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Case Studies of Growing Stock and Height Growth Evolution in Spanish Forests

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Abstract

The objective of this chapter is to analyse the importance of the *increment of forest growth rates* in Spain during the last 150 years by giving a retrospective view of growth trends of Spanish forests. Two studies were carried out: (1) study of growing stock evolution of the Spanish forests during the past century; (2) study of forest growth evolution at site level of a forest in Central Spain. Data from inventories of large forests all around Spain are used for the first purpose and individual tree stem analysis data (*Pinus sylvestris*) from Central Spain are used for the second study. Through both studies it is possible to conclude that growing stocks and forest growth followed increasing trends. Increases in growing stocks were caused by changes in silvicultural practices, but changes in site productivity could be associated with changes in climatic and soil conditions. This chapter discusses the relationships between environmental factors and recorded growth increment, concluding that further research efforts are necessary to characterize the processes that drive growth changes.

1. Introduction

From the northern European foresters' point of view, forest growth is mainly understood in terms of wood production. This prevalence is difficult to be applied to most of the Mediterranean forests, where wood is one among other direct products; in many cases it is actually one of the least important ones. Therefore, forest growth is a more complex concept in Mediterranean forests; important direct products (cork, cone, pinyon, resin, firewood, mushroom, pasture, etc.) as well as indirect ones (soil protection, erosion control, water supply, fire prevention, recreation) must be taken into consideration. Consequently, evaluation of forest growth and site productivity is not a simple task in the Mediterranean context, and currently the com-

In the case of Spain, the mentioned conceptual and methodological limitations affect the evaluation of 80% of the total country area, where true mediterranean climatic conditions prevail. On the other hand, wood is the main produce of forests located in both Northern Atlantic and Central Mountain regions of Spain with very important oceanic influences: these forests amount to 36% of the total forested area of Spain (9.3 million ha), and are the main contributors to the total national wood production. The Spanish wood production has increased sixfold from 2.3 million m³ in 1950 to 14.1 million m³ in 1993. This important increment was allegedly caused by several factors: (1) extensive application of silvicultural practices that resulted in higher density and growing stock of the stands; (2) increment of forest growth rates; (3) reforestation in forest gaps; (4) progressive intensification of silvicultural practices; (5) afforestation of new lands and gradual harvesting of the areas afforested since 1940, mainly fast-growing species plantations.

Although the forest administration in Spain is more than 150 years old, it is necessary to emphasize that neither surveys nor studies aiming to assess forest growth trends have been carried out. Consequently, there are no specific data available for undertaking the analysis of forest growth at site level. Nevertheless, there is forest information available, obtained periodically from inventories of the most important forests, since their management planning started at the end of the nineteenth century. In order to reach, at the Spanish level, some of the objectives of the EPI Project on *Growth Trends of European Forests*, this chapter analyses the inventory data available together with tree stem analysis data.

The main objective of this chapter is to analyse how important the *increment of forest growth rates* has been in Spain during the past century by giving a retrospective view of the development of forest productivity. In order to fulfill this objective, the paper has been divided in two parts: (1) Analysis of the evolution of the Spanish forests in terms of growing stock during the last 100 years. For this analysis, case studies are presented using data from five important forests, periodically inventoried since the 1890s. (2) Study of forest growth evolution at site level of a *Pinus sylvestris* forest, using stem analysis of trees with different ages growing in stands of the same site quality.

The results of the two components of the study might allow us to establish if an increment of forest growth has occurred and to analyse possible causes for the growth trends that may be found.

2. Evolution of Growing Stocks: Five Case Studies

2.1. Case Study Location and Description

The first step in our approach has been to analyse the growing stock evolution of Spanish forests. Obviously, increment in growing stock does not mean increment in

Table 1. Case study ecological description

Case	Tree species	Latitude / Longitude	Phytoclimate	Bedrock
Case 1	<i>P. sylvestris</i>	41° 03' N 3° 49' W	Supramediterranean	Granite & Gneiss
Case 2	<i>P. nigra</i>	40° 06' N 1° 57' W	Supramediterranean	Calcareous
Case 3	<i>P. sylvestris</i>	40° 54' N 4° 03' W	Supramediterranean	Gneiss
Case 4	<i>Quercus suber</i> <i>Q. canariensis</i>	36° 35' N 5° 28' W	Mesomediterranean	Sandstone
Case 5	<i>Fagus sylvatica</i>	42° 56' N 1° 59' W	Mountain Eurosiberian	Calcareous

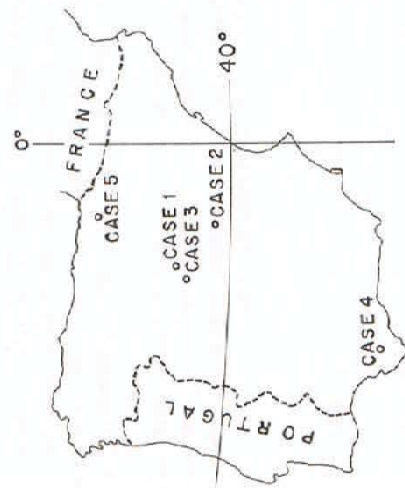


Fig. 1. Map of Spain showing the study case locations.

ies representative of the most important Spanish tree forest species will be presented showing trends in forest growing stocks. Their location and ecological characteristics are shown in Fig. 1 and Table 1. In all the cases, the forested area remained stable during the studied period.

As far as the tree species is concerned, three Central European species (*Pinus sylvestris*, *Fagus sylvatica* and *Pinus nigra*) and two Mediterranean species (*Quercus suber* and *Quercus canariensis*) are analysed.

2.2. Woodstock Evolution Since the 1890s

The oldest data concerning the cases come from their management plan; most of these were started in the 1890s. Permanent compartment method and regular short-rotation system with artificial regeneration, if needed, were applied. Data of study cases 1, 2, 3 and 5 come from the inventories carried out each 10-year period. Data include number of trees, growing stock, allowable cut and real stock harvested during the period of applicability. Tables 2, 3, 4, and 6 show the above described information.

On the other hand, in case 4 the main forest species is *Quercus suber*, devoted to cork production; consequently, Table 5 shows only data of number of trees, lacking any other woodstock information. As number of debarked trees is highly related to cork production, it could be used for assessing changes in site productivity.

Study cases 1 and 2 are examples of *Pinus sylvestris* and *Pinus nigra* forests where more intensive silviculture with aided regeneration has been applied. In contrast, more extensive silviculture has been applied to the *Pinus sylvestris* forest of the study case 3 and *Fagus sylvatica* forest of the study case 5. In the study case 4, a very typical Mediterranean forest with cork as the main direct product, a specific extensive silviculture not aiming for wood but rather for cork production was applied.

The diagram in Fig. 2 shows the growing stock evolution (m³/ha) in study cases 1, 2, 3 and 5. In all the cases, with the exception of case 2 (*Pinus nigra* forest), woodstocks have progressively increased, being compatible with their harvesting (Table 2 to 6). On the other hand, case 2 shows a quite stable trend.

2.3. Discussion

After 100 years of forest management planning, the results - analysed through the evolution of stocks and allowable cuts calculated in the decennial revisions - show an increase in growing stock in most of the cases, both in forests where silviculture was more intensive (cases 1 and 2; Tables 2 and 3) and in those where regeneration aid was less and silviculture more extensive (case 3; Table 4). In case 4 (Table 5), with cork oaks (*Quercus suber* L.) and Murbeck's oaks (*Quercus canariensis* Willd.), intensification is much less evident because the main yield is cork.

Project	Period of applicability	Number of trees		Stocks	Allowable cut during the period	Harvested during the period	Total
		Non metric	Metric				
Management	1896-1905	-	476,825	93,63	45,527	45,596	680,285
1st Revision	1907-16	-	579,266	105,15	46,755	46,856	
2nd Revision	1918-27	-	559,469	108,21	53,031	53,166	
3rd Revision	1928-37	-	619,251	112,92	58,750	58,760	
4th Revision	1938-47	-	707,100	128,45	65,749	73,416	
5th Revision	1948-57	478,386	664,254	136,52	71,418	70,969	
6th Revision	1958-67	476,080	718,412	162,88	90,092	109,008	
7th Revision	1968-77	606,513	722,676	179,25	112,928	111,859	
8th Revision	1979-88	774,134	736,532	184,08	115,541	110,655	
9th Revision	1989-98	925,109	743,752	186,54	135,183	-	659,791 ^a

^aorder to compare allowable cut and stock harvested total values, the last decade is not included.

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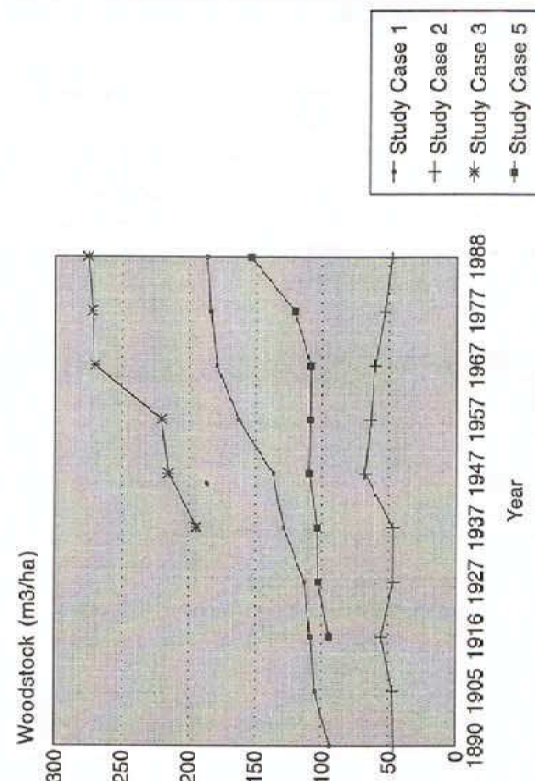
Project	Period of applicability	Number of trees	Stocks	Allowable cut during the period	Harvested during the period
		Non metric Metric	m ³ ha ⁻¹	m ³	m ³
Management	1890-99	-	-	238.01	192.140
	1900-09	-	-	-	142.044
	1910-19	-	-	-	140.054
	1920-29	-	-	-	147.593
	1930-39	-	-	-	119.453
1st Revision	1941-48	852.726	1.854.212	194.40	156.120
2nd Revision	1948-57	708.619	1.862.408	215.20	205.562
3rd Revision	1958-64	808.044	1.868.122	219.27	163.193
4th Revision	1965-77	945.402	1.804.284	270.55	427.699
5th Revision	1978-87	1.151.749	1.841.368	-	232.532
6th Revision	1990-99	2.114.976	2.098.618	275.72	-
Total				2.797.429 ^a	1.927.190

order to compare allowable cut and stock harvested total values, the last decade is not included.

Project	Period of applicability	Number of trees	Stocks	Allowable cut during the period	Harvested during the period
		Non metric Metric	m ³ ha ⁻¹	m ³	m ³
Management	1896-1905	-	429.292	45.62	32.608
1st Revision	1905-15	-	466.776	45.67	34.286
2nd Revision	1915-25	-	511.890	55.37	44.062
Annual plan	1925-28	-	-	-	12.860
3rd Revision	1928-38	-	462.285	46.39	42.697
Annual plan	1938-41	-	-	-	6.867
4th Revision	1941-51	-	456.779	46.49	37.233
5th Revision	1951-60	605.613	521.625	67.64	40.630
Prorogation	1960-65	-	-	-	59.292
6th Revision	1966-75	733.507	506.809	60.16	70.291
7th Revision	1976-81	748.481	493.555	52.88	71.184
8th Revision	1986-95	558.532	450.501	47.72	-
Total				432.929 ^a	452.010

Table 5. Evolution of number of trees in case 4, *El Robledal Forest*. Species: *Quercus suber* and *Quercus canariensis* (5,024 ha)

Project	Date	Number of trees			Mirbeck's oak
		Cork oak		Total	
		Undebarked	Debarked		
Management	1894	0	55,874	55,874	26,278
1st Revision	1904	87,721	117,823	205,544	40,088
2nd Revision	1914	135,239	139,295	274,534	37,298
3rd Revision	-	-	-	-	-
4th Revision	1936	184,963	269,275	454,238	48,642
5th Revision	1944	139,908	276,287	416,195	40,251
6th Revision	1955	161,498	283,222	444,720	35,187
7th Revision	1963	56,357	309,182	365,539	31,981
8th Revision	1971	69,180	324,762	393,942	29,768
9th Revision	1981	109,871	318,537	428,408	27,764
10th Revision	1990	189,767	308,426	498,193	52,002



le 6. Evolution of number of trees, stocks, allowable cut and harvesting in case 5: *Arzalar forest*. Species: *Fagus sylvatica*

7 Ha total; 1144 Ha forested)

Project	Period of applicability	N° of trees $\phi > 20$ cm	Stocks $m^3 ha^{-1}$	Allowable cut during the period of applicability m^3	Harvested during the period m^3
Management	1900-1922	230,790	50.66	43,357	45,787
1st Revision	1923-1936	249,726	53.94	49,215	54,157
2nd Revision	1937-1944	250,387	54.46	32,320	29,947
3rd Revision	1945-1957	251,854	57.48	37,500	41,485
4th Revision	1958-1972	258,428	56.97	32,325	35,666
5th Revision	1973-1993	255,145	60.33	59,240	50,703
6th Revision	1994-2008	255,879	80.75	51,735	-
Total				253,957 ¹⁰	257,745

order to compare allowable cut and stock harvested total values, the last decade is not included.

The following results can be drawn from Tables 2 to 6:

- *Pinar de Navafria* Forest (Table 2): After 100 years of forest management, wood stocks (in m^3) have increased twofold and the number of metric trees (diameter ≥ 20 cm) increased by 1.6. Non metric trees (10 cm $\leq$ diameter < 20 cm) doubled between 1948 and 1989. These increases occurred after extracting 680 285 m³ between 1896 and 1989, which means that the wood harvested was 2.6 times the initial stock. Another indication of the grade of planning fulfillment and the level of the applied silviculture is that actual fellings are almost exactly as proposed in the decennial plans.
- *Los Palancares y Agregados* Forest (Table 3): Current stocks (1985), both in number of metric trees and in m^3 , are slightly higher than the initial stocks (1885). The amount of wood produced by the forest and harvested in 100 years is twice as much as the initial stocks. Data show that the silviculture applied is almost as intensive as in *Pinar de Navafria* with regard to harvesting, but regeneration achieved has not been so intense, shown by the fact that the number of metric trees and stocks remain nearly the same as the initial ones, whereas in *Pinar de Navafria* they have been multiplied by the factors 1.6 and 2, respectively. As in the previous case, the stock harvested coincides almost exactly with what was planned in the management.
- *Pinar de Valsain* Forest (Table 4): Current stocks (1990) remain almost the same as the initial ones (1890). Extractions have been of 1 927 190 m³, slightly higher than the initial volume (1 814 150 m³). This fact, and the fact that only 70% of what had been planned has been extracted, shows that an extensive or less intensive silviculture has been and is being applied in this forest, compared to the two discussed above.
- *El Robledal* Forest (Table 5): Debarked trees («segunderos», producers of high quality cork) were multiplied by a factor of 5.5 between 1894 and 1990, unde-barked trees («bornizos») by factor 2, and the total number of trees by factor 9. Cork yield - according to the current managers - was tripled (enough information to elaborate a complete series of yields is not available).
- *Aralar* Forest (Table 6): In 100 years, the growing woodstock (m^3) was multiplied by a factor of 1.6 and the number of metric trees (diameter ≥ 20 cm) by 1.1. These increments were reached after harvesting 257 745 m^3 . This growth trend shows that the wood harvested during these 100 years is 2.34 times the initial woodstock (110 290 m^3). Although the length of revision periods was rather irregular, the planning objectives were reached surprisingly. There are no data on non metric trees, but regional foresters are sure that the current number is twice the initial figure. The major portion (2177-1144=1033 ha) of area in *Aralar* Forest not covered by trees is a consequence of grazing practices: sheep and cattle are responsible for the fact that the silvicultural plans are not completable at their highest efficiency. The already mentioned irregularity of revision periods is a result of the grazing pressures.

Manuel 1992; Jimenez 1992; Manuel et al. 1993). Although these data are aggregated by forest, they can be considered significant enough and representative of the woodstock evolution in Spanish forests during the past 100 years.

Forest primary production (wood or cork) has increased and other products - environmental or even landscape protection - have not decreased since management started. In no case, not even in the forests with the most intensive silviculture, was soil degradation observable; on the contrary, yields per hectare are either the same or higher compared to the time when forest management plans started, since the forests have more trees and these are more uniformly distributed. Certain European authors (Susmel 1980) in Germany, Switzerland, Austria, Italy etc., have mentioned and in some cases confirmed a possible loss of fertility due to clearcutting followed by artificial regeneration and intense soil preparation. This fact has not been evident in Spanish forests where the silvicultural treatments applied were much less intense than in the cases referred to by this author, although it often included small compartments clearcutting. There is not enough information to confirm - not even to suggest - a certain degradation which should be evident by a decrease of growth and yield of the forests treated with this type of cutting in rotations of nearly 100 years.

A. Evolution of Forest Site Growth

A.1. Theoretical Bases and Methodological Background

From an ecosystemic conceptual view of wood stands, it is generally assumed that any forest site type, defined by its geomorphological, climatic, soil and plant components, has a determined efficiency for biomass production. Such production does not fully coincide with wood production, traditionally considered in economical terms as the only true forest produce.

For traditional foresters, the more accurate methodological approach to evaluate the forest site efficiency for wood production is the repetitive measurement of growing, dead and harvested stocks, along the stand rotation period. This approach is a time- and cost-intensive method, especially when it is applied to long and medium rotation species; consequently, foresters had to develop indirect indicators of forest production, based on measurements of stand attributes such as top height, maximum mean growth, final woodstock or interception. They allow assessment of stand production efficiency in a fast and simple way using data well known to forest managers.

Among these indicators, top height is the most accurate attribute used for wood stand productivity. This accuracy has been empirically demonstrated for determined species and age stand where top height reaches the highest correlation to total volume and consequently wood production. Following Eichhorn's Law established in 1904, the relationship between total production and top height does not depend on the average site quality or stand density. Later researchers have analysed sev-

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better to conifer species than to hardwood species stands; (2) the relationship is more accurate when using stand total volume (growing plus harvested woodstock) than using only stand existing volume; (3) the law is applicable to stand density ranging among the basal area limits established by Wiedemann (1939) and Assmann (1961).

The former considerations give the theoretical bases for using stand top height as indicator of site productivity. If stand top height has varied, and no significant variation in its basal area has occurred during a certain period of time, it is because site productivity has changed in similar quantity.

If site quality curves (top height/age) exist for the studied species, the simplest method for analysing forest growth variation should be to apply these to dominant trees of stands whose site quality has periodically been assessed long beforehand through inventory measurements. Nevertheless, the lack of mathematical accuracy of most of the site quality curves does not allow the use of this method. Comparison between data of stem analysis of dominant trees growing in the same site quality stands but of different age is as the alternate appropriate method for evaluating changes in forest growth at site level.

3.2. Results from *Pinar de Valsain Forest*

Following the previous considerations in the Spanish case, we obtained dominant tree stem analysis data from *Pinar de Valsain Forest* (case study 3) stands of different ages but located on contiguous compartments with the same site quality.

According to the distribution shown in Table 7, two separate samples of dominant trees were selected and measured in 1992: (1) eight old dominant trees, located in different quality sites, aged more than 170 years, from natural regeneration during the period between 1820 and 1840; (2) nine young dominant trees, belonging to stands contiguous to the oldest ones but with their same site quality, aged from 40 to 70 years, from natural regeneration during the period between 1920 and 40.

Both samples were highly representative of the site diversity existing in this 7623 ha forest of *Pinus sylvestris*.

The selected trees were felled and stem analysed, counting tree rings at every 2 m height. From these data, curves of tree height evolution were drawn as shown in Figures 3, 4, 5 and 6.

Table 7. Number of sample trees distributed among site qualities. site index 100 is the stand top height at 100 year age

Site quality	Site index 100	> 170 years	> 70 years
I	> 24.5 m	2	3
II	18.5 to 24.5	3	3

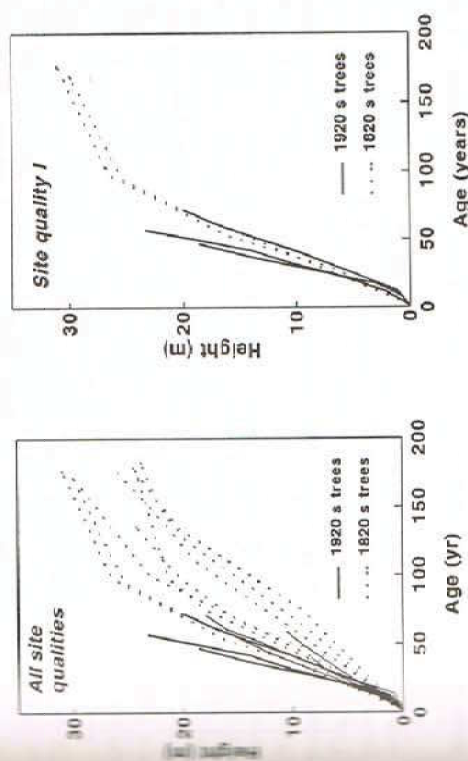


Fig. 3. Stem analysis curves of all sample trees in *Pinar de Valsain Forest*.

Fig. 4. Stem analysis curves of site quality I trees in *Pinar de Valsain Forest*.

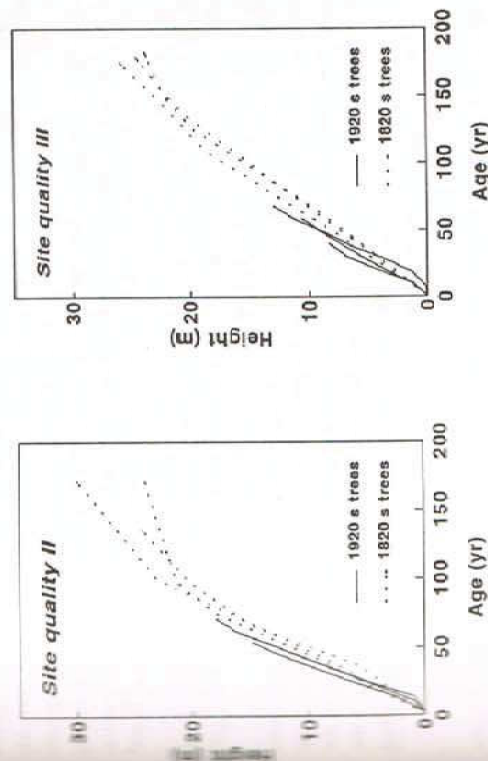


Fig. 5. Stem analysis curves of site quality II dominant trees in *Pinar de Valsain Forest*.

Fig. 6. Stem analysis curves of site quality III dominant trees in *Pinar de Valsain Forest*.

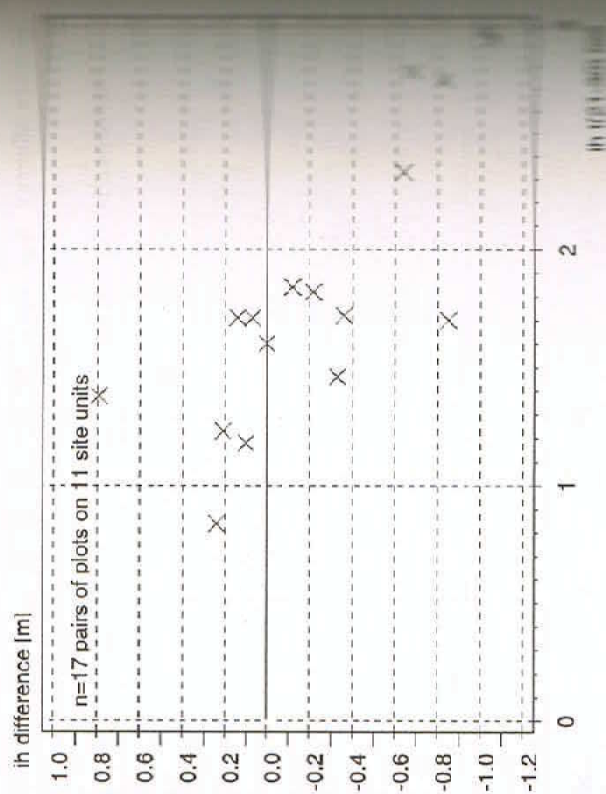


Fig. 5. Difference of 10-year height increment of top height trees between pairs of sample plots within a site unit. Tree age is approximately the same at two different points in time (decade 0-10 and 21-30, difference of 20 calendar years). The maximum age difference of a pair of two plots is 7 years (not plotted). Height increment seems to be smaller in the decade 0-10, smallest increments are linked with high increments in the decade 21-30.

The analysis of data on radial growth shown in Table 2 indicates that radial increment in the last decade (t_{0-10}) is higher than in the decade before (t_{11-20}) in 39 sample plots. This can also be observed in the third decade (t_{21-30}) in comparison to the second decade (t_{11-20}) in 42 sample plots. In the most recent decade (t_{0-10}) radial increment of top height trees increased in 33% of sample plots. In an even greater number of sample plots (46%) the increment of top height-trees increased in the second decade (t_{11-20}) if compared with that in the third decade (t_{21-30}). Thus, radial increment increase already occurred in these plots more than 10 years ago. This increase may be affected by changes in competition, although the analysed trees were generally not thinned, and by climatic influences.

Figure 6 shows the results from applying the second method of trend detection to the radial increment data. No positive trend can be observed. Radial increments seem even to be smaller in the decade 0-10, smallest increments are linked with high increments in the decade 21-30.

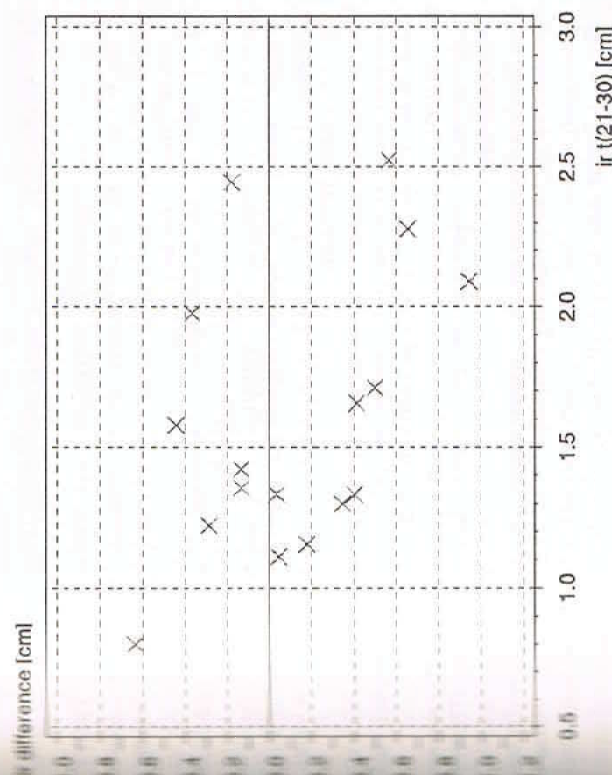


Fig. 6. Difference of 10-year radial increment of top height trees between pairs of sample plots within a site unit. Tree age is approximately the same at two different points in time (decade 0-10 and 21-30, difference of 20 calendar years). The maximum age difference of a pair of two plots is 7 years (not plotted). Radial increment seems to be smaller in the decade 0-10, smallest increments are linked with high increments in the decade 21-30.

Conclusions

No clear answers to the question of whether site productivity changes occurred in beech forests in Slovenia can be given due to methodological problems. A yield table comparison shows clear increases in CAI and height increment but yield tables do not represent sites and silvicultural conditions of the analysed stands in detail. The second approach for the analysis of growth trends, the comparison of growth parameters at the same age of trees or stands regenerated at different periods, only showed a positive trend for top height. CAI, height and radial increment remain unchanged or even decreased with later regeneration period. The method could not be applied on many site units because the ages of the plots on them were not extensive enough.

Generally, it has to be considered that in many parts of the country, diminishing radial growth has been observed due to a high level of SO₂ pollution. This is especially

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Growth Trends in Portuguese Forests: An Exploratory Analysis

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Abstract

The objective of this chapter is to give a retrospective view of growth trends of Portuguese forests to identify possible causes for the observed trends, and, when possible, to quantify their effects. Growth trends were studied for two of the most important forest tree species in Portugal, maritime pine and eucalyptus, using growth data available from other research projects. Poplar (*Populus* sp.) is also included in the study. Different sources of data have been used: (1) individual tree stem analysis data (maritime pine and poplar); (2) permanent plots or long-term experiments (eucalypt); (3) forest inventories of small domains (maritime pine). Meteorological information from four climatic stations was also obtained. The permanent plots and continuous forest inventory data were restricted in order to minimise the heterogeneity in the silvicultural treatments present that could induce changes in growth and therefore lead to incorrect assumptions concerning changes in site productivity. Different methodologies were used for the plot growth data and for the stem analysis data. The first were analysed using multivariate linear regression analysis with the objective of testing the significance of adding the year at the start of the growing period and/or precipitation during the growing season to a base model expressing stand growth as a function of stand variables such as age, site index or stems per ha. The analysis of the residuals from existing growth models was also used to confirm the trends that could be found in the previous analysis. The stem analysis data from maritime pine, representing a relatively long time series, were analysed by fitting a mean height growth curve and plotting the mean annual differences (residuals from the mean curve) over year. Climate-dominant height relationships were studied by modelling the mean annual differences in growth with the meteorological data available, using a stepwise regression procedure. The growth of two generations of poplar trees available was compared by fitting the Richard's function to the whole data set and then separately to the data corresponding to different generations. These analyses indicate that volume growth has been decreasing during the last two decades both for maritime pine and eucalyptus, although the trends in dominant height growth are positive for maritime pine and negative for eucalyptus. The negative