THE EFFECT OF GROUNDWATER DECREASE ON SHORT AND LONG TERM VARIATIONS OF RADIAL GROWTH AND DIEBACK OF MATURE PEDUNCULATE OAK (*Quercus robur* L.) STAND

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Abstract

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Recent changes in the groundwater regime are often regarded as the most influential factor of forest decline and decreased productivity of pedunculate oak forests in Croatia. A groundwater monitoring system was established in all main pedunculate oak forest complexes to collect information and trace changes in the groundwater regime. Research was undertaken to determine the influence of decrease in the groundwater level on forest growth and dieback on a short-term seasonal scale and a long-term scale of 13 years of permanent monitoring. Fluctuations with similar cyclical behaviour of groundwater recharges and seasonal radial growth were found with the aid of Fast Fourier Transform, which confirmed a mutual relationship. Patterns of radial growth were analysed in order to explore the possibilities of early seasonal prediction of decrease in forest productivity influenced by drought. According to these results an improvement of forest managerial practice by using groundwater monitoring data could be done in order to recognise and reduce seasonal drought impact.

Key words: groundwater, tree growth, pedunculate oak, Fast Fourier transform, forest dieback

Introduction

The main ecological factor, which determines survival and productivity of pedunculate oak (*Quercus robur* L.) forests, is abundance of soil water (Matić, 2000). High groundwater tables and groundwater regime on these sites have a key role in holding sufficiently high soil water content. Intensive hydro-ameliorative changes during the last few decades, such as riverbed canalisation and changes in the global climate, have as a result decreased the groundwater tables (Mayer, 1996; Prpić, Anić, 2000). The frequent occurrence of droughts caused by insufficient recharges of soil water has had a negative influence on retaining stability and productivity of pedunculate oak ecosystems (Mayer, Bušić, 1995; Pilaš, Vrbek, 1998). The role of forest management besides economic issues is also to systematically reduce damage and improve forest conditions. However, very little has been done to implement information of present ecological conditions in managerial practice especially in short periods, i.e. vegetation seasons. The primary reason for this inflexibility has been lack of knowledge regarding the relationship between tree growth and groundwater level decrease. Although a huge effort has been done in enlightening tree–soil–water relations (Adamczyk, Fajto, 1987; Bréda et al., 1995; Becker et al., 1996; Kozlowski 1997; Lyngs Ladekarl, 1998) many important questions remain open. The main questions connected to this issue are how to recognize and eventually predict the effect of drought and how to reduce its negative influence on pedunculate oak stand condition and productivity. An excellent basis for analysing this problem is long term groundwater data series collected from a monitoring network that presently consists of 130 piezometric stations on the whole area of pedunculate oak forests in Croatia (Mayer, 1993). The aim of the research was to improve understanding of groundwater and pedunculate oak growth and dieback with the aim of achieving some practical application of these results in forest management. As such, research was undertaken on two smaller groups of trees on a seasonal scale with the aim of determining the temporal (wet and dry season) and spatial (in stand) behaviour of radial growth. In addition to seasonal, the long-term relationship between groundwater, growth and dieback of trees was also investigated on a larger stand scale so as to obtain a wider aspect of their relationship.

Methods

Study site

Research was undertaken in the Varoški Lug forest in northeastern Croatia. The surface area of the forest is 843 ha, and is between 102 and 109 m a. s. l. The parent material consists of swamp clay sediments, clayey silts and sludge, while in the upper layers there is non-calcareous swamp loess. Planosol, gleyic planosol and partly drained gleysol are predominant soil types. The pedunculate oak along with other species in the region makes up the phytocoenosis of the pedunculate oak and the common hornbeam on planosol and gleyic planosol and phytocoenosis of pedunculate oak with great green weed and quaking sedge on gleysols. The groundwater and surface water regimes have changed significantly due to hydrotechnical activities, canalisation of the nearby Glogovnica river as well by internal surface drainage caused by network canals next to forest roads.

Data collection

Groundwater data was obtained through permanent monitoring on 7 piezometric stations installed in the Varoški Lug forest from 1988 to 2000. Pipes that were 4 m deep were processed, and measurements were taken twice a week. Data regarding seasonal radial growth dynamics was collected from two groups made up of up to five trees from 1991 to 1996. So as to look into the stand growth variations, five trees were chosen that were alongside the canal near the forest road while another five trees were chosen that were further inside the stand. A cost effective method of growth measurement was implemented. Metal profiles with bent sharpened edges were pierced into the wood at breast height (immobile part). In the bark of the tree, below the metal profiles, thin plates were placed that would move during tree growth. The distance between the metal profiles and the plates was measured through a growth season with the aid of a vernier calliper gauge, twice a week. Measurements were taken up to the end of 1996 and ended after all five trees placed inside the stand deceased. Data regarding long term radial stand increments were collected from average samples consisting of forty oak trees per stand in three stands around the groundwater measurement stations. A dendrochronological method of analysing the series of annual ring width from 1988 to 2000 was adopted. Research was undertaken in mature oak stands. Additionally, the yearly volume of declined trees was also monitored during the same period in identical forest compartments or stands.

Data analysis

Analysis of groundwater and growth relations on a seasonal scale were performed by exploration of cyclical patterns of data. It was assumed that if groundwater influence on radial growth exists then it would show similar seasonal fluctuations, i.e. a wavelength similar to the groundwater. To avoid the influence of strong seasonal trends, preanalysis included data transformation by differencing. As such, the cyclical behaviour of average rates of changes was compared i.e. the increment of trees and groundwater recharge. This approach was adopted because of large dissimilarities of observation scales, i.e. an increase of groundwater between two observations could be up to one meter and total annual radial tree growth is usually just a few millimetres. Comparisons were made by the use of Fast Fourier Transform (FFT) (Vesala et al., 2000) and computation with Statsoft Statistica 6.0 software. Relationships between growth, annual tree increment and dieback on a long-term scale were analysed by Pearson r correlation and linear regression analysis.

Results

During the few years of intensive seasonal radial growth measurements, relatively favourable soil water conditions were met, especially in 1991, 1994 and 1995. During these three years the groundwater levels were above or close to the thirteen year average level (Fig. 1). The condition of extreme drought occurred in 1993 with groundwater levels quite below the average for piezometers KV1, KV2 and KV4, -48 cm, -58 cm and -53 cm respectively.

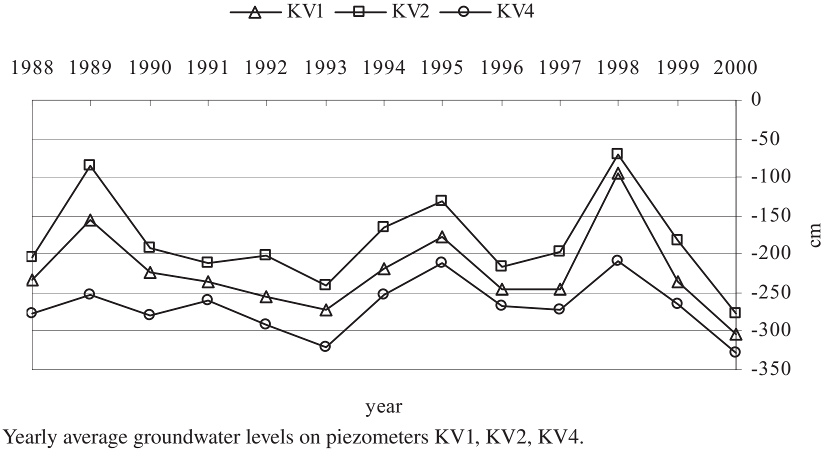

Fig. 1. Yearly average groundwater levels on piezometers KV1, KV2, KV4.

Radial tree growth in the two sample groups in total cumulative amounts (it) was larger in the sample at the forest's edge than the sample inside the forest stand (Table 1). Maximal seasonal average growth of 3.92 mm in the group near stand edge and respectively 2.36 mm in the group inside the stand was found in 1991. The minimal growth of 0.64 mm was found in the plot inside the stand in 1993, or during the season of extreme drought. After dieback of all five trees inside the stand at the end of 1996, measurements ceased. From seasonal behaviour of growth rate some of its characteristics could be deduced. In seasons with larger total growth, its duration throughout the season (Ni) was also longer. From the growth patterns, fluctuations could be separated to which amplitudes are temporally related. Maximal amplitudes in all cases occurred at the beginning of the vegetation season, in the first week of May (initial growth, (iV)). The magnitude of amplitudes decreased towards the end of vegetation season.

T a b l e 1. Total (i_T) and initial (i_V) growth and its duration (Ni) in two sample groups.

		Stand edge		Inside stand		
Year	Total growth iT (mm)	Initial growth iV (mm)	Growth duration Ni (cases)	Total growth iT (mm)	Initial growth iV (mm)	Growth duration Ni (cases)
1991	3.92	0.26	48	2.36	0.18	41
1992	2.22	0.24	41	1.22	0.16	36
1993	2.70	0.18	46	0.64	0.08	28
1994	2.78	0.18	43			
1995	3.50	0.2	44			
1996	3.16	0.34	43			

Quantitatively, the maximal amplitude was determined to be 0.34 mm and there were significant decreases in their magnitude during the season of extreme drought in 1993 (Figs 2, 3). The relationship between growth characteristics was investigated through the use of Pearson correlations (Table 2), and it was found that significant positive correlations (for $p < 0.05$) existed between total growth (i_t) and initial growth, (i_V) (Fig. 4) and the total growth (i_T) and growth duration (Ni).

T a b l e 2. Pearson correlations.

	Total growth i_T	Initial growth i_V	Growth duration Ni
i_T	1		
i_V	0.71	1	
Ni	0.93	0.67	1

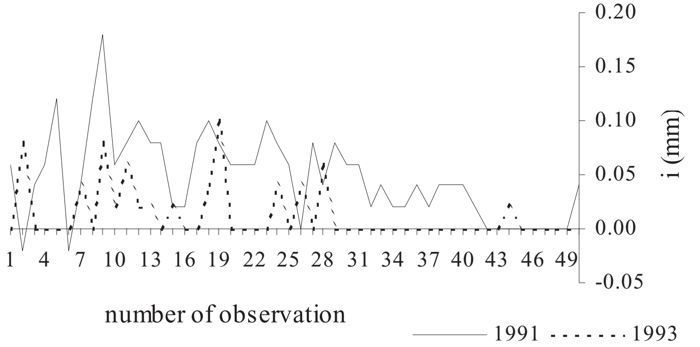

Fig. 2. Seasonal patterns of tree diameter growth of the sample group inside the stand.

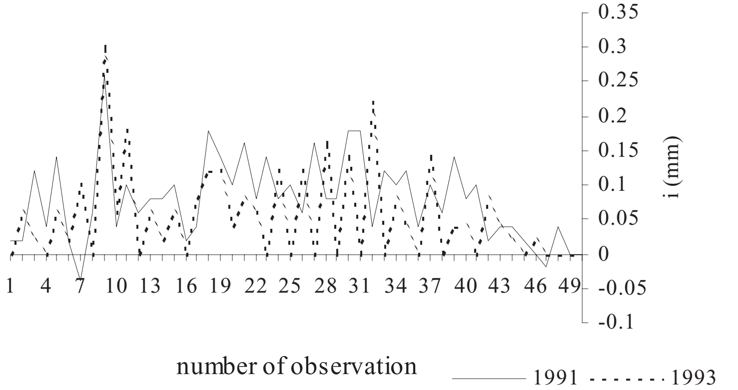

Fig. 3. Seasonal patterns of tree diameter growth of sample group at the stand's edge.

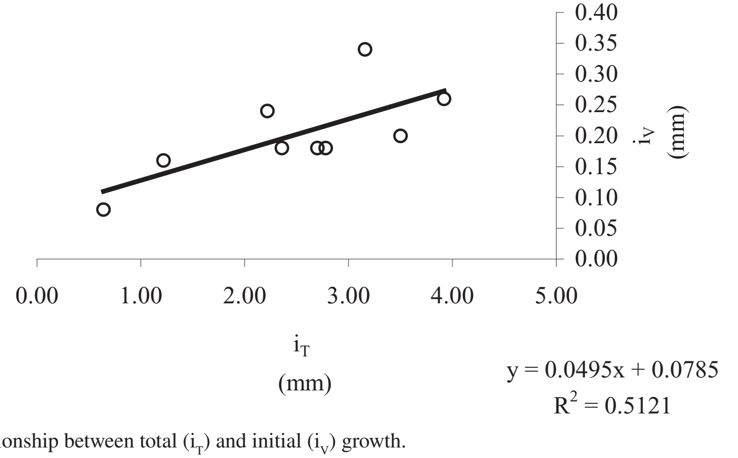

Fig. 4. Relationship between total (i_T) and initial (i_V) growth.

An analysis of growth and groundwater relationships performed by Fast Fourier Transform of data from April to June, (groundwater during this period is usually still within the reach of the tree root system) showed particular existence of cyclical behaviour. Similar periodical behaviour was found in these two elements especially when conditions were favourable as was the case in 1991, and maximal magnitude on the spectral density plot was in both cases 4.8, i.e. approximately 2.5 weeks (Fig. 5). On the other hand some dissimilarities of cyclical behaviour were found in the drought season of 1993 related to a lack of more intensive groundwater recharges that caused a rapid decrease in the groundwater level.

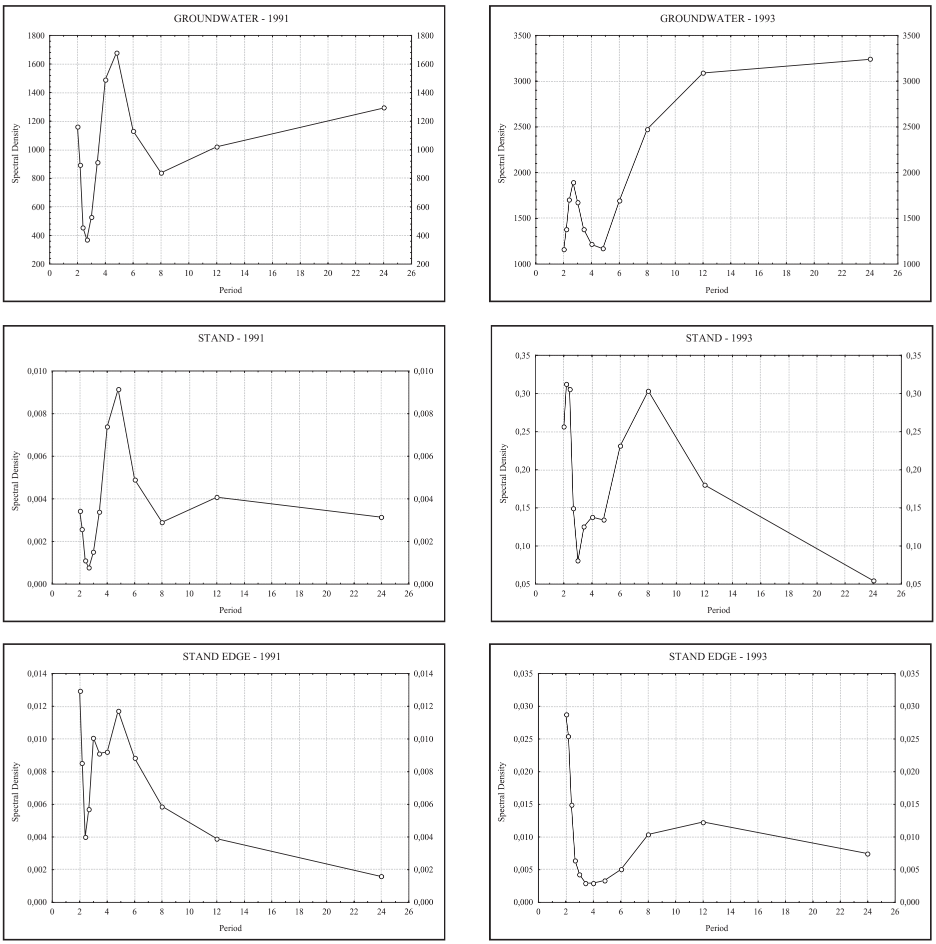

Fig. 5. Spectral density plots of groundwater recharge and fluctuations of radial growth of two sample groups in respective seasons 1991 (left column) and 1993 (right column).

Investigated long-term data series of yearly average groundwater levels (KV1, KV2, KV4), yearly stand radial increments ($i_y c17$, $i_y c7$, $i_y c23$) and yearly volume of dieback trees (V17, V7, V23) on the three sampling plots (Figs 6, 7) showed mutual relationships. Extremely low groundwater levels on all piezometric stations were found in 1993 and 2000. Average stand radial increments were also lowest during these particular years. Significant correlations ($p < 0.05$) between yearly groundwater levels and increment were found but no correlations existed between these two elements in comparison to the volume of dieback trees, Table 3. The largest intensity of dieback was found in the period between 1991 and 1993. In addition, it was determined that in 2000, when groundwater levels were at their lowest level since monitoring began, no significant increase of dieback trees occurred.

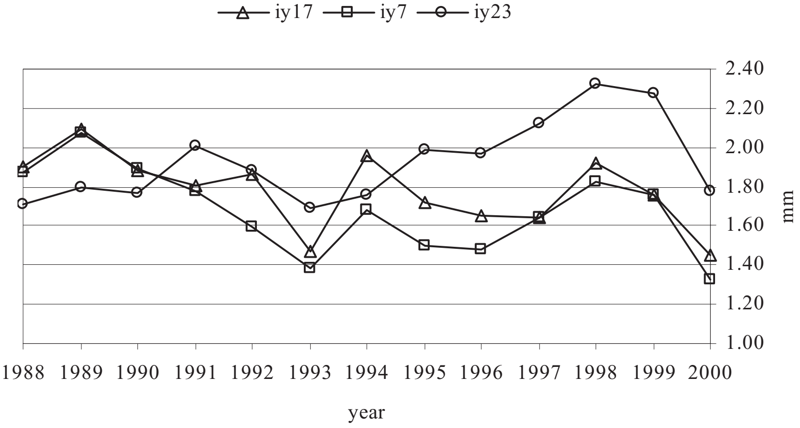

Fig. 6. The average yearly radial increment on sample plots.

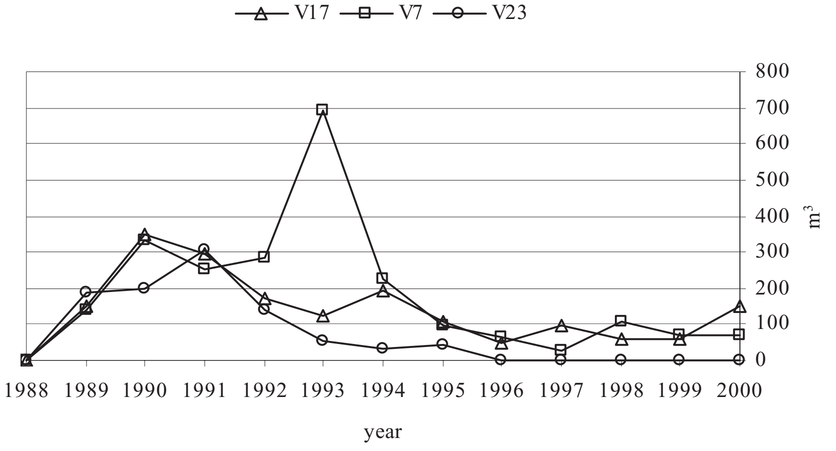

Fig. 7. Forest dieback in volume of dried trees.

T a b l e 3. Pearson correlations.

	Yearly average groundwater level KV2	Yearly radial increment iy7	Volume of declined trees V7		Yearly average groundwater level KV4	Yearly radial increment iy23	Volume of declined trees V23
KV2	1			KV4	1		
iy7	0.64	1		iy23	0.57	1	
V7	-0.23	-0.23	1	V23	0.01	-0.21	1
	KV1	iy17	V17				
KV1	1						
iy17	0.67	1					
V17	-0.13	0.17	1				

Discussion

Tree growth is directly connected to absorbed sun radiation and the efficiency of energy utilisation is affected by plant water status (Kozlowski, 1997; Landsberg, Gower, 1997). Groundwater serves as a very strong ascendant source of soil moisture whose role is crucial for sustaining processes in trees, which generate growth. That is particularly obvious from the results obtained through the presented results on a seasonal basis, i.e. during the vegetation period. Radial increment occurred most intensively during spring, when groundwater was closest to the soil's surface, and decreased towards the end of the vegetation period when the groundwater level fell to minimal values. Radial growth, however, is not continuous but fluctuated where amplitudes are highest during spring and fell towards the end of the vegetation period. Amplitudes are higher in magnitude when the total increment is higher and also when the duration of the season is longer. Fluctuations of radial growth are related to short term increases in soil water whose major source was groundwater and was ascertained with the assistance of FFT. In order to maintain ecologically satisfactory groundwater levels, a recharge in periods of approximately two and a half weeks are required. A prolonged period of groundwater recharge during the vegetation period leads to an imbalance of growth mechanisms, which is reflected in tree productivity (Kozlowski, 1997). In cases of low groundwater levels, the amplitudes of tree increment fluctuations, particularly at the onset of the season, are smaller and increment during the vegetation period have shorter duration. On an annual level, this leads to a smaller annual ring width, i.e. annual increment.

From a forest managerial point of view, it is vital to recognise the size of the radial increment amplitude at the onset of the vegetation period. In establishing autoregression of these values with the total growth values at the end of the season the possibility of early detection and prediction of drought stress and lower annual tree production exists. Although, at this stage, one cannot discuss an objective possibility of estimating productivity at the end of the vegetation season on the basis of a relatively small sample number, the established relationship is significant and helps in explaining the nature of the problem. Pattern of growth is mostly physiologically tempered especially the intense growth at the beginning of May. Enormous water flow through tree stems at the beginning of a season is due to energy needed for formation of leaf biomass (Landsberg, Gower, 1997) when buds begin to swell, while translocation of nutrients from the soil as well as from the tree's reserves, takes place within the tree. With inadequate water in the soil, whose role in the tree is mainly a medium by which nutrients from the soil is transported, the intensity of flow in the tree is diminished. Therefore, groundwater serves as a force that moderates growth patterns. Understanding the momentary intensity of growth can be used to undertake action in terms of forestry activities, mainly thinning (Bréda et al., 1995; Matić, 2000), which can create improved growth conditions for the remaining trees. However, with continuous monitoring of the momentary state of the stand, one is faced with the existence of significant internal and inter-stand variability, which makes the collection of information from various forest surfaces difficult. This is made obvious in the differences of the obtained growth analysis from two groups of trees from this research. It is possible to undertake the transfer of validated rules on large forest surfaces, not in directly monitoring the state of tree growth, but indirectly monitoring inputs, i.e. the actual dynamics of the groundwater. Spatial interpolation of the momentary condition of water table through geostatistical and similar GIS methods (Heuvelink, Webster, 2001) on large surfaces compared to the respective average critical values, as such, this factor can be under control and its effect on the forest could be estimated. Having this information at one's disposal in real time can be extremely useful to forestry managers in the field as on the basis of these indicators, activities for the upcoming season can be planned ahead and warnings regarding increased drought impact and predisposition to increased declining can be brought. In this way, through better utilising knowledge about the ecological conditions for the upcoming season, of which the role of groundwater is a major one, it is possible to maintain sustainable productivity and better protection of pedunculate oak forest ecosystems in the long term.

Conclusion

The investigated relationship between groundwater and forest growth was found either on seasonal and long-term scale. On seasonal scale visible fluctuations of groundwater movement compared to very small fluctuation of seasonal radial tree growth showed similar cyclical behaviour what is proved by aid of Fast Fourier Transform. Seasonal relationship was more visible in state of favourable growth condition with relatively high groundwater level and in that case periodical fluctuations of approximately two and half weeks were found. We estimated that for relatively high total growth on the end of the growing season critical duration of groundwater recharges should be equal or less than two and half week period. In season with extreme drought with strong decrease of groundwater level the shift of that estimated rule was found what resulted with decreased radial tree growth in total.

Particular pattern of seasonal growth was determined therefore amplitudes of short term changes, i.e. weekly increment was highest on the beginning of vegetation season with rate of decreasing to its end. From the forest managerial point of view there are significant importance of determination of relationship between magnitude of weekly radial increment in the beginning of May, which is strongly dependent on groundwater decrease, and total seasonal growth. Knowledge of magnitude of growth in the beginning of vegetation season could give some information of trees condition regarding soil water availability and also total productivity on the end of particular season. Instead of monitoring forest growth on seasonal basis we could also get similar type of information from available groundwater monitoring network. Knowledge of seasonal soil water status obtained by groundwater monitoring data can give important information of momentary water inputs in forest ecosystem. Presentation of groundwater tables by GIS and geostatistical interpolation on large oak forest areas could be useful in improving flexibility of forest management with aim of reduction of eventual seasonal drought by sylvicultural methods.

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