BS – thesis May 2011

Tree-ring studies of Chestnut (*Castanea sativa*) in the Belasitsa Mountain in southern Bulgaria

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Forest Science

Yfirlýsing höfundar

Hér með lýsi ég yfir að ég samdi þessa ritgerð og vann að gagnasöfnun og úrvinnslu gagna sjálfur með aðstoð leiðbeinenda. Ritgerðin hefur hvorki að hluta til né í heild sinni verið lögð fram til hærri prófgráðu.

Reykjavík, 3 maí 2011

Abstract

As a BSc forestry-student at the Agricultural University of Iceland in Hvanneyri, I participated in an international research project on ecology of the European chestnut (*Castanea sativa*) forest which took place in Belasitsa Mountain in southern Bulgaria. I worked with experts at the Icelandic Forest Research in Mógilsá, who work in cooperation with the Forest Research Institute in Sofia. The project is funded by the European Economic Area (EEA) Grants and Norway Grants. The chestnut forest in Belasitsa is considered one of the best preserved in the Balkans. The forest health has deteriorated over the past few decades and that is the reason for this project discussed here. The role of the Icelandic team in the project is to build dendrochronological timescales for the chestnut, which makes it possible to explore the history of the forest growth and the environmental factors that are controlling the growth and development of chestnuts in southern Bulgaria. The Chestnut is crucial for many countries in Central and Southern Europe. It is a multi-functional tree species and through the ages it has been cultivated for wood and seed production. It has a considerable economic value, as well as being a large part of the culture and landscape of the Mediterranean countries.

Field work was conducted in June 2010 in the northern slopes of the Belasitsa mountain range in southern Bulgaria. Increment cores were collected from about 150 chestnut trees in 19 plots in which the chestnut was the dominant species. The mean age of the sample trees at breast height(BH) is 60 years, with the oldest trees over 200 years old. Average height of sample trees was 19 m and average diameter at breast height (DBH) was 48 cm.

The results show similar growth patterns in the radial growth until about 1975. Then decline begins in their growth and the mean annual tree ring width, goes from 3.5 mm to about 2 mm. After about 1990 the trees seem to recover slightly. The most likely explanation for the decline in the growth of the trees after 1975 is that at this time it is believed that the fungal pathogen (*Cryphonectria parasitica*) was spreading into the area, causing infection in the trees which resulted in growth loss. High precipitation in May and June lead to increased radial growth of the trees and vice versa. High temperature during the growing season has negative influence on the annual tree-ring growth in the Belasitsa.

Ágrip (Abstract in Icelandic)

Sem BS nemandi í Skógfræði við Landbúnaðarháskóla Íslands að Hvanneyri , er ég þátttakandi í alþjóðlegu rannsóknarverkefni um vistfræði Evrópukastaníu (Castanea sativa) skóga í Belasitsa fjallgarðinum í suður Búlgaríu. Ég starfaði með sérfræðingum Rannsóknarstöðvar Skógrækt ríkisins á Mógilsá sem eiga í samstarfi við Rannsóknarstofnun skógræktar í Sofíu. Verkefnið er styrkt af Þróunarsjóðum Evrópska efnahags svæðisins (EEA) og Noregs. Kastaníuskógurinn í Belasitsa er talinn einn sá best varðveitti á Balkanskaga en heilbrigði skógarins hefur hrakað síðastliðinna áratugi og er það kveikjan að þessu verkefni sem hér er fjallað um. Þáttur Rannsóknarstöðvarinnar á Mógilsár í verkefninu er að byggja upp árhringjatímatal fyrir kastaníutrén þannig að meðal annars verði hægt að kanna vaxtarsögu skógarins og hvaða umhverfisþættir eru ráðandi fyrir vöxt og viðgang kastaníu í suður Búlgaríu. Evrópukastanían hefur mikla þýðingu fyrir fjölmörg lönd í mið og suður Evrópu. Hún er fjölnytja trjátegund sem gegnum aldirnar hefur verið ræktuð til viðar og frænytja (kastaníuhnetur). Hún hefur því mikið efnahagslegt gildi, auk þess að vera stór hluti af menningu og landslagi landa við Miðjarðarhafið.

Vettvangsvinna fór fram í júní 2010 í norðurhlíðum Belasitsa fjallgarðsins í suður Búlgaríu. Kjarnasýnum til árhringjarannsókna var safnað úr um 150 kastaníutrjám frá mælireitum þar sem kastanían er ríkjandi tegund. Meðalaldur trjánna í brjósthæð var um 60 ár, en elstu trén eru yfir 200 ára. Meðalhæð sýnatökutrjáa var 19 m og meðalþvermál í brjósthæð 48 cm.

Fyrstu niðurstöður sýna frekar jafnan vöxt alla síðustu öld fram til um 1975. Þá er eins og hnignun hefjist í vexti þeirra og meðalárhringjabreiddin fer úr 3,5 mm niður í um 2 mm. Eftir um 1990 virðast trén taka við sér aftur. Líklegasta skýringin á hnignuninni í vextinum eftir 1975 er sú að á þessum tíma er talið að asksveppur (*Cryphonectria parsitica*) berist inn á svæðið, valdi sýkingu í trjánum og vaxtartapi.

Góð fylgni er milli meðalárhringjabreidda í kastaníutrjánum og úrkomu í frá maí til júní.

Acknowledgements

I want to thank all of those who provided me with support and helped me with the processing and preparation of this paper.

To my colleagues at the Forest Service, I appreciate the encouragement, tolerance and flexibility to be able to conduct this study. My professor Bjarni Diðrik Sigurðson receives thanks for having faith in me and giving me encouragement. I'd also like to thank Tzvetan Z., Georgi H, Margarita G., Ivaylo V. and Georgi G, my Bulgarian friends for their great hospitality and good cooperation. My supervisor Ólafur Eggertson I thank especially for all the help given, and very good guidance. My parents Hreiðar and Jónía I thank for the use of their car when it was needed. And finally, I want to thank my partner Rakel, and our children Diljá and Emil, for the support and tolerance. The project is supported by EEA and Norway Grants in cooperation with the Forest Research Institute in Sofia and the Icelandic Forest Research, Mógilsá.

Þakkir og tileinkun (Acknowledgement in Icelandic)

Hér vil ég þakka öllum þeim sem veittu mér stuðning og aðstoðuðu mig við vinnslu og gerð þessarar ritgerðar.

Samstarfsfólki mínu hjá Skógrækt Ríkisins þakka ég fyrir hvatningu, umburðarlyndi og auknu svigrúmi til að sinna náminu. Prófessor Bjarni Diðrik Sigurðson fær bestu þakkir fyrir að hafa trú á mér og hvetja mig til dáða. Ég vil líka þakka Tzvetan, Georgi, Margarita, Ivaylo og Georgi yngri, sem ég kynntist og átti mjög gott samstarf við í Búlgaríu. Leiðbeinanda mínum Ólafi Eggertssyni sérfræðingi á Mógilsá þakka ég sérstaklega fyrir alla hjálpina, og mjög góða leiðsögn. Foreldrum mínum Hreiðari og Jóníu þakka ég fyrir afnot af bíl þegar þess þurfti. Síðast en ekki síst þakka ég Rakel og börnum okkar Diljá og Emil fyrir veittan stuðning og umburðarlyndi. Verkefnið er styrkt af Þróunarsjóð EFTA.

Contents

1 Introduction

1.1 General background

During the last few decades severe health decline has been observed in the chestnut forests in the Belasitsa Mountains of Bulgaria, which is the reason for the establishment of an international research project lead by Dr. Tzvetan Zlatanov at the Bulgarian Forest Research Institute. The title of the project is "*State and prospects of the Castanea sativa population in Belasitsa Mountains, climate change adaption, maintenance of biodiversity and sustainable ecosystem management*". The main focus of the project is to contribute significantly to the improvement of the state and management of chestnut that dominate natural forests in Bulgarian part of the Belasitsa Mountain, and to maintain the critical elements of biodiversity associated with these forests (Forest Research Institute, 2010).

A team of experts within different fields of science including: dendrochronology, ecology, entomology, genetics, soil science, and silviculture analysed the current state of the forest. Icelandic Forests Research, Mógilsá carried out the dendrochronological study as a part of the project and the present B.Sc. thesis is a part of that subproject.

The aim of this BSc thesis is to study the age of the chestnut trees and to build up dendrochronological timescales for the chestnut in the Belasitsa mountains, which makes it possible to examine the forest's growth history and to address environmental issues that are dominant for the growth and successiveness of the chestnut forest in Bulgaria. The project is supported financially by EEA and Norway Grants in cooperation with the Forest Research Institute in Sofia.

1.2 The natural habitat of Chestnut

The natural habitat of European chestnut trees (*Castanea sativa* Mill.) is within the temperate deciduous forest biome, which is found in eastern North America, eastern Asia and central Europe (Fig. 1). Biomes are climatically and geographically defined as similar climatic conditions on the Earth, such as communities of plants, animals, and soil organisms, and are often referred to as ecosystems. Temperate deciduous forests are found in areas with continental or maritime climates with warm, moist summers and cold sometimes snowy winters (Guruvitch, et al., 2006).

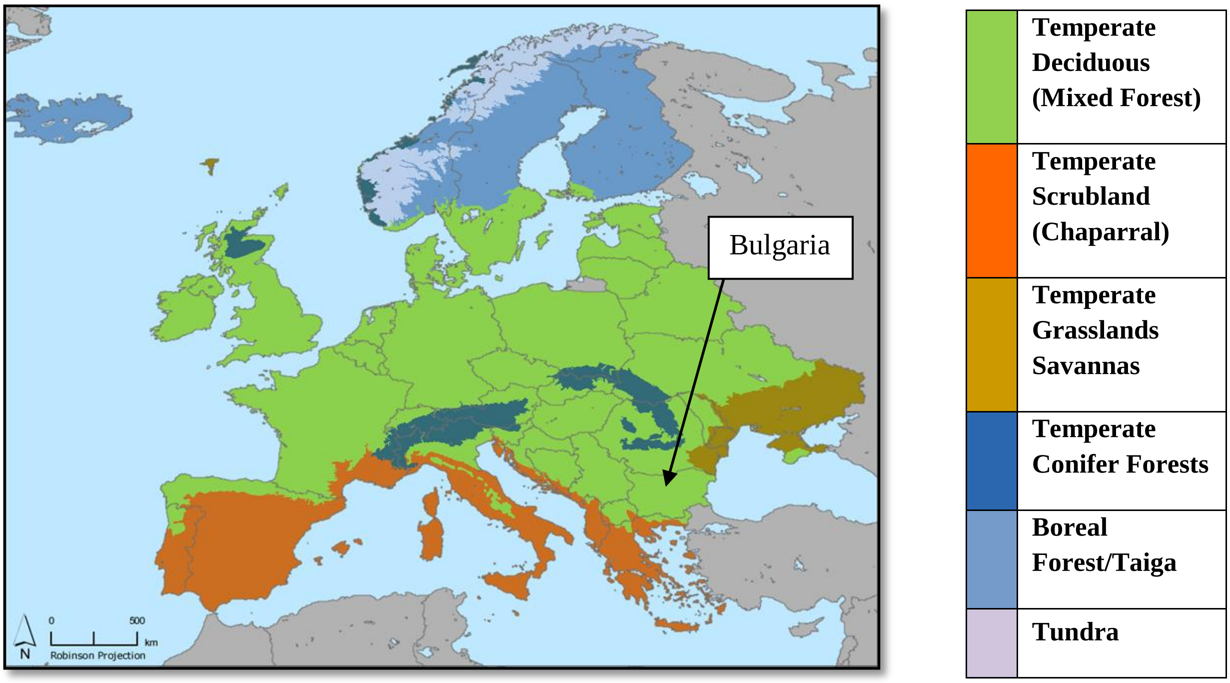

Figure 1. Biomes in Europe (CIESIN, 2007).

Bulgaria is classified within the temperate deciduous forests biome. The southern part of the country is under the influence of the Mediterranean climate, which belongs to another biome, the temperate scrubland (chaparral), is characterised by cool, wet winters and warm dry summers (Fig. 1). According to Konstantinidis, et al., (2007) the best climatic conditions and areas for the growth and development of the European chestnut in Bulgaria are determined by lower local temperature and higher precipitation due to physiographic and maritime influences. The genera of the dominant trees common to the temperate deciduous forests include *Acer, Castanea, Fagus, Quercus, Tilia* and *Ulmus.* These forests are generally growing on young soils that have formed after the last Ice Age, with both continental and maritime climates, warm, moist summers and cold snowy winters with mean annual precipitation in the range of 500 – 2500 mm (Guruvitch, et al., 2006).

1.3 Taxonomy of Castanea

According to Govaerts & Frodin, (1998) the genus *Castanea* from the Fagaceae family are including American, Asian and European chestnuts as well as American and Asian chinquapins. The chestnuts produced three seeds per bur but some species only produced one seed per bur and are classified by the name chinquapins (American Chestnut Cooperators' Foundation, 1997).

Family: Fagaceae

Genus : *Acer, Castanea, Fagus, Quercus, Tilia, Ulmus.*

The *Castanea* species:

North America

American chestnut (*C.dentata*)

Ozark chinkapin (*C.ozarkensis*)

Allegheny chinkapin (*C.pumila*) “dwarf chestnut”

Asia

Chinese chestnut(*C.molissima*)

Henry chinkapin (*C.Henryi*),

Seguin chestnut (*C.seguinii*)

Japanese chestnut (*C.crenata*)

Europe

European chestnut (*C. sativa*) the only native species of the genus in Europe (Fig. 2 and 3)

Figure 2. Chestnut (*Castanea sativa)* (Thomé, 1885)

Figure 3. Chestnut in Belasitsa mountain in southern Bulgaria (Photo SH, 2010)

1.4 Characteristis and qualities of European chestnut

European chestnut, also known as Spanish or sweet chestnut, is common in southern Europe where it is an important multipurpose tree, used for both nut and wood production. For centuries the chestnut has been managed in the native forests or cultivated in orchards (Condera, et al., (2004). Condera, et al., (2004) point out that countries in Europe that cultivate the chestnut do it along the mountain ranges, which highlights the mountainous (oreophilous) character of the species. According to Horvat., (1974) the most favourable altitudinal range for European chestnut in the Balkan Peninsula is between 600 and 900 m. a. s. l. Results from pollen studies indicate that the chestnut took refuge during the last ice age at the northern coast of Spain, at the roots of the Apennine mountains in Italy, southern slopes of the Caucasus mountains, at the southern cost of the Black sea and in southern Bulgaria (Krebs et al., 2004). It spread to western and northern parts of Europe with the Romans which like the Ancient Greeks, managed and cultivated the Chestnut. The second Latin name: *sativa* means “to sow”, which indicates the use and cultivation of the species from an ancient time. In 1997 the dominant Chestnut forests covered 2.25 mill. ha in Europe (Condera, et al., 2004). The European chestnut is a long-lived and fast growing tree, it can reach up to a maximum height of around 35 m, attain diameter of 300 cm and age up to 200 - 300 years. The leaves are very long (10-25 cm) and have an easily identified toothed edge (Fig. 2). It is monoecius, has separated staminate and carpellate flowers on the same tree (Raven et al., 1999), they are largely self-incompatible and are pollinated by the wind, which secures sexual reproduction between individuals and results in genetic variability within the population. The chestnut regenerates by seed and by sprouting from the stump after cutting (coppice) and from the base of older trees. The chestnut wood has high decay resistance (Hoadley, 2000) and is therefore durable and valuable as a building material (Militz et al., 2003). It does best in sandy, well drained soils and is highly tolerant of acidic soils. Genetic and physiological research has revealed that chestnut can adapt to water shortage, it is among a only few other tree species that can do so. This suggests that the ability to tolerate drought, is a significant factor in the successful colonization of the species in varying environments (Lauteri et al., 2004). Healthy chestnut trees can withstand periods of drought, but when it is infected by e. g. fungus it loses that ability and is less tolerant (Waldboth, 2009). Today the health condition of the European chestnuts are threatened by both fungal pathogen (*Cryphonectria parasitica*), and climate changes (mainly droughts) and in some cases because of human influence (utility and an inappropriate forest management). These three major factors are better explained in chapter 1.5, 1.6 and 1.7.

1.5 The chestnut blight disease

In the beginning of the 20th century a fungal pathogen (*Cryphonectria parasitica*) that causes chestnut blight (Fig. 4 and 5), nearly eliminating the American chestnut that once covered the eastern United States (Sinclair & Lyon, 2005). The fungus was accidentally introduced from Asia with Chestnut seeds or seedlings from northern China (Raven, et al., 1999). However according to Anagnostakis, (1987) the first case of chestnut blight on the American chestnut was reported in New York Zoologist Garden in 1905, where the fungus spread from dwarf chestnut imported from Japan. The fungus also affects many other woody plants, primarily belonging to the Fagaceae family (Sinclair & Lyon, 2005). In Europe the chestnut blight was first observed in 1938 near Genoa, Italy. It spread rapidly within Italy and to neighbouring chestnut growing areas. The only areas not affected by the fungus in Europe are in the Netherlands and southern England (Robin & Heiniger, 2001). It has not been confirmed when the fungus (*Cryphonectria parasitica*) was introduced to Bulgaria, but it is concluded that it first invaded around 1975. In neighbouring countries the Chestnut blight, caused by the fungus, was first observed 1963 in Greece, in 1968 in Turkey, in 1974 in Macedonia, and 1984 in Rumania (Robin & Heiniger, 2001). The fungus is native to China, where it causes an inconsequential disease of Chinese chestnut (Forestpathology.org, 2007). It occurs also on Chestnut trees in Japan and northern India (Sinclair & Lyon, 2005). The fungus invades through an open wound or a scratch in the bark and infects the vascular cambium. When the tree is infected the trunk swells up and often causes cankers (Fig. 4). Ultimately the transport of water is reduced and brought to an end, where the part of the tree above the canker dries out (die back) (Fig.5). One discovery that has been very successful for controlling chestnut blight in Europe is a biological control (BC) method called hypo-virulence. Hypo-virulence is a virus that infects the chestnut blight and reduces its ability to cause disease. Biological control in infected chestnut stands has led to a decrease in blight severity, spread of hypovirulence, and change in *C. parasitica* populations (Robin, et al., 2000). The virus occurs and spreads naturally in Europe. Climatic conditions can also be important for the spread of the hypovirulence (Turchetti, et al., (2008). Chestnut blight is still one of the major causes of the degradation of chestnut woodland in many areas in Europe. In the research area Belasitsa mountain, 60-95% of the chestnut stand is infected by the fungus that causes the chestnut blight (Fig. 4), the plots that were studied are located between 500 to 800 m. a. s. l., the trees were less infected at higher altitude (Georgieva et al., 2011).

Figure 4. Chestnut blight infection in a young tree in Belasitsa, (Photo Georgi H, 2010)

Figure 5. Die back in Belasitsa, (Photo SH, 2010)

1.6 Climate change.

The Earth's temperature is rising due to increased emissions of carbon dioxide that causes the greenhouse effect (Kump, 2002) (Fig. 6). As the temperature rises, drought will become more common as the water evaporation outstrip increases in precipitation. It is expected that global warming will continue throughout the twenty-first century (Cowie, 2007).

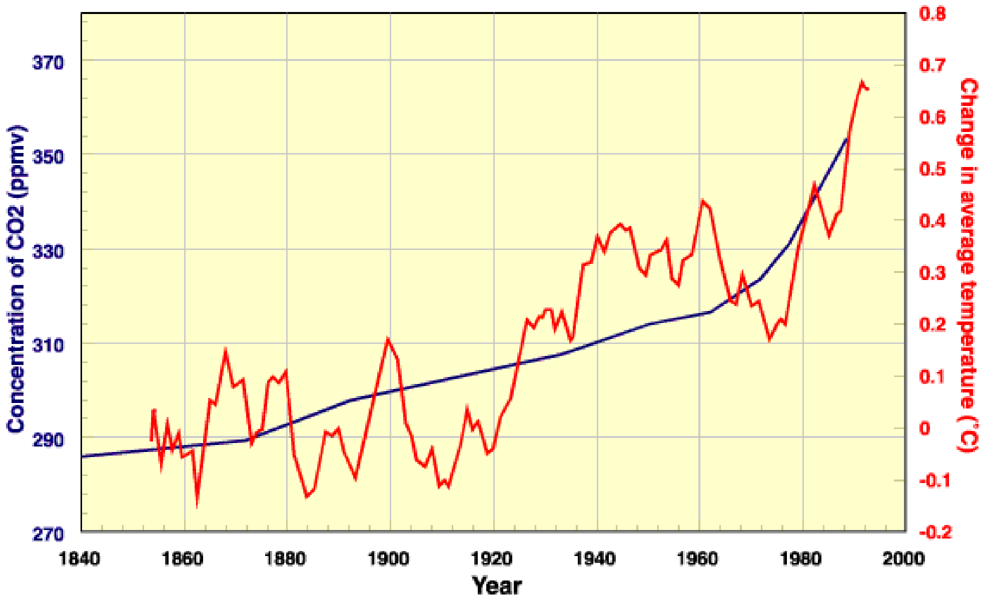

Figure 6. Correlation of the rise in atmospheric carbon dioxide concentration (blue line) with the rise in global average temperature (red line) (Bowden & Honsberg, 2010)

1.7 Climate in southern Bulgaria.

In the southern part of Bulgaria close to the border of Turkey and Greece the climate is under the influence of the Mediterranean Climate. The nature of the Bulgarian climate is mainly controlled by changes in the circulation frequency and the route of Atlantic and Mediterranean cyclones. This results in periods of drought at different time of the year (Knight, et al., 2004). From the last quarter of the 19th century, when meteorological observation started in Bulgaria, periods of drought have been observed in every part of the country at different times of the year. In the southern part of the country, spring droughts occurred repeatedly in the years from 1937 to 1946. Characteristic for spring droughts are low humidity, normal air temperatures and strong winds (Knight, et al., 2004). The most striking period was when Bulgaria suffered severe drought 1984 to 1994 " record breaking drought affecting almost all of the nation" (Knight, et al., 2004).

1.8 General about Bulgarian Forests.

Of the total area of Bulgaria, 111.000 km^2 forests covers ca. 33% or 36.000 km^2. Broadleaved forests comprise 68.9% and Conifers 31.9% of forested land. In 2005 the growing stock in the forests and other wooded land were 568 million cubic meters over bark (FAO, 2011). There are 128 native tree species in Bulgaria and it is estimated that native or virgin forest covers 103,356 ha (Veen et al., 2010). Around 80% of the forested land in Bulgaria belongs to the Bulgarian state, and the remaining 20% is in the hands of municipalities and the private sector. The main tree species in Bulgarian forests are: *Pinus sylvestris, P.nigra, P. peuce, Picea abies, Abies alba, Fagus sylvatica, Populus sp, Quercus robur, Q.petrea, Q. franetto, Q. cerris.* Chestnut forest covers an area of 3315 ha only 0.1% of the total forest area in Bulgaria (Directive 92/43/EEC)

1.9 Management of the chestnut forest at the research site in Belasitsa mountain

From ancient times inhabitants of the villages at the foothills of the Belasitsa mountain managed the chestnut forest as pasture for wood and seed production (Krawczyk & Jacke, 2011; Zlatanov et al., 2010). Seed pasture is a form of coppice management were the tops of the trees are removed from suitable trees for seed production (pollards) (Smith, et al., 1997) (Fig. 7). For keeping the chestnut trees widely spaced the competing trees were cut down and used as timber and firewood. Domestic animals also grazed in the forest, goat's, sheep's and cattle's. The Chestnut fruit was important as a food supply for the people, and every town had certain areas of chestnut forest for their use. Every household paid taxes for Chestnut fruit and the wood usage (Zlatanov, et al., 2010). Shortly after the Second World War the forests of Bulgaria were nationalised (1947) (Buzov, 1993) and the management of the Chestnut forest changed. Traditional utility of the forest, which was cultivated for centuries, came to an end and a period of less organized forest management took place (Zlatanov, et al., 2010). In the last 60 years a new generation of native species are growing in the forest shading out the old pollard trees. When the chestnut forest is not carefully managed like in the past and the canopy gets denser the chestnut, which is not shade tolerant species, gets overrun by other native more shade tolerant species like: Beech (*Fagus sylvatica*), Hornbeam (*Carpinus betulus*) and Silver lime (*Tilia tomentosa*). In assessment of the possibilities for sustainable management of sweet chestnut in Bulgaria, it is pointed out that the effects from management of the chestnut forest is different compared to other common species in Bulgarian forestry i.e. oak, beech, pine and spruce. In some areas were the forest is protected and traditional management is over, the presence of the chestnut were threatened by other native species (Mihaylov, et al., 2005). The first survey of the chestnut stand in Belasitsa mountain took place in 1914. At that time the stand was estimated to be 5000 ha, and it was concluded that the forest was introduced by the Romans (Zlatanov, et al., 2010). Resent pollen studies show that the chestnut forest in Belasitsa is more than 7000 years old, implicating that the forest is native. (Tzvetan Zlatanov pers. comm.). In the year 1964 the Petrich Forest station conducted a forest inventory on the northern slopes of the Belasitsa mountain. At that time (1964) chestnut as co-dominating and dominating forest covered 1923 ha In 2009 the area had decreased to 1678 ha. The Chestnut dominating forest was 1319 ha in 1964 and had decreased to 648 ha in 2009 (Forest Researce Institute Sofia, 2010). In the Balkan peninsula the chestnut forest in the Bulgarian part of Belasitsa mountain is the largest in area. According to Petrich forest enterprise management plan from the year 2009, 94% of the forested land in Belasitsa mountain belonged to the state, and the remaining 6% was in the hands of municipalities and the private sector (Zlatanov, et al., 2010). Today the stand is included in the network of Natura 2000, which is a network of nature protection areas established by the European Union. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats (European Commission Environment, 1992).

Figure 7. An old chestnut (seed tree, pollard) in the Belasitsa mountain. Two coppice from around 1950 can also be seen (Photo OE, 2010)

1.10 The method of dendrochronology

A simple translation of the word dendrochronology which is Greek in origin, does describe its meaning dendro = tree, chrono = time, logy = study ; tree-time-study or dating and study of the tree rings (The University of Arizona, 2010). Tree rings can be seen in a horizontal cross section cut through the trunk of a tree (Fig. 8). Tree rings are the result of new growth in the vascular cambium. The rings are more visible in temperate zones, where the seasons differ more markedly. In tropical forests the trees are growing al year around, and it will not form any clear borders in the wood between years. By applying the methods of dendrochronology a broad range of ecological parameters can be studied and analysed, including variation in climate, disturbance, competition, insect outbreaks, and other phenomena.

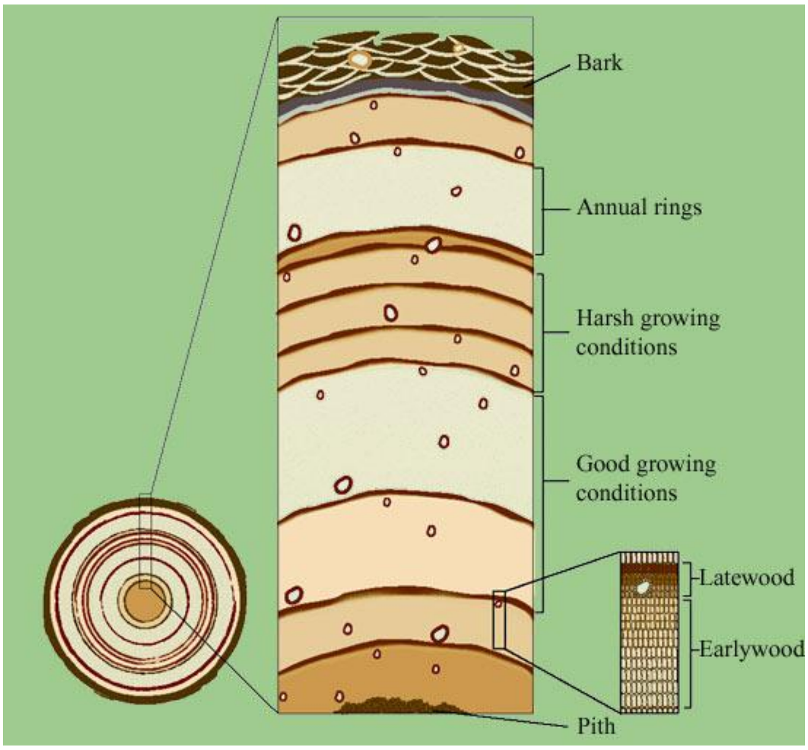

Figure 8. Cross section cut through trunk (Yukon, 2003)

2 Material and method

2.1 Study area

The location of the research site is in the Northern slopes of the Belasitsa mountain in south west Bulgaria (Fig. 9). The Belasitsa mountain range, with the highest peak Radomir reaching 2029 m.a.s.l., is about 60 km long and seven to nine km wide, and touches the Greek border on the southern side and the Macedonian border on the northern side. The chestnut forest covers around 827 ha at an altitude of 400 m to 850 m.a.s.l. It is one of the most important and best preserved native chestnut forests in the Balkan peninsula. During the past few decades decline of the chestnut in the region has been observed (Zlatanov, et al., 2010).

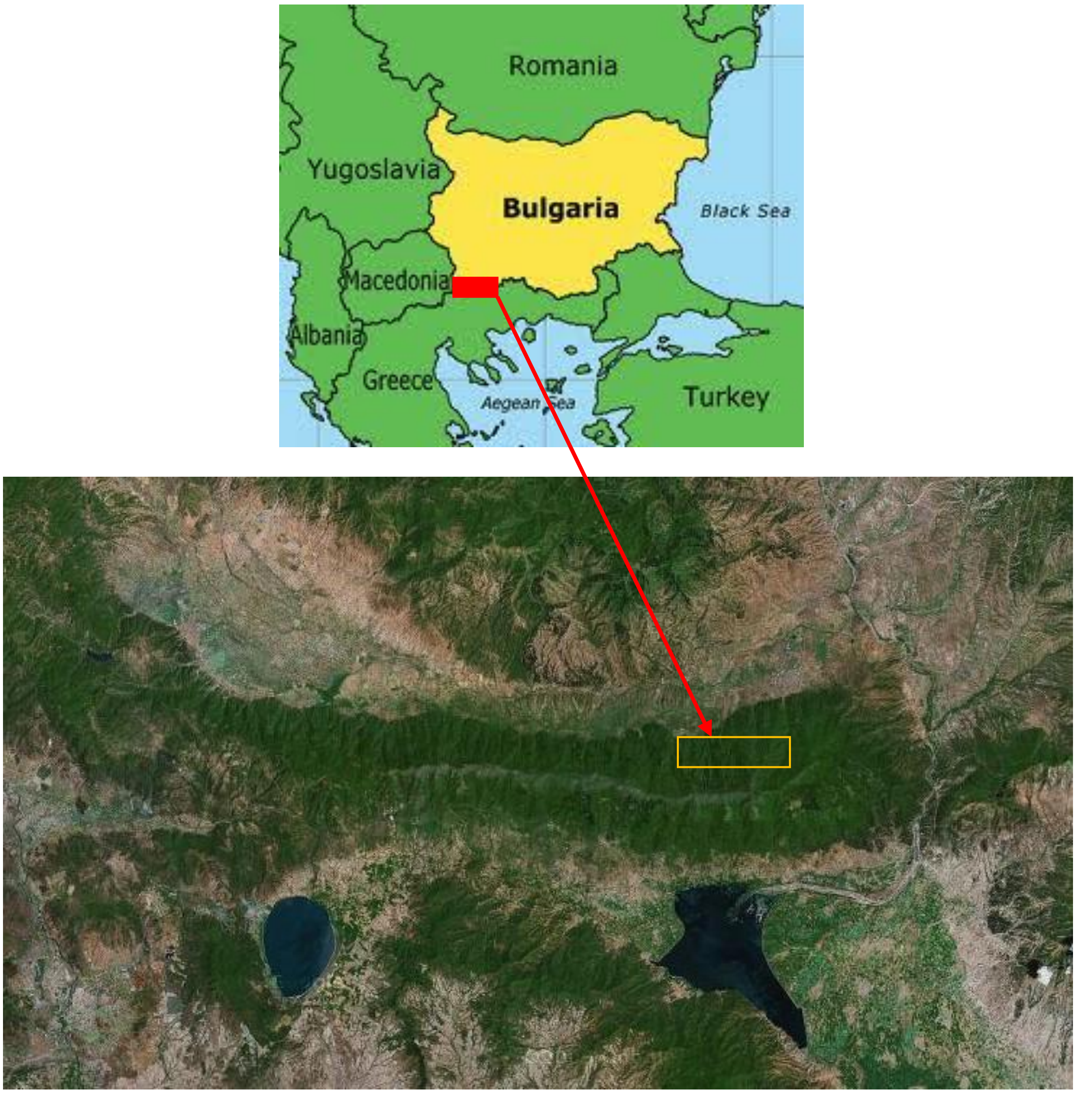

Figure 9. Maps showing the study site in Belasitsa mountain (NASA, 2007)

2.2 General background

The height of the studied chestnut trees range from 6 to 27.5 m in average 19.2 m. The diameters at breast height vary from 14 cm to 240 cm, with average of 48 cm. There are several differences in the slope angel between the sites, with variations from 8°to 43°. The sampled trees are in different health condition and the density of the forest differs from 1.7 m to 20 m in between the chestnut trees, average for all the plots is 12 m (Zlatanov, et al., 2010).

2.3 Climate data

Total monthly precipitation and mean monthly temperature data was collected from a meteorological station in Sandanski, dating back to 1942 The station is located 20 km from the study site (Fig. 10). Table 1 gives the main climatic parameters for the station in Sandanski and figure 11 shows the sum of precipitation and the average temperature range during the vegetation period (May – September). The severe drought period that was recorded over all of Bulgaria between 1985 and 1995 (Knight, et al., 2004) can be seen in the data from Sandanski (Fig. 11).

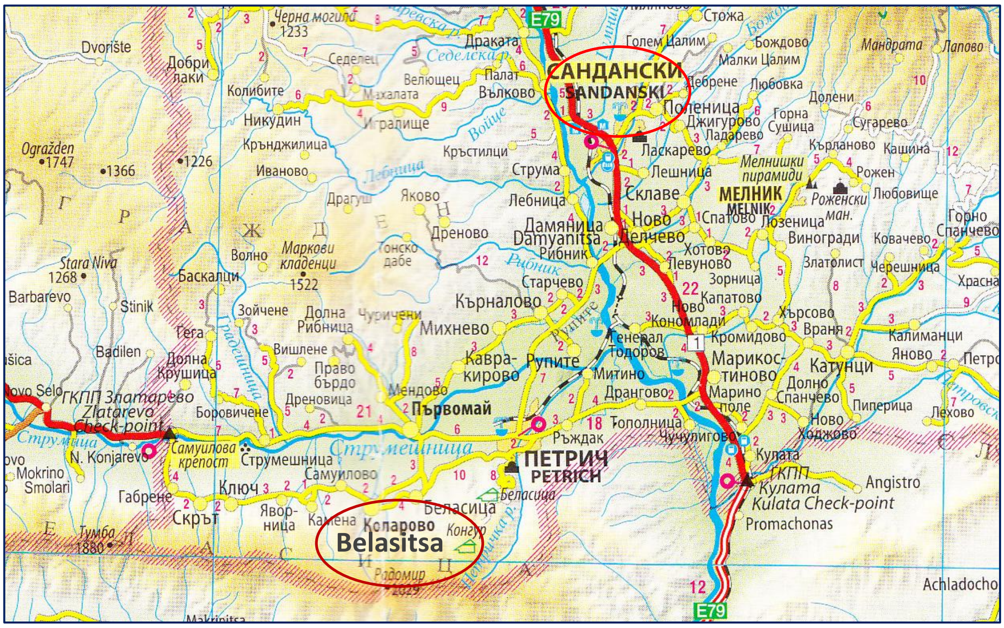

Figure 10. Location of the climate station in Sandanski and the research site in Belasitsa mountain (Domino, 2010)

Table 1. The main climate parameters for Sandanski

Sandanski 1942 - 2009		
	Sum of precipitiation mm	Average temperature
Annual	494	14
Range	234 -724	12.8 - 15.4
May - Sept.	181	22.3
Range	59 - 415	19.9 - 24.1

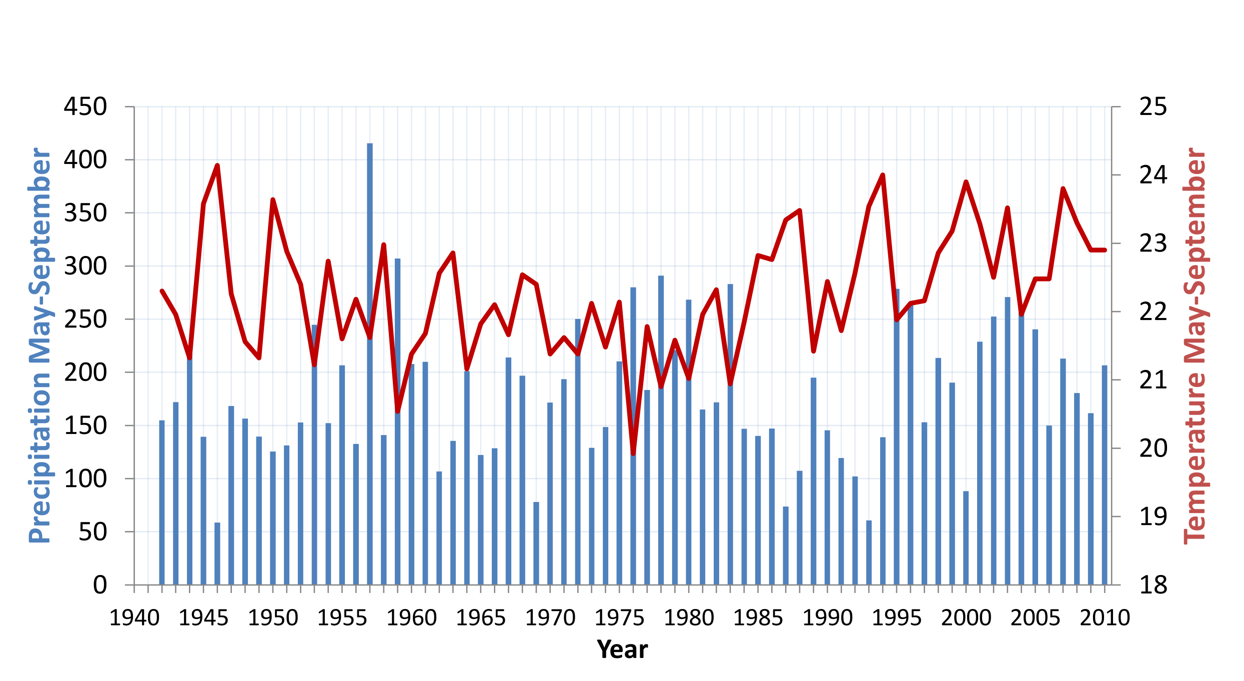

Figure 11. The Sum of precipitation and average temperature during the vegetation period (May – September) in Sandanski, 20 km from the research site in the Belasitsa Mountain. The drought starts in 1984 and lasts for 10 years.

2.4 Fieldwork in Bulgaria

The fieldwork took place from the 31st of May to the 5th of June 2010. Tree ring samples were collected from 19 different plots randomly selected from 67 permanent sample plots. The 67 permanent sample plots were already selected and laid out by the Bulgarian partners of the project. The 19 plots are located in random parts and altitude of the study area. Samples from 150 chestnut trees were extracted, two cores from each tree. In each plot cores from eight trees in different age groups were collected. Trees were of various sizes and health conditions. The samples (cores) were taken at breast height (1.3 m) with a Haglöf increment borer (Fig. 14). The borer was directed 90° against the vertical side of the tree trunk and aimed to the centre of the tree. After each coring, the holes in the tree were filled with antiseptic material (Fig. 13) and the increment borers disinfected with ethanol to prevent infection.

Figure 13. Antiseptic material (Photo SH, 2010)

Figure 14. The samples (cores) were taken at breast height (1.3 m) with Haglöf increment borer (Photo OE, 2010)

2.5 The tree rings of chestnut

The chestnut wood is a ring porous species (Fig. 15) and the tree rings are usually clearly visible. Most of the samples collected from the chestnut in Belasitsa are suitable for tree ring studies. By applying talk on the cores the tree rings become more visible. It is not always possible to determine the exact ages of the older trees, either the borer could not reach in to the pith or because of wood decay in the stem.

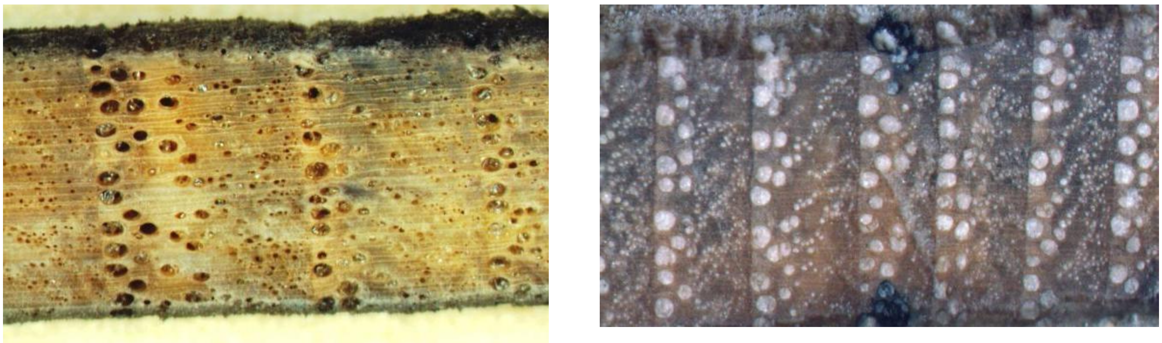

Figure 15. The tree rings seen through the stereoscope (Photo SH, 2010)

2.6 Sample preparation and data analyse

At the laboratory the cores were dried carefully to prevent them from curving and then mounted on a wooden core holder with the transverse surface facing up. After the glue had hardened the cores were sliced with a scalpel to make the cells more visible under a microscope. The cores were measured with a LINTAB (for "linear table"), measuring table were the encoder is precise to 0.001 mm (Figure 16). The measurements are saved in a Time Series Analysis (TSAP), a software program that works in conjunction with the LINTAB measuring table. TSAP software was used for measurement, analysing and crossdating of tree-ring time series (Rinn, 1996). After measuring the sample with LINTAB, the raw ring width were cross dated the second time with the COFECHA software (a quality-control program used to check the crossdating and overall quality of tree-ring chronologies) (Mayer, 2001).

The tree-ring measurements were converted to Excel for further analysis of the data and for visual presentation (diagrams). Statistical calibrations between ring-width chronologies and monthly climate variables were tested by applying the software package Dendroclim2002 (Biondi, 1997; Biondi & Waikul, 2004). The Dendroclim2002 software allows correlation and response function analyses of the climate/tree growth relationship using both evolutionary and moving intervals. Bootstrapping is performed to ensure robust estimates of confidence intervals. Input data required are monthly temperature and precipitation data as well as the tree-ring index chronology. Growth–climate relationships were determined using a tree-ring index calculated by the program CHRONOL (Mayer, 2001) and climate data from the meteorological station in Sandanski.

Figure 16. Measuring the sample at the laboratory on a LINTAB machine (Photo OE, 2010)

3 Results

3.1 Age of the sampled chestnut trees

It was possible to measure the tree rings in 90% of the 150 collected trees. The age of the 135 trees ranges from 19 years to 186 + at breast height (BH). The cores from the oldest trees did not reach the pith. Some of them are more than 200 years at BH. The mean age of sampled trees was 60 years. Over 70% of the trees were younger than 65 years at BH. The majority of the trees are therefore from the regeneration of the forest after 1946 but after that the forest management changed (se chapter about forest management, page 19) (Fig. 17 and 18). The change of forest age distribution after 1950 is a clear example of how forest management effects the growth and development of the forest. The regeneration after 1950 is perhaps temporary and not sufficient enough to maintain the forest sustainably. It is difficult for the chestnut forest in Belasitsa to maintain itself while the trees are suffering from fungal disease and at the same time have to adapt to climate change (with more frequent drought periods?) (climate becomes more Mediterranean with climate change?). The chestnut is also in competition with other tree species for space and nourishment, supplying products for humans and animals, and do not receive sufficient care to prosper (because of pour or no forest management plan taken place at the moment).

3.2 Building Chronologies

During the measurements of the tree-ring samples it was soon noticed that there was a considerable variance in the annual tree ring growth (Table 2) and the tree ring pattern was highly synchronous between the different trees. Specific pointer years were also noticed during the measurements of the tree rings. That indicated a strong influence by some limiting environmental factor controlling the growth of the chestnut in the area. According to the result from the COFECHA program, 121 trees or 82% of the sampled trees gave good intercorrelation ($r = 0.574$) and could therefore be used to build a mean chronology for the chestnut in the Belasitsa mountain. Figure 17 shows the raw data (mm) mean chronology for the chestnut. The sample replication can be seen of figure 18, good sample replication is from 1930 and onwards, relatively few samples comprise the chronology from 1850 to 1930. (Fig. 17).

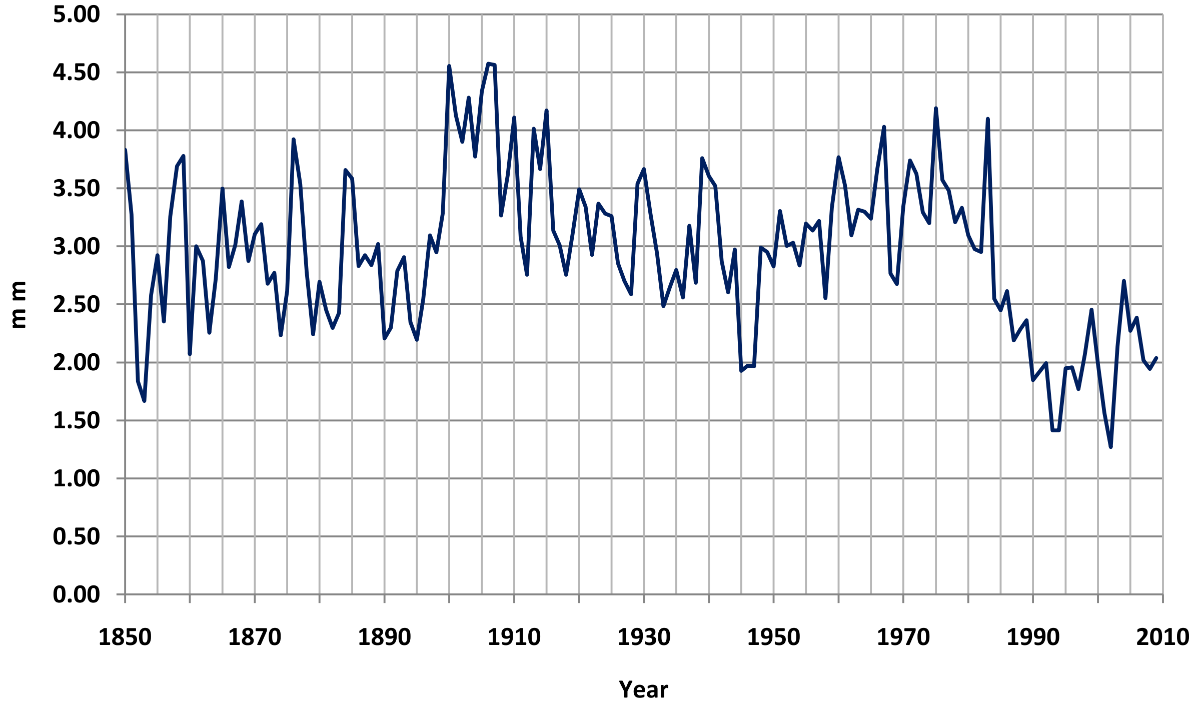

Figure 17. The mean tree-ring chronology for the chestnut in Belasitsa from 1850 to 2009, raw data (mm).

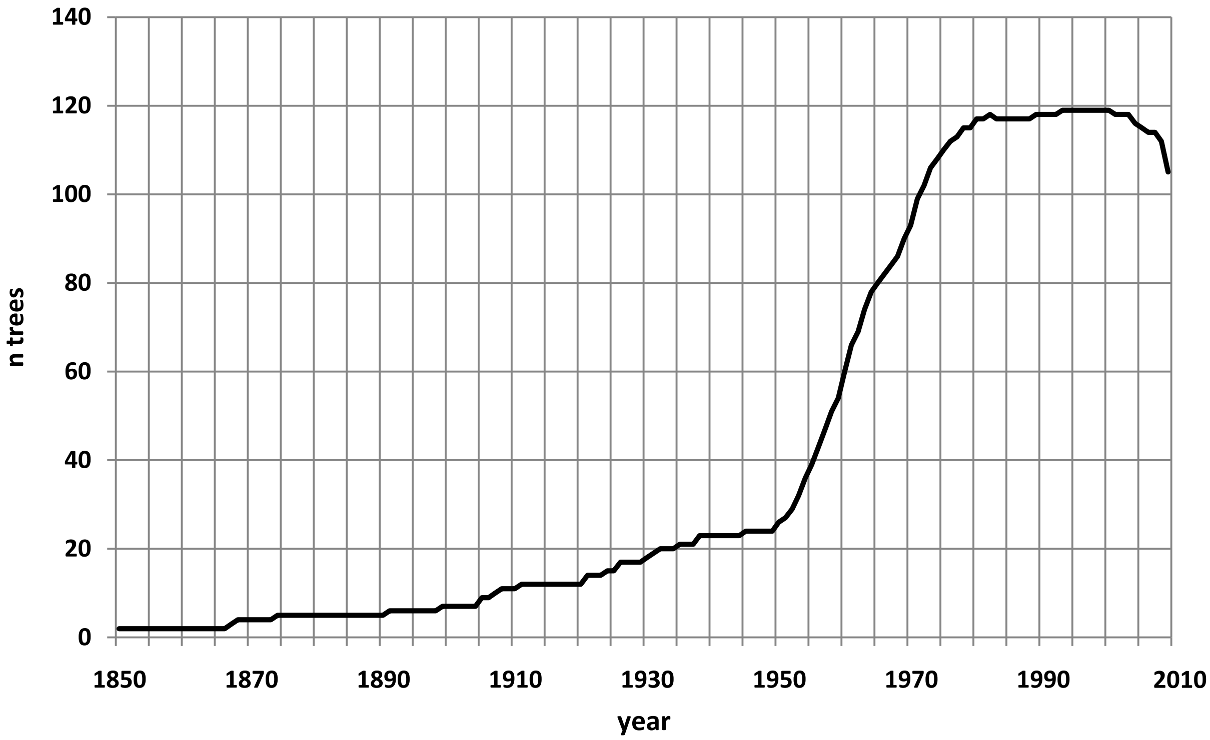

Figure 18. Number of trees comprising the mean tree ring chronology over time. The age distribution of the trees indicates increased regeneration after 1950 (n = 121)

Table 2. Statistics for the mean tree ring chronology between 1900 – 2009. The chestnut are fast growing but the tree ring width can be quite variable between years

Mean tree ring width	2.99
Standard Error	0.07
Median	3.02
Standard Deviation	0.74
Sample Variance	0.55
Range	3.30
Minimum	1.27
Maximum	4.57
Number of trees	110

By dividing the trees into age classis and comprising different chronologies for each classes of trees (trees established before 1940, between 1940 -1970, and after 1970) and comparing the average tree rings width, it can be seen that all the groups are showing the downward trend after 1983. The drop after 1983 occurs within all the age groups and the slow recovery are also in pattern within all the groups (Fig. 19). This indicates that the environmental factor affecting the growth of the trees is synchronous in all generations of the chestnut forest. However after 1993 the youngest trees (blue line in fig. 19) are showing more significant recovery than the older trees.

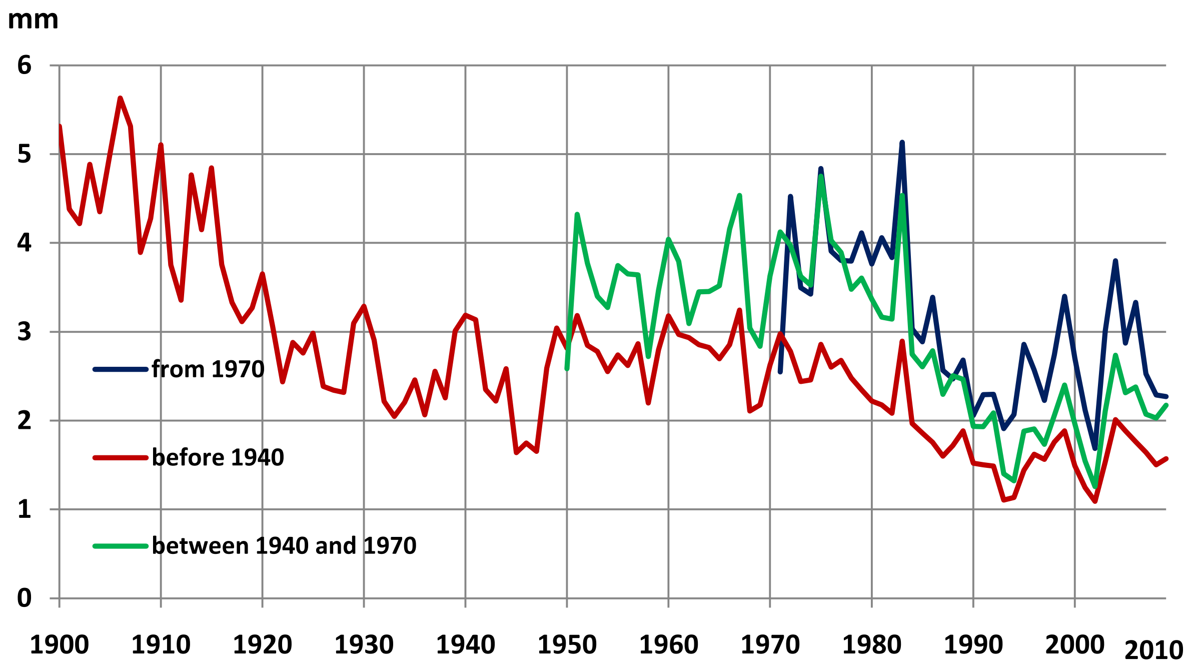

Figure 19. Tree ring widths averaged into three different age classes. The drop in growth after 1983 are clear within all the age classes and the slow recovery after 1995 is also in pattern within all the classes.

It can be seen on figure 17 that the radial growth is minimal from 1945 to 1947, which matches the ongoing drought period in Bulgaria at that time. Despite of the downfall in growth and development of the chestnut trees for the three years they did reach full recovery in the following years (Fig. 17 and 22). The severe drought period from 1983 to 1994 caused a clear decline in the growth of the tree rings, were the average growth dropped in the period of 10 years, from 4.19 mm and down to 1.27 mm (Table 3).

3.3 Defoliation (crown die-back) and tree-ring growth

The oldest tree with defoliation under 20 % is 77 years old and the oldest tree with defoliation more than 70 % is 160 years (Georgieva, et al., 2011). This means that the defoliation is greater among the older trees. After 1984 the annual tree ring growth drops in all studied trees. Trees with less defoliation have not fully recovered and the trees which have defoliation over 70% are clearly not recovering. (Fig.20)

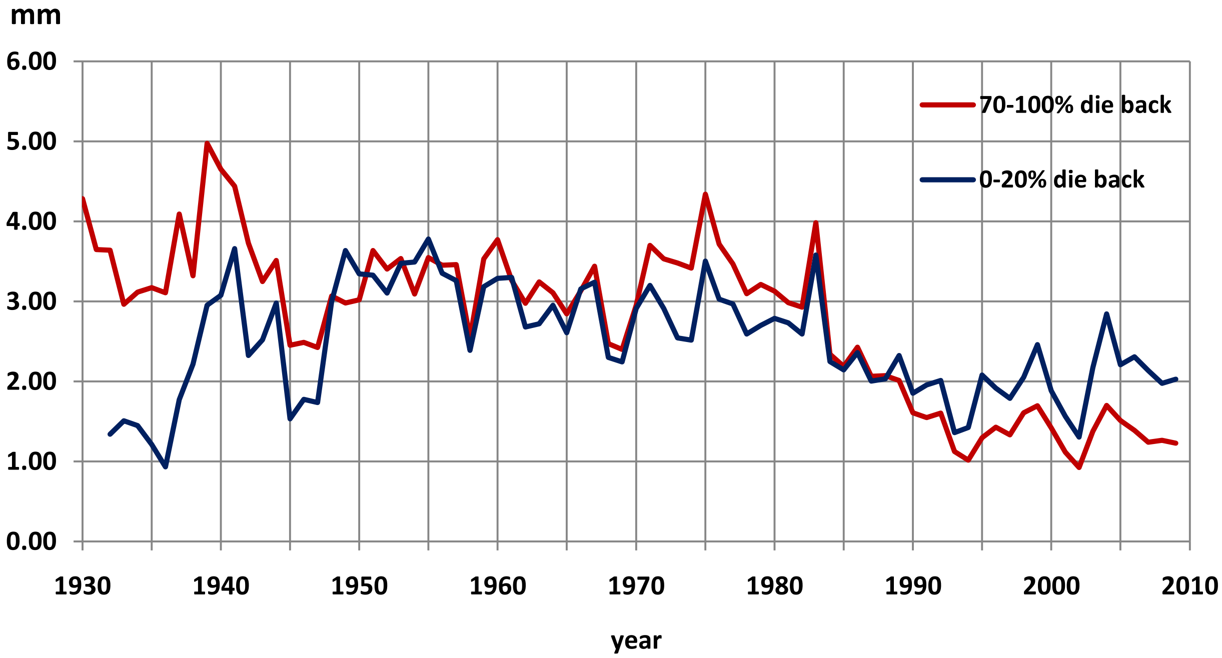

Figure 20. Average tree ring curves for trees with different stage of defoliation (die back). Trees with 70 – 100% dieback (n = 18) and trees with 0 – 20% dieback (n = 34)

3.4 The annual tree rings growth at different altitude

According to Georgieva, et al., (2011) the chestnut trees at higher altitude in Belasitsa mountain are less infected by the fungus and less defoliated (the measuring plots in the mountain slopes, are located between 450 m and 950 m.a.s.l (Zlatanov et al 2010)). The tree rings are wider in average at lower altitude of the mountain (3.25 mm under 500 m and 2.95 mm over 700 m). Figure 21 shows periods where growth is equal between trees at different heights over sea level, and in other periods where the growth is better at lower altitude. For example, from 1970 to 1990 the trees are showing better growth further down the mountain while there is almost no difference between trees growing at different height from 1990 to 2004. During the last five years the trees have grown better at lower altitude despite higher rate of infection of the chestnut blight fungi and more defoliation (Fig.21) (67% infected above 700 m and up to 95% rate of infection below 500 m) (Georgieva, et al., 2011).

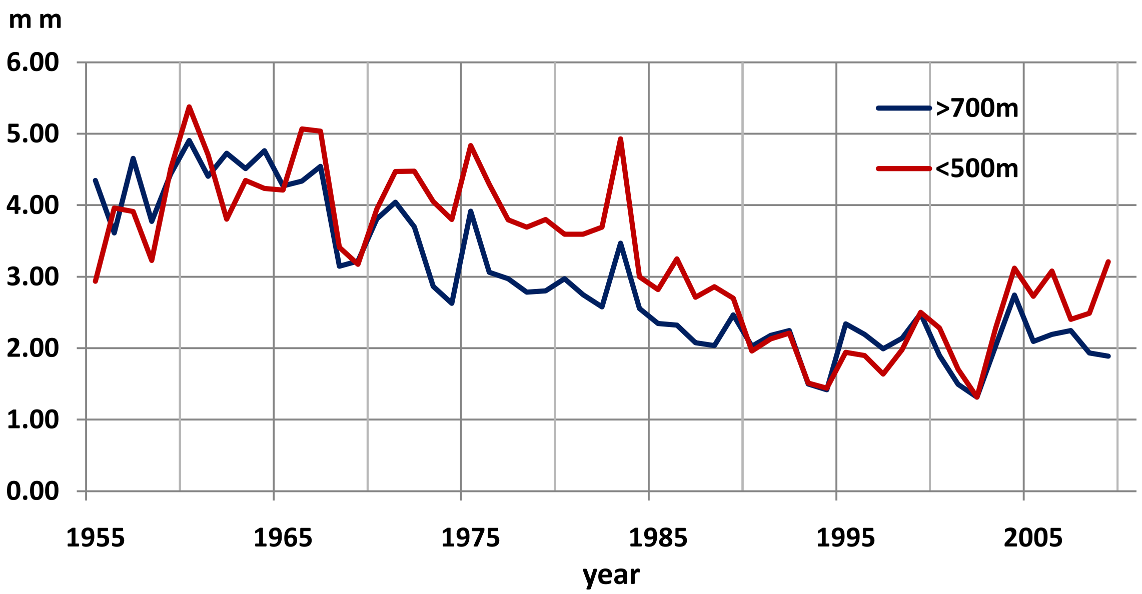

Figure 21. Average tree ring widths for trees growing in different height above sea level ; <500 (n = 26) >700 (n = 19), for the period 1955-2009.

Table 3. The average tree ring widths for the mean chronology (1850 – 2009) divided into several periods with significant changes

Years	Range mm	Mean mm	Number of trees
1850 to 2009	1.27 - 4.57	2.94	119
1850 to 1899	1.67 - 3.92	2.84	7
1900 to 1915	1.27 - 4.57	3.92	12
1916 to 1944	2.48 - 3.76	3.07	23
1945 to 1947	1.93 - 1.97	1.96	24
1948 to 1983	2.55 - 4.19	3.27	117
1984 to 2009	1.27 - 2.70	2.06	119

3.5 Growth–climate relationships

The results from the analysis of chestnut response to climate calculated by the program Dendroclim2002 from December of the previous year to September of the current year of growth for the period 1942-2009 showed positive respond to precipitation during the months May and June, and positive respond to temperature in December of the previous year and to January of the current year. The chestnut responds negatively to temperature during the growing season (Fig. 22). Figure 23 shows some years (pointer years) correlating with precipitation in June.

As previously mentioned is there a significant and positive correlation between the temperature in January and December growth of the trees in the following growth periods. On closer inspection it turned out that it is little correlation of temperature and precipitation in these same months.

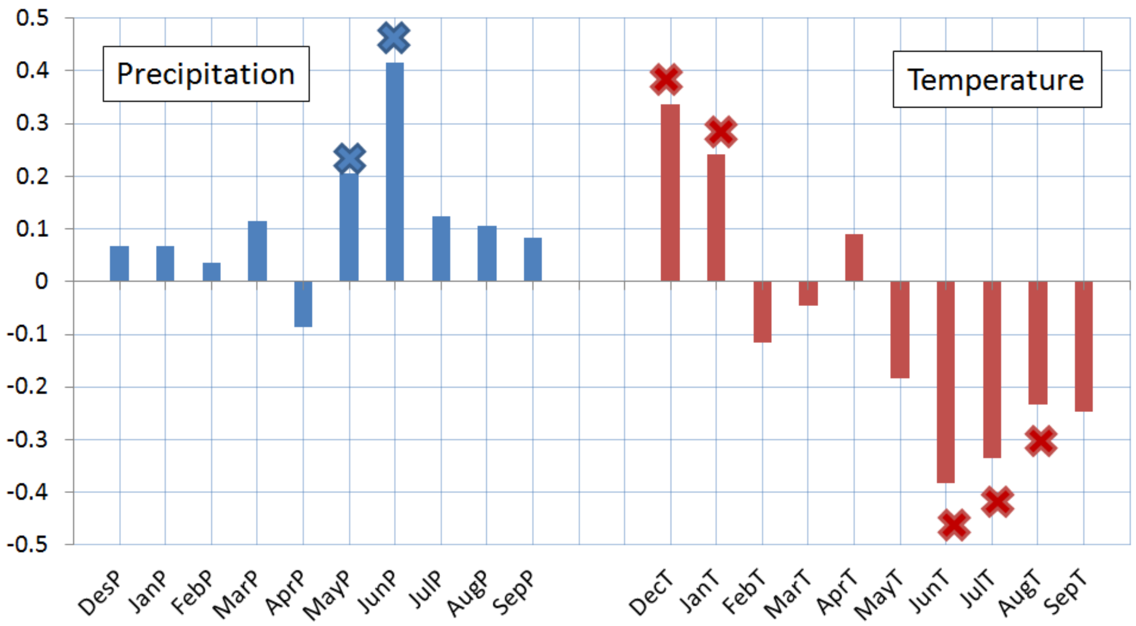

Figure 22. Response function of the tree ring chronology of chestnut with sum of precipitation and mean monthly temperature for a period from December of the previous growth year to September of the current growth year. The stars mark the 95% significance level of the response function coefficients.

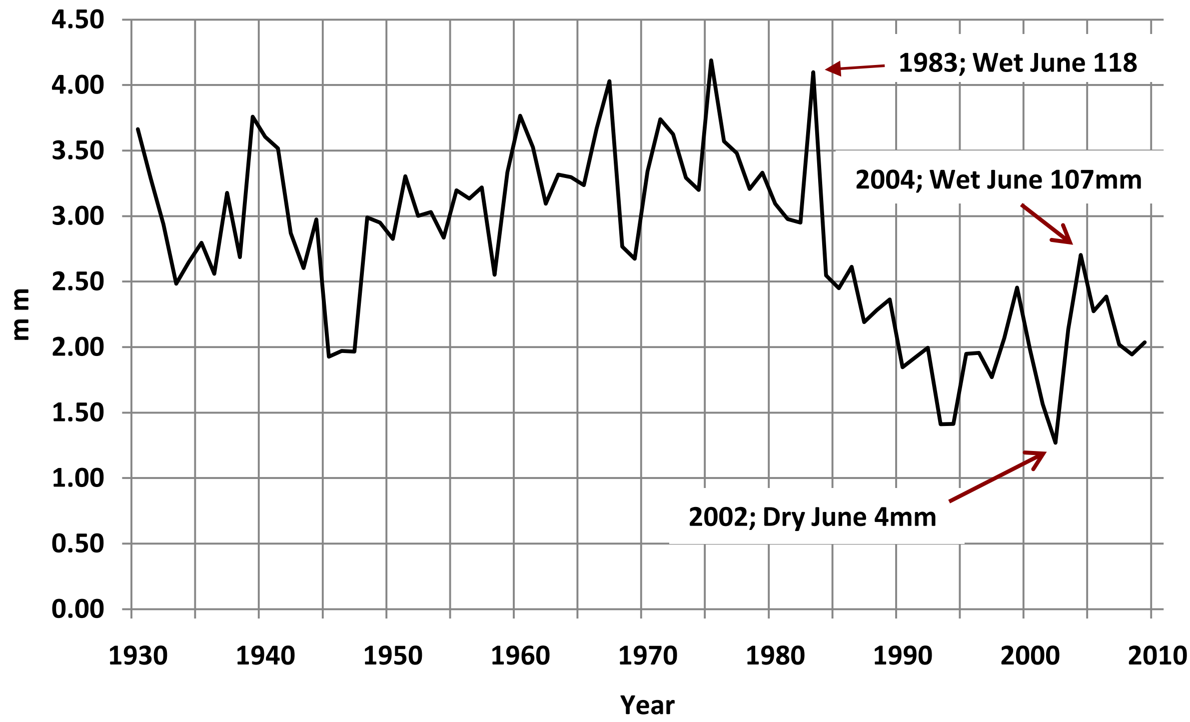

Figure 23. The arrows are pointing to the highest and lowest ring width having strong correlation with rainfall in June.

4 Discussion and conclusion

4.1 Age structure of the forest

In the spring 2010 the average age of the chestnut in Belasitsa was 60 years at BH and larger part of the population was under 60 years at BH. This indicates increased regeneration after 1950. The chestnut forest consists of relatively young trees compared to the age range of the species. When the chestnut forest in Belasitsa was still managed as pasture and for seed production, the old seed trees were standing relativity spread where the crown canopy was thinned out systematically to encouraged the seed production (Smith, et al., 1997). The trees were under good care and therefore kept a good health and vigour leading to good seed production. It is probably the transformation of the forest management which has lead to a denser stand and reduced the rate of larger and older trees, which previously was given more space.

In unmanaged broadleaf forests it is normal that the age distribution vary in longer or shorter periods, because the forest is dynamic and goes through natural succession. In managed forest the age distribution depends on: methods of regeneration (natural/ artificial), silvicultural treatments, rotation length etc. Today, the forest in Belasitsa is partially protected and therefore not operated as in traditional forest management.

4.2 Growth decline

There is a clear decline in the radial growth of the trees from around 1975 in the old trees and 1983 in the young trees (Fig.18 and 19). This decline continues until 1993. After that the radial growth seems to stabilize and in some cases the radial growth increases, especially in the young trees and trees with less defoliation (crown dieback) (Fig. 19 and 20).

This severe decline in growth is most likely the effect of the chestnut blight fungi entering the area and infecting the trees. Today close to 80% of the studied trees are infected with the fungi causing e. g dieback in the tree crown and less radial growth (Fig. 19 and 20). At the same time as the decline starts in the young trees there was a severe drought period in Bulgaria (Knight, et al., 2004). The draught can be seen in the meteorological data from

Sandanski (Fig. 11). This draught has probably also affected the trees but normally the chestnut is able to recover from droughts (Lauteri, et al., 2004). Therefore the severe decline and defoliation of the trees is probably a combination of the fungus entering the area and the severe draught period. The drought might have reduced the resistant of the trees, which enabled fungal attack and further spread of the blight. If the infection by the fungi had not occurred then the trees had most likely been able to recover more rapidly from the drought. It can be seen on figure 17 that the radial growth is minimal between 1945 and 1947, which matches a drought period in Bulgaria at that time. Despite of the reduction in the growth 1945 – 1947 they reach full recovery in the following years (Fig. 17 and 22). Waldboth & Oberhuber, (2009), studying the growth and decline of chestnut in northern Italy, concluded that although the chestnut blight fungi is the main course of the growth decline of chestnut in Northern Italy, less soil water availability in the years of drought strongly affects how fast the trees in the area are able to recover.

The density of the trees has a major impact on the growth and the health of the forest, where suitable thinning contributes to maximizing the growth and maintain healthy trees.

The dieback of the chestnut in the Belasitsa is still today an on-going process.

4.3 Growth and climate

The results show that there is a strong relationship between the sum of precipitation during the growing season and the radial growth of the chestnut trees (Fig. 22). High precipitation in May and June lead to increased radial growth of the trees and vice versa. High temperature during the growing season has negative influence on the annual tree-ring growth in the Belasitsa. High temperature leads to increased water evaporation and hence less soil water availability for the chestnut. Meteorological data from Sandanski shows negative correlation between monthly mean temperature and sum of precipitation e. g dry months area normally warmer than rainy months during the growing season (May-September) in Sandanski.

Damage to the cambium by chestnut blight infection can substantially damage water and nutrient transport during growth, because ring-porous trees as the chestnut conduct water mainly through the early wood vessels of the current year (Waldboth & Oberhuer, 2009).

4.4 Occurrence of the Hypovirulence

Indication of the slow recovery of the younger trees in recent years (Fig. 19) may indicate that the hypo virulent virus is present at the study site. According to George Hinkov (pers. comm., 2010) some young trees have recover from the chestnut blight in the Belasitsa mountain. If it turns out that the hypo virulent virus is in the area the virus can be used as a bio control. If not, it is possible to use some variants of the virus which have been detected and used successfully e.g. in Greece and other European countries (Robin, et al., 2000; Robin & Heiniger, 2001)

4.5 Future steps

In order to improve the analysis of the precise effects of different environmental factors on the chestnut in Belasitsa, a similar investigation of other tree species that grow in the area could be carried out, and the results then compared.

The aim of the forest authorities in Bulgaria is to develop high chestnut forests to make quality wood. An attempt was made by using a specific regeneration method which has unfortunately been without adequate results (Ivaylo Velichkov pers. comm., 2011).

A silvicultural method for improving the condition, of the chestnut forest in Belasitsa, is already underway and will hopefully bring answers to whether it will be possible to reverse the decline of the stand. In order to valuate if the methods are giving the intended results it is necessary to take samples again after few years.

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5.1 Personal communications

Hinkov, G. (2010, pers. comm. June)

Velcikov, I (2011, pers. comm. April)

5.2 List of figure

Figure on front page. The town Petrich at the roots of Belasitsa mountain,. Photo taken by Saevar Hreidarsson in June 2010.

Figure 1. (CIESIN), T. C. f. I. E. S. I. N. (2007). Map Collection » Biome. New York: Columbia University. American Chestnut Cooperators' Foundation. (1997). Genus Castanea,. Retrieved 12 mars, 2011, from http://www.ppws.vt.edu/griffin/accfcast.html

Figure 2. Thomé, O. W. (1885). Flora von Deutschland Österreich und der Schweiz: Kurt Stueber.

Figure 3. Chestnut in Belasitsa mountain in southern Bulgaria,. Photo taken by Saevar Hreidarsson in June 2010.

Figure 4. Chestnut blight infection in a young tree in Belasitsa,. Photo taken by Georgi Hinkov the winter 2009 – 2010.

Figure 5. Die back in Belasitsa,. Photo taken by Saevar Hreidarsson in June 2010.

Figure 6. Bowden, S., & Honsberg, C. (2010). Correlation of the rise in atmospheric carbon dioxide concentration with the rise in average temperature,. Retrieved 20 april, 2011, from http://www.pveducation.org/pvcdrom

Figure 7. An old chestnut (seed tree, pollard) in the Belasitsa mountain. Two coppice from around 1950 can also be seen,. Photo taken by Olafur Eggertsson in June 2010.

Figure 8. Cross section cut through trunk, Yukon, B. I. C. (2003). 2.6 Million Years of Climate Change (pp. Tree rings). Whitehorse: Government of Yukon,. Retrieved 20 April, 2011, from http://www.beringia.com/climate/content/treerings.shtml

Figure 9. Maps showing the study site in Belasitsa mountain NASA, U. (2007). The Belasitsa ridge as seen from the space (pp. PD-LAYOUT): NASA,. Retrieved 2 April, 2011, from http://www.ask.com/wiki/Belasica

Figure 10. Location of the climate station in Sandanski and the research site in Belasitsa mountain,. Domino (Cartographer). (2010). Bulgaria travel map.

Figure 11. The Sum of precipitation and average temperature during the vegetation period (May – September) in Sandanski, 20 km from the research site in the Belasitsa Mountain. The drought starts in 1984 and lasts for 10 years.

Figure 13. Antiseptic material,. Photo taken by Saevar Hreidarsson in June 2010.

Figure 14. The samples (cores) were taken at breast height (1.3 m) with Haglöf increment borer,. Photo taken by Olafur Eggertsson in June 2010.

Figure 15. The tree rings seen through the stereoscope,. Photo taken by Saevar Hreidarsson in December 2010.

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5.3 List of table