RESEARCH NOTE

Estimating stemwood nutrient concentration with an increment borer: a potential source of error

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Summary

Two methods of sampling stemwood nutrients have been compared on 10 *Pinus pinaster* (Ait.) trees: the increment borer method (non-destructive but producing samples which are not weighed according to the tissues' proportion) and the disc method (destructive but producing weighed samples). The samples were divided into sapwood and heartwood, and nutrient concentrations were determined for major nutrients (N, P, K, Ca, Mg). Compared with the disc sampling method, the increment borer sampling method significantly underestimated N, P and K concentration in sapwood, whereas it overestimated Ca and Mg concentration in heartwood. The mean error ranged from −13 per cent (N and P in sapwood) to +14 per cent (Ca in heartwood). These results were in agreement with previous studies which showed horizontal variations in the nutrient concentration of stemwood.

Introduction

The increment borer sampling method is often used for dendrochemistry (e.g. DeWalle *et al.*, 1995), stemwood nutrient concentration determination (Okada *et al.*, 1993; Arthur *et al.*, 1999) or trace elements studies (Kardell and Larsson, 1978). Nevertheless, when the estimation of the global stemwood nutrient concentration is the objective of sampling, core samples without dividing them into, for example, annual rings assumes that the wood nutrient concentration does not significantly vary from the pith to the cambium. The proportions in a core of two compartments, e.g. sapwood and heartwood, are different from the real proportions of a stem section (Figure 1). A similar limitation exists within any compartment with a radial concentration gradient. Such a gradient may cause systematic error of nutrient concentration estimations when the increment borer sampling method is used and the longer the core sample, the higher the error. The objective of the present work was to quantify this potential bias.

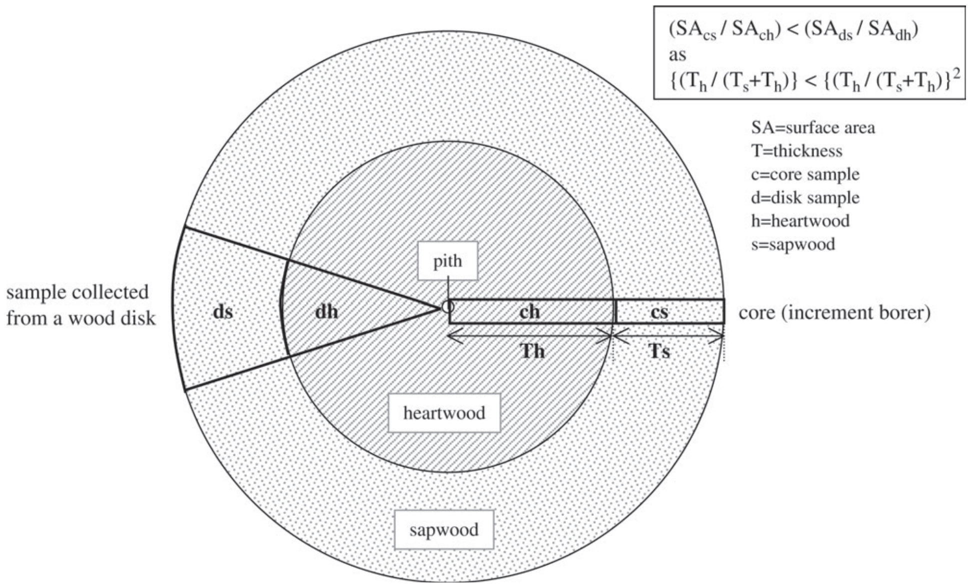

Figure 1. Impact of the sampling method on the representativity of the covected sample.

Materials and methods

Sites

The 'les Landes' forest covers more than 900 thousand hectares in south-western France. It is mainly composed of even-aged stands of maritime pine (*Pinus pinaster* Ait.) growing on poor and sandy podzosols and arenosols. The site classification shows three main classes determined by the depth of the water-table: dry moorland, mesophylous moorland and wet moorland. The latter is the most widespread (Trichet *et al.*, 1999).

Two stands, each located in an experimental forest on wet moorland (Berganton, 32 years old; Pierroton, 16 years old) were used for the present work. These stands were P fertilized before sowing (120 kg P_2O_5 ha^{-1}) and similarly managed (see Lemoine *et al.* (1988) for Berganton; Cucchi and Bert (2003) for Pierroton).

Stemwood sampling

A total of 10 trees were selected. The trees were felled and one or more growth unit(s) were sampled. A 'growth unit' is here considered as the vertical section of the trunk formed during one growing season. Several wood cores (n = 4–6) were collected in the middle of the growth unit with a Pressler's increment borer (diameter = 5 mm). The cores were located as close as possible to each other. Only cores without wound or node and including the pith were kept for analysis. A disc, 5–10 cm thick, was cut next to the sampling zone of the cores. Between 5 and 15 per cent of the angular section of the disc was sawn as close as possible to the core holes. A total of 18 pairs of cores/disc were collected from the selected trees: at Berganton, nine trees of different competitive status were selected and one growth unit was sampled per tree at the bottom of the trunk (growth unit age of 31–32 years). At Pierroton, 10 growth units were sampled along the trunk of a single tree (growth unit age ranged from 6 to 15 years). The sampling scheme was designed to obtain a data set with wide ranges of nutrient concentration. That is why samples were taken from different sites, different trees of same age, trees of different age, and growth units of different age, integrating several gradients of nutrient concentration.

The bark and the phloem of all samples were discarded. The samples were then split into sapwood and heartwood + pith according to wood colour and light transmittance (for cores) and oven-dried at 65°C until weight stabilization. We obtained 52 samples as eight of the 18 cores/disc pairs contained heartwood: (8 × 2 compartments × 2 sampling methods) + (10 × 1 compartment × 2 sampling methods).

Laboratory analysis and data processing

The samples were ground with a Willey-ED5 grinder before analysis. Nitrogen concentration was determined by thermal conductimetry (Horneck and Miller, 1998). For P, K, Ca and Mg, the analyses were performed by dry acid digestion (Pinta, 1971) followed by ICP spectrophotometry quantification (Masson and Esvan, 1995) calibrated with certified references.

The statistical analyses were computed with the SAS-STAT software (SAS Institute, 1999). One-way ANOVA and Bonferroni *t*-tests were used.

Results and discussion

Sapwood and heartwood nutrient concentration

The sapwood samples collected with the increment borer showed significantly lower N, P and K concentration than sapwood sampled from discs (Table 1). The mean underestimation due to core sampling was 10–13 per cent. The error was not systematic and some scattering was observed for the three elements (Figure 2). There was no significant difference of Ca and Mg concentration between the two sampling methods.

On the contrary, heartwood samples showed non-significant differences for N, P and K concentration, whereas they were significantly different for Ca and Mg concentration (Table 1). In the last case, the overestimation due to the core sampling (14 and 11 per cent, respectively) was systematic (Figure 3).

Interpretation

Previous studies have established some horizontal variations in nutrient concentration in the sapwood and heartwood of the tree stem. Helmisaari and Siltala (1989), Finer and Kaunisto (2000) and, to a lesser extent, Wright and Will (1958) demonstrated these gradients in *Pinus sylvestris*. All these authors observed a decrease of N, P and K concentration from the outer part to the inner part of sapwood. Helmisaari and Siltala (1989) also showed that Ca and Mg concentrations increased toward the inner part of heartwood whereas the concentrations of other nutrients were quite constant. It may be noticed that Penninckx *et al.* (2001) and Saint-André *et al.* (2002) observed similar results for N, P and K in broadleaved species. These findings are in agreement with the results of the present study which observed errors in nutrient concentration estimation when the wood samples were not balanced according to tissues' proportion. As expected, the increment borer method led to an underestimation of the N-P-K concentration in the sapwood and to an overestimation of the Ca-Mg concentration in the heartwood. The difference of behaviour between N-P-K and Ca-Mg was probably due to differences in their capacity to be

Table 1: Mean relative differences of nutrient concentration between the two sampling methods

	Sapwood (n = 18)			Heartwood (n = 8)		
Nutrient	Mean	SE	*P*	Mean	SE	*P*
N	−13%	±5%	<0.001	−6%	±15%	n.s.
P	−13%	±10%	0.025	+5%	±11%	n.s.
K	−10%	±4%	0.032	+4%	±4%	n.s.
Ca	−1%	±2%	n.s.	+14%	±2%	<0.001
Mg	+1%	±4%	n.s.	+11%	±2%	0.004

Relative difference = core value/disc value; %.
Statistical significance was analysed with Bonferroni *t*-tests.

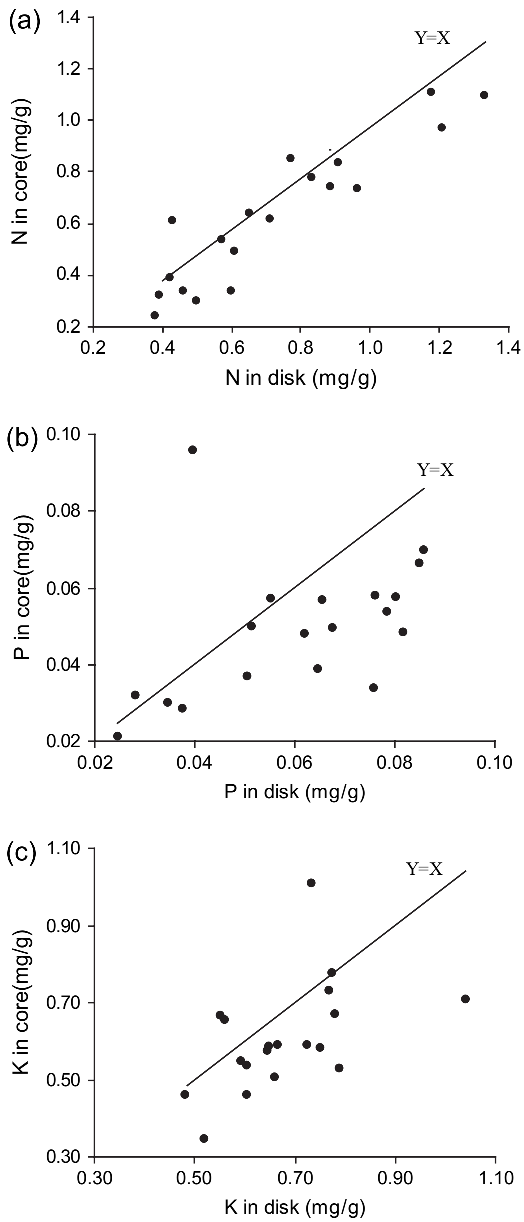

Figure 2. Comparison of the two sampling methods for N, P and K sapwood concentration. (a) Nitrogen. (b) Phosphorus. (c) Potassium.

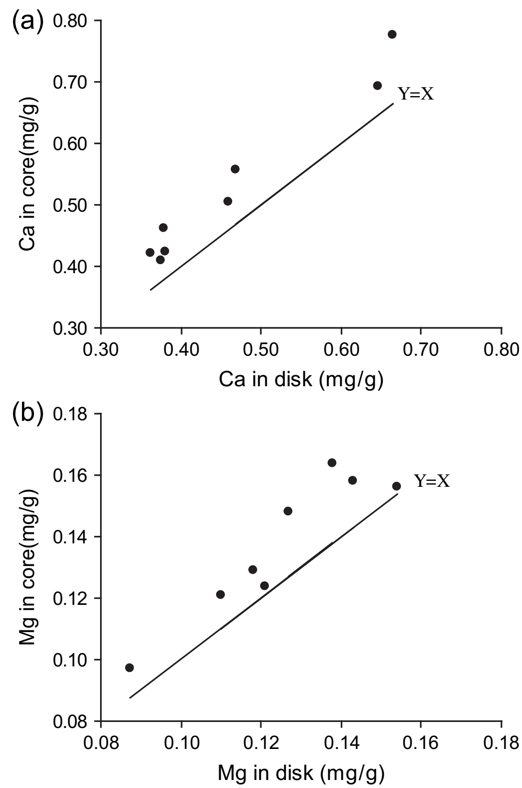

Figure 3. Comparison of the two sampling methods for Ca and Mg heartwood concentration. (a) Calcium. (b) Magnesium.

translocated from the old rings to the young rings (Colin-Belgrand *et al*., 1996; Laclau *et al*., 2001; Elhani *et al*., 2003). N, P and K are very mobile nutrients and are then easily translocated. On the contrary, Ca and Mg are almost immobile (Laclau *et al*., 2001). Moreover, it should be noted that the proportion of older ring volume is greater in core samples compared with disc samples, which also explains the difference in concentration for mobile and immobile nutrients.

Studies dealing with nutrient concentration of stemwood should take into account these gradients when designing the sampling protocol. The potential bias is higher if stemwood is not divided into sapwood and heartwood because these two compartments show very significant differences in nutrient concentration (heartwood/sapwood concentration ratios: N = 0.76; P = 0.36; K = 0.78; Ca = 1.25; Mg = 1.20; data from Meerts's review (Meerts, 2002)). More generally, the greater nutrient concentration gradient and the longer the core sample, the greater the potential bias due to core sampling.

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References

Arthur, M.A., Siccama, T.G. and Yanai, R.D. 1999 Calcium and magnesium in wood of northern hardwood forest species: relations to site characteristics. *Can. J. For. Res.* 29, 339–346.

Colin-Belgrand, M., Ranger, J. and Bouchon, J. 1996 Internal nutrient translocation in chestnut tree stemwood. III. Dynamics across an age series of *Castanea sativa* (Miller). *Ann. Bot.* 78, 729–740.

Cucchi, V. and Bert, D. 2003 Wind-firmness in *Pinus pinaster* Ait. stands in southwestern France: influence of stand density, fertilisation and breeding in two experimental stands damaged during the 1999 storm. *Ann. For. Sci.* 60, 209–226.

DeWalle, D.R., Sharpe, W.E. and Swistock, B.R. 1995 Dendrochemistry and the soil chemical environment. In *Tree Rings of Ecosystem Health*. T.E. Lewis (ed.). CRC Press, Boca Raton, FL, pp. 81–93.

Elhani, S., Fernandez-Lema, B., Zeller, B., Brechet, C., Guehl, J.M. and Dupouey, J.L. 2003 Inter-annual mobility of nitrogen between beech rings: a labelling experiment. *Ann. For. Sci.* 60, 503–508.

Finer, L. and Kaunisto, S. 2000 Variation in stemwood nutrient concentrations in Scots pine growing on peatland. *Scand. J. For. Res.* 15, 424–432.

Helmisaari, H.S. and Siltala, T. 1989 Variation in nutrient concentrations of *Pinus sylvestris* stems. *Scand. J. For. Res.* 4, 443–451.

Horneck, D.A. and Miller, R.O. 1998 Determination of total nitrogen in plant tissue. In *Handbook of Reference Methods for Plant Analysis*. Y.P. Kalra (ed.). CRC Press, Boca Raton, FL, pp. 75–83.

Kardell, L. and Larsson, J. 1978 Lead and cadmium in oak tree rings (*Quercus robur* L.). *Ambio* 7, 117–121.

Laclau, J.P., Bouillet, J.P., Ranger, J., Joffre, R., Gouma, R. and Saya, A. 2001 Dynamics of nutrient translocation in stemwood across an age series of a eucalyptus hybrid. *Ann. Bot.* 88, 1079–1092.

Lemoine, B., Ranger, J. and Gelpe, J. 1988 Qualitative and quantitative distributions of nutrient elements in a young stand of maritime pine (*Pinus pinaster*). *Ann. Sci. For.* 45, 95–116.

Masson, P. and Esvan, J.M. 1995 Détermination simultanée par spectrométrie d'émission en plasma induit de N, P, K, Ca, Cu, Mg, Fe, Mn et Zn dans les végétaux, à partir d'une minéralisation unique. *Analusis* 23, 437–440.

Meerts, P. 2002 Mineral nutrient concentrations in sapwood and heartwood: a literature review. *Ann. For. Sci.* 59, 713–722.

Okada, N., Katayama, Y., Nobuchi, T. and Ishimaru, Y. 1993 Changes of the distribution of trace elements in the formation of heartwood. *Bull. Kyoto Univ. For.* 65, 14–20.

Penninckx, V., Glineur, S., Gruber, W. and Herbauts, J. 2001 Radial variations in wood mineral element concentrations: a comparison of beech and pedunculate oak from the Belgian Ardennes. *Ann. For. Sci.* 58, 253–260.

Pinta, M. 1971 *Spectrométrie d'absorption atomique – applications à l'analyses chimique*. Tome II. Masson (Ed), Paris, France, pp. 466–539.

Saint-André, L., Laclau, J.P., Deleporte, P., Ranger, J., Gouma, R., Saya, A. and Joffre, R. 2002 A generic model to describe the dynamics of nutrient concentrations within stemwood across an age series of a *Eucalyptus* hybrid. *Ann. Bot.* 90, 65–76.

SAS Institute 1999 SAS/STAT *User's Guide, Version 8.01*. SAS Institute, Cary, NC.

Trichet, P., Jolivet, C., Arrouays, D., Loustau, D., Bert, D. and Ranger, J. 1999 Le maintien de la fertilité des sols forestiers landais dans le cadre de la sylviculture intensive du pin maritime. *Etude Gestion Sols* 6, 197–214.

Wright, T.W. and Will, G.M. 1958 The nutrient content of Scots and Corsican pines growing on sand dunes. *Forestry* 31, 13–25.

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