Open Journal of Forestry, 2020, 10, 377-387
https://www.scirp.org/journal/ojf
ISSN Online: 2163-0437
ISSN Print: 2163-0429

The Growth Pattern of *Chamaecyparis obtusa* Stand along Longevity in Gyeongnam Province, South Korea

Moon Hyun Shik[1], Tamirat Solomon[1,2*]

[1]Department of Forest Environmental Resources, Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, South Korea
[2]Department of Natural Resources Management, College of Agriculture, Wolaita Sodo University, Wolaita Sodo, Ethiopia
Email: *tasolmame@gmail.com

How to cite this paper: Shik, M. H., & Solomon, T. (2020). The Growth Pattern of *Chamaecyparis obtusa* Stand along Longevity in Gyeongnam Province, South Korea. *Open Journal of Forestry, 10,* 377-387.
https://doi.org/10.4236/ojf.2020.104023

Received: July 19, 2020
Accepted: September 11, 2020
Published: September 14, 2020

Abstract

Tree growth is affected by environmental factors, climate condition and tree age. The objective of this study was to evaluate the growth patterns of *Chamaecyparis obtusa* (*C. obtusa*) stand in the Gyeongnam province. Data was collected from two cities and one county by using sample quadrats of 20 * 20 m. A total of 11 quadrats were used to collect tree height, diameter at the breast height (DBH), annual growth rings and soil data. The data analysis of soil moisture content, pH, organic matter (%), EC (cmol + /kg of soil), and available phosphorous was conducted. Growth ring was analyzed by using computer based software and the ages of the trees were identified. Average growth of height and DBH was computed from the surveyed data and annual growth of each tree was assessed by computer based reading of annual growth rings. The results of the study revealed that tree growth showed a reducing trend along the longevity. It was identified that soil pH, age, variation in annual average temperature, and altitude were the main factors related with growth of *C. obtusa* trees along the life of the stand.

Keywords

Growth Pattern, Soil Properties, Longevity, Climate Change, Growth Rings

1. Introduction

Changes in climate and other environmental conditions can cause influence on the growth condition of forests (Metsaranta & Bhatti, 2016). Alterations in the climate and environmental conditions affect the structure and function of vegetation (Ding et al., 2019; Anderson-Teixeira et al., 2013). As a result of a variation in soil properties (Soong et al., 2020; Wilcke et al., 2008), changes in temperature and precipitation patterns and increases of carbon dioxide concentration are likely to drive significant modifications in forests (Kirilenko & Sedjo, 2007). Seasonal patterns of wood growth are related to water availability (Worbes, 1999), temperature and soil water (Beedlow et al., 2013), and the length of the growing season, implying that soil properties and climate change related factors are likely to affect forest growth. In this regard, silvicultural systems based on the concept of sustainable use require knowledge of the long term diameter increment of tropical forest trees and their response to climate (Worbes, 1999). Thus, understanding the factors influencing tree growth is the essential component of forest ecology.

In order to get information about the growth of trees, growth analysis is a unique method to obtain growth information (Husch et al., 2003). Among the growth evaluation methods, analysis of annual tree-rings is a potential source of long term information (Haines et al., 2018). Soil and tree-ring analysis is also often used to assess long-term trends in tree growth (Peters et al., 2015; Park et al., 2015). Those methods are powerful tools to reconstruct historical growth changes and have been widely used to assess tree responses to global warming (Duchesne et al., 2019). Study on soil and tree-ring analysis provides important contributions in understanding the climate sensitivity of trees and the effects of global change on forests (Brienen et al., 2016). On the other hand, investigation of annual tree ring is best in estimating the ages of the trees (Brienen et al., 2009), so as to examine the pattern of growth of trees over a long period of time (Rozendaal et al., 2011).

The forms of growth, activity and renewal of stems and branches are primary determinants of ecosystem function and strongly influence net primary productivity (Rossatto et al., 2009). Thus, this study was aimed to evaluate the growth patterns of *C. obtusa* species along longevity focusing on the relationship between growth of the species and soil and ecological factors; climate variables mainly change in temperature and precipitation.

2. Materials and Methods

2.1. Study Areas

The study was conducted at two cities and one county of Gyeongnam province (**Figure 1**). Sample site selection was made based on the regional representation of cities and counties considering the south, east and western Gyeongnam province. In a 20 * 20 m area a total of 11 quadrats were laid under the plantation stand of *C. obtusa.* A number of quadrats located at Hadong (three quadrats), Gimhae (four quadrats) and Tonyeong (four quadrats) respectively. Mature stands with an estimated age of greater than 25 years were considered. To avoid the biasness of data quality, all the sample quadrats were placed away from the margin and road sides of the stands and trees with defect were excluded. **Table 1** shows the background information of the stands included in the study.

Table 1. Background information (environment, climatic conditions and tree status)[a] of the study areas.

Site	Environment conditions			Weather conditions		Tree status					
	Altitude (m)	Slope (%)	Aspect	Temp (˚C)	Precipitation (mm)	DBH (cm)	Height (m)	Volume (m^3/ha)	Age (year)	Growth (cm)	Spacing (m)
Gimhae	246.5 (14.5)	20 (0.0)	SE, W	15.2 (0.0)	1310 (0.0)	25.9 (3.9)	18.7 (1.1)	803.3 (240.4)	38.6 (9.2)	3.1 (0.7)	2.9 (0.4)
Hadong	244 (14.8)	16 (8.6)	SW	13.2 (8.8)	1494.5 (2.3)	26.2 (3.0)	18.5 (0.7)	812.1 (203.9)	32.4 (5.2)	3.3 (0.6)	4.2 (0.8)
Tongyeong	261 (0.0)	10 (0.0)	NE	14.6 (0.0)	1541.3 (0.0)	34.3 (4.0)	23.4 (1.8)	1746.3 (393.2)	72 (9.0)	2.2 (0.4)	3.8 (0.9)

[a]averages of DBH, height, volume, age, annual growth, spacing, altitude and (ten years averages of annual temperature and total precipitation). The values in parentheses are standard errors of the mean.

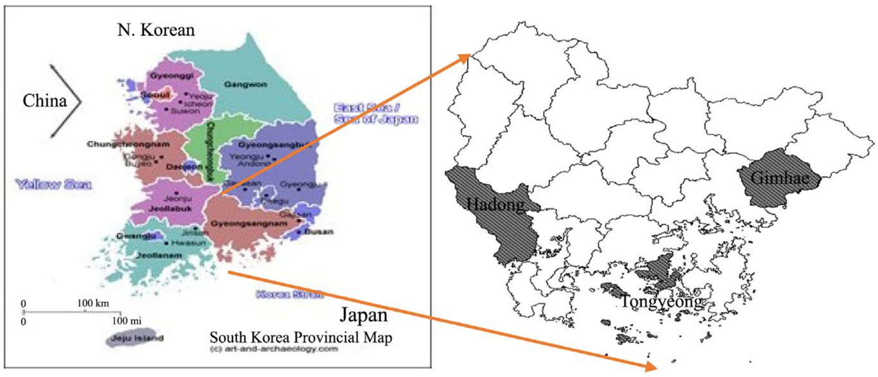

Figure 1. Locations of the study areas (shaded areas represent sample study cities and county).

2.2. Data Collection and Analysis

A total of 141 trees were selected for the data collection. Mora Swedish wood increment borer was used to collect data of annual growth rings of trees to study lifetime growth patterns and age of the species. In addition, Vernier caliper, Hypsometer and meter were used to measure tree height and DBH. Ten years of annual average temperature and total precipitation were gathered, and soil sample was also collected from each quadrat.

Growth pattern evaluation of the mature stand was evaluated by the annual growth rings collected from diameter at the breast height (DBH). All the core samples were air-dried and polished with the sand paper to get the fine grains. Age determination processing was done by using a computer based software WinDENDRO version 6 - 36 Canada for automatic annual ring detection with the accuracy of 1/1000 mm measurement. Age of a tree was identified from the pith of the trees. To study the properties of the soils, the samples were air-dried and passed through 2 mm-sieves to obtain fine earth separates. From each soil sample of different study areas, over 5 mg of fine soil samples were prepared and measured for the moisture content and dried at 105˚C for 12 hrs and measured again for their dry weight. The organic matter content (%) of the soil was measured. Determination of soil pH was made from 1:5 ratio of soil and water (5 g: 25 ml) after shaking for 30 minutes by using pH meter, Orion, USA. The cations exchange capacity (CEC, cmol (+)/kg) was determined by adding Ammonium Acetate (NH_4OAc) saturation of pH 7. From the prepared sample analysis of soil moisture content, pH, organic matter (%), EC (cmol + /kg of soil), and available phosphorous was conducted. A statistical software (SPSS version 25) was used for data analysis in order to evaluate the significance of variables and its relation to trends of growth of the tree species.

3. Results

From the results of the analysis of the annual growth rings, it was identified that trends of growth patterns of *C. obtusa* species were declined while the age increase (Figure 2). Development of growth was higher at young age (ages from time of planting to 30's) but the growth condition changed while the trees mature. This implies the impact of tree age on the annual growth and its cause of growth decline along longevity. Annual average temperature was positively correlated ($p < 0.01$) with height growth indicating that changes in the condition of climate resulted in impacts on the growth pattern of the trees (Table 2).

Statistically, there was no significant correlation between growth factors (height and DBH) to annual total precipitation, some soil properties such as moisture content, organic matter, and available phosphorous, and slope, and tree age (Table 3). However, soil pH significantly was correlated to DBH growth indicating that *C. obtusa* growth was influenced by level of pH in the soil.

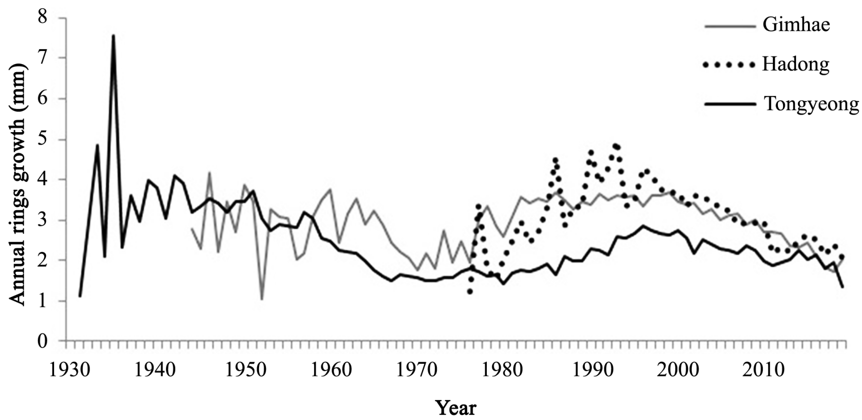

Figure 2. The growth patterns of stands along age at the studied cities and county.

Table 2. Pearson's correlation in between tree growth to soil, climate and ecological factors.

	Height (m)	DBH (cm)	Age (year)	OM (%)	MC (%)	Av. P (ppm)	pH (H_2O)	Slope (%)	Temp (˚C)	Precipi (mm)	Altitude (m)	Spacing (m)
Height (m)	1	0.636**	0.571**	0.572**	0.504**	0.442**	00.161	−0.469**	0.054	0.469**	0.163	0.010
DBH (cm)		1	0.704**	0.627**	0.479**	0.576**	0.054	−0.543**	0.159	0.571**	−0.011	0.128

**Correlation is significant at the 0.01 level (2-tailed), Av. P = available Phosphorous, OM = organic matter, MC = moisture content, Temp (˚C) = annual average temperature, precipitation (mm), annual total precipitation.

Table 3. Averages of soils properties of the study sites.

Site	MC (%)	OM (%)	pH (H_2O)	Available P (ppm)	Ex. cations (cmol + /kg)			
					K^+	Ca^{2+}	Mg^{2+}	Na^+
Hadong	31.53 (2.47)	4.08 (0.63)	4.77 (0.11)	31.5 (9.86)	0.19 (0.04)	0.37 (0.14)	0.15 (0.03)	0.07 (0.03)
Gimhae	17.37 (4.00)	1.13 (0.82)	4.10 (0.14)	15.82 (7.90)	0.20 (0.11)	0.31 (0.08)	0.12 (0.03)	0.07 (0.07)
Tongyeong	34.4 (6.97)	6.19 (2.43)	4.41 (0.13)	42.02 (12.08)	0.30 (0.11)	0.69 (0.35)	0.26 (0.09)	0.17 (0.07)

The values in parentheses are standard errors of the mean.

Moreover, there was a negative significant relation ($p < 0.01$) between DBH growth and altitude. Also it was revealed that the average annual growth of DBH was relatively higher for younger stands than old mature stand aged above 70 years (**Table 1**).

Spacing was found to be one of the factors related to the growth patterns of *C. obtusa* trees. From the Pearson's correlation, there was a positive and significant relationship ($p < 0.01$) in between tree height and spacing. Trees planted at narrower spacing showed higher mean total height growth than at wider spacing, however, the volume growth increased as the spacing increased.

4. Discussion

Factors Influencing the Growth Patterns of the *C. obtusa* Stands

To obtain a measure of growth pattern, one might first think of examining the correlation between growth, environmental, soil, and climatic factors. From the study results, it was identified that growth trends of *C. obtusa* species declined while the age increased. The same result was reported by different studies showing an inverse relationship between annual growth rate and age along the longevity, as the age increase, the amount of annual growth decrease (Johnson & Abrams, 2009; Binkley et al., 2002; McMurtrie et al., 1995). A study on another species (*Pinus koraiensis*) in S. Korea resulted in the way of growth percentages of DBH, height and volume tended to decrease with age particularly rapidly at age 20 - 30 (Seo et al., 2014, 2018). Likewise, in the eastern region of S. Korea the diameter and height growth of *Pinus densiflora* species felled down rapidly with longevity until age 30 (Seo et al., 2015). These indicate that tree growth pattern variation after maturation and changes through life time. The pattern of tree growth varies through life time. Plantation tree grew fast at the young age (under 20 years) but annual increments then decreased (Worbes, 1999). Consequently, although the productivity of forest is basically regulated by the genetic traits of the species and the site conditions, it also differs according to the stand development stage or stand age (Fujimori, 2001; Smith & Long, 2001).

By investigating the determinant causes that may result growth decline along longevity, different studies suggested various reasons. For instance, a study by

(Black et al., 2008) showed that long-lived species maintained slower radial growth rates than shorter lived species on the same sites, showing the influence of tree age on growth of stands. The gradual decline of productivity of forest is assumed to be aging mechanisms (Murty & McMurtrie, 2000), which is due to the nutrient availabilities declines with age (McMurtrie et al., 1995), and change in climate conditions (He et al., 2012), causing growth decline. On the other hand, part of the universal age-related decline in forest growth derives from competition-related changes in stand structure and the resource-use efficiencies of individual trees (Binkley et al., 2002; Alen, 1986). However, competition related changes might be much higher at the young age of the stand but as forest get mature, it develops self-thinning and reduce potential competent on the available resources, and thus the possibility of competition in reducing DBH growth is real (Buechling et al., 2017), but might not be stronger as to the young stands.

Similarly, there is a strong positive relationship between soil properties and forest dynamics of growth (Soong et al., 2020) and growth decline occurs when there are changes in the supply rate of required soil resources (Ryan et al., 1997). Fast-growing species seem to benefit from initially higher pH in the soil indicating that soil properties favor the growth of some species (Carrasco-Carballido et al., 2019; Martínez-Garza et al., 2016). In this study the growth decline was resulted where there was higher soil moisture content, organic matter and available phosphorous; implying that the relationship between some soil properties and growth decline of *C. obtusa* along longevity was insignificant. However, soil pH was found to be an influential factor in the DBH growth pattern of the species. Previous studies also noted that the species prefers moist but well-drained, loamy, somehow acidic soil for optimum health and growth (Larum, 2018; Park et al., 2015).

Temperature is one of the main factors regulating the growth of trees as it might induce growth declines due to drought stress at lower elevations particularly for old trees (Primicia et al., 2015). Understanding the effect of temperature on individual tree species growth is one of the primary elements of the response to climate change and designing method of suitable forest management. The effect of temperature on tree growth varies as it influences the amount and exposure to sunlight, moisture evaporation and related. Increasing temperature directly affects plant growth through effects on photosynthetic and respiration rates (Kirschbaum, 2000). Variation in the temperature influences the growth as it affects the soil hydrological and thermal regimes (Hagedorn et al., 2014); water and nutrient availability, the timing of the warming and rising atmospheric CO_2 (Way & Oren, 2010). Thus, the significant relationship between *C. obtusa* growth and annual average temperature indicates the intimate relation of growth decline to the climate variability (Aubry-Kientz et al., 2019).

Trees cannot grow everywhere; meaning growth of trees is limited by its growth requirements. Altitude is among the limiting factor of growth of trees, despite it varies with the type of species and their adaptation capacity. Some trees become small and have more open canopies at high altitudes, growth pattern varies when the altitude changes; and it declines with the altitude (Coomes & Allen, 2007; Büntgen et al., 2019). This is related with the temperature fluctuation along the altitude caused by climate changes (Paulsen et al., 2000), as the altitude increases, air condition varies, and soil properties change which affect life of trees and its growth condition.

Furthermore, growth form of a tree depends on the spacing. Widening of spacing results higher DBH growth and trees planted at narrower spacing grow taller in height. This is related with the number of plants growing at a certain areas and the form of competition. The result revealed that at a close spacing the average height can be increased substantially and also the volume growth increased as the spacing increased. One of the possible reasons for such kind of relationship is the result of intraspecific competition (Akers et al., 2013; Zhu et al., 2007; Watt et al., 2006).

5. Conclusion

Despite a wide range of results of studies reporting about the decline of tree growth along longevity, it is still not clear whether tree longevity depends on slow growth rates and whether or not this relationship is species-specific, genetic and/or environmentally controlled (Büntgen et al., 2019). Growth patterns of most studied plantation and confer trees tend to decline along lifetime; however, trees in the natural forest showed a positive trend of diameter growth (Kohl et al., 2017). Thus, specific studies that focus on the relationship between environmental, and/or genetic and species-specific factors and forest growth decline along the longevity could provide a sort of information about the causes. According to the results of the current study, different factors were found to be responsible for the growth decline of *C. obtusa* species along the longevity. Age, soil pH, change in temperature and altitude were the main factors that were identified for their effects on the growth pattern along the life of the stands.

Acknowledgements

We are grateful to the lab members of silviculture in the department of Forest Resources, Gyeongsang National University for their unreserved support during collection and processing of data for the study.

Conflicts of Interest

The authors declare that they have no competing interests.

Data Availability Statement

Necessary data would be made available when requested.

Funding Statement

Not available.

References

Akers, M. K., Kane, M., Zhao, D., Teskey, R. O., & Daniels, R. F. (2013). Effects of Planting Density and Cultural Intensity on Stand and Crown Attributes of Mid-Rotation Loblolly Pine Plantations. *Forest Ecology and Management, 310,* 468-475. https://doi.org/10.1016/j.foreco.2013.07.062

Alen, J. C. (1986). Soil Properties and Fast-Growing Tree Species in Tanzania. *Forest Ecology and Management, 16,* 127-147. https://doi.org/10.1016/0378-1127(86)90014-9

Anderson-Teixeira, K. J., Miller, A. D., Mohan, J. E., Hudiburg, T. W., Duval, B. D., & Delucia, E. H. (2013). Altered Dynamics of Forest Recovery under a Changing Climate. *Global Change Biology, 19,* 2001-2021. https://doi.org/10.1111/gcb.12194

Aubry-Kientz, M., Rossi, V., & Cornu, G. (2019). Temperature Rising Would Slow down Tropical Forest Dynamic in the Guiana Shield. *Scientific Reports, 9,* Article No. 10235. https://doi.org/10.1038/s41598-019-46597-8

Beedlow, P. A., Lee, E. H., Tingey, D. T., Waschmann, R. S., & Burdick, C. A. (2013). The Importance of Seasonal Temperature and Moisture Patterns on Growth of Douglas-Fir in Western Oregon, USA. *Agricultural and Forest Meteorology, 169,* 174-185. https://doi.org/10.1016/j.agrformet.2012.10.010

Binkley, D., Stape, J. L., Ryan, M. G., Barnard, H. R., & Fownes, J. (2002). Age-Related Decline in Forest Ecosystem Growth: An Individual Tree, Stand-Structure Hypothesis. *Ecosystems, 5,* 58-67. https://doi.org/10.1007/s10021-001-0055-7

Black, B. A., Colbert, J. J., & Pederson, N. (2008). Relationships between Radial Growth Rates and Lifespan within North American Tree Species. *Ecoscience, 15,* 349-357. https://doi.org/10.2980/15-3-3149

Brienen, R. J. W., Lebrija-Trejos, E., van Breugel, M., Pérez-García, E. A., Bongers, F., Meave, J. A., & Martínez-Ramos, M. (2009). The Potential of Tree Rings for the Study of Forest Succession in Southern Mexico. *Biotropica, 41,* 186-195. https://doi.org/10.1111/j.1744-7429.2008.00462.x

Brienen, R. J. W., Schöngart, J., & Zuidema, P. A. (2016). Tree Rings in the Tropics: Insights into the Ecology and Climate Sensitivity of Tropical Trees. In G. Goldstein, & L. Santiago (Eds.), *Tropical Tree Physiology* (pp. 439-461). Tree Physiology Vol. 6, Cham: Springer. https://doi.org/10.1007/978-3-319-27422-5_20

Buechling, A., Martin, P. H., & Canham, C. D. (2017). Climate and Competition Effects on Tree Growth in Rocky Mountain Forests. *Journal of Ecology, 105,* 1636-1647. https://doi.org/10.1111/1365-2745.12782

Büntgen, U., Krusic, P. J., Piermattei, A., Coomes, D. A., Esper, J., Myglan, V. S. V. S., Kirdyanov, A. V., Camarero, J. J., Crivellaro, A., & Körner, C. (2019). Limited Capacity of Tree Growth to Mitigate the Global Greenhouse Effect under Predicted Warming. *Nature Communication, 10,* Article No. 2171. https://doi.org/10.1038/s41467-019-10174-4

Carrasco-Carballido, V., Martínez-Garza, C., Jiménez-Hernández, H., Márquez-Torres, F., & Campo, J. (2019). Effects of Initial Soil Properties on Three-Year Performance of Six Tree Species in Tropical Dry Forest Restoration Plantings. *Forests, 10,* 428. https://doi.org/10.3390/f10050428

Coomes, D. A., & Allen, R. B. (2007). Effects of Size, Competition and Altitude on Tree Growth. *Journal of Ecology, 95,* 1084-1097. http://www.jstor.org/stable/4496061 https://doi.org/10.1111/j.1365-2745.2007.01280.x

Ding, Y., Liang, S., & Peng, S. (2019). Climate Change Affects Forest Productivity in a Typical Climate Transition Region of China. *Sustainability, 11,* 2856.

https://doi.org/10.3390/su11102856

Duchesne, L., Houle, D., Ouimet, R., Caldwell, L., Gloor, M., & Brienen, R. (2019). Large Apparent Growth Increases in Boreal Forests Inferred from Tree Rings Are an Artefact of Sampling Biases. *Scientific Reports, 9,* Article No. 6832. https://doi.org/10.1038/s41598-019-43243-1

Fujimori, T. (2001). *Ecological and Silvicultural Strategies for Sustainable Forest Management*. Amsterdam: Elsevier Science, B.V. https://doi.org/10.1016/B978-044450534-7/50012-8

Hagedorn, F., Shiyatov, S. G., Mazepa, V. S., Devi, N. M., Grigor'ev, A. A., Bartysh, A. A., Fomin, V. V., Kapralov, D. S., Terent'ev, M., Bugman, H., Rigling, A., & Moiseev, P. A. (2014). Treeline Advances along the Urals Mountain Range—Driven by Improved Winter Conditions? *Global Change Biology, 20,* 3530-3543. https://doi.org/10.1111/gcb.12613

Haines, H. A., Gadd, P. S., Palmer, J., Olley, J. M., Hua, Q., & Heijnis, H. (2018). A New Method for Dating Tree-Rings in Trees with Faint, Indeterminate Ring Boundaries Using the Itrax Core Scanner. *Palaeoecology, 497,* 234-243. https://doi.org/10.1016/j.palaeo.2018.02.025

He, L., Chen, J. M., Pan, Y., Birdsey, R., & Kattge, J. (2012). Relationships between Net Primary Productivity and Forest Stand Age in U.S. Forests. *Global Biogeochemical Cycles, 26,* GB3009. https://doi.org/10.1029/2010GB003942

Husch, B., Beers, T. W., & Kershaw Jr., J. A. (2003). *Forest Mensuration* (4th ed.). Hoboken, NJ: Wiley.

Johnson, S. E., & Abrams, M. D. (2009). Age Class, Longevity and Growth Rate Relationships: Protracted Growth Increases in Old Trees in the Eastern United States. *Tree Physiology, 29,* 1317-1328. https://doi.org/10.1093/treephys/tpp068

Kirilenko, A. P., & Sedjo, R. A. (2007). Climate Change Impacts on Forestry. *PNAS, 104,* 19697-19702. https://doi.org/10.1073/pnas.0701424104

Kirschbaum, M. U. F. (2000). Forest Growth and Species Distribution in a Changing Climate. *Tree Physiology, 20,* 309-322. https://doi.org/10.1093/treephys/20.5-6.309

Kohl, M., Neupane, P. R., & Lotfiomran, N. (2017). The Impact of Tree Age on Biomass Growth and Carbon Accumulation Capacity: A Retrospective Analysis Using Tree Ring Data of Three Tropical Tree Species Grown in Natural Forests of Suriname. *PLoS ONE, 12,* e0181187. https://doi.org/10.1371/journal.pone.0181187

Larum, D. (2018). *False Cypress Care: How to Grow a False Cypress Tree*. Gardening Know How. https://www.gardeningknowhow.com/ornamental/trees/false-cypress/growing-hinoki-cypress.htm

Martínez-Garza, C., Campo, J., Ricker, M., & Tobón, W. (2016). Effect of Initial Soil Properties on Six-Year Growth of 15 Tree Species in Tropical Restoration Plantings. *Ecology and Evolution, 6,* 8686-8694. https://doi.org/10.1002/ece3.2508

McMurtrie, R. E., Gower, S. T., & Ryan, M. G. (1995). Forest Productivity: Explaining Its Decline with Stand Age. *Bulletin of the Ecological Society of America, 76,* 152-154.

Metsaranta, J. M., & Bhatti, J. S. (2016). Evaluation of Whole Tree Growth Increment Derived from Tree-Ring Series for Use in Assessments of Changes in Forest Productivity across Various Spatial Scales. *Forests, 7,* 303. https://doi.org/10.3390/f7120303

Murty, D., & McMurtrie, R. E. (2000). The Decline of Forest Productivity as Stands Age: A Model-Based Method for Analyzing Causes for the Decline. *Ecological Modelling,* *134,* 185-205. https://doi.org/10.1016/S0304-3800(00)00345-8

Park, S. G., You, Oh, H. C., & Choi, W. K. (2015). Analysis of the Correlation between Site Environmental Factors and Tree Ring Growth in *Chamaecyparis obtusa* Stands in Jeonnam Province. *Korean Journal of Environment and Ecology, 29,* 777-784. https://doi.org/10.13047/KJEE.2015.29.5.777

Paulsen, J., Weber, U. M., & Körner, Ch. (2000). Tree Growth near Treeline: Abrupt or Gradual Reduction with Altitude? *Arctic, Antarctic, and Alpine Research, 32,* 14-20. https://doi.org/10.1080/15230430.2000.12003334

Peters, R. L., Groenendijk, P., Vlam, M., & Zuidema, P. A. (2015). Detecting Long-Term Growth Trends Using Tree Rings: A Critical Evaluation of Methods. *Global Change Biology, 21,* 2040-2054. https://doi.org/10.1111/gcb.12826

Primicia, I., Camarero, J. J., Janda, P., Čada, V., Morrissey, R. C., Trotsiuk, V., Bače, R., Teodosiu, M., & Svoboda, M. (2015). Age, Competition, Disturbance and Elevation Effects on Tree and Stand Growth Response of Primary *Picea abies* Forest to Climate. *Forest Ecology and Management, 354,* 77-86. https://doi.org/10.1016/j.foreco.2015.06.034

Rossatto, D. R., Hoffmann, W. A., & Franco, A. C. (2009). Differences in Growth Patterns between Co-Occurring Forest and Savanna Trees Affect the Forest-Savanna Boundary. *Functional Ecology, 23,* 689-698. https://doi.org/10.1111/j.1365-2435.2009.01568.x

Rozendaal, D. M. A., Soliz-Gamboa, C. C., & Zuidema, P. A. (2011). Assessing Long-Term Changes in Tropical Forest Dynamics: A First Test Using Tree-Ring Analysis. *Trees, 25,* 115-124. https://doi.org/10.1007/s00468-010-0478-x

Ryan, M. G., Binkley, D., & Fownes, J. H. (1997). Age-Related Decline in Forest Productivity: Pattern and Process. *Advances in Ecological Research, 27,* 213-262.

Seo, Y. W., Balekoglu, S., & Choi, J. K. (2014). Growth Pattern Analysis by Stem Analysis of Korean White Pine (*Pinus koraiensis*) in the Central Northern Region of Korea. *Forest Science and Technology, 10,* 220-226. https://doi.org/10.1080/21580103.2014.929052

Seo, Y. W., Lee, D., & Choi, J. K. (2015). Growth Analysis of Red Pine (*Pinus densiflora*) by Stem Analysis in the Eastern Region of Korea. *Journal of Forest and Environmental Science, 31,* 47-54. https://doi.org/10.7747/JFES.2015.31.1.47

Seo, Y., Lee, D., & Choi, J. (2018). Growth Pattern Analysis of Major Coniferous Tree Species in South Korea. *Forest Science and Technology, 14,* 1-6. https://doi.org/10.1080/21580103.2017.1409660

Smith, F. W., & Long, J. N. (2001). Age-Related Decline in Forest Growth: An Emergent Property. *Forest Ecology and Management, 144,* 175-181. https://doi.org/10.1016/S0065-2504(08)60009-4

Soong, J. L., Janssens, I. A., & Grau, O. (2020). Soil Properties Explain Tree Growth and Mortality, But Not Biomass, across Phosphorus-Depleted Tropical Forests. *Scientific Reports, 10,* Article No. 2302. https://doi.org/10.1038/s41598-020-58913-8

Watt, M. S., Moore, J. R., Façon, J. P., Downes, G. M., Clinton, P. W., Coker, G., Davis, M. R., Simcock, R., Parfitt, R. L., & Dando, J. (2006). Modelling the Influence of Stand Structural, Edaphic and Climatic Influences on Juvenile *Pinus radiata* Dynamic Modulus of Elasticity. *Forest Ecology and Management, 229,* 136-144. https://doi.org/10.1016/j.foreco.2006.03.016

Way, D. A., & 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,* 669-688. https://doi.org/10.1093/treephys/tpq015

Wilcke, W., Oelmann, Y., Schmitt, A., Valarezo, C., Zech, W., & Homeier, J. (2008). Soil Properties and Tree Growth along an Altitudinal Transect in Ecuadorian Tropical Montane Forest. *Journal of Plant Nutrition and Soil Science, 171,* 220-230. https://doi.org/10.1002/jpln.200625210

Worbes, M. (1999). Annual Growth Rings, Rainfall-Dependent Growth and Long Term Growth Patterns of Tropical Trees from the Caparo Forest Reserve in Venezuela. *Journal of Ecology, 87,* 391-403. https://doi.org/10.1046/j.1365-2745.1999.00361.x

Zhu, J., Scott, C. T., Scallon, K. L., & Myers, G. C. (2007). Effects of Plantation Density on Wood Density and Anatomical Properties of Red Pine (*Pinus resinosa* ait.). *Wood and Fiber Science, 39,* 502-512.