Dendrochronologia, 15, 1997: 129-137

GIORGIO STRUMIA - RUPERT WIMMER - MICHAEL GRABNER
Institute of Botany, University for Agricultural Sciences Vienna, Austria

DENDROCLIMATIC SENSITIVITY OF *PINUS NIGRA* ARNOLD IN AUSTRIA

Key-Words: *Pinus nigra*, response function, rainfall, dendroclimatology, Austria.
Parole chiave: *Pinus nigra*, funzione di risposta, precipitazioni, dendroclimatologia, Austria.

Abstract

Dendrochronological research with Austrian pine (Pinus nigra *Arnold) in the pannonic region of Austria – south of Vienna – shows that it is highly sensitive to summer rainfall with July rainfall being strongly related to the tree growth during this century. Due to its longevity, Austrian pine has a high potential for dendroclimatology.*

Introduction

Austrian pine (*Pinus nigra* Arnold) was scientifically first described by the Viennese physician Arnold in his "Journey to Mariazell" (1785). Austrian pine has five subspecies in the mediterranean and submediterranean mountains between Spain and Asia Minor. The Austrian subspecies (sub. *nigra*) has its main distribution on the Balkan peninsula as well as in Italy. In Austria it comprises areas in south Carinthia and in the eastern part of the northern Alps. The latter has its extension south of Vienna (Vienna Basin), between Rodaun and Rax-Schneeberg (about 52 km). Longitudinally, Austrian pines can be found between the Traisen river in the west and the eastern edge of the Alps in the east (about 45 km). This area is the most northern one reached by this species. It remains unclear if Austrian pine migrated from the south into this area after the last Ice Age or if this area was a refuge for this species during the Ice Age.

The southern Vienna basin belongs to the subpannonic climatic region. The climate has continental characteristics with strong winters but warm and dry summers. The months between May and July are occasionally very dry, and therefore, the low precipitation could limit tree growth.

The Austrian pine used to be commercially important as a pitch tree to yield resin. Many Austrian pine plantations go back to Maria Theresia, emperor of Austria, who has especially supported this industry. But due to the rise of synthetic resinous products, the pitch industry has ceased completely in the 1960s. The first monography on Austrian pine was published by SECKENDORFF (1881) who described accurately the distribution in Lower Austria and Hungary. A recent dissertation by FRANK (1991) has compared the ecology of Austrian pine in Corsica and in the eastern edge of the Alps.

So far, no Austrian pine chronology was established in Austria and very few even are

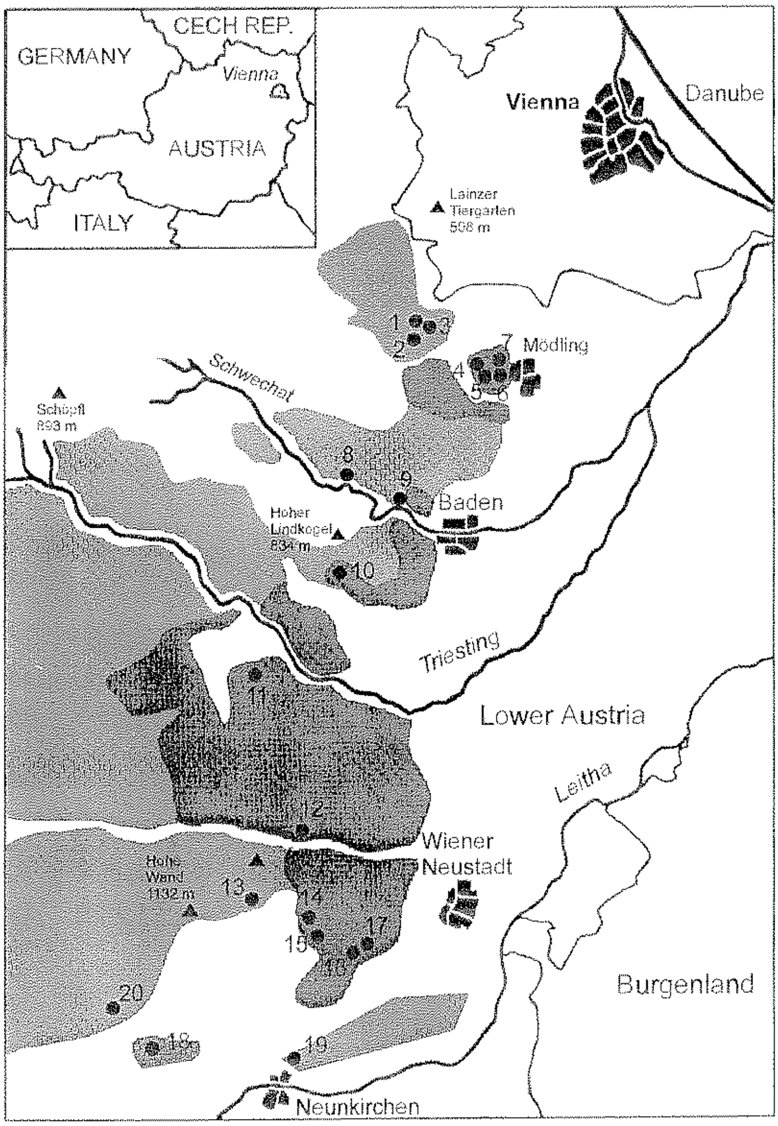


Fig. 1 - Distribution map of Austrian pine (*Pinus nigra* Arnold) in Lower Austria (dark grey: dominant; light grey: scattered) and localisation of the sites sampled: 1 - Bierhäuselberg; 2 - Kammersteinhütte; 3 - Parapluiberg; 4 - Hinterbrühl; 5 - Föhrenhof; 6 - Vorderbrühl; 7 - Schwarzer Turm; 8 - Helenental Sattelbach; 9 - Helenental; 10 - Merkenstein; 11 - Pöllau; 12 - Ruine Starhemberg; 13 - Hohe Wand Köhlröserlhaus; 14 - Ruine Emmerberg; 15 - Winzendorf; 16 - Weikersdorf; 17 - Weikersdorf Harzung; 18 - Stixenstein; 19 - Großer Föhrenwald; 20 - Edenhof.

known from other countries. Kuniholm, Striker (1987) built almost a 1000-year long chronology with historic and prehistoric wood from Greece and Turkey. Dendroclimatological investigations were conducted in Cyprus (Kienast 1985) and Spain (Richter 1988; Richter et alii 1991; Fernandez et alii 1996).

In general, the reconstruction of precipitation is less common than a temperature reconstruction for two reasons. First, the high geographical variation of rainfall makes it difficult to find homogenous growth responses in trees and second, especially Central Europe has few areas where tree growth is restricted by precipitation (Serre-Bachet et alii 1992). Rainfall reconstruction has been successfully applied in arid and semi-arid regions such as in the American Southwest (Grissino-Mayer 1996) and in North Africa (Till, Guiot 1990). In this paper, several chronologies for Austrian pine (*Pinus nigra* Arnold) will be presented and their potential suitability for dendroclimatological reconstruction is discussed.

Material and methods

A network of chronologies was established in the area of the Vienna Basin (Fig. 1) that covered the entire north-south extension of Austrian pine (50 km) whereas the east-west extension was about 20 km. In total, 238 trees were cored at 20 different sites with two cores from each tree by the use of a standard increment borer. We selected sites that exhibited poor and dry soil conditions typically for natural Austrian pine stands with low competition by other species. These Austrian pines growing on shallow soils showed usually an umbrella-shaped crown. Only dominant trees were considered in this investigation.

The tree rings were measured to the nearest 0.01 mm by a LINTAB© measuring device. We have measured separately the widths of earlywood, latewood as well as the total ring width. Problems occurred occasionally with density fluctuations, particularly during the initial 30 years around the pith. But this problem did not effect the good cross-dating which was first checked visually and later controlled statistically using t-values and 'Gleichläufigkeit' computed by TSAP© (Rinn 1996). In addition, quality control of our data was performed by the COFECHA program (Holmes 1994).

In order to improve the climatic strength we have grouped the trees from the 20 sites into 5 regional chronologies according to their geographical association:

- Sites 1, 2, 3 (BIE, KAM, PAR)
  Perchtoldsdorf (39 trees)
- Sites 4, 5, 6, 7 (HBR, FOH, VBR, SWT)
  Mödling (39 trees)
- Sites 8, 9, 10 (HES, HET, MES)
  Helenental (67 trees)
- Sites 11, 12, 13, 18, 20 (POL, STB, HWK, STI, EBH)
  Hohe Wand (44 trees)
- Sites 14, 15, 16, 17, 19 (EMB, WZD, WKD, WKH, GFH)
  Wiener Neustadt (49 trees)

The raw data from the 5 chronologies were standardised using ARSTAN (Cook, Holmes 1986) and we came up with a two step detrending procedure: first, we eliminated mainly the age trend by means of a negative exponential curve or alternatively a linear regression line and second, possible non-climatic disturbances due to stand dynamics were eliminated by using a cubic spline curve with fixed 50%-frequency cut-off of 20, 50 and 100 years (Cook, Briffa 1990). The results were used to model climate-growth relationships using response-function analyses calculated by PRECON (Fritts, Shashkin 1995). We finally have used a spline with a fixed 50% frequency cut-off of 50 years which has shown to fit the data best because it retains high signal-to-noise ratio (SNR) combined with the best response function calibration (Cook, Briffa 1990). Climatic data were made available by the Zentralanstalt für Meteorologie und Geodynamik, and go back to 1845 for temperature and precipitation. The station is located at the head-quarter of the Zentralanstalt, 202 m a.s.l., at Hohe Warte in the city of Vienna.

Results and discussion

Descriptive statistics

Figure 2 represents the standardised regional chronologies between 1700 and 1995. Single trees were found with maximum ages of 680 years. Descriptive statistics for the re-

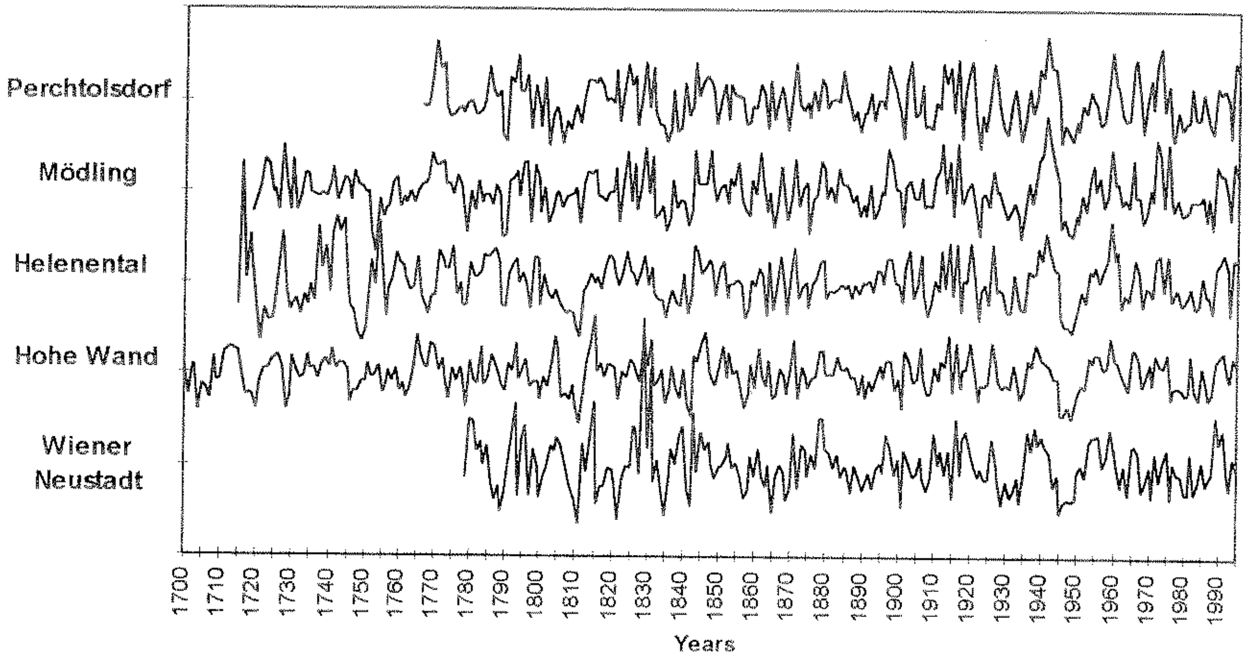


Fig. 2 - Chronologies of Austrian pine from the 5 regions since 1700.

gional chronologies are given in Table 1. The data of the chronology are symmetrical and normally tailed. Only the Wiener Neustadt chronology is slightly left-skewed and has a positive tail. This can be explained because a few sites with rapid growth rates were included in this chronology. SNR is considerably high, especially for the regions Helenental and Perchtoldsdorf. But the numbers should be handled with caution when com-

ID	Perchtolsdorf	Mödling	Helenental	Hohe Wand	Wiener Neustadt
Beginning	1766	1719	1715	1319	1779
End	1995	1995	1995	1995	1995
Years	230	277	281	677	217
N. Trees (N. Cores)	39(79)	39(93)	67(86)	44(89)	49(93)
Median [mm]	0.981	0.985	0.985	1.006	0.973
Minimum value [mm]	0.481	0.321	0.355	0.233	0.359
Maximum value [mm]	1.707	1.867	2.322	1.974	2.61
Sensitivity	0.248	0.237	0.23	0.239	0.277
Standard deviation	0.252	0.239	0.27	0.259	0.293
Skewness	0.302	0.326	0.563	0.175	0.085
Kurtosis	-0.4	0.388	1.538	0.655	3.954
First order autocorrelation	0.273	0.236	0.35	0.336	0.208
Signal-to-Noise Ratio (SNR)	40.69	28.44	46.63	37.73	44.02
Variance of first eigenvector	55.24	49.25	48.13	37.73	44.02
Mean correlation between trees	0.538	0.471	0.463	0.325	0.416

Tab. 1 - Descriptive statistics calculated after standardisation for each regional chronology.

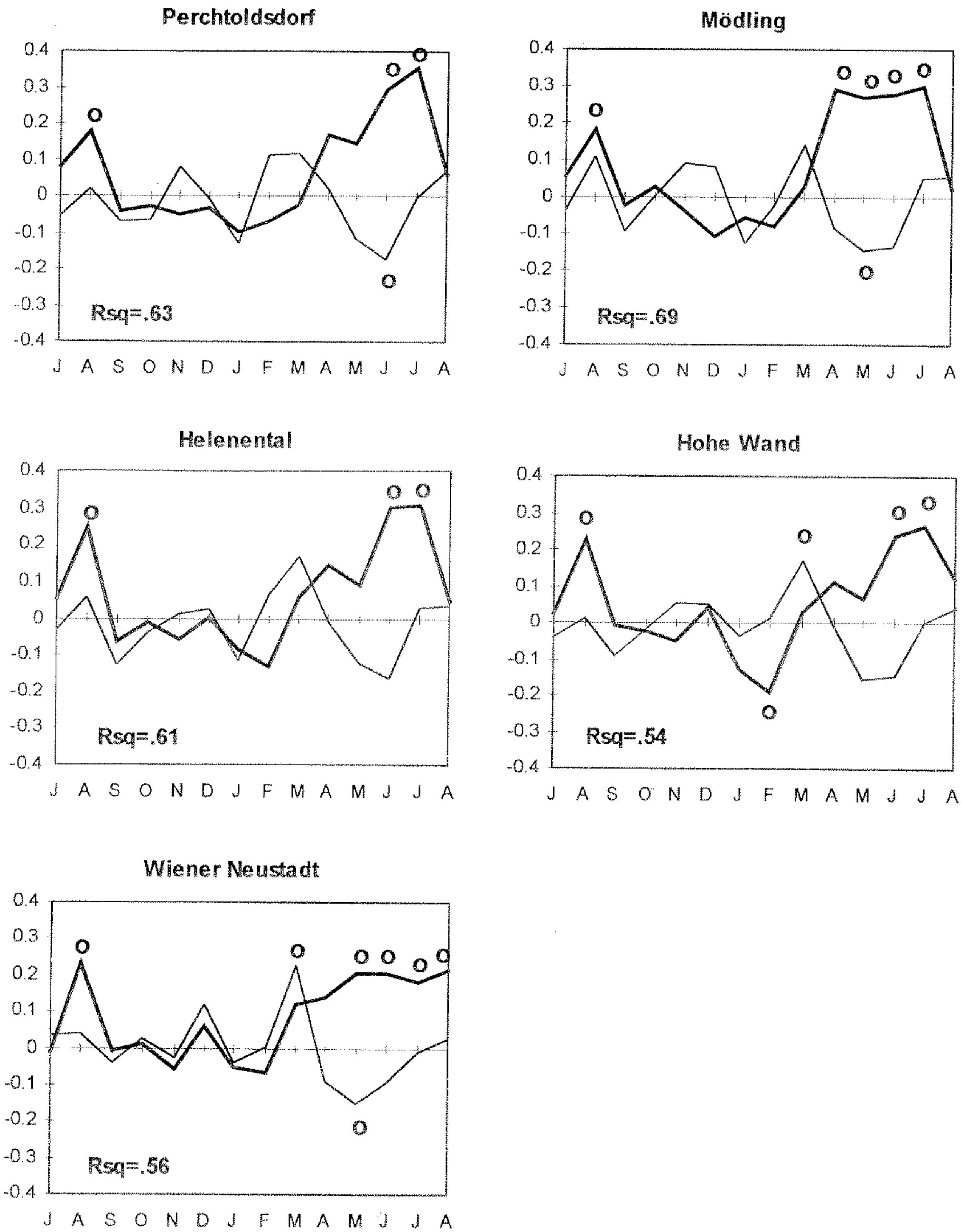


Fig. 3 - Response functions for the period 1900-1990 (14 predictors: from July of the previous year to August of the current year): the thick line represents the relationship between growth and rainfall, the thin line between growth and temperature; circles indicate significance at 5% level. Regression coefficients (x-axis) range from 0.4 to -0.4

pared with other studies since SNR is strongly related with the number of trees investigated on a site.

First order autocorrelations were less pronounced and first-order eigenvector variance was high compared with the data for *Pinus nigra* of those obtained by Richter (1988). Mean sensitivities obtained after detrending are also high. But this is already told by the other parameters since this mean sensitivity is directly related to first-order autocorrelation and firstzeigenvector variance (Strackee, Jansma 1992). In summary, descriptive statistics show some climatic potential of this species.

Response function analysis

The calculated response function for the period between 1900-1990 (Fig. 3) provides a significant pattern of the climate-growth relationships. Percentages of explanation of the response functions with no previous growth included were thoroughly above 50% with a maximum of 70% observed with the Mödling chronology. All the chronologies show high positive regression coefficients for summer rainfall: above average June and July pretcipitation significantly affects growth in all investigated regions. In Mödling also precipitation of the months April and May is significant. For Wiener Neustadt a significant precipitation influence is shown between May and August. In addition, precipitation of the preceding August is significant for all the chronologies.

This is because favourable conditions at the end of a vegetation period increases the growth of the upcoming year. In opposite, unfavourable climate conditions may suppress food reserve accumulation. All five chronologies show a negative relationship between above average summer temperatures and growth of the current year. Although temperature has less impact on growth than precipitation, the results support our hypothesis that dryness in summer limits the growth of Austrian pine trees. On the other hand, cooler and moister summers favour growth.

Shift of rainfall sensitivity

Since the Modling chronology exhibited the strongest relationship with climate, the indexed growth curve was compared with the May and July precipitation. Curves were smoothed with a 11-year running mean filter. July rainfall seems to be well related with ring widths in this century but no superior relationships was seen in the previous century. In opposite, May precipitation seems to follow well the radial growth between 1845 and the 1940s but not during the most recent 40 years (Fig. 4). For a closer look we calculated running response functions for a 50-year window and moved it 10 times in 10-year steps between 1850 and 1990. The partial regression coefficients for the months May, June and July are shown (Fig. 5). June rainfall remains relatively stable over the last 150 years but the July and May coefficient curves exhibit a significant change. The response of annual growth to July rainfall has constantly increased during the last 150 years while the regression coefficient for May rainfall has dropped beyond significance. Long-term rainfall analysis of the eastern region of Austria shows a continual increase from the beginning of this century with a maximum around 1940. Low summer rainfall years

Fig. 4 - Mödling chronology (39 trees) compared with May and July rainfall. All curves were smoothed with a 11-year running mean. May precipitation follows the radial growth between 1845 and the 1940 while July precipitation seems to be better related with tree growth in the last century.

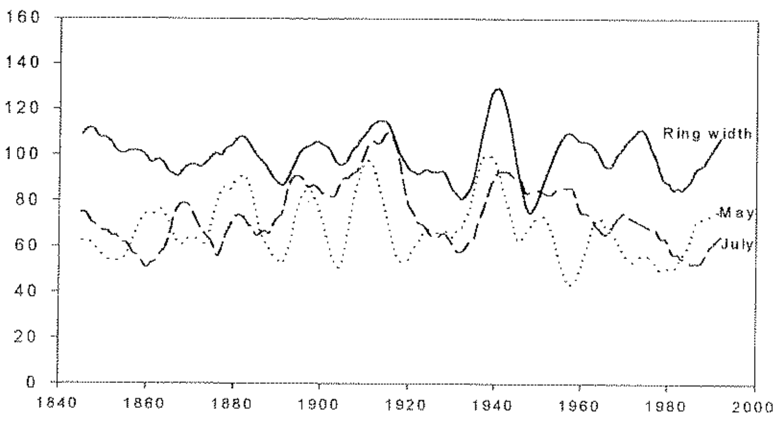
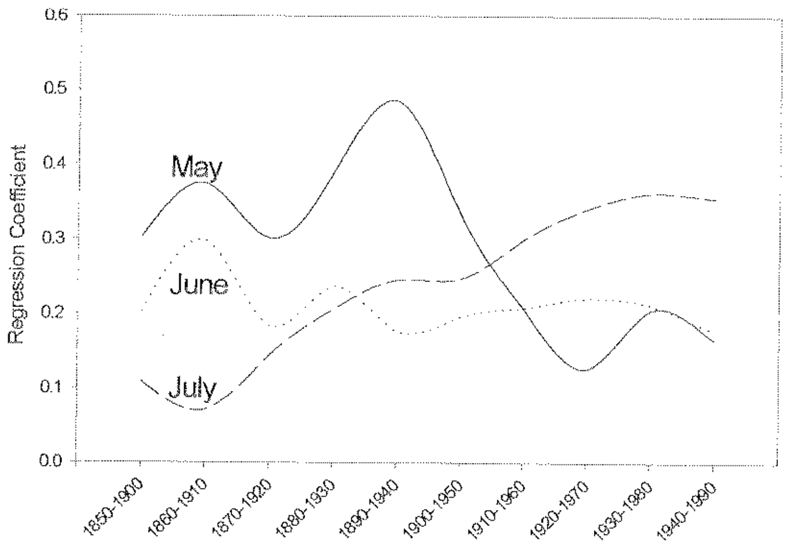


Fig. 5 - Partial regression coefficients calculated for a 50-year window wich was moved 10 times with 10-year steps between 1850 and 1990 for the months of May, June and July of the current year. June is stable for the entire period while May decreases and July increases significantly over the last 150 year (coefficients above 0.28 are significant at 5% level).



were measured especially between 1971 and 1990 with up to 25% under the 1901-1990 rainfall average (AUER 1993). The low rainfall in the summers over the last 20 years has probably favoured July to become more limiting for the growth of Austrian pine.

ACKNOWLEDGMENTS

This research was supported by the Austrian Science Foundation P9200-GEO. Fieldwork assistance by Stefan Liebert is gratefully acknowledged. We also like to thank Prof. Kurt Zukrigl for helpful discussions and all the public forest managers and private forest owners for their generous support during the fieldwork.

LITERATURE

AUER I., 1993. Niederschlagsschwankungen in Österreich. *Österreichische Beiträge zu Meteorologie und Geophysik.* Heft 7. 73 pp.

BRADLEY R.S., JONES P.D. (eds.), 1992. Climate since A.D. 1500. Routledge Publ., London, New York. 706 pp.

COOK E.R., HOLMES R. H., 1986. Users manual for Program ARSTAN. In: Tree-Ring Chronologies of Western North America: California, Eastern Oregon and Northern Great Basin. Laboratory of Tree-Ring Research, The University of Arizona: 50-60.

COOK E.R., BRIFFA K., 1990. Data analysis. In: COOK E.R., KAIRIUKSTIS L.A. (eds.). Methods of dendrochronology: applications in the environmental science. Kluwer Academic Publ. Dordrecht: 97-162.

FERNANDEZ A., GENOVA M., CREUS J., GUTIERREZ E., 1996. Dendroclimatological investigation covering the last 300 years in central Spain. In: DEAN J.S., MEKO D.M., SWETNAM T.W. (eds.). Tree Rings, Environment and Humanity. *Radiocarbon:* 181-190.

FRANK G., 1991. Bestandestypen der Schwarzkiefer (*Pinus nigra* Arnold) im Forêt d'Aitone, Korsika und am Niederösterreichischen Alpenostrand. Diss. Univ. für Bodenkultur Wien, 200 pp.

FRITTS H.C., SHASHKIN A.V., 1995. Modeling tree-ring structure as related to temperature, precipitation, and day length. In: LEWIS T.E. (ed.), Tree Rings as Indicators of Ecosystem Health. CRC Press, Boca Raton: 17-57.

GRISSINO-MAYER H.D., 1996. A 2129-year reconstruction of precipitation for north-western New Mexico, USA.In: DEAN J.S., MEKO D.M., SWETNAM T.W. (eds.), Tree Rings, Environment and Humanity.*Radiocarbon:* 191-204.

HOLMES R.L., 1994. Dendrochronology program library - Users manual. Laboratory of Tree-Ring Research. University of Arizona, Tucson, Arizona, USA, 51 pp.

KIENAST F., 1985. Dendroökologische Untersuchungen an Höhenprofilen aus verschiedenen Klimabereichen. Diss. Univ. Zürich.

KUNIHOLM P.L., STRIKER C.L., 1987. Dendrochronological investigation in the Aegean and neighboring region, 1983-1986. *J. Field Arch.* 14: 385-398.

RICHTER K., 1988. Dendrochronologische und dendroklimatologische Untersuchungen an Kiefern (*Pinus* spp.) in Spanien. Diss. Univ. Hamburg, 296 pp.

RICHTER K., ECKSTEIN D., HOLMES R.L., 1991. The dendrochronological signal of pine trees (*Pinus* spp.) in Spain. *Tree-Ring Bull.* 51: 1-13.

RINN F., (1996). TSAP Time Series Analysis and Presentation. Version 3.0 Reference manual. 262 pp.

SECKENDORFF A.F., 1881. Beiträge zur Kenntniss der Schwarzföhre. *Mitteilung aus dem forstlichen Versuchswesen Oesterreichs.* Carl Gerold Verlag, Wien, 66 pp.

SERRE-BACHET F., GUIOT J., TESSIER L., 1992. Dendroclimatic evidence from south-western Europe and north-western Africa. In: BRADLEY R.S., JONES P.D. (eds.). Climate since A.D. 1500. Routledge Publ., London, New York: 349-365.

STRACKEE J., JANSMA E., 1992. The statistical properties of mean sensitivity - A reappraisal. *Dendrochronologia* 10: 121-135.

TILL C., GUIOT J., 1990. Reconstruction of precipitation in Morocco since 1100 AD based on *Cedrus atlantica* tree-ring widths. *Quaternary Research*, 33: 337-351.

SUMMARY

Dendroclimatic sensitivity of Pinus nigra *Arnold in Austria*

Dendrochronological results using Austrian pine (*Pinus nigra* Arnold) sampled in the pannonic region of Austria – south of Vienna – are presented. A response functions analysis shows that Austrian pine is highly sensitive to summer rainfall with July rainfall being strongly related to the tree growth of this century. In the previous century, no such relationship could be observed. May rainfall on the other hand used to have strong effects on growth but this relationship ceased during the last 40 years. Due to its high climate sensitivity as well as its longevity, Austrian pine has a high potential for dendroclimatology. But seasonal climate-growth relationships shift over time which has to be taken into account when using this species for climate reconstruction purposes.

RIASSUNTO

Sensitività dendroclimatologica del Pinus nigra *Arnold in Austria*

In questo articolo vengono presentati i risultati di una ricerca dendrocronologica condotta con il Pino d'Austria (*Pinus nigra* Arnold) nella regione pannonica dell'Austria, a sud di Vienna. Un'analisi delle funzioni di risposta mostra che questa specie è altamente sensitiva alle precipitazioni estive ed in particolare la crescita diametrale nell'ultimo secolo è strettamente legata alle piogge del mese di luglio. Nel secolo scorso non è stato possibile osservare tale correlazione. Anche le piogge del mese di maggio hanno avuto una forte influenza sulla crescita, che però cessa negli ultimi 40 anni. Grazie alla sua sensibilità al clima e alla sua longevità, il Pino d'Austria dimostra un notevole potenziale dendroclimatologico. Le relazioni stagionali tra clima e crescita possono però variare nel corso del tempo e devono pertanto essere tenute in considerazione nell'usare questa specie per ricostruzioni climatiche.

ZUSAMMENFASSUNG

Dendroklimatologische Sensitivitat von Pinus nigra *Arnold in Österreich*

Diese Arbeit präsentiert dendrochronologische Ergebnisse für Schwarzkiefer (*Pinus nigra* Arnold) aus dem pannonischen Raum südlich von Wien. Eine Responsefunktionsanalyse zeigt, daß das Wachstum der Schwarzkiefer besonders empfindlich auf Sommerniederschlag reagiert. Die Juli-Niederschläge in diesem Jahrhundert korrelieren sehr gut mit dem Wachstum. Im letzten Jahrhundert konnte hingegen ein nur geringer Zusammenhang gefunden werden. Die Mai-Niederschlage zeigten einen starken Einfluß auf das Wachstum, der aber in den letzen 40 Jahren nicht mehr nachzuweisen ist. Aufgrund ihrer Klimasensitivitat sowie ihres hohen Lebensalters ist die Schwarzkiefer für dendroklimatologische Untersuchungen besonders gut geeignet. Jedoch muß besonders bei Klimarekonstruktionen bedacht werden, daß Klima-Wachstumsbeziehungen sich im Laufe der Zeit signifikant verändern können.

Indirizzo degli Autori:

GIORGIO STRUMIA - RUPERT WIMMER - MICHAEL GRABNER
Institute for Botany
University for Agricultural Sciences, Vienna (Boku)
Gregor Mendel Strasse, 33
A-1180 Wien, Austria