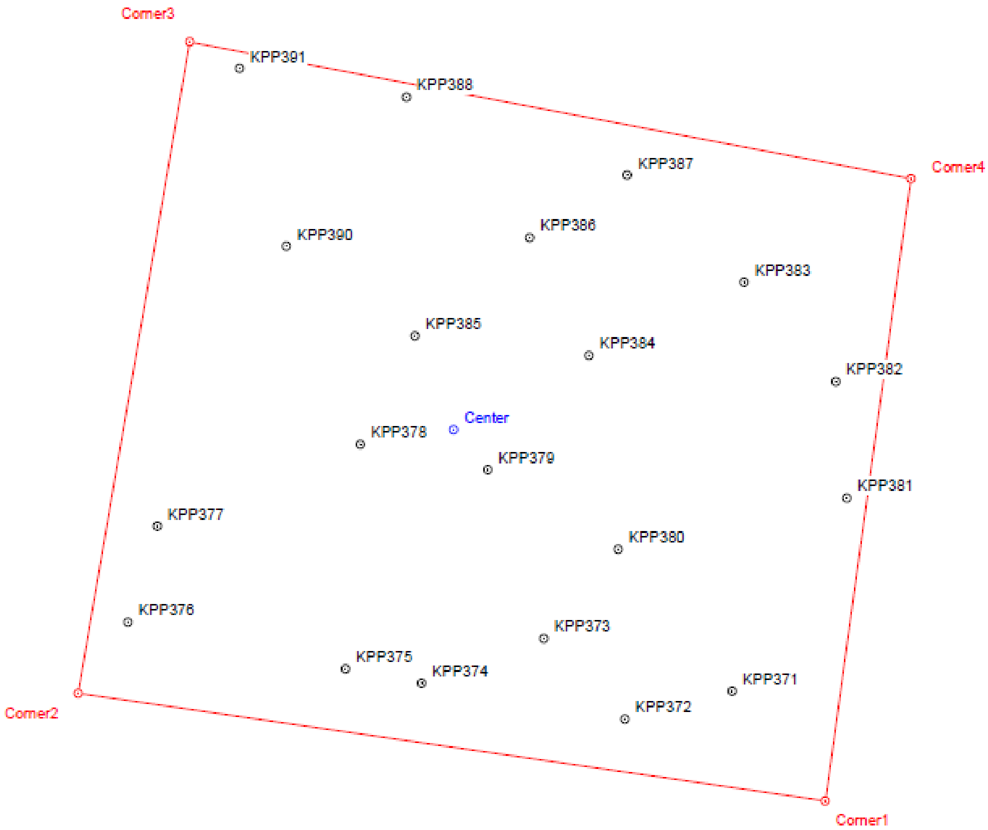

Fig. 14. Map of pine sample plot in Kivik

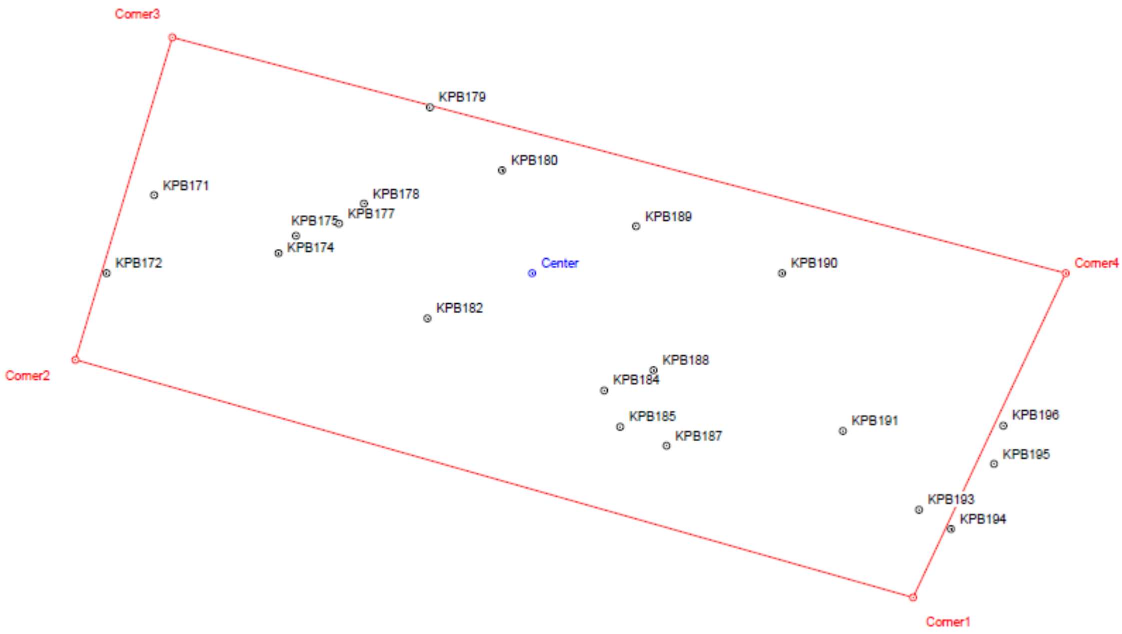

Fig. 15. Map of beech sample plot in Kivik

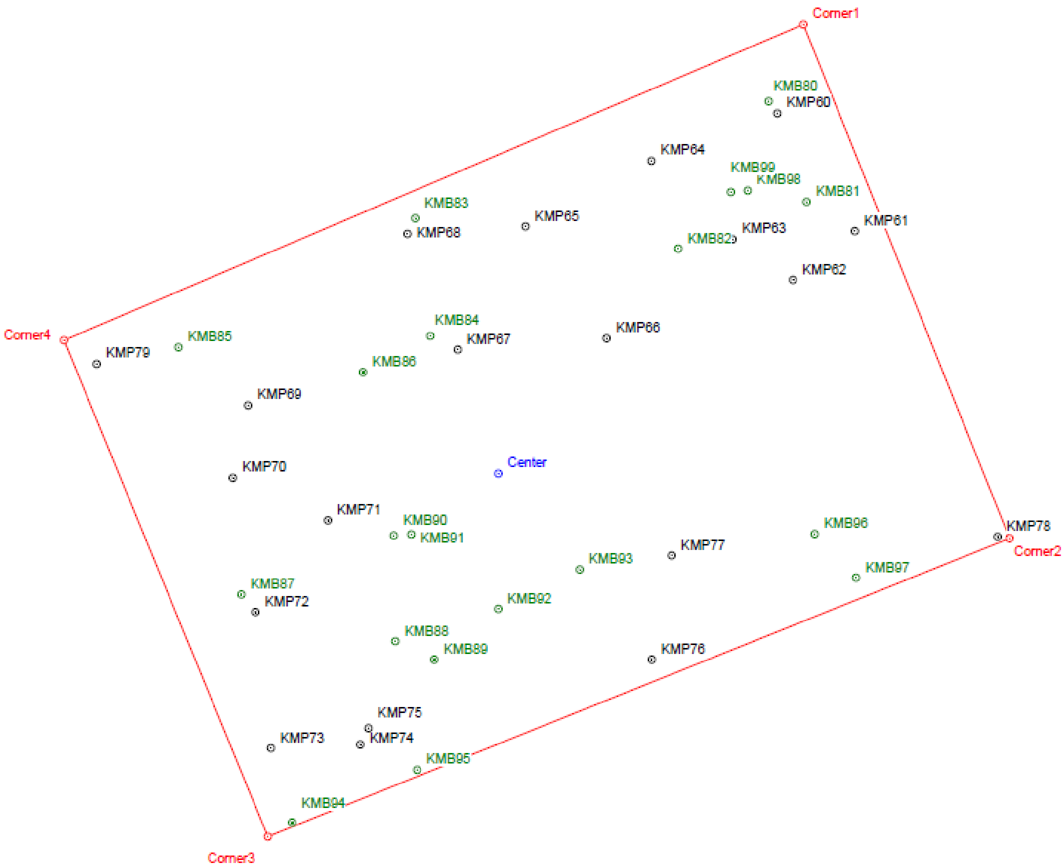

Fig. 16. Map of mixed sample plot in Kivik