Management and Impacts of Climate Change Programme
GICC
CRP 2000

7/00 – Dendro-ecological indicators of the effects of environmental changes on the wood characteristics and growth of major forest species

Summary of Final Report

Coordinator: Jean-Marc Guehl -INRA

A major finding of recent years in forest research is the discovery that, in different parts of Europe, forest productivity has increased since the beginning of the 20^{th} century, and even in the course of recent decades. The exact underlying causes of these observations cannot be clearly identified among the various components of environmental change (atmospheric CO_2, nitrogen deposits, etc.) as we still lack the operational methods (such as simple environmental indicators and growth models) that would allow us to distinguish silviculture effects from environmental effects in the analysis of the long-term trends in tree growth.

In this project, we sought to develop tools for dendro-ecological retrospective approaches, not only in order to assess past and current changes in productivity, but also to understand the causes of these changes. In particular, we examined the potential input of isotopic tools in combination with the conventional study of the width of annual growth rings. This extension is an as yet little explored line of research, but a promising one, since natural isotopic signatures can be associated with functional characteristics on the scale of the individual tree or on that of the ecosystem – making it possible to define new reliable environmental indicators. We followed a dual isotopic approach:

- Nitrogen isotopic composition ($\delta_{15}N$). The magnitude of atmospheric nitrogen deposits may affect the variation of the $_{15}N$ signal in trees through the direct effect of the isotopic composition of the nitrogen source of trees and through the indirect effects of isotopic discrimination linked to the processes that lead to the loss of soil nitrogen (denitrification, drainage, etc.). The interpretation of these $_{15}N$ signatures is complicated by the fact that part of the nitrogen contained in the wood is extremely mobile from year to year, which weakens the inter-annual resolution of the signal. A methodological validation phase remained necessary.

- Carbon isotopic composition ($\delta_{13}C$) of plant matter. This is an indicator of water-use efficiency (WUE, phytosynthesis to transpiration ratio). The retrospective analysis of $\delta_{13}C$ in growth rings was undertaken on the cellulose fraction (fixed carbon) according to a procedure tested and validated over several years in our research unit.

The project involved different teams from the INRA-Henri Poincaré Nancy I University UMR research unit 'Ecology and Forest Ecophysiology', with complementary tasks:

- The Bioclimatology and Ecophysiology team: S. ELHANI (post-doctorate UE-RTN Netcarb project), J.-M. GUEHL (DR). Isotopic approaches for $_{15}N$ and $_{13}C$ and ecophysiological interpretations.

- The Phytoecology and Atmospheric Pollution team: J.L. DUPOUEY (DR), C. ROSE (AI), F. GEREMIA (TR), B. FERNANDEZ (PhD thesis). Field sampling and growth ring analyses.
- The Cellular Ecophysiology team: P. DIZENGREMEL (PR), J. GERARD (TR). Adaptation and implementation of chemical extraction techniques.
- The Analytical Pole: C. BRECHET (IE), M. OURRY (CES). Elemental and isotopic analyses, with specific adaptations for the measurement of $_{15}N$ on small-sized samples.

In a first phase, we designed and tested the growth rings $_{15}N$ approach, focusing on Beech (*Fagus silvatica* L.) and drawing on an existing heavy artificial marking experiment. More precisely, it was a matter of determining whether the elimination, by chemical extraction, of compounds not tied to the parietal structures – thus giving access to a parietal nitrogen compounds fraction – improves the analysis of the temporal resolution of the $_{15}N$ signal in the successive growth rings. The concentration [N] and the isotopic composition ($\delta_{15}N$) of nitrogen were measured in the annual growth rings of trees from a young 16-year-old stand of the North-East of France. The analyses were carried out on wood samples before and after the extraction of labile compounds with organic solvents. The trees had been given $_{15}N$-enriched fertilization through the spraying of an urea solution on the leaves. This enriching procedure was undertaken in three successive years, in 1993, 1994 and 1995. The trees were sampled in 2001. The wood $\delta_{15}N$ of unmarked trees ranged between –4 and –7 ‰. The marking led to a significant increase of $\delta_{15}N$ in raw timber in 1994, 1995 and 1996. High values of $\delta_{15}N$ were also found in growth rings formed before and after the marking period. This highlights the high inter-ring mobility of nitrogen. The extraction procedure eliminated 36 % of the total nitrogen and 14 % of the total carbon. This improved the inter-annual resolution of [N] and $\delta_{15}N$. Applying this procedure makes it possible to use these variables in dendro-ecology in order to detect isotopic variations in the N sources used by the trees.

In a second phase, we undertook a more fine-tuned validation of the growth rings $_{15}N$ approach by drawing on an artificial marking situation closer to natural conditions, linked to a fertilization experiment in a 82-year-old Beech stand in Fougères forest (Brittany). The temporal resolution was examined, in this case, by comparing the rings formed before and after the fertilization. Joint analyses were carried out of the growth rings' width (growth in diameter) and $\delta_{13}C$. Four different fertilizing treatments (N, Ca, NPKCa and unfertilized control) were considered. Fertilization had taken place in two successive years (1973 and 1974), twenty years before the collection of the wood core samples. In the control (unfertilized treatment), a progressive decrease of $\delta_{15}N$ was recorded over time. A clear divergence of the $\delta_{15}N$ was noted in fertilized treatments (increase in $\delta_{15}N$) in comparison to the unfertilized treatment (decrease in $\delta_{15}N$) from the start of the fertilization event (1973). We were thus able to detect retrospectively, with precision, the appearance of the new source of nitrogen associated with the fertilizing event. The NPKCa treatment was the most effective in terms of radial growth (+ 29 % compared to the control), while the N treatment had no significant effect on growth. With the latter treatment, we also recorded a decrease in WUE (compared to the control) during the six years that followed the fertilizing event, whereas WUE was not significantly affected by the NPKCa treatment.

In conclusion, the recourse to multiple isotopes ($_{13}C$, $_{15}N$ and probably $_{18}O$) in conjunction with the more conventional dendro-ecological tools was found to be potentially highly relevant for interpreting observed trends in forest productivity in terms of environmental causes. It is now possible to progress to the fully operational phase regarding the use of stable isotopes as environmental dendro-ecological indicators. We are now focusing on finding the means and situations that would allow us to put this into practice with due consideration given to geographical gradients within the framework of European large-scale observation networks. In the longer term, we would consider it necessary to extend this approach to incorporate modelling aspects.