TREE – RING GROWTH RESPONSE OF SCOTS PINE *(PINUS SYLVESTRIS L.)* TO CLIMATE CHANGE

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Abstract

Dendrochronology is the scientific discipline of determining the relationship between tree growth and climate, and is determined using the annual growth rings. This provides a potential method for monitoring climate change. Climate usually acts as a major factor influencing the tree growth. Here, the effects of climate of a conifer species was assessed in relation to measured climatic variables. Tree cores of Scots Pine (Pinus sylvestris) were sampled from a forestry plantation at Hordron Edge, Derbyshire to determine the relationship between annual growth increment and four climate variables (maximum temperature, minimum temperature, grass minimum temperature and rainfall). Standard dendrochronological techniques were used to collect, prepare and measure tree–ring width increments. Climate data were derived from the British Atmospheric Data Centre (BADC) from 1921–2013. Tree-ring widths were as cross referenced to the climate data to enable growth dynamics of (Pinus sylvestris) to be investigated. In this study there was no significant correlation between growth and climatic variables; overall average mean sensitivity (m_S) was 0.28 mm, only five of the 20 trees were sensitive to climate ($m_S > 0.3$) with the other 15 trees being complacent ($m_S < 0.3$). The growth increment index portrayed a cyclic pattern of tree growth through time with peaks (fast growth) and troughs (slow growth) throughout the period. There were no significant first-order relationships found between tree growth indices and any of the four climatic variables tested. This result suggests that climatic variables were not significant in controlling tree growth at this site.

Keywords: Dendrochronology, Scots Pine (*Pinus sylvestris*), Tree–rings, Climate change

1.   Introduction

Forest ecosystems have been recognized as an essential component of the biosphere (Hooper *et. al.,* 2005). One of the most widely–distributed conifers tree in the world is Scots Pine (*P. sylvestris*) (Royal Forestry Society, 2014). It is found naturally in Great Britain mainly in the Scottish Highlands (Steven and Carlisle, 1959) but is planted extensively throughout the country. It is evergreen, reaching heights of 25 m to 45 m when mature, and is classified as softwood which makes it easy to extract tree cores. According to Ellenberg (1974), (*P. sylvestris*) has a very extensive eco-logical range and grows on very dry sites in semiarid climates as well on wet bog sites. It is subjected to continental Mediterranean climates which can undergo both cold winter temperatures and summer drought stress.

Therefore, (*P. sylvestris*) is considered to have a wider geographical distribution than many other pine species (Ohlson, 1995; Richardson Rundel, 2000). The ecology of (*P. sylvestris*) may lead to biological responses in tree growth which may reflect in the wood structure by stress tolerance,

allowing it to occupy habitats that are unfavorable to other species as a result of climatic or soil conditions, including low temperatures, extremes of acidity and alkalinity waterlogging and drought (Kelly and Connolly, 2000). Therefore, to achieve greater benefits from trees, it is essential to recognize the growth, forest management, environmental effect of the utilization (Downes *et. al.,* 2002) through the global climate change of the earth.

1.1 Global Climate Change

The earth's climate is a dynamic system. Yet, concern about climate change is increasing due to many uncertainties which exist as regards to possible changes on the ecosystems in the current century (Franklin *et al.,* 1991, Loele Le Blanc, 1996, IPCC, 2007). Bluemle (1999) stated the recent compilation of proxy data revealed that the global mean annual temperatures of the earth have experienced a global average increase by approximately 0.98($^\circ$C) from 1866 to 1998. Moreover, data obtained from NASA's Goddard Institute for Space Studies (GISS) revealed the Earth was the warmest from 134 records in the year 2014. A major challenge in climate research has been the attribution of cause for this temperature trend (San- ter *et al*., 1996). Globally, the earth's temperatures are expected to continue rising to at least the end of the present century (IPCC, 2013) and it is expected that human influence has been detected in the warming of the atmosphere and the oceans since the mid– 20th century. This may alter the current growth dynamics for tree species at different scales from the species to the community. Previous studies in China indicated that there is a strong relationship between terrestrial vegetation and climate variability (Kaufmann *et al., 2003*).

Moreover, Northern Europe has also experienced significantly increased precipitation during the 20th century which has contributed to an alteration in peat–land wetness (Van der Linden *et al.,* 2008). Apart from experiencing climatic change that is partly a result of natural variations in the Earth's system (IPCC, 2001), human anthropogenic activities have also influenced on the alteration of the geosphere, biosphere and atmosphere (Schimel *et al.,* 1996; Tett *et al.,* 1999). Despite this, a recent study revealed that mankind is the significant impact whether it is done directly or indirectly on the carbon balance of temperate and boreal forests (Magnani *et al., 2007*). Therefore, an alternative has been done to reconstruct records on the exact effects of past climatic environmental changes indirectly from trees using dendrochronology.

1.2 Relationship between climate and tree growth

During the early 20th century, the field of dendrochronology was born when it discovered that tree- ring width was dependent on climatic and environmental parameters (Fritts, 1976). Tree-rings are formed by the vascular cambium (Larson 1994), a cell tis- sue located between the xylem and phloem, which produces new xylem (wood) to the inside and new phloem to the outside. Differential activity in the cambium layer in response to climate produces xylem rings of different thicknesses and is in effect a measure of response to climate. According to Amato (1988), dendrochronological studies specified that chemical make-up of tree-rings also reflected the chemistry of the environment in which it is growing. This shows that radial growth can also be influence by pulse disturbance events such as volcanic eruptions, earthquakes and insect outbreaks (Fritts and Swetnam, 1989). The relationships be- tween growth decline and climate can be evaluated using correlation analyses between year–to–year variation in tree–ring width and seasonal mean temperature and total precipitation.

Trees are recognized t o be very sensitive to climate changes, where changes in the ecosystem can disturb the metabolism and physiological process of the trees and affect the wood

structure (Schweingruber, 1996). Extreme changes of environmental conditions forms tree–rings that are either much wider or narrower compared to neighboring tree-ring widths (Kaennel Schweingruber, 1995). One example is drought conditions which can exaggerate the concentrations of contaminates in groundwater and results in increased mortality or decreased tree radial growth. However, until today drought stress was not the utmost source of localized in forest decline (Sutherland and Martin, 1990). Fox *et al.,* (1985) stated that air and water pollutants such as heavy metals and sulphur dioxide have been common long-term factors affecting forest health and vigor.

The analysis for research study by using tree–ring width can be very precise for long–term bio–monitoring as it provides records which can extends for the entire duration of the tree age (Speer, 2010) for many decades, centuries and millennia. This makes dendrochronology a significant environmental source of proxy data for both naturally and human induced environmental change (Speer, 2010). McGraw (2003) stated that the essential relationship between climate and vegetation growth was pioneered by Andrew Ellicott Douglass, a scientist who was credited with developing tree–ring dating between 1919 and 1936. He was considered the founder of dendrochronology (Webb, 1983) and established dendrochronology as a provider of a calendar of tree- rings (McGraw, 2003) which in turn gives important proxy data for paleo–environmental studies and reconstructions (Luckman, 1996).

Fritts (2001) stated that many dendro–climatological studies have substantiated that climate explains a relatively large part of the temporal variability in tree–ring width. It is known that the relationship between tree–ring width and climate occurs due to the plant growth which is affected by specific conditions in the habitat environment. Depending on the climatic variation at the site, the annual growth increment of the tree is recorded by a series of either narrow or wide rings (Fritts, 1976). A study stated by Speer (2010), proved where past events recorded within the tree–rings series had successfully provided a long–term record of historical temperature, precipitation, landslides and fire events.

Tree–ring width chronologies can, therefore, provide a retrospective record of the past tree growth, which allows scientists to surmise the history of environmental change. It is thought that the dynamics of the tree–line are very sensitive to a change in climate (Holtmeier, 2009), because tree–line eco- tones are sensitive to climate change with increases in temperature being associated in tree density and tree–line position (Camerero and Gutierrez, 2004; Fang *et al.,* 2009). Tree–line ecotones are sensitive and good indicators of climate change (Payette Fil- ion, 1985; Szeicz Macdonald, 1995; Weisberg Baker, 1995) where the trees are often respond to climatic warming, increases in recruitment, tree density as well as upward advances in the tree line. Here, the width of tree–rings is in part, as a function of temperature. These chronologies have also been used to date structures, such as archaeological ruins, historic buildings and early Dutch paintings (Anon, 1977; Baillie, 1982; Trefil, 1985).

Fritts (1966) demonstrated the practical application of dendrochronology in evaluating fluctuations of past climate records, which extends the entire duration of the tree's life (Speer, 2010). As a result, dendrochronology is one of the significant environmental recording techniques for determining climate impacts on living organisms. Although climate has been acknowledged as a major driver of growth, Galvan *et al*., (2014) mentioned that site and tree features can respectively modify how the trees response to climatic variables at different spatial scales. Since trees undergo physiological changes as they age, the response of trees (*P. sylvestris*) to environmental conditions may vary over time. Typically, trees show divergent climate–growth associations as growth responsiveness to climate depends on site and tree characteristics such as forest composition (Pretzsch and Dieler, 2011), tree–to–tree competition intensity (Linares *et al.,* 2010), tree age and size (Carrer and Urbinati, 2004) and disturbance the woodland has experienced (Cook, 1990). In consequence,

studying the response of trees to climate change today and in the past, is necessary to provide tools to help predict the future development of forest resources.

Accordingly, in this study, tree–ring increment data of (*P. sylvestris*) from the Peak District National Park will be collected and compared to climate data collected from a nearby weather station. The aim will be to test the hypothesis that climate fluctuations at this site controls tree growth, and if possible, to produce predictive relationships.

2. Methods

2.1 The study area

This study was conducted at Hordron Edge site in the Peak District, Derbyshire (Latitude and Longitude; $53°23'$N, $1°41'$W within the North Peak Environmentally Sensitive Area (ESA) (Fig. 1). Most of the area is covered with acid grassland and bracken (*Pteridium aquilinum (L.) Kuhn*) along with some other few plantations of (*P. sylvestris*). Here, a study was made of the growth of (*P. sylvestris*) in one of these plantations. Sheep are grazed at a low stocking density, determined by the ESA agro-environment scheme prescriptions (ca. 0.5 sheep ha^{-1}; Pakeman *et al.,* 2000). In this study sheep had been excluded by fencing.
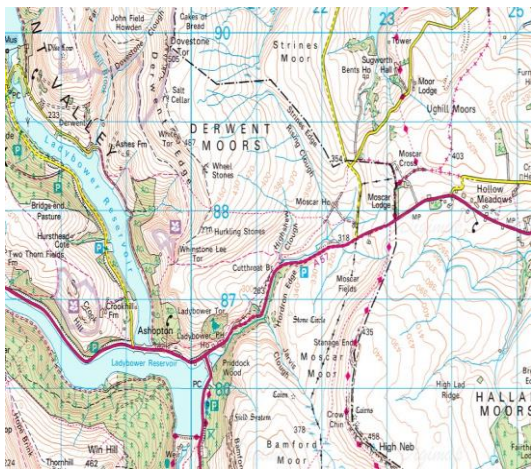

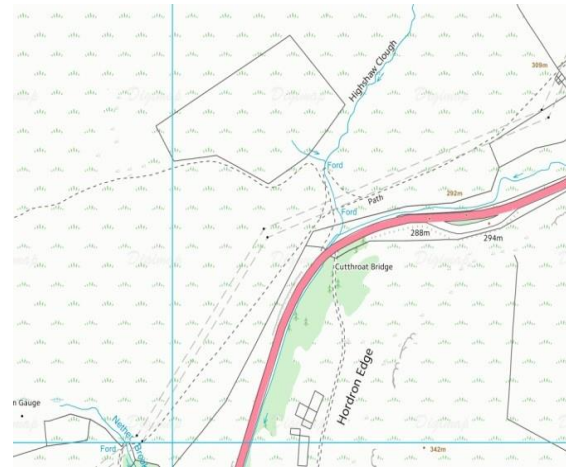Figure 1: Peak District National Park, Sheffield

Figure 2: Hordron Edge site in Peak District, Derbyshire

2.2 Dendrochronological sampling

Sampling was completed at the site using standard dendrochronological methods (Fritts, 1976). Twenty tree cores were extracted (5mm diameter) using a Haglof manual increment borer on 5th May 2015 from randomly – selected individuals of (*P. sylvestris*) (see the total number of cored Scots Pine tree in Table. 1). For each tree, height was recorded using a Haglof Vertex IV Ultrasonic Hypsometer (Krooks *et al.,* 2014) along with girth at breast height (1.3 m above the ground). Cores were always taken from the southern side of the tree to minimize differences between each cores (Graham, 1963). Cores were labelled and glued into a wooden block until processed. The cores were left to dry overnight and then glued into the wooden core blocks with multipurpose while adhesive in a way that exposes the transverse cross – sectional surface (Fritts, 1976). Cores were then progressively sanded

and polished with successively different grades of emery paper (120, 240 and 320) until the wood cells were clearly visible under the microscope (Stokes and Smiley, 1968). Core were then scanned using an Epson scanner (Expression 11000XL) at 1200 dpi resolution to provide a computerized image of the cores. The scanned images of the cores were then viewed using CoolDendro software and distances between annual rings counted (Fritts, 1976). All samples of cores were visually cross – dated to avoid miscounting by missing or false rings which were either locally – absent or present as multiple rings (Yamaguchi, 1991).

2.2   The climate data

The regional climatic data (air temperature and precipitation) was derived from the British Atmospheric Data Centre (BADC) website (badc.nerc.ac.uk) for the period 1921–2013 from the Buxton weather station (Station 539) approximately 25 km from the study site. The station was located at latitude 53.2577 N, longitude −1.91242 W at an elevation of 312 m. The climate data were reordered into plant growth years (October the preceding year through to the September of the year the ring responded to). This ensured that the ring being viewed related to the weather experienced during its period of growth. Data were available for tree growth between 1921 and 2013.

2.4   Data analysis

2.4.1 Standardizing the growth increments

Annual growth–ring increments were recalculated as indices to consider the effects of tree age us standardizing procedure (Fritts, 1976). First a polynomial regression was fitted to the relation- ship between growth increment and year in MINITAB (Minitab, 2010); thereafter the index was calculated using equation 1:

$$I_t = \frac{W_t}{Y_t}$$

Where for any year (t) growth increment the Index (I) is a function of the measured growth increment (W) and the predicted growth increment (Y) from the regression equation.

2.4.2   Assessing climatic sensitivity

Mean sensitivity (m_S) is a measurement of the year to year variability in tree ring width ranging from 0 to 1 (Speer, 2010). Mean sensitivity to climate (m_S) was assessed using the equation (2) (Fritts, 1976):

$$m_s = \frac{1}{n-1} \Sigma \frac{2\,(x_t + 1 - x)}{x_t\ + 1 + x_t}$$

where n is the number of rings in the sequence, t is time and x_t represents each ring width (Speer, 2010). The values of (m_S) range from 0–1 and can be used to define a tree as sensitive to climate (m_S >0.3) or complacent (m_S <0.3), i.e. not-sensitive to climate (Fritts, 1976).

3.   Results

3.1   Description of trees height and growth

Twenty cores of (*P. sylvestris*) from Hordron Edge in a Derbyshire forestry plantation were analyzed. In this study the annual growth increments of the trees were investigated. An initial

analysis compared basal area (m^2), height (m) and girth (cm) of each tree are shown below in (Table. 1).

The sample trees were between 10–43 m tall; 25% were greater than 20 m tall and 75% were less than 20 m. The trees had a girth at breast height between 102 and 199 cm, basal area between 0.1 and 0.5 m^2 and cores had a girth below than 2m.

Mean sensitivity is the mean first difference in a time series. Lower mean sensitivity typically results from less annual variability in growing condition, while the opposite patterns result from greater variability. Since the analysis has been successfully carried out, the mean sensitivity data (Table. 2) shows that five of the trees were sensitive to climate (m_S >0.3) and with the remainder being complacent (m_S <0.5). Data could then be compared to similar studies later.

Table 1. Field data recorded for the sampled trees.

Tree Number	Basal Area ($m^{2)}$)	Height (m)	Girth (cm)
1	0.5	19.8	102
2	0.4	16.0	136
3	0.3	17.6	149
4	0.3	13.1	157
5	0.4	11.4	117
6	0.2	20.4	108
7	0.3	30.5	153
8	0.1	42.7	158
9	0.2	28.5	161
10	0.3	14.6	162
11	0.3	12.8	126
12	0.2	18.7	160
13	0.2	15.2	141
14	0.2	14.1	161
15	0.2	20.7	195
16	0.4	11.6	199
17	0.1	16.1	132
18	0.3	19.8	113
19	0.3	17.5	125
20	0.2	18.5	178

Table 2. Mean sensitivity index (m_s) of the sampled trees between 1921 and 2013.

Index	Value	Index	Value
X1	0.334661	X11	0.264927
X2	0.343427	X12	0.291131
X3	0.240574	X13	0.263699
X4	0.276445	X14	0.237490
X5	0.204431	X15	0.242670
X6	0.324100	X16	0.284279
X7	0.294154	X17	0.233689
X8	0.259630	X18	0.287822
X9	0.299880	X19	0.327476
X10	0.319091	X20	0.292650

3.2   Change in (*P. sylvestris*) growth through time

The growth–index data in (Figure 3) indicated considerable fluctuations through the study period. A steady increase in annual growth was found between 1921 and 1928 followed by peaks in growth in 1927, 1935, 1975, 1982, 2011 and troughs in 1931, 1949, 1968 and 1987.
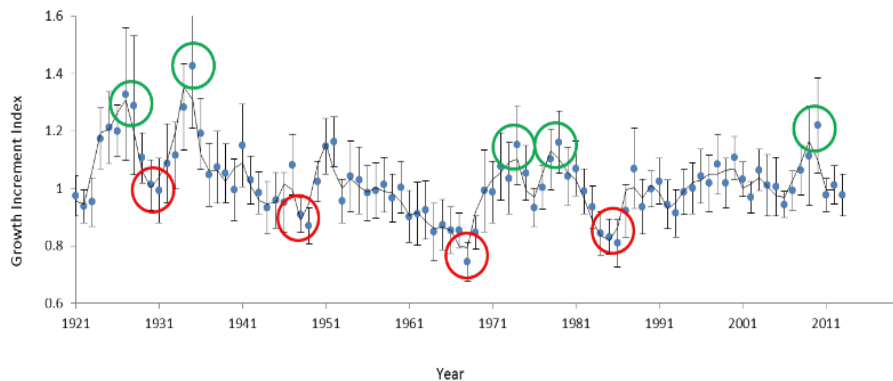

Figure 3: Mean Growth Index with Standard Error; a 2–period moving average line has been fitted.

3.3   Change in climate through the study period

The climate variables through time from 1921 to 2013 are shown in (Figure 4); with fitted linear regression lines were fitted to depict trends over the duration of the study. The responses of each are variable are discussed in turn.

3.3.1   Maximum Air Temperature

There was a significant positive correlation (Figure 4a) between average maximum air temperature and time with an equation of y= 0.0101x – 8.8567 ($R^2 = $ 0.1217; (P<0.001). The average maximum annual air temperature ranged between 9.0($^\circ$C) and 12.5($^\circ$C).

3.3.2   Minimum Air Temperature

There was an increasing trend in the data (Figure 4b) towards the present day an equation of y = 0.008x - 11.011 ($R^2 = $ 0.1541; (P<0.001). The lowest year for temperature was recorded in 1960 and 1977 with values of 3.3($^\circ$C).

3.3.3   Minimum Grass Temperature

The average minimum grass temperature showed no significant trend (Figure 4c) with an equation o f y= - 0.0029x + 8.9669 ($R^2 = $ 0.0116; (P>0.05).

3.3.4   Rainfall

Rainfall also showed no significant trend (Figure 4d) through time with an equation of y = 2.7715x - 4195.3 ($R^2 = $ 0.0902; (P>0.05).
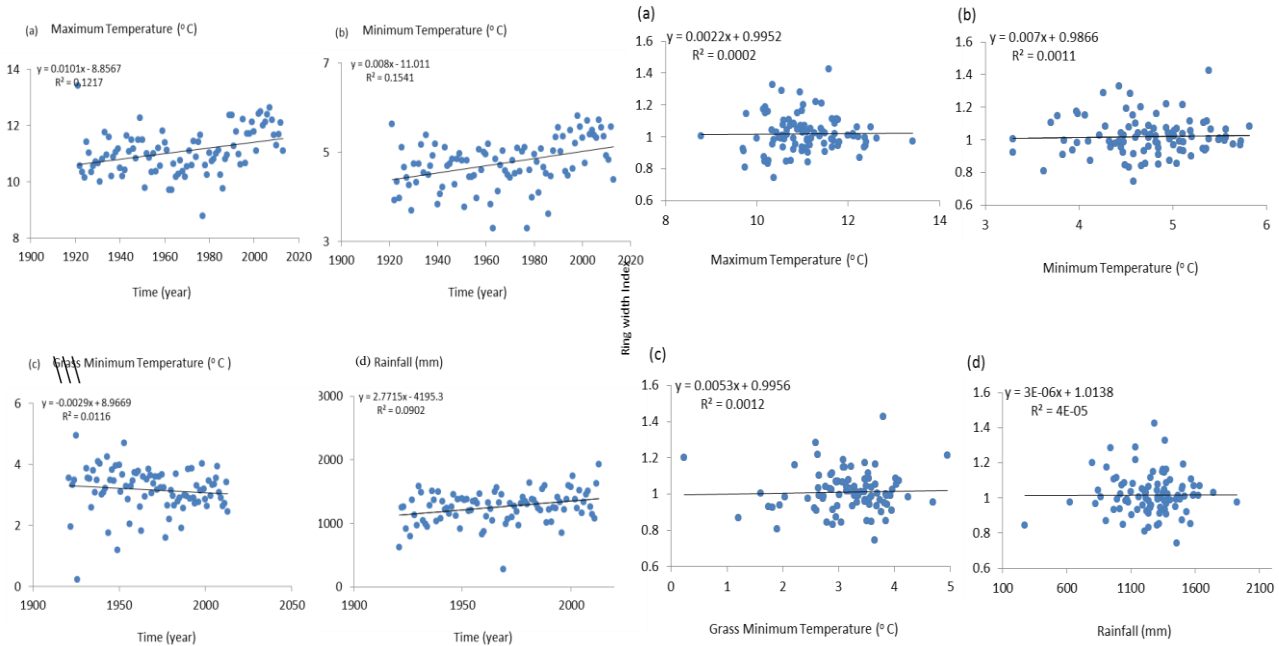
Figure 4: Changes in climatic data between 1921 and 2013 at the Buxton Weather station: (a) average maximum air temperature, (b) average minimum air temperature, (c) average grass minimum temperature, (d) average rainfall.

Figure 5: Relationship between tree growth and the climatic variables between 1921 and 2013 at Hordron Edge; Linear regression equations have been fitted: (a) average maximum air temperature, (b) average minimum air temperature, (c) average grass minimum temperature, (d) average rainfall.

3.4   Relationship between tree growth and climatic variables

No significant first – order relationships found between tree growth indices and any of the four climatic variables tested (Figure 5); higher – order polynomials and multiple regressions include temperature and rainfall were fitted, but these were also not significant. These calculations were re – run using just the five trees with ($m_s > 0.3$) to see if there was any link between growth and climate for the sensitive trees, here all correlations were not significant ($P > 0.05$).

4.   Discussion

Dendroclimatology is the science of measuring annual tree growth – ring widths to infer environmental, usually that of climate (Ecktein, 1990) and the reconstruction of past climate changes and monitoring current one (Fritts, 1976). Such studies can provide indicators of environmental conditions which can be important for the evaluation of long term impacts on forest health.

4.1   Change in (*P. sylvestris*) growth through time

The growth increment index portrayed a cyclic pattern of tree growth through time with peaks and troughs throughout the period. The cyclic pattern (Figure. 3) showed different periods of faster growth and slower growth which could be driven by environmental dynamics such as temperature (Li *et al.,* 2009). Slower growth advocates that the tree growth is limited by high

or low temperatures or drought; the red circled lines in (Figure. 3) suggest poor growth in 1931, 1949, 1968 and 1987. The years of faster growth circled in green (1927, 1935, 1975, 1982, 2011) indicated peak growth through the sampling period. According to Garcia – Suarez *et al.,* (2009) the width of the tree ring can be influenced by few other factors which relate to a combination of such as unique location of the tree, its age, management and micro – climate, and a wider environmental factor such as temperature, rainfall and tree density.

4.2   Change in regional climate through the study period

In relation to climate variables through time, result from this study shows there were no significant first – order relationships found between tree growth indices and any of the four climatic variables tested (Figure. 5); higher – order polynomials and multiple regressions include temperature and rainfall were fitted, but these were also not significant. These calculations were rerun using just the five trees with ($m_s > 0.3$) to see if there was any link between growth and climate for the sensitive trees however, here all correlations were not significant ($P > 0.05$).

4.3   Relationship between tree growth and climatic variables

There were no positive or negative correlations between ring width indices and any of the climatic variables tested (Figure. 5). Instead the growth cycles seem to be under constant environmental conditions which appear to be regular "rhythmic growth", Greathouse *et al.,* (1971). This result suggests that climatic variables were less influential on tree growth at tree–line. Correlations are not proof of causation (Collins *et al.,* 2000) m hence; this revealed that even though climatic variables could be one of the most influence variables still, correlation would not provide a significant answer and hypotheses. Elsewhere, tree–rings have provided important proxy data for paleo–environmental studies and reconstructions (Bradley and Jones, 1993, Luck- man, 1996) and major strengths as climate change indicators. The results from this site suggest that for *(P. sylvestris)* tree species, the correlation between growth and climatic variables is not significant. This might be due to lack of sensitivity t o climate; the overall average (m_S) was 0.281mm, and only five of the 20 trees were sensitive ($m_S > 0.3$) with the other 15 trees being complacent ($m_S < 0.3$). According to Carrer (2011), each tree will produce different value of complacency as they all experiences different micro–environmental conditions and may also reflect genetic differences. In this study, (*P. sylvestris*) was planted so would be derived from a similar seed batch, hence genetic variation would be expected to be low.

5.   Conclusion

Using samples data from 20 (*P. sylvestris*) trees, the results show that the tree ring index growth prediction models could not be developed for annual radial growth in Derbyshire. The research does not show any relationship between tree growth and climate relationships, as there were no significant first–order relation- ships found between tree growth indices and any of the four climatic variables tested. This suggested that (*P. sylvestris*) growth was not governed by climate variables at this site hence, our initial was rejected. Given this it was not possible to produce predictive relationships between trees (*P. sylvestris*) performance and climate at this site.

As climate change is not static and is fluctuating continually, the dynamics of tree growth towards climate will likely depend on many factors comprising of water and nutrient availability, the timing of the warming, rising atmospheric CO_2 and the ability of species to acclimate to new growing conditions (Way and Oren, 2010). The variability of environmental drivers between years may have had different effects on tree growth performance. Therefore, the ability to predict the impact of climate change on tree growth

of *(P. sylvestris)* is limited, unless we understand the physiological processes governing tree species productivity.

However, it may also be worthy to evaluate the patterns of tree growth which considered to be declining by drought or other organisms such as fungi and insects in the future. It might be more valuable to consider similar research on other coniferous species imported into Britain for forestry purposes (Larix decidua Mill, Larix x eurolpis Henry, Pseudotsuga menziesii (Mirb.) Franco, Picea sitchensis (Bong.) Carr.), tackling a hard wood species such as oak (Quercus robur L., Q. petraea (Matt.) Leibl., Silver birch (Betula pendula), Ash (Fraxinus excelsior), Beech (Fagus sylvatica) or trees which are at climatic extremes could be better potentials to investigate the dynamics of trees response towards the climate change. It also might be better to consider trees at the limits of their geographical distribution with respect to climate, for example at the tree line.

Acknowledgment

References

Anonymous. (1977). Tales the tree-rings tell. Mosaic 8(5), National Science Foundation, Washington, DC, 10 pp.

Amato, I. (1988). Tapping tree-rings for the environmental tales they tell. Analytical Chemistry 60: 1103A1107A.

Baillie, M.G.L. (1982). Tree-Ring Dating and Archaeology. University of Chicago Press, Chicago.

Bluemle, J.P. (1999). Global warming: a geological perspective. www.azgs.state.az.us/vol29no4.htm.

Bradley, R.S. and Jones, P.D. (1993). Little Ice Age summer temperature variations: their nature and relevance to recent global warming trends. The Holocene 3: 367376.

Carrer M, and Urbinati C. (2004). Age-dependent tree-ring growth responses to climate in Larix decidua and Pinus cembra. Ecology 85:730740.

Carrer, M. and Urbinati C. (2011). Individualistic and time varying tree ring growth to climate sensitivity, PLoS One 6(7): 6.

Camarero, J.J. and Gutirrez, E. (2004). Pace and pattern of recent treeline dynamics: response of ecotones to climatic variability in the Spanish Pyrenees. Climatic Change 63: 181200.

Collins, C., Le Duc, M.G., McAllister, H.A and Marrs, R.H. (2000). The effects of changing weather between 1967 and 1997 on the growth of Corsican Pine. Arboricultural Journal 24: 5-11.

Cook, E.R. and Briffa, K.R. (1990). A comparison of some tree-ring standardization methods. In: E.R. Cook, L.A. Kairiukstis (Eds), Methods of Dendrochronology: Applications in the Environmental Sciences, Kluwer Academic Publishers, Dordrecht (1990), pp. 153-62.

Downes, G.M., Wimmer, R., and Evans, R. (2002). Understanding wood formation: Gains to commercial forestry through tree-ring research. Dendrochronologia 20(1-2): 37-51.

Eckstein, D. (1990) Qualitative assessment of past environmental changes. In: E.R. Cook, L.A. Kairiukstis (Eds) Methods of Dendrochronology: Applications in the Environmental Sciences, Kluwer Academic Publishers, Dordrecht (1990), pp. 220223.

Ellenberg, H. (1974). Zeigerwerte der Gefasspflanzen Mitteleuropas. Scr. geobot. Goltze, KG. Gottingen. 4: 371-383.

Fang, K., Gou, X., Chen, F., Peng, J., DArrigo, R., Wright, W. and Li, M.H. (2009). Response of regional tree line forests to climate change: evidence from the north eastern Tibetan Plateau. Trees-Structure and Function 23, 13211329.

Fox, C.A., Kincaid, W.B., Nash, III, T.H., Young, D.L., and Fritts, H.C. (1985). Tree-ring variation in western larch (Larix occidentalis) exposed to sulfur dioxide emissions. Canadian Journal of Forest Research 16: 283292.

Franklin J.F. and Spies T.A. (1991). Ecological definitions of old-growth Douglas-Fir forests. In Wildlife and vegetation of unmanaged.

Fritts, H.C. (1966). Growth-rings of trees: their correlation with climate. Science 154, 973.

Fritts, H.C. (1976). Tree Rings and Climate. Academic Press, New York.

Fritts, H.C., and Swetnam, T.W. (1989). Dendroecology: A tool for evaluating variations in past and present forest environments. Advances in Ecological Research 19: 111188.

Fritts, H.C. (2001). Tree Rings and Climate. Blackburn Press, Caldwell, New Jersey.

Garcia-Suarez, A.M., Butler, C.J. and Bail- lie, M.G.L. (2009) Climate signal in tree ring chronologies in a temperate climate: A multi- species approach, Dendrochronologia 27, pp.183.

Galvn, J.D., Camarero, J.J., Ginzler, C. and Bnt- gen, U., (2014). Spatial diversity of recent trends in Mediterranean tree growth. Environment Re- sources Letter. 9: 84001.

Graham, S.A. (1963). Aspens: Phoenix Trees of the Great Lakes Region. University of Michigan Press, Ann Arbor, MI.

Greathouse, D.C., Laetsch, W.M. and Phinney, B.O. (1971). The shoot growth rhythm of a tropical tree, Theobroma cocao, American Journal of Botany 58: 281-286.

Holtmeier, F.K. (2009). Mountain timberlines: ecology, patchiness and dynamics. Advances in Global Change Research 36: 14.

Hooper D.U., Chapin F.S., Ewel J.J., Hector A., Inchausti P., Lavorel S., Lawton J.H., Lodge D.M., Loreau M., Naeem S., Schmid B., Setala H., Symstad A.J., Vandermeer J. and Wardle D.A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Eco- logical Monographs 75, 3-35.

IPCC (2001). Climate Change. 2001: The Scientic Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovern- mental Panel on Climate Change [Houghton, J.T., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

IPCC (2007). IPCC. Climate Change 2007: The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge (2007).

IPCC (2013). IPCC. Climate Change 2007: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge (2013).

Kaennel M. and Schweingruber F.H. (1995). Mul- tilingual glossary of dendrochronology. Terms and denitions in English, German, French, Spanish, Italian, Portuguese and

Russian. Birmensdorf, Swiss Federal Institute for Forest, Snow and Land- scape Research, Berne, Stuttgart, Vienna, Haupt, pp. 467.

Kaufmann RK, Zhou L, Myneni RB, Tucker CJ, Slayback D, Shabanov NV and Pinzon J. (2003). The effect of vegetation on surface temperature: a statistical analysis of NDVI and climate data. Geophysical Research Letters 30(22): 2147.

Kelly, D.L. and Connolly, A. (2000). A review of the plant communities associated with Scots pine (Pinus sylvestris L.) in Europe, and an evaluation of putative indicator/specialist species. In- vest. Agr.: Sist. Recur. For.: Fuera de Serie no.1-2000, 15-39.

Krooks, A., Kaasalainen, S., Kankare, V., Joen- suu, M., Raumonen, P. and Kaasalainen, M. (2014). Predicting tree structure from tree height using terrestrial laser scanning and quantitative structure models. Finish Society of Forest Science 48: 4.

Larson, P.R. (1994). The Vascular Cambium Development and Structure Berlin: Springer Verlag. Heidelberg Berlin. Springer Series in Wood Science, 725 pp.

Li. W,F., Cui. K.M. and He. X.Q. (2009) Regula- tion of cell cycle regulators by environmental signals during growth-dormancy cycle of trees. Plant Signal Behaviour. 4(10): 959-961.

Linares JC, Camarero JJ and Carreira JA. (2010). Competition modulates the adaptation capacity of forests to climatic stress: insights from recent growth decline and death in relict stands of the Mediterranean r Abies pinsapo. Journal of Ecology 98: 592603.

Loehle C and LeBlanc D. (1996). Model-based assessments of climate change effects on forests: A critical review. Ecological Modelling 90: 1-31.

Luckman, B.H., (1996). Dendrochronology in global change research. In: Dean, J.S., Meko, D.M., Swetnam, T.W. (Eds.) Tree rings, environment and humanity. Tucson, Arizona, Radiocar- bon. pp. 324.

Magnani, F. et al. (2007). The human footprint in the carbon cycle of established temperate and boreal forests. Nature 447: 848850 (2007).

McGraw, D.J. (2003). Andrew Ellicott Douglass and the giant sequoias in the founding of dendrochronology. Tree-Ring Research 59: 21.

Minitab (2010). Minitab v 16.1.0.0. Minitab Inc., State College PA, USA.

Ohlson, M. (1995). Growth and nutrient characteristics in bog and fen populations of Scots pine (Pinus sylvestris L.). Plant Soil 172: 235-245.

Pakeman, R.J., Marrs, R.H. and Le Duc, M.G. (2000). Bracken distribution in Great Britain: strategies for its control and the sustainable man- agement of marginal land. Annals of Botany 85B:37-46.

Payette, S. and Filion, L. (1985). White spruce expansion at the tree line and recent climatic change. Canadian Journal of Forest Research 15, 241251.

Pretzsch H and Dieler J. (2011). The dependency of the size growth relationship of Norway spruce (Picea abies (L.) Karst.) and European beech (Fagus sylvatica [L.]) in forest stands on long term site conditions, drought events, and ozone stress. Trees 25: 355-369.

Richardson, D.M. and Rundel, P.W. (2000). Ecology and biogeography of Pinus, an introduction. In: Ecology and Biogeography of Pinus (Richard- son, D.M., ed.), Cambridge University Press, Cambridge, pp. 3-46.

Royal Forestry Society (2014). Scots Pine. Royal Forestry Society, East England,http://www.rfs.org.uk/learning/scots pine.

Santer, B.D. and Coauthors. (1996). A search for human influences on the thermal structure in the atmosphere. Nature 382: 3945.

Schimel, D.S., Braswell, B.H., McKeown, R., Ojima, D.S., Parton, W.J. and Pulliam, W. (1996). Climate and nitrogen controls on the geog- raphy and times scales of terrestrial biogeochemical cycling, Global Biogeochemistry Cycles 10: 677-692.

Schweingruber, F.H., (1996). Tree Rings and Environment. Dendroecology. Swiss Federal Institute for Forest, Snow and Landscape Research, Bir- mensdorf. Paul Haupt Verlag, Berne. pp.609.

Steven HM and Carlisle A. The Native Pinewoods of Scotland. (1959). Edinburgh: Oliver and Boyd.

Stokes, M.A. and Smiley, T.L. (1968). An Introduction to Tree-ring Dating. University of Chicago Press, Chicago, pp.73.

Sutherland, E.K., and Martin, B. 1990. Growth response of Pseudotsuga menziesii to air pollution from copper smelting. Canadian Journal of Forest Research 20: 10201030.

Speer, J.H. (2010). Introduction. In Hansen-Speer, K.(eds) Fundamentals of tree-ring research. The University of Arizona Press, United State, p1, p5, p107.

Szeicz, J.M. and MacDonald, G.M. (1995). Recent white spruce dynamics at the subarctic alpine treeline of north-western Canada. Journal of Ecology 83, 873885.

Tett, P.A., Stott, M.R. Allen, W.J. Ingram, and Mitchell, J. F. B. (1999). Causes of twentieth century temperature change near the earth's surface. Nature 399: 569572.

Trefil, J.S. (1985). Concentric clues from growth rings unlock the past. 16, (4), pp. 46-55.

Van der Linden, M., Vickery, E., Charman, D. J. and Van Geel, B. (2008). Effects of human impact and climate change during the last 350 years recorded in a Swedish raised bog deposit. Palaeo- geography, Palaeoclimatology, Palaeoecology 262, 1-31.

Way DA, Oren R. (2010). Differential responses to changes in growth temperature between trees from different functional groups and biomes: a review and synthesis of data. Tree Physiology 30, 669688.

Webb, G.E. (1983). Tree Rings and Telescopes: The Scientific Career of A.E. Douglass. University of Arizona Press, Tucson.

Weisberg, P.J. and Baker, W.L. (1995). Spatial variation in tree regeneration in the forest-tundra ecotone, Rocky Mountain National Park, Colorado. Canadian Journal of Forest Research 25:13261339.

Yamaguchi, D.K. (1991). A simple method for cross-dating increment cores from living trees. Canadian Journal of Forest Research 20: 246-2.