TREE-RING RESEARCH, *Vol. 57(2), 2001, pp. 191–196*

^{14}C BOMB EFFECT IN TREE RINGS OF TROPICAL AND SUBTROPICAL SPECIES OF BRAZIL

CLAUDIO S. LISI, LUIZ C. R. PESSENDA

^{14}C Laboratory
Center for Nuclear Energy in Agriculture, University of São Paulo
Av. Centenário 303, CP 96, CEP 13 400-970, Piracicaba, Brazil

MARIO TOMAZELLO F°

Tree-Ring Laboratory
Department of Forest Sciences, University of São Paulo
Av. Pádua Dias 11, CP 09, CEP 13 418-900, Piracicaba, Brazil

and

KAZIMIERS ROZANSKI

University of Mining and Metallurgy
Faculty of Physics and Nuclear Techniques
Krakow, Poland, 30-059

ABSTRACT

Atmospheric nuclear tests in the early 1960s introduced large amounts of radiocarbon into the atmosphere, which resulted in an increase of tropospheric $^{14}CO_2$ concentration by nearly 100% during the years 1964–1965. The bomb-produced ^{14}C was then gradually incorporated within the global carbon cycle. The history of ^{14}C concentration in the troposphere is preserved within annual growth layers of trees and can be reconstructed for those areas where direct measurements of ^{14}C in the atmosphere were not performed. The paper presents results of ^{14}C activity measurements in tree rings of tropical and subtropical species from Brazil, for the period 1945–1997. We investigated two species (*Araucaria angustifolia* and *Parkia* sp.) growing at three sites covering the latitudinal band between 7°S and 24°S. The results indicate that the maximum ^{14}C activity in the Southern Hemisphere occurred in 1965, with the $\Delta^{14}C$ values reaching around 700‰. Significant differences in $\Delta^{14}C$ were recorded among the studied sites for the period of maximal ^{14}C levels in the atmosphere, with the highest level observed at the tropical site and lowest in the subtropical zone. This reflects the dynamics of interhemispheric transport of ^{14}C during the years of high spatial and temporal gradients of this isotope in the atmosphere.

Keywords: ^{14}C bomb effect, tree-ring, *Parkia* sp., *Araucaria angustifolia.*

INTRODUCTION

The nuclear bomb atmospheric tests began in 1952 (see *e.g.* Enting 1982) and resulted in a massive input of several radioactive isotopes into the atmosphere. Among them was ^{14}C, which is naturally produced by interaction of cosmic rays with the atmosphere. As a result, the ^{14}C levels in atmospheric CO_2 nearly doubled during the years 1960–1965. Measurements of $^{14}CO_2$ content in the Northern Hemisphere indicate $\Delta^{14}C$ values up to 1036‰ (71°06′N) in 1963 (Nydal and Lovseth 1996) (all ‰ figures are relative to pre-1950 levels). In the Southern Hemisphere Vogel and Marais (1971), analysed atmospheric $^{14}CO_2$ in a site close of Pretoria, South Africa, and determined the ^{14}C contents for the years of 1968–1970. The $\Delta^{14}C$ values varied from 577‰ to 517‰. The maximum

$^{14}CO_2$ content for this hemisphere was recorded by Manning *et al.* (1990) in 1965 at Wellington (41°S, 174°E), New Zealand, where they found a $\Delta^{14}C$ value of 695‰. After this period, the ^{14}C levels have gradually declined, mostly due to transfer of ^{14}C into the ocean, assimilation of radiocarbon by plants, and fossil fuel dilution (*e.g.* Nydal and Gislefoss 1996; Hua *et al.* 1999).

In this study, we measured the ^{14}C content in tree rings of three trees from tropical and subtropical sites in Brazil. The species studied were *Parkia* sp. from Amazonia tropical rainforest and pantropical forests, and *Araucaria angustifolia* from subtropical sites in Brazil. *Parkia* sp. attain heights of 20–40 m, and trunk diameters of 100 cm. The wood is used for civil construction (Lorenzi 1992; Camargos *et al.* 1993; Paula and Alves 1997; Ribeiro *et al.* 1999). *A. angustifolia* is a majestic tree that attain heights of 25–50 m, with a straight trunk 1–2 m in diameter. This species occurs in natural stands in southeastern Brazil and northeastern Argentina and Paraguay (Seitz and Kanninen 1988; Tomazello Fº *et al.* 2000). The annual growth rings of these species are distinct in trunk cross sections, allowing dendrochronological dating.

The objectives of this study were to determine the ^{14}C bomb effect in the tree-rings of tropical (Humaitá, southern Amazon state, Amazon region, 7°S) and subtropical (Camanducaia, Minas Gerais state, 22°S, southeastern Brazil and Arapotí, Paraná state, 24°S, southern Brazil) species (*Parkia* sp. and *Araucaria angustifolia,* respectively), during the pre- and post-nuclear tests periods (1943–1997), and to compare the results with previous work in the Northern and Southern hemispheres.

METHODS

In the tropical region, the study sites are located in the Humaitá-AM region (7°56′S, 63°20′W), at an elevation of ca. 90 m.a.s.l. The mean temperature is around 26°C and the annual precipitation varies around a mean of 2,600 mm. In the subtropical regions the sites are (1) Camanducaia-MG (22°50′S, 46°04′W), at an elevation of 1,300 m.a.s.l., with a mean annual temperature of 18°C and mean annual rainfall of 1,660 mm; and (2) Arapoti-PR (24°11′S, 49°58′W), at an elevation of 722 m.a.s.l., with a mean annual temperature of 20°C and mean annual rainfall of 1,670 mm. In both regions the analyzed trees were located in native forest, far from any sources of anthropogenic pollution.

For the wood anatomical analysis and identification of tree rings boundaries by X-ray densitometry, we collected disk samples at 1.3 m BHD (Breast Height Diameter) from the trees, dried them in the laboratory and polished the disk cross sections with a series of increasingly fine sand papers. For the X-ray densitometry method, 1 mm thick pith to bark wood samples were conditioned in a climate controlled room and exposed to an X-ray source. The wood X-ray films were analysed microdensitometrically and revealed radial wood density profiles (Schweingruber 1988; Amaral and Tomazello Fº 1998).

The tree rings were dated by wood anatomy and dendrochronological methods. For ^{14}C analysis we selected the annual growth rings formed before, during and after the nuclear testing period. In each annual tree ring, we separated the earlywood and part of the latewood of the following years: 1943, 1952, 1956, 1957, 1959, 1960, 1962 to 1966, 1968, 1971 to 1973, 1977, 1981, 1985, 1997. These are fragmented, crushed to ca. 0.2 mm and homogenised. The extraction of cellulose was based on the modified method of Green (1963). To remove the resins the wood samples received alcohol-toluene extraction, followed by alcohol extraction in the Soxhlet, and washed with distilled water. Then to remove lignin the samples were treated with sodium chlorite solution and acetic acid solution in a hot water bath (80°C). Finally, the extracted celluloses were washed several times with distilled water to remove any residual lignin and sodium chlorite. The cellulose samples were burned to carbon dioxide and converted to benzene (Pessenda and Camargo 1991). The ^{14}C activities were measured by liquid scintillation spectrometry. The results are expressed in $\Delta^{14}C$ (‰) and corrected for isotopic fractionation using $\delta^{13}C$ values (Stuiver and Polach 1977).

The dendrochronological and $\Delta^{14}C$ and $\delta^{13}C$ determinations were carried out at the Tree-Ring Laboratory, Department of Forest Sciences, and

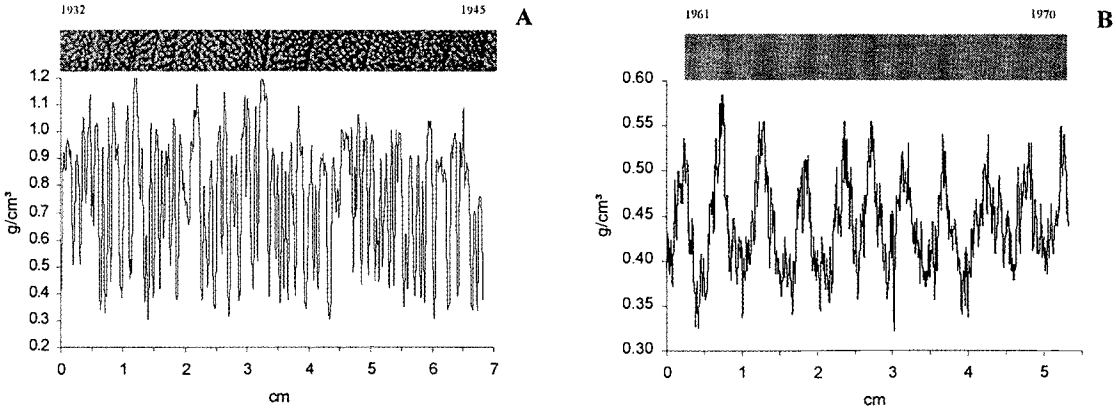

Figure 1. Wood anatomical structure and density profile by X-ray densitometry of *Parkia* sp. (A) and *A. angustifolia* (B) trees.

Radiocarbon and Stable Isotopes Laboratories, Center for Nuclear Energy in Agriculture, University of São Paulo, respectively.

RESULTS

The wood density profiles by X-ray densitometry and the respective wood anatomical structure of microsections are shown in Figure 1, representing the years 1932–1945 and 1960–1970 for *Parkia* sp. and *A. angustifolia* trees, respectively. The wood anatomical struture of *Parkia* sp. is characterized by growth rings delimited by thin confluent parenchyma bands and fibrous zones. The annual growth rings of *A. angustifolia* are delimited by latewood with thick tracheid walls (Figures 1A, B) (Camargos *et al.* 1993; Seitz and Kanninen 1988; Tomazello F° *et al.* 2000).

The *Parkia* sp. trees growing in Humaitá had 121 rings (1869–1989), and the *A. angustifolia* trees had 72 (1926–1997) and 51 annual growth rings (1945–1995) from Camanducaia and Arapoti, respectively. Table 1 and Figure 2 summarize the $\Delta^{14}C$ and $\delta^{13}C$ values of 27 tree rings of the selected years from the three trees. Six samples represent the pre-bomb period (1943 to 1959) and reveal the natural level of ^{14}C, with $\Delta^{14}C$ values fluctuating around 0‰ (−32.2‰ for Humaitá to 15.2‰ for Arapoti).

From 1960–1965 a significant increase was observed in the $\Delta^{14}C$ values in the three locations, rising from 212.9‰ to 702.3‰, for Camanducaia site. Between 1966–1997 the values gradually decreased in all three locations, declining from 673.6‰ to 159.5‰, in the Camanducaia record.

DISCUSSION

The fibrous zones of *Parkia* sp. and the latewood of *A. angustifolia* trees were correlated with the higher values of X-ray wood density, permitting the establishment of an absolute chronology of the surveyed tree species. The ^{14}C level for Humaitá in 1952 ($\Delta^{14}C$ = −32.2‰) is lower than observed for the same year at Camanducaia ($\Delta^{14}C$ = 13.7‰) and Arapotí ($\Delta^{14}C$ = 15.2‰). This may reflect a regional effect associated with recycling of CO_2 through the Amazon rainforest system. The significantly lower $\delta^{13}C$ values for the Humaitá tree, compared with two other analyzed localities, seem to support this hypothesis. The ^{14}C analyses of trees growing in the Manaus region, Central Amazon, published by Worbes and Junk (1989) revealed very similar $\Delta^{14}C$ values during the same period (1950–1954). The respiration flux of CO_2 from the soils would have slightly lower ^{14}C concentrations due to an ageing effect in the soil reservoir. Differences of up to several per cent between the current ^{14}C level in the atmosphere and respiration CO_2 were observed in a European forest (Dörr and Münnich 1986). Further measurements are needed to test this hypothesis in the context of tropical climate and the extent of the Amazon rainforest.

The highest ^{14}C levels in the analyzed tree-ring sequences occurred in 1965–1966 (Figure 2), ap-

Table 1. $\Delta^{14}C$ and $\delta^{13}C$ values in 1943–1997 annual growth rings of *Parkia* sp. (Humaitá) and *A. angustifolia* (Camanducaia and Arapotí).

	Humaitá—AM 7°56′S, 63°20′W			Camanducaia—MG 22°50′S, 46°04′W			Arapotí—PR 24°11′S, 49°58′W		
Years	Lab n°	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)	Lab n°	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)	Lab n°	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
1943	—	—	—	679	−22.5	8.2 ± 7.4	—	—	—
1952	—	—	—	973	−23.1	13.7 ± 7.8	—	—	—
1956	707	−26.9	−32.2 ± 7.8	—	—	—	658	−21.3	15.2 ± 7.5
1957	708	−26.2	−31.1 ± 7.2	—	—	—	—	—	—
1959	709	−26.1	−9.2 ± 8.5	—	—	—	—	—	—
1960	—	—	—	747	−23.5	212.9 ± 9.1	—	—	—
1962	—	—	—	680	−22.9	212.4 ± 8.5	—	—	—
1963	718	−27.2	520.9 ± 10.1	681	−22.1	498.5 ± 10.2	662	−21.8	317.5 ± 9.2
1964	—	—	—	683	−23.1	652.9 ± 11.1	—	—	—
1965	—	—	—	677	−23.4	702.3 ± 11.4	661	−22.0	651.6 ± 11.1
1966	—	—	—	676	−22.7	673.6 ± 11.3	740	−22.5	608.5 ± 10.6
1968	717	−27.7	598.4 ± 10.7	—	—	—	—	—	—
1971	—	—	—	—	—	—	739	−20.8	479.0 ± 9.8
1972	716	−27.4	490.6 ± 9.9	—	—	—	738	−22.6	445.9 ± 9.6
1973	—	—	—	750	−23.5	418.9 ± 10.5	—	—	—
1977	—	—	—	682	−22.1	378.5 ± 9.5	660	−23.8	321.9 ± 9.2
1981	—	—	—	675	−22.2	245.8 ± 8.8	—	—	—
1985	—	—	—	749	−23.7	233.3 ± 9.4	659	−22.8	230.8 ± 8.7
1997	—	—	—	674	−23.2	159.5 ± 8.3	—	—	—

proximately two years later than the maximum recorded in the Northern Hemisphere in 1963–1964 (Vogel and Marais 1971; Nydal *et al.* 1979; Levin *et al.* 1985; Dai and Fan 1986; Manning *et al.* 1990; Dai *et al.* 1992). This agrees with other tree-ring studies carried out on the South American continent (Worbes and Junk 1989; Yonenobu *et al.* 1995) and at other sites in the Southern Hemi-

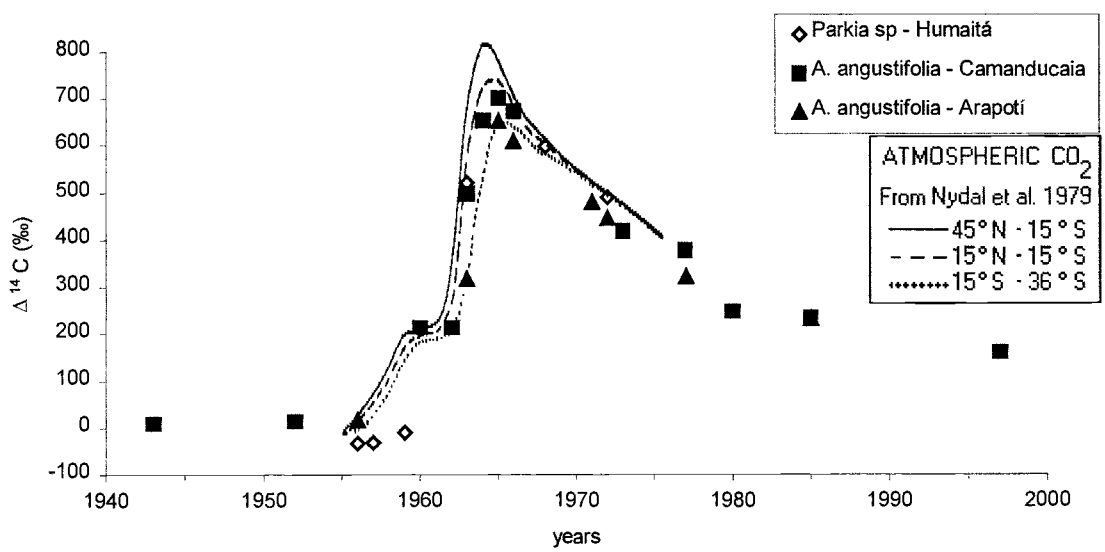

Figure 2. $\Delta^{14}C$ in annual growth rings of *Parkia* sp. and *A. angustifolia* trees from three sites and determined by Nydal *et al.* (1979).

sphere (Vogel and Marais 1971; Manning *et al.* 1990; Yonenobu *et al.* 1995). The observed north-south gradient in $\Delta^{14}C$ reflects the dynamics of the inter-hemispheric transport of bomb-produced ^{14}C in the atmosphere. Figure 2 also illustrates the differences between the results obtained by Nydal with atmospheric CO_2 in the Northern and Southern Hemispheres and the results obtained in this study.

As observed in the Figure 2, the years of maximum $^{14}CO_2$ content in the Northern Hemisphere (1963–1964) reveal differences between Nydal's results and this study. Table 1 also show the same tendency among the analysed trees of Humaitá (7°S) and Arapoti (24°S). A distinct north-south gradient in the ^{14}C content is observed: in 1963 in both sites, with $\Delta^{14}C$ value of 521‰ at Humaitá and 317‰ at Arapotí. The apparent gradient in $\Delta^{14}C$ is reduced from ca. 200‰ in 1963–1964 to approximately 45‰ in 1972–1973.

As reported in other publications (Vogel and Marais 1971; Nydal *et al.* 1979; Manning *et al.* 1990) and as can be seen in the Figure 2, after the years of maximum ^{14}C content the values gradually decreased in the Northern and Southern Hemispheres, mainly due to the CO_2 dilution from fossil fuels. The lowest value of 159.5‰ was obtained for Camanducaia site in 1997, and at present the value is around 90 to 100‰ in atmospheric CO_2 (Levin and Kramer 1997).

CONCLUSIONS

The anatomy and X-ray densitometric analysis of wood samples of *Parkia* sp. and *Araucaria angustifolia* allowed us to establish an absolute chronology and to correlate to calendar years with ^{14}C activity and $\delta^{13}C$. ^{14}C analysis of tree-ring sequences, including the atmospheric nuclear bomb test period, allowed reconstruction of atmospheric ^{14}C levels during the period of relatively rapid changes of this isotope in the global atmosphere.

The results of ^{14}C content measurements in tree-ring sequences belonging to tropical and subtropical Brazilian species (*Parkia sp* and *Araucaria angustifolia*) are consistent with available data for the Southern Hemisphere. Our results confirm that the maximum atmospheric ^{14}C concentration occurred in the Southern Hemisphere during 1965–1966 and was considerably lower than that observed in the Northern Hemisphere. Our results also suggest the existence of a north-south gradient in $^{14}CO_2$ concentration within the Southern Hemisphere and characteristic changes of this gradient with time. This reflects the dynamics of inter-hemispheric transport of ^{14}C during the years of high spatial and temporal gradients of this isotope in the atmosphere, and the possible influence of the respiration CO_2 flux from the Amazon rainforest. New sample collections should be carried out in the southern Amazon region, in order to improve the data base of this tropical site. Finally, the bomb ^{14}C record in tropical trees may be a usefel tool for evaluating the growth rates of trees in cases where classical dendrochronological analysis provides doubtful results.

ACKNOWLEDGMENTS

The authors are thankful to the Cia. Melhoramentos de São Paulo Arbor, especially to Dr. Antônio Sérgio Diniz, and Cia Impacel–Indústria de Papel Arapotí S.A. for providing the wood samples of *Araucaria angustifolia* trunk disks, and to the Fundação Coordenação de Aperfeiçoamento de Pessoal de Nível Superior–CAPES, for fellowship.

REFERENCES CITED

Amaral, A. C. B., and M. Tomazello F°
1998 Avaliação das características dos anéis de crescimento de *Pinus taeda* L. segundo a microdensitometria de raios X. *Ciência & Tecnologia.* UNIMEP Piracicaba. 6(11/12):17–23.

Camargos, J. A. A., M. H. B. Marques, and V. T. R. Coradin
1993 Caracterização tecnológica de madeiras denominadas fava e/ou faveira. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis–IBAMA; 91 pp.

Daí, K., and C. Y. Fan
1986 Bomb produced ^{14}C content in tree rings grown at different latitudes. *Radiocarbon* 28(2A):346–349.

Daí, K., Y. Quian, and C. Y. Fan
1992 Bomb-produced ^{14}C in tree rings. *Radiocarbon* 34(3): 753–756.

Dörr, M., and K. Münnich
1986 Annual variations of the ^{14}C content of soil CO_2. *Radiocarbon* 28:338–345.

Enting, I. G.
1982 Nuclear weapons data for use in carbon cycle modelling. *CSIRO Division of Atmospheric Physics Technical Paper* 44, 18 pp.

Green, J. W.
1963 Wood cellulose. In *Methods in Carbohydrate Chemistry,* edited by R. L. Whistler. New York: Academic Press 3:9–24.

Hua, Q., M. Barbetti, M. Worbes, J. Head, and V. A. Leuchenko
1999 Review of radiocarbon data from atmospheric and tree ring samples for period 1945–1997 AD. *IAWA Journal* 2(3):261–283.

Levin, I., and B. Kromer.
1997 Twenty years of high precision atmospheric $^{14}CO_2$ observations at Schauinsland station, Germany. *Radiocarbon* 2:205–218.

Lorenzi, H.
1992 Árvores Brasileiras: Manual de identificação e cultura de plantas arbóreas nativas do Brasil. *Editora Plantarum,* l, 352 pp.

Manning, M. R., D. C. Lowe, W. H. Melhuish, R. J. Sparks, G. Wallance, C. A. M. Brenninkmeijer, and R. C. McGrill
1990 The use of radiocarbon measurements in atmospheric studies. *Radiocarbon* 32(1):37–58.

Nydal, R., K. Lovseth, and S. Gullicksen
1979 A survey of radiocarbon variation in nature since the test ban treaty. In *Radiocarbon Dating,* edited by R. Berger and H. E. Suess, pp. 313–323. University of California Press, Berkeley.

Nydal, R., and K. Lovseth
1996 Carbon-14 measurement in atmospheric CO_2 from Northern and Southern Hemisphere sites, 1962–1993. Carbon Dioxide Information Analysis Center, World Data Center-A for Atmospheric Trace Gases, Oak Ridge National Laboratory, Tennessee; 26 pp.

Nydal, R., and J. S. Gislefoss
1996 Further application of bomb ^{14}C as a tracer in the atmosphere and ocean. *Radiocarbon* 38(3):389–406.

Paula, J. E., and J. L. H. Alves
1997 Madeiras nativas: anatomia, dendrologia, dendrometria, produção e uso. *Fundação Mokiti Okada–MOA,* Brasília; pp. 33–413.

Pessenda, L. C. R., and P. B. Camargo
1991 Datação radiocarbônica de amostras de interesse arqueológico e geológico por espectrometria de cintilação líquida de baixa radiação de fundo. *Química Nova* 14(2):98–103.

Ribeiro, J. E. L. S., M. J. C. Hopkins, A. Vicentini, C. A. Sothers, M. A. S. Costa, J. M. Brito, M. A. D. Souza, L. H. P. Martins, L. G. Lohmann, P. A. C. L. Assunção, E. C. Pereira, C. F. Silva, M. R. Mesquita, and L. C. Procópio
1999 Flora da Reserva Ducke: guia de identificação das plantas vasculares de uma floresta de terra-firme na Amazônia Central. *Inpa DFIP.* Manaus; 816 pp.

Schweingruber, F. H.
1988 *Tree Rings. Basics and Applications of Dendrochronology.* Dordrecht, Reidel Publications (English Edition); 276 pp.

Seitz, R. A., and M. Kanninen
1988 Dendrochronology of *Araucaria angustifolia* in Southern Brazil: Preliminary results. *Floresta* 18(1–2):55–60.

Stuiver, M., and H. A. Polach
1977 Radiocarbon: discussion, reporting of ^{14}C data. *Radiocarbon* 19:355–363.

Tomazello Fº, M., C. S. Lisi, and P. C. Botosso
2000 *Araucaria angustifolia* (Bert.) O. Kunt., the Brazilian pine, as a potential species for dendrochronological studies. In *International Conference on Dendrochronology for the Third Millenium,* Mendoza, 2000. *Abstracts.* Mendoza: Laboratório de Dendrocronología–IANIGLA/CONICET, 165 pp.

Vogel, J.C., and M. Marais
1971 Pretoria radiocarbon dates I. *Radiocarbon* 13(2):378–394.

Worbes, M., and W. J. Junk
1989 Dating tropical trees by means of ^{14}C from bomb tests. *Ecology* 70(2):503–507.

Yonenobu, H., F. Moroshita, Y. Hattori, Y. Kikata, and S. N. Marsoem
1995 Growth rates of tropical species from the ^{14}C concentration variations in tree stems. In *Proceedings of International Workshop an Asian and Pacific Dendrochronology,* edited by S. Ohta, T. Fojii, M. K. Hughes, D. Eckstein. Tsukuba, and Ohutama, Japan. March 4–9, 1995, pp. 210–215.

Received 30 January 2001; accepted 20 August 2001.