Comparative Dendroclimatological Studies of the Impact of Temperature and Rainfall on *Pinus nigra* Arnold and *Pinus sylvestris* in Northwestern Poland

ANNA CEDRO

Laboratory of Climatology and Marine Meteorology, Institute of Marine Sciences, Faculty of Natural Science, University of Szczecin, Waska 13, 71-415 Szczecin, Poland, Phone: 0048 91 4441641, e-mail: Anna.Cedro@univ.szczecin.pl

Cedro, A. 2006. Comparative Dendroclimatological Studies of the Impact of Temperature and Rainfall on *Pinus nigra* Arnold and *Pinus sylvestris* in Northwestern Poland. *Baltic Forestry*, 12 (1): 110–116.

Abstract

The research focused on two pine species; the native one for the investigated area - *Pinus sylvestris*, and species introduced from S Europe – *Pinus nigra*. The analysed trees grow in the municipal forests in Szczecin (NW Poland). The chronology established for the black pine spans 108 years (1895-2002), and the master pattern for the Scots pine consists of 115 annual growth rings (1886-2000). The constructed chronologies were used as a basis for dendroclimatological analyses: response function and signature years. Both analyses have demonstrated different relations between the increments and climate at the investigated pine species, in spite of high similarity of the discussed chronologies (Gl = 71.9%, t = 5.21). The native pinus display high sensitivity on thermal conditions in winter (especially February) and in the beginning of spring, whereas the amount of rainfall in the vegetation season proves to be of lower importance. On the contrary, the cambium activity of the black pine is highly dependent on the amount of rainfall in the vegetation season (positive significant values of correlation and regression for May, June and July), whereas winter (February) thermal conditions may be considered as an additional factor affecting the tree growth.

Key words: tree-ring width, dendroclimatology, climatic conditions, signature years, response function, *Pinus nigra* Arnold, *Pinus sylvestris* L., NW Poland

Introduction

At a limited number of native tree species in NW Europe, an effect of a row of Pleistocene glaciations combined with longitudinal orientation of main mountain ranges, numerous foreign species of the dendroflora have been imported to the region. The foreign species were introduced for an increase in the growth and productivity of the tree stands, production of timbers of better technical parameters and higher resistance to parasites, soil recultivation, higher resistance against industrial pollution, as well as for aesthetical reasons. The research plots were established in order to check the adaptation of the imported tree species to the local climate and habitat conditions, the possibilities of the seed germination and regeneration of tree stands and also the productivity of the latter in the conditions of intensive cultivation.

In Poland, the foreign tree species are considered to form below 1% of the total tree stands (Szwagrzyk 2000). The most abundant exotic species is *Pseudotsuga menziesii* Franco, then, among the coniferous trees, *Pinus strobus* L., and the next introduced species of the *Pinus* genus is *Pinus nigra* Arnold (black pine).

The natural distribution of the *Pinus nigra* Arnold encompasses southern parts of Europe and Asia Minor, as well as the mountainous regions of NW Africa. Trees of this species are characterised by low soil requirements and resistance against atmospheric pollution and frosts. (Seneta and Dolatowski 1997). In Poland the black pine was presumably introduced in the second half of the nineteenth century, not only as a park tree, but also into the forest cultures (Szymanowski 1960, Tumilowicz 1970). The most often cultivated subspecies is the Austrian variety (*Pinus nigra* subsp. *nigra*), (Seneta and Dolatowski 1997).

In Szczecin, old specimens of this tree species may be often encountered in parks, cemeteries, and private gardens (Stachak *et al.* 2000). Two research plots, of which one was investigated by the author, are located in the sub-urban forests.

The study presents results of dendroclimatological research of *Pinus sylvestris* L., the native, predominating in Poland pine species, and *P. nigra* Arnold from the Municipal Forests of the city of Szczecin (NW Poland, Fig. 1).

Figure 1. The area of investigation

Material and methods

Material

The first investigated research plot is situated within the Beech Primeval Forest (Puszcza Bukowa), near the Emerald Lake (Jezioro Szmaragdowe), in the habitat of the fresh mixed forest (the Municipal Forests of the city of Szczecin, division 125a). The tree stand is composed of 119-year-old black pines, 26 m in height and 34 cm in diameter. The brushwood consists of the beech, oak, and rowan tree. Samples were taken from 21 black pines, predominating in the investigated tree stand.

The research plot representing the tree stand of *Pinus sylvestris* L. is located in the division 54b of the Municipal Forests of the city of Szczecin. This area is a part of the Warszewo Hills (Wzgorza Warszewskie) – a moraine bank formed during the last glaciation, composed of glacitectonically distorted Quaternary sediments. Around 120-year-old tree stand, composed of various coniferous tree species (*Pinus sylvestris*, *P. strobus*, *Pseudotsuga menziesii*, and *Larix decidua*), grows in a habitat of the fresh mixed forest

Methods

Dendrochronological analysis was carried out for 43 selected black and Scots pine, growing in the Municipal Forests of the city of Szczecin ($53^0$26'N, $14^0$33'E). The cores were sampled with a Pressler increment borer, 1.3 m above the ground level (Les 1988). In order to prevent any possibility of the attack of pathogenic factors, cored sites were protected with wooden sticks of the same diameter as the borer and with a bacteria- and fungicide substance (Lac-Balsam).

For every cored sample, ring width measurements were performed within 0.01 mm accuracy. Matching of individual series with calendar years and construction of the chronology were made following the classical methods of dendrochronological dating, presented in numerous published works (Cedro 2004, Cook and Kairiukstis 1992, Kaennel and Schweingruber 1995, Schweingruber 1989, Zielski and Krapiec 2004). Thereafter, with the help of the computer program *Arstan* (Holmes 1983, 1994) the long-term trends (*e.g.* age trend) were eliminated from the chronology, and the year-to-year variability in widths of the annual tree rings was accentuated.

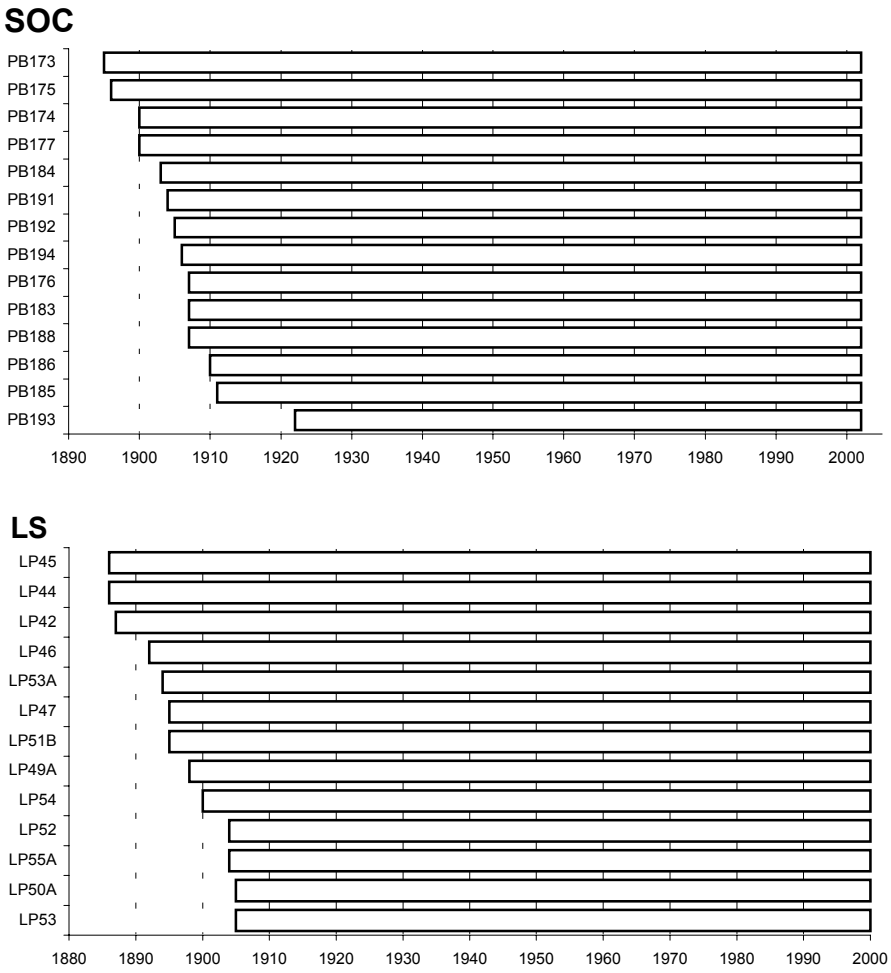
The conducted chronology was used as a basis for dendroclimatological analyses: response function and signature years. The response function analyses were based on meteorological data (average monthly air temperatures and total monthly rainfall) from the meteorological station Szczecin-Dabie for the period 1948-2000 (52 years), and the indexed values of the annual tree-ring widths. Analysis was carried out using climate variables of 16 months: from July of the previous year to September of the current year according to Blassing *et al*. (1984), *i.e.,* impact of thermal and pluvial conditions of the preceding summer, autumn, winter and current vegetation season on the formation of tree rings was investigated. The years in which over 90% of the analysed trees exhibited similar growth trends were defined as signature years. When the increments were narrower than a year ago, the signature years were negative, and in the opposite case – positive. Signature years were determined with the aid of program TCS (Walanus 2002). Analysis of climatic conditions inducing the signature years was conducted.

Results

Chronologies

The chronology labelled SOC represents trees of the species *Pinus nigra* from the analysed site. The 108-year chronology (1895-2002) was produced from 14 individual series. The shortest sequence (PB193) consisted of 80 annual growth rings, whereas samples PB173, 175, 174, and 177 contained more than 100 years (Fig. 2). The average width of the analysed tree-rings is 1.8 mm. The chronology revealed years with strong reductions of radial growth rings (1917, 1925, 1929, 1940, 1945, 1952, 1959, 1963, 1976, and 1983), as well as years with the increments higher than the average: 1916, 1920, 1926-28, 1942, 1958, 1961, 1965-68, 1979-80, and 1997 (Fig. 3).

In October 2000 sixteen samples of *Pinus sylvestris* were taken from the second research plot. The local chronology LS, based on the 13 mutually best



Fiure 2. Spans of individual series of the radial growth of *Pinus nigra* (SOC) and *Pinus sylvestris* (LS)

matching growth sequences, is 115 years long and represents the period 1886-2000 (Fig. 2). Analysis of the series forming the chronology LS demonstrated numerous characteristic years; with minimal increments (1931, 1940, 1947, 1969, and 1983), and with the annual growth widths higher than the average (1945-46, 1962, 1967, 1991-94, and 1997). Generally, the radial growth reductions were in the 1970s and 1980s, and higher radial growth rates - in the last decade of the twentieth century (Fig. 3). The average width of the annual increments in the analysed trees was 1.38 mm.

Signature years

Chronology SOC displays high similarity of individual dendrograms, as well as a high number of signature years (29 years; 10 positive and 19 negative). The chronology LS contains also ten positive years, but only eight negative ones, altogether 18 signatures. The years 1916 and 1920 were positive, and the years 1909, 1911, 1917, and 1940 – negative in both of the discussed chronologies (Figure 4).

Analysis of climatological conditions for the positive signature years of *Pinus nigra* have revealed the strong connection between the radial growth and summer rainfall; the rainfall higher than usual has triggered positive growth reactions. Negative signature years were attributed to dry summers (drought in May, June or July, often combined with high temperatures), and with extremely low winter temperatures, especially in February. For example, a positive signature year, 1960, was marked by the highest annual rainfall in the period 1948-2000 (718 mm, almost 200 mm above the average) and humid summer (especially July, with unusually heavy rainfall). The winter of that year (February) was relatively frosty, which was not, however, reflected in growth reactions of the analysed trees. One of the negative signatures for the analysed species, the year 1963, was characterised by very frosty February (-6.6˚C, the average for that month -0.2˚C) and very low annual rainfall of 390 mm (the average above 530 mm), as well as dry and hot May, June and July.

The link radial increment-climate is different for the native pine species (*Pinus sylvestris*). The posi-

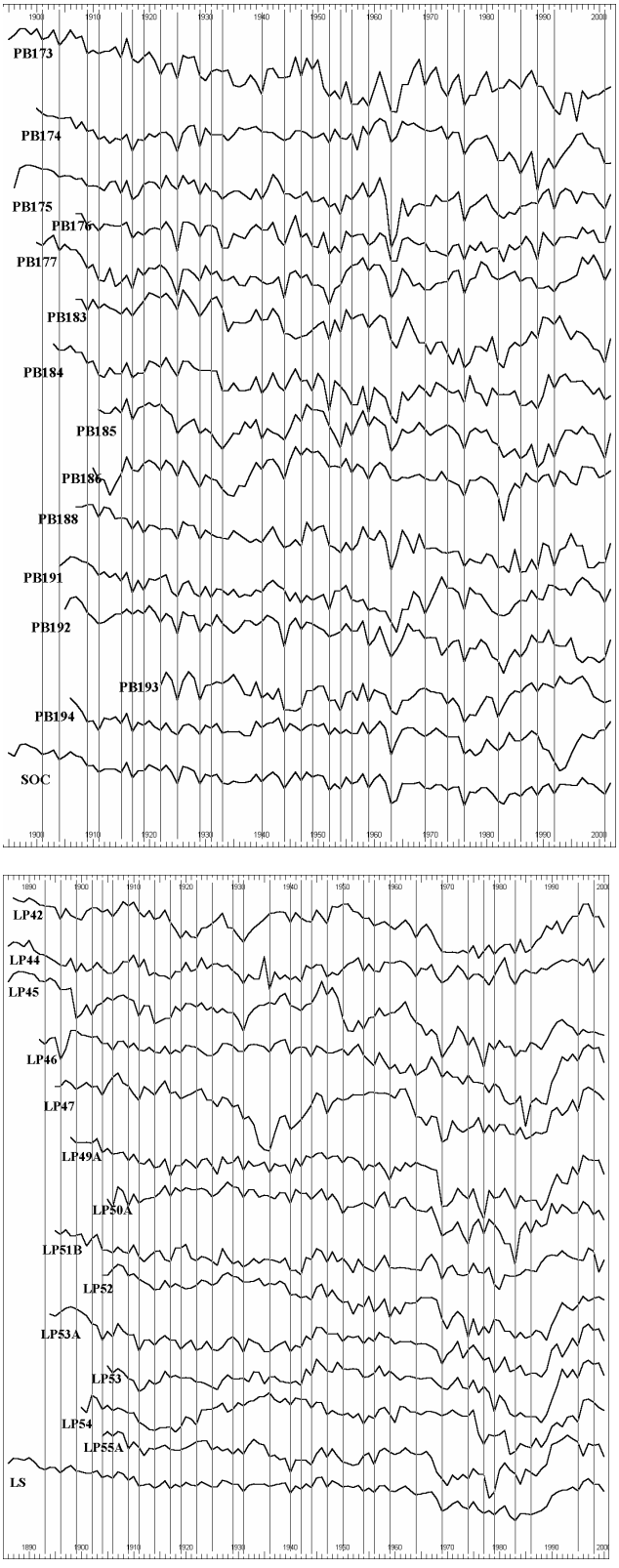


Figure 3. Dendrochronological patterns of *Pinus nigra* and *Pinus sylvestris* radial growth

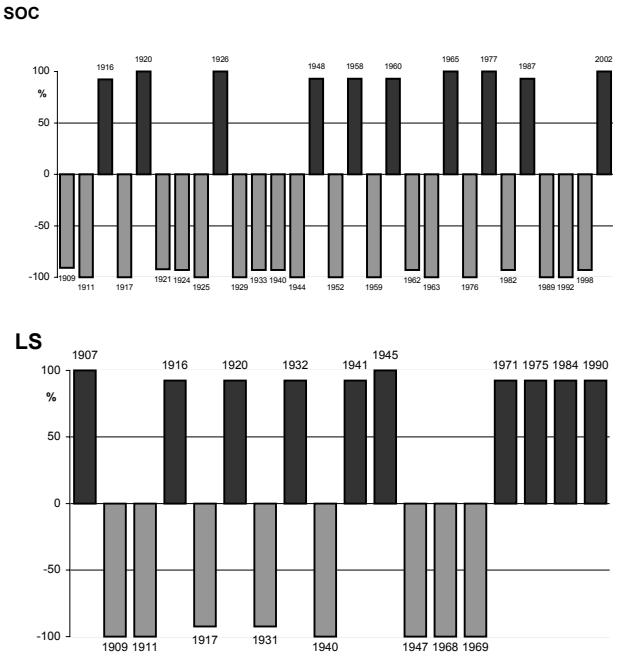


Figure 4. Positive and negative signature years of *Pinus nigra* (SOC) and *Pinus sylvestris* (LS)

tive signatures are mostly connected with mild winters and early and warm springs, whereas the summer rainfall is of lower significance. The conditions favouring positive growth reactions of trees took place, among others, in 1945, when the short and mild winter was followed by the humid summer. In most cases of the negative signature years, they were induced by unfavourable thermal conditions of winter and beginning of spring, in particular February and March. Diminution of the cambial activity could be additionally caused by summer droughts. The increment reductions noted for the year 1969 should be related to very frosty winter and cool March combined with shortage of rainfall in June and July.

The positive signatures common for both of the discussed pine chronologies (1916 and 1920) were marked by mild winters and heavier than usual summer rainfall. On the other hand, in the negative years (1909, 1911, 1917, and 1940) the winters were long and frosty, whereas the summers dry and hot.

Response function analysis

The results of the response function analysis are presented in Figure 5. The results indicate high positive relations between the annual growth widths of *Pinus nigra* Arnold and precipitation in the end of spring and summer months: May, June, and July. Positive values of the correlation and regression prevail for precipitation in the whole analysed period, statistically significant values also appear for February

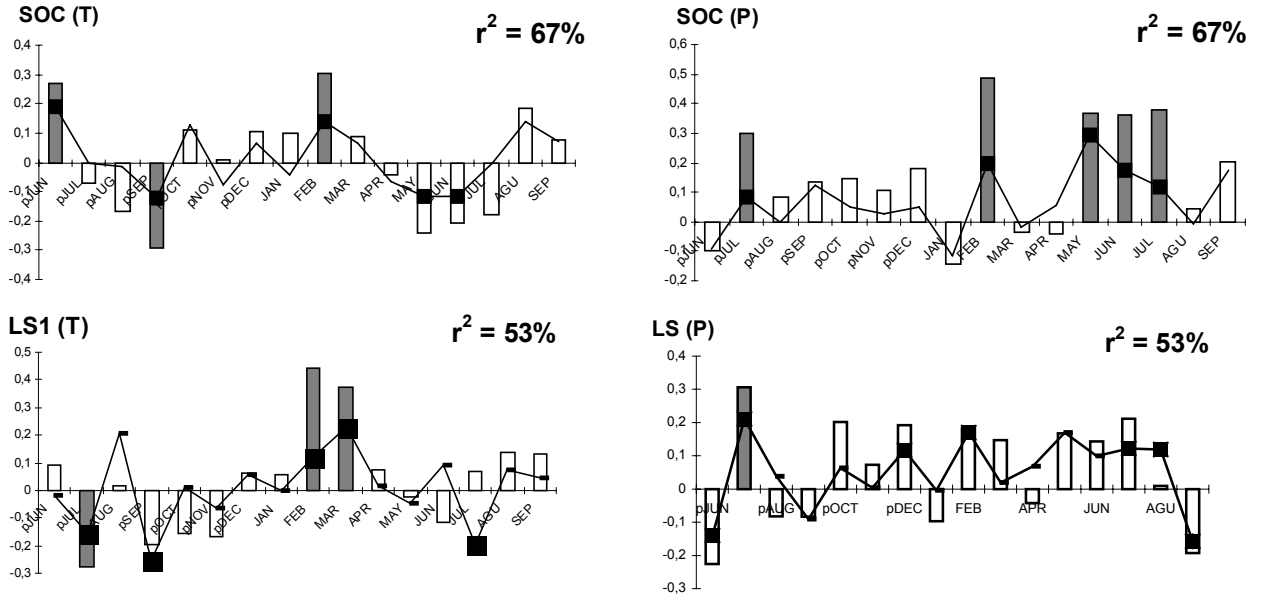


Figure 5. Results of the response function analysis and correlation coefficients for temperature (T) and rainfall (P); simple correlation coefficients – bars, regression coefficients – lines. Values statistically significant for $\alpha = 0.05$ – gray bars and black squares, SOC – *Pinus nigra,* LS – *Pinus sylvestris*

and for July of the previous vegetation season. Temperatures in February have significant positive impact on the annual increments of the analysed species; the temperatures higher than the average (-0.2˚C) and relatively high rainfall (above 29 mm) are connected with domination of cyclonal systems from the Atlantic Ocean in this month. Negative regression values for May and June demonstrate fragility of the trees for summer heats, especially when combined with shortage of rainfall. The determination coefficient (r^2) for the analysed research plot reaches a high value of 67%, expressing the strength of relations between the analysed features.

For *Pinus sylvestris* the relationships between the analysed climatic conditions and the increment widths are lower (53%). The obtained values of correlation and regression are lower as well. It shows that the cambial activity in the growth season was mostly determined by thermal conditions of February and March. Winter and early spring without heavy frosts positively affect the growth of trees in the forthcoming vegetation season. Positive values of regression prevail with rainfall (*e.g.* February, July August), attaining, however, a low level of 0.1-0.2.

Discussion and conclusions

The two analysed pine species display different reactions between the increment and climate, in spite of high similarity of the chronologies (Gl = 71.9%, t = 5.21). The native species (*Pinus sylvestris*) is highly sensitive to thermal conditions of winter and beginning of spring, but the effect of rainfall in the vegetation season is relatively low. Such relationships are typical of northern Poland, as well as of the whole area of southern coast of the Baltic Sea (Cedro 2004, Läänelaid and Eckstein 2003, Wilczynski *et al.* 2001, Zielski 1997). The cambial activity of the *Pinus nigra* is mostly dependent on the amount of rainfall in the vegetation season, an additional factor being thermal conditions of winter. This may be illustrated by comparison of the annual increment widths of black pine with the amount of rainfall in May, June and July during 1948-1998 (Fig. 6).

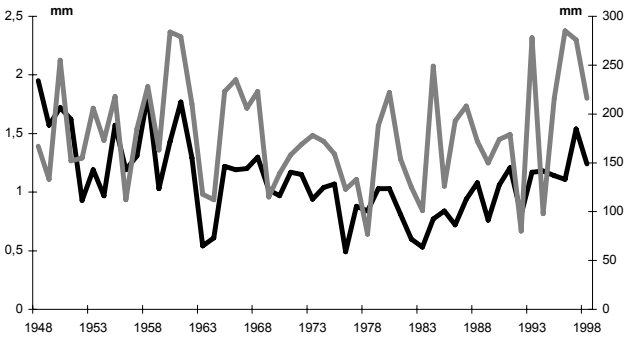


Figure 6. Similarity between tree ring width chronology of the Pinus nigra (black) and amount of May-July rainfall (gray)

Due to low economic importance and a small area of occurrence of *Pinus nigra* in Poland, dendrochronological studies on this species are scarce. The trees from southern Poland (Forest district Olkusz) were investigated by Feliksik (1999). Based on the response function analysis, the radial growth of the analysed black-pine trees was mostly determined by thermal conditions of the winter months (December-March). Low total rainfall in the summer season was an additional factor limiting the growth of trees (Feliksik 1999).

In the areas of its natural occurrence *Pinus nigra* is more often used in dendroclimatological studies. The reactions increment-climate are highly dependent on the nature of the investigated area (altitude, habitat, etc.), as well as on the climate type. In the Middle East the principal factor limiting the growth of this species is the amount of rainfall in the winter-spring season (Touchan *et al.* 2001). In Turkey the summer temperatures have the predominating impact, whereas the winter rainfall has no significant importance (Akkemik 2001). In the Austrian Alps the cambial activity is mostly dependent on temperatures in winter months and, to a lesser degree, on the amount of rainfall in the vegetation season (Leal *et al.* 2004). In the vicinity of Vienna the radial growth of trees may be limited by summer droughts (Wimmer and Strumia 1998).

Comparison of the observed relations between the annual growth and the weather conditions seems to indicate that the *Pinus nigra* growing in NW Poland reacts similarly to the trees from the Austrian lowlands, whereas the growth reactions of the trees from S Poland are close to those from the Austrian Alps.

References

Akkemik, Ū. 2001. A long master chronology of *Pinus nigra* Arn. and its contribution to Climatology and pollen analysis. *Book of abstracts, Eurodendro 2001*: 3.

Blasing, T.J., Solomon, A.M. and Duvick, D.N. 1984. Response functions revisited. *Tree-Ring Bulletin* 44: 1-15.

Cedro, A. 2004. Zmiany klimatyczne na Pomorzu Zachodnim w swietle analizy sekwencji przyrostow rocznych sosny zwyczajnej, daglezji zielonej i rodzimych gatunkow debow [Climatic changes in Western Pomerania in the light of analysis of tree-ring sequences of Scots Pine, Douglas Fir and native species of Oak]. Oficyna In Plus: 30-36 (In Polish, with English summary).

Cook, E.R. and Kairiukstis, A. 1992. Methods of dendrochronology. Kluwer Academic Publishers: 97-162.

Feliksik, E. 1999. Klimatyczne uwarunkowania przyrostow radialnych jedlicy zielonej (*Pseudotsuga menziesii* Franco), sosny wejmutki (*Pinus strobus* L.) i sosny czarnej (*Pinus nigra* Arnold). [Climatic conditioning of the radial growth of *Pseudotsuga menziesii* (Franco), *Pinus strobus* (L.), *Pinus nigra* (Arnold)]. Klimatyczne uwarunkowania zycia lasu: 87-94 (In Polish).

Holmes, R.J. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bull*. 43: 69-78.

Holmes, R.J. 1994. Dendrochronology program library. Users manual. University of Arizona, Tucson.

Kaennel, M. and Schweingruber, F.H. 1995. Multilingual glossary of dendrochronology. WSL FNP, Haupt: 133, 162, 184, 292, 331.

Läänelaid, A. and Eckstein, D. 2003. Development of a tree-ring chronology of Scots pine (*Pinus sylvestris* L.) for Estonia as a dating tool and climatic proxy. *Baltic Forestry* Vol. 9, No. 2 (17): 76-82.

Leal, S., Melvin, T.M., Grabner, M., Wimmer, R. and Briffa, K.R. 2004. Tree-ring width variability in the Austrian Alps and its relation with climate. *Abstract. Eurodendro 2004*: 29-30.

Les, J. 1988. Increment core sampling techniques for high quality cores. Forintek Canada Corporation. Special Publication No. SP-30.

Schweingruber, F.H. 1989. Tree rings. Basics and applications of dendrochronology. Kluwer Academic Publishers.

Schweingruber, F.H. 1993. Trees and wood in dendrochronology. Springer-Verlag.

Schweingruber, F.H. 1996. Tree rings and environment dendroecology. Haupt. Berne, Stuttgart, Vienna: 441-446.

Seneta, W. and Dolatowski, J. 1997. Dendrologia [Dendrology]. PWN, Warszawa: 62-63 (In Polish).

Stachak, A., Grinn, U., Haas-Nogal, M., Kubus, M., Nowak, G. and Nowakowska, M. 2000. Zielen Szczecina [Greening of Szczecin]. Oficyna In Plus: 152 (In Polish).

Szymanowski, T. 1960. Kiedy wprowadzone zostały obce gatunki drzew do uprawy w Polsce? [When foreign species of trees were introduced for cultivation in Poland?] *Rocz. Sekc. Dendr.* 14: 81-99 (In Polish).

Szwagrzyk, J. 2000. Potencjalne korzysci i zagrozenia zwiazane z wprowadzaniem do lasow obcych gatunkow drzew [Potential profits and threats of introduction of foreign tree species into the forests]. *Sylwan* 2: 99-106 (In Polish).

Touchan, R., Hughes, K. and Erkan, N. 2001. Tree rings and climate in the Near East. *Book of abstract. Tree rings and people:* 104.

Tumilowicz, J. 1970. Obce gatunki drzew w naszych lasach [Non-native tree species in our forest]. *Sylwan* 8-9: 60-65 (In Polish).

Walanus, A. 2002. Instrukcja obslugi programu TCS. Program TCS do obliczania lat wskaznikowych [User's manual of TCS software. TCS software for calculation of signature years]. Kraków: 1-13 (In Polish).

Wilczyński, S., Krapiec, M., Szychowska-Krapiec, E. and Zielski, A. 2001. Regiony dendroklimatyczne sosny zwyczajnej (*Pinus sylvestris* L.) w Polsce [Dendroclimatic regions of Scots pine (*Pinus sylvestris* L.) in Poland]. *Sylwan* 8: 53-61 (In Polish).

Wimmer, R. and Strumia, G. 1998. Spring drought indicated by intra-annual density fluctuations in *Pinus nigra*. *Eurodendro 1998:* 139-147.

Zielski, A. 1997. Uwarunkowania srodowiskowe przyrostów radialnych sosny zwyczajnej (*Pinus sylvestris* L.) w Polsce Polnocnej na podstawie wielowiekowej chronologii [Environmental factors affecting radial growth at Scots pine (*Pinus sylvestris* L.) in N Poland on the basis of the multi-century chronology]. Toruń, 1997: 18-35 (In Polish).

Zielski, A. and Krąpiec, M. 2004. Dendrochronologia [Dendrochronology]. PWN, Warszawa: 131-170 (In Polish).

Received 26 October 2005
Accepted 26 May 2006

СРАВНИТЕЛЬНЫЕ ДЕНДРОКЛИМАТИЧЕСКИЕ ИССЛЕДОВАНИЯ ВЛИЯНИЯ ТЕМПЕРАТУРЫ И ОСАДКОВ НА *PINUS NIGRA* ARNOLD И *PINUS SYLVESTRIS* L. В СЕВЕРО-ЗАПАДНОЙ ПОЛЬШЕ

А. Цедро

Резюме

Предметом исследований были два вида сосны: местный вид - *Pinus sylvestris* и завезенный с Южной Европы - *Pinus nigra*, распространенные в городских лесах Щецина (Северо-западная Польша). Хронология, репрезентирующая сосну черную насчитывает 108 лет (1895-2002), а для сосны обыкновенной получена дендрограмма, насчитывающая 115 приростов (1886-2000). Указанные хронологии приняты за основу для дендроклиматологических анализов: функции отклика и реперных лет. Оба анализа указывают на различные зависимости прирост-климат для исследованных видов сосны, невзирая на большую схожесть в характере хронологий (Gl=71.9%, t=5.21). Местный вид сосны отличается большой чувствительностью к температурным условиям зимнего периода (особенно февраля) и начала весны, проявляя небольшую зависимость от осадков в период вегетации. Камбиальная активность сосны черной связана в первую очередь с величиной осадков в период вегетации (позитивные показатели корреляции и регрессии для мая, июня и июля). Дополнительным фактором могут быть температурные условия зимнего периода (февраль).

Ключевые слова: ширина годичных колец, дендроклиматология, метеорологические условия, реперные годы, функция отклика, *Pinus nigra* Arnold, *Pinus sylvestris* L., Северо-западная Польша