Variations in Northeast Asian Environments over the Last 350,000 Years Reconstructed from Pollen Records from the Northwest Pacific Ocean

Linda Heusser, Joseph Morley, and Nicholas Shackleton

Abstract: Recent analyses of terrestrial (pollen) and marine microfossils (foraminifera and radiolaria) in cores V28-204 and RC14-99 from the northwest Pacific Ocean extend the continuous, chronostratigraphically-controlled records of the regional vegetation of the Pacific coast of Japan and offshore marine environments through three full glacial cycles. The high-resolution pollen time series show systematic relationships between fluctuations in Japanese vegetation and global ice volume over the last 350 kyr. Intervals of expanded mesothermal vegetation characterized by *Cryptomeria japonica* (Japanese cedar) coincide with periods of significant isotope depletion associated with global warming. Conversely, representation of mesothermal vegetation in eastern Japan is minimal during intervals of isotope enrichment and extensive northern hemisphere glaciation. Comparison with solar insolation at 30°N and with an index of orbital parameters suggests that variation in northeast Asian summer monsoon intensity is related to orbital forcing.

Introduction

Understanding the effects of past and future climate changes on the terrestrial biosphere is severely hampered by the deficiencies of presently available terrestrial paleoclimatic data. Lengthy paleoclimatic records on land, such as the Chinese and central European loess deposits and pollen data from singular sediment cores taken in California, Colombia, Japan, and Europe generally lack continuous, high-resolution chronostratigraphic control and are inadequate for rigorous analysis in either the time or frequency domain (Adam 1988; Hooghiemstra 1989; Fuji 1988; Kukla 1989). Paleoclimatic reconstructions based primarily on deep-sea records provide little direct evidence of the effect of climatic change on the terrestrial biosphere. Only marine pollen data that are directly correlated with global marine chronostratigraphies precisely document the response of terrestrial ecosystems to climatic oscillations over long time spans (Heusser 1986/1987; Hooghiemstra 1988; DuPont and Hooghiemstra 1989).

These pollen data from deep-sea sediment cores clearly show that patterns of temperate forest development and climatic changes in northwest North America, Europe, and Japan over the last 140 kyr parallel global changes in climate reconstructed from marine microfossils (Heusser and Shackleton 1979; Heusser 1989; Morley and Heusser 1989; Rossignol-Strick and Planchais 1989). Particularly striking in the marine pollen records from Japan is the correlation between fluctuations in abundance

In K.T. Redmond, Editor, 1992. Proceedings of the Eighth Annual Pacific Climate (PACLIM) Workshop, March 10-13, 1991: California Department of Water Resources, Interagency Ecological Studies Program Technical Report 31.

of *Cryptomeria japonica* and global ice volume during the last glacial cycle (Heusser 1989). *C. japonica* (Japanese cedar), which is now indigenous to temperate and mixed mesophytic forests of Japan and southern China (Ohwi 1984; Numata 1974; Wang 1961) is frequently used as a paleoclimatic indicator because of the close association between the present natural distribution of *Cryptomeria* and humid maritime monsoon climates in northeast Asia (Tai 1973; Tsukada 1982; Tsukada 1986). Here we extend the record of the relative abundance of *Cryptomeria* to ~340 kyr and use the records of *Cryptomeria* in V28-304 and RC14-99 as a marine pollen index of variation in northeast Asian monsoon climates over the past 350 kyr.

Background

Core RC14-99 (36°58'N, 147°56'E, 5652 m water depth) was taken ~1000 km east of the warm-temperate and temperate forests of Japan, where average January temperature is 4°C and mean August temperature is 22°C (Fukui 1977). The site of V28-304 (28°32'N, 134°08'E, 2942m water depth) is ~500 km south of subtropical Japan, where mean January and August temperatures are 8°C and 26°C, respectively. Annual precipitation on the Pacific coast of Japan, which decreases from 4000 mm in the south to ~1500 mm on the north coast of Honshu, reflects the early summer monsoon rains, as winters on the lee side of the mountains are relatively dry.

Zonal distribution of vegetation, closely related to latitudinal temperature and precipitation variations, is highly influenced by large-scale circulation changes associated with the Asian monsoon. Potential natural montane vegetation of Honshu consists of evergreen and deciduous broad-leafed and evergreen coniferous forests. Characteristic dominants of the warm-temperate forests include evergreen members of the Fagaceae, such as *Quercus* and *Castanopsis*, along with conifers such as *Cryptomeria japonica*, and the secondary species, *Pinus densiflora*. Temperate, deciduous broad-leafed forests are characterized by *Quercus*/*Fagus* associations in which *Pinus* and *Cryptomeria* are present (Ohwi 1984).

Both cores were sampled at no less than 10-cm intervals. Pollen, radiolaria, and foraminifera, subsets of the same sediment samples, were prepared and analyzed using techniques described previously (Heusser 1979; Morley and Heusser 1989; Heusser 1990). *Cryptomeria* values are based on counts of 300 arboreal and nonarboreal pollen grains representing 35 taxa. Depth of each *Cryptomeria* sample was converted to time using age models constructed from correlation of the oxygen isotope and radiolarian (*Cycladophora davisiana*) records in these two cores with the SPECMAP "stacked" isotope curve and its associated timescale (Imbrie *et al* 1984; Martinson *et al* 1987). The average interval between consecutive samples is ~2-3 kyr.

Results

Well-preserved and relatively abundant (up to 2,000 grains/gm), pollen assemblages from RC14-99 and V28-304 reflect systematic changes in the vegetation of Japan, the principal source of pollen in these cores. Lengthy intervals characterized by boreal elements are punctuated by brief episodes in which warm-temperate components expand (Heusser 1989; Morley and Heusser 1989; Heusser 1990). The 16m-record of the relative frequency of the mesothermal indicator *Cryptomeria* in core RC14-99 shows three sets of high-frequency, high-amplitude oscillations separated by longer intervals of little change (Figure 1). Two bipartite sets of high-amplitude oscillations in *Cryptomeria* occur in the shorter (8m) record from V28-304.

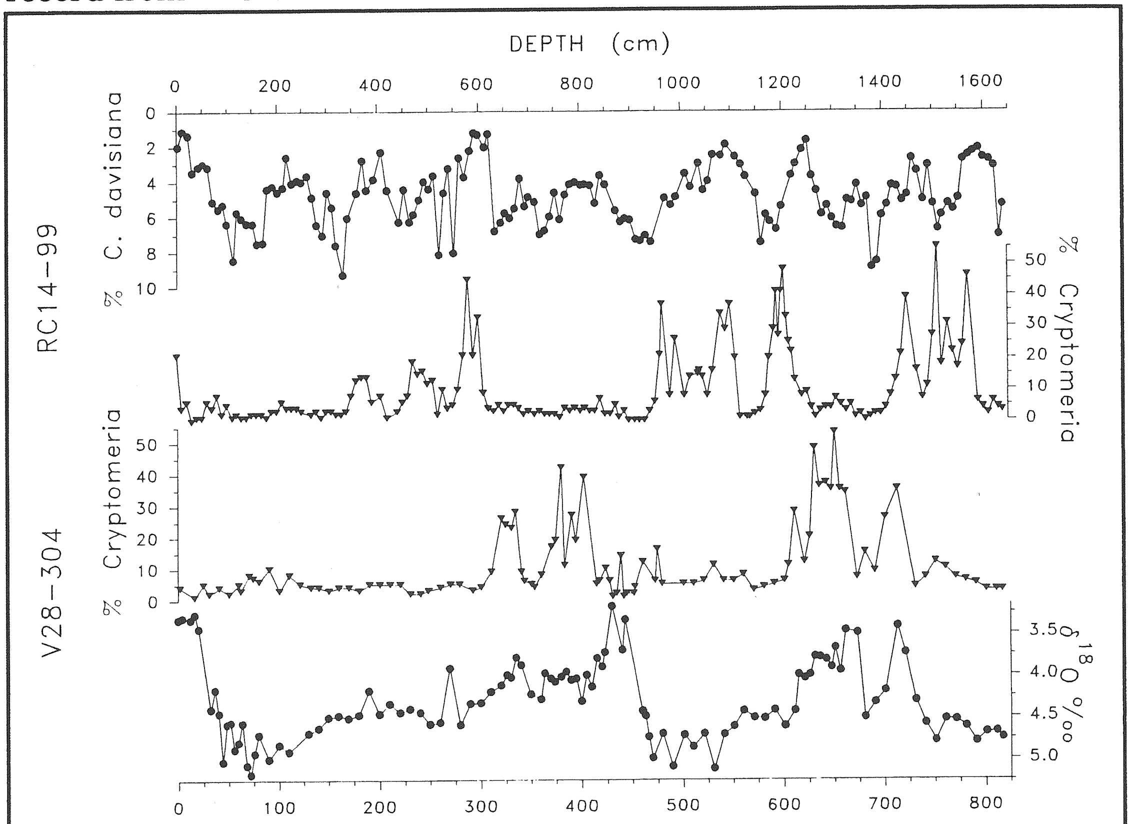

Figure 1. Depth plot of variations in relative abundance of *Cryptomeria japonica* and the oxygen isotope record in Core V28-304 (left) and of variations in abundance of *Cryptomeria* and of the radiolarian *C. davisiana* in Core RC14-99 (right).

When plotted in the time domain (Figure 2), high-amplitude fluctuations of *Cryptomeria* in the two cores appear to be nearly synchronous over the last 250,000 years. Except for a peak in early isotope stage 6 (~181 kyr), all *Cryptomeria* maxima occur within interglacial periods. In RC14-99 and V28-304, a bipartite increase in *Cryptomeria* is separated from a maximum between 230-235 kyr by a brief, deep minimum centered at ~228 kyr. During the last glacial cycle, *Cryptomeria* peaks form a decreasing triad beginning ~122 kyr in the RC14-99 record; in the southern core, V28-304, the basal peak occurs at 105 kyr. A 3-peaked expansion of *Cryptomeria*, centered at ~310 kyr, marks the base of the oldest glacial cycle in the RC14-99 record.

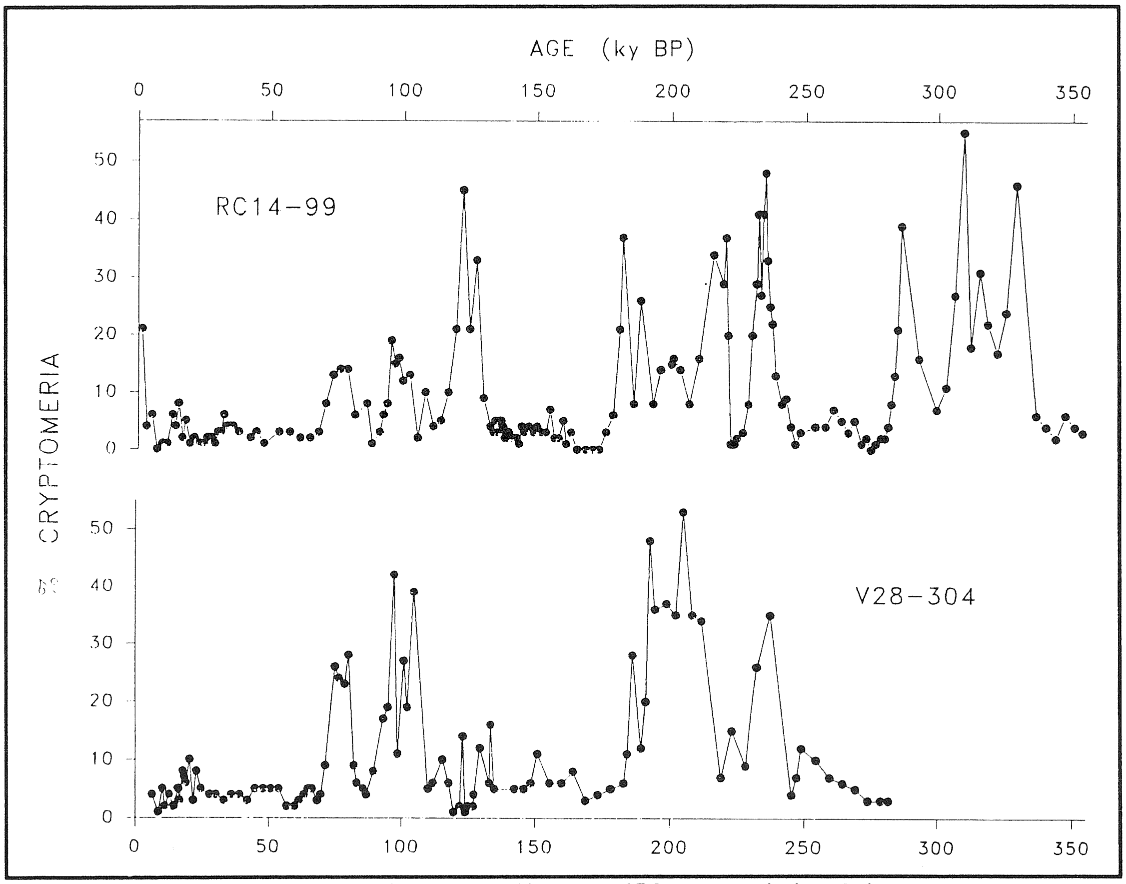

Figure 2. Time series of *Cryptomeria* abundance in Cores V28-304 and RC14-99 over the last 350 kyr.

Discussion

During the past 350 kyr, optimal development of mesothermal *Cryptomeria* forests and inferred climatic optima on the Pacific coast of Japan occur during interglacials (in isotope stages 5, 7, and 9) when northern hemisphere ice sheets, as reconstructed from oxygen isotope analyses, were minimal (Imbrie *et al* 1984; Martinson *et al* 1987). The small but significant differences in the precise timing of some of the *Cryptomeria* optima in the two cores and the absence of a high-amplitude *Cryptomeria* peak at 122 kyr in V28-304 suggests regional differences in the response of temperate and warm-temperate/subtropical environments on the Pacific coast of Japan to climatic changes during the last three glacial cycles.

These results from the direct correlations of northeast Asian and global paleoclimatic variations from deep-sea cores V28-304 and RC14-99 would seem to corroborate previous observations from records of late-Pleistocene terrestrial climatic variations that were indirectly correlated with and/or tuned to deep-sea oxygen isotope chronologies on the assumption that terrestrial climatic variations were synchronous with and of about the same order of magnitude as ice volume fluctuations (Woillard 1978; Prell and Kutzbach 1987; Adam 1988; Fuji 1988; Hooghiemstra 1989; Kukla 1989; Mangerud 1989, 1990). The differences in magnitude of the vegetational and inferred climatic changes in temperate and sub-tropical Japan suggest that variations in terrestrial paleoenvironments elsewhere may not be the same magnitude as global ice volume fluctuations and that all terrestrial environments do not necessarily exhibit responses of similar magnitude to specific climatic forcing. These differences in magnitude of response — as well as differences in timing of the response relative to global climatic events, such as in ice volume minima — are critical to understanding how the climate system works. Determining the precise timing of responses of various parts of the climate system — including terrestrial components — to Quaternary climatic perturbations is obviously basic in establishing causal relationships and, thus, is critical to evaluating models of past and future climate change.

The *Cryptomeria* records from V28-304 and RC14-99 also suggest terrestrial interglacial environments of the last three glacial cycles are not the same — at least in Japan. Earlier interglacials are not necessarily replicates of the Holocene nor of each other. Although some of these differences in our records from Japan may reflect Holocene anthropogenic influence on the vegetation of Japanese archipelago and/or sediment missing from the core-tops, clear differences exist in the duration and amplitude of *Cryptomeria* development in earlier interglacials of the last 350 kyr (isotope stages 5, 7, and 9). Therefore, our data suggest that, contrary to standard geologic wisdom and practice, the present interglacial is not necessarily a precise analogue for past interglacials — and vice versa.

Comparison of variability in northeast Asian environments over the last ~350 kyr (as represented here by the *Cryptomeria* record from RC14-99) with variations in solar insolation at 30°N and ETP, a composite curve of orbital variations constructed by adding normalized values for eccentricity, obliquity, and precession (Imbrie *et al* 1984) shows a consistent relationship between these proxy climatic indices (Figure 3). With the exception of the peak at 181 kyr, the high-amplitude *Cryptomeria* peaks closely follow maxima in summer insolation and corresponding peaks in ETP. This suggests these changes in the vegetation of Japan are responding to climatic changes related to orbital forcing. Analyses of marine pollen data elsewhere have shown similar relationships between long-term changes in terrestrial environments of Africa and orbital parameters (Prell and VanCampo 1986; DuPont and Hooghiemstra 1989).

Because precipitation, regarded as a prime factor in limiting the present and past distribution of *Cryptomeria*, is concentrated in summer on the Pacific coast of Japan (Fukui 1977), we suggest fluctuations in relative abundance of *Cryptomeria* pollen in RC14-99 and V28-304 serve as a proxy for changes in the position and intensity of the summer (Bai u) monsoon. Therefore, we interpret the relationships between variations in *Cryptomeria*, summer insolation, and orbital parameters (ETP) over the last 350 kyr as suggesting that variability in northeast Asian summer monsoons, like southeast Asian monsoons (Prell and Kutzbach 1987), is related to orbital forcing.

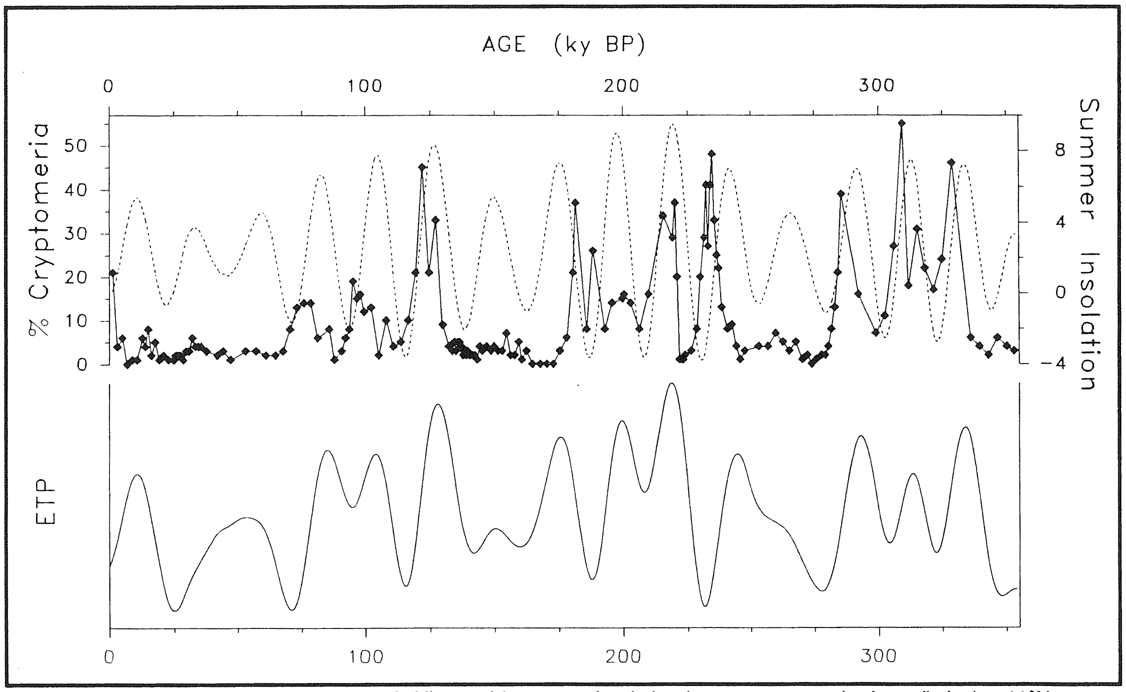

Figure 3. Time series of percent *Cryptomeria* (diamonds), summer insolation (summer averaged solar radiation) at 30°N (expressed as percent difference from present), and ETP (composite curve of eccentricity, obliquity, and precession).

Acknowledgments

This work was supported by National Science Foundation grant ATM 8711397 to L.E.H. and J.J.M. and NERC grants to N.J.S. We are grateful to E. Stock, C. Heusser, and R. Lotti for assistance. Support for the curating facilities of the Lamont-Doherty Geological Observatory Deep-Sea Sample Repository is provided by the National Science Foundation through Grant OCE88-00001 and the Office of Naval Research through Grant N00014-87-K-0204.

Literature Cited

Adam, DP, 1988. Correlations of the Clear Lake, California core CL 73-4 pollen sequence with other long climate records. Pgs. 81-96 in JD Sims (Ed.), *Late Quaternary Climate, Tectonism, and Sedimentation in Clear Lake, Northern California Coast Ranges*. Boulder, CO:Geological Society of America.

DuPont, L, and H Hooghiemstra, 1989. The Saharan-Sahelian boundary during the Brunhes chron. *Acta Botanica Neederland.* 38:405-415.

Fuji, N, 1988. Palaeovegetation and palaeoclimate changes around Lake Biwa, Japan during the last ca. 3 million years. *Quaternary Science Reviews*. 7:21-28.

Fukui, E, 1977. *The Climate of Japan.* 317. New York:Elsevier.

Heusser, L, 1990. Northeast Asian pollen records for the last 150,000 years from deep-sea cores V28-304 and RC14-99 taken off the Pacific coast of Japan. *Review of Palaeobotany and Palynology*. 65:1-8.

_______, 1989. Northeast Asian Climatic Change over the last 140,000 years inferred from pollen in marine cores taken off the Pacific Coast of Japan. Pgs. 665-692 in M Leinen and M Sarnthein (Eds.), *Paleoclimatology and Paleometerology*. Dordrecht:Kluwer.

Heusser, L, and N Shackleton, 1979. Direct marine-continental correlation: 150,000-year oxygen isotope-pollen record from the North Pacific. *Science*. 204:837-839.

Heusser, LE, 1986/1987. Pollen in marine cores: evidence of past climates. *Oceanus*. 29:64-70.

Heusser, LE, and JJ Morley, 1990. Northeast Asian monson climates during the last 350,000 years: correlative evidence from terrestrial and marine microfossils. *Eos*. 71:543.

Hooghiemstra, H, 1989. Quaternary and Upper-Pliocene glaciations and forest development in the tropical Andes: evidence from a long high-resolution pollen record from the sedimentary basin of Bogota, Colombia. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 72:11-26.

_______, 1988. Palynological record from northwest African marine sediments: a general outline of the interpretation of the pollen signal. *Philosophical Transactions of the Royal Society of London B*. 318:431-449.

Imbrie, J, J Hays, D Martinson, A McIntyre, A Mix, J Morley, N Pisias, W Prell, and N Shackleton, 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine $\delta^{18}O$ record. Pgs. 269-306 in A Berger, J Imbrie, J Hays, G Kukla and B Saltzman (Eds.), *Milankovitch and Climate*. Dordrecht:Reidel.

Kukla, G, 1989. Long continental records of climate — an introduction. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 72:1-9.

Mangerud, J, 1990. Correlation of the Eemian and the Weichselian with deep-sea oxygen isotope stratigraphy. *Quaternary International*. 3/4:1-4.

_______, 1989. The last interglacial-glacial cycle in Fennoscandia. *Quaternary International*. 3/4:21-29.

Martinson, D, N Pisias, J Hays, J Imbrie, TC Moore Jr, and N Shackleton, 1987. Age dating and the orbital theory of the Ice Ages: development of a high-resolution 0 to 300,00-year chronostratigraphy. *Quaternary Research*. 27:1-29.

Morley, JJ, and LE Heusser, 1989. Late Quaternary atmospheric and oceanographic variations in the western Pacific inferred from pollen and radiolarian analyses. *Quaternary Science Reviews*. 8:263-276.

Numata, M, 1974. *The Flora and Vegetation of Japan*. New York:Elsevier.

Ohwi, J, 1984. *Flora of Japan*. Washington DC:Smithsonian Inst.

Prell, E, and E VanCampo, 1986. Coherent response of Arabian Sea upwelling and pollen transport to late Quaternary monsoonal winds. *Nature*. 323:526-528.

Prell, W, and J Kutzbach, 1987. Monsoon variability over the past 150,000 years. *Journal of Geophysical Research*. 92:8411-8425.

Rossignol-Strick, M, and N Planchais, 1989. Climate patterns revealed by pollen and oxygen isotope records of a Tyrrhenian sea core. *Nature*. 342:413-416.

Tai, A, 1973. A study of the pollen stratigraphy of the Osaka Group, Plio-Pleistocene deposits in the Osaka Basin, Memoirs of the Faculty of Science Kyoto University. *Series of Geology and Minerology*. XXXIX:123-165.

Tsukada, M, 1986. Altitudinal and latitudinal migration of *Cryptomeria japonica* for the past 20,000 years in Japan. *Quaternary Research.* 26:135-152.

______, 1982. *Cryptomeria japonica*: glacial refugia and late-glacial and postglacial migration. *Ecology.* 63:1091-1105.

Wang, C-W, 1961. *The Forests of China.* Cambridge:Harvard University.

Woillard, G, 1978. Grande Pile Bog: a continuous pollen record for the last 140,000 years. *Quaternary Research.* 9:1-21.