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RELATIONSHIP BETWEEN RING SHAKE INCIDENCE AND EARLYWOOD VESSEL CHARACTERISTICS IN CHESTNUT WOOD

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SUMMARY

This paper investigates whether in chestnut (*Castanea sativa* Mill.) a relationship exists between anatomical features of earlywood vessels lumina, which may contribute in weakening the wood structure, and the incidence of ring shake. The study compared two groups of 30 wood discs with and without ring shake, collected in three coppice stands in Southern Switzerland. Comparison of means indicates that shake-prone stems are not characterised by more numerous, larger and higher amount of earlywood vessel lumina than the unshaken ones. Hence the hypothesis that ring shake is favoured by the weakening effect of earlywood cell lumina is rejected.

***Key words*: *Castanea sativa*, earlywood vessels, anatomical wood structure, ring shake, coppice.**

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INTRODUCTION

Chestnut wood (*Castanea sativa* Mill.) displays excellent technical features: it has good mechanical properties, high durability and a pleasant appearance. Such qualities make it one of the most versatile woods available in Europe (Bourgeois 1992). Nevertheless chestnut wood is today a largely neglected natural and renewable resource. The huge economical potential of the timber, especially for uses with a high added value, is strongly obstructed by the widespread presence of ring shake. In effect ring shake is a circular failure that develops in the tangential plane of the trunk in the woody tissue between two contiguous annual rings or within growth rings (Chanson et al. 1989), which strongly downgrades the timber and prevents further processing.

In the case of chestnut, ring shake failure mainly arises in the earlywood zone, where it occurs running across the large earlywood vessel lumina which are disposed in rows along the ring boundary (Fig. 1) (Fonti et al. 2002). It is well known that ring porous wood species, like chestnut, have a reduced radial strength when loaded in the radial direction (Dinwoodie 1975; Beery 1983). In fact the earlywood zone, which has plenty of large vessels, represents a natural weak zone and can consequently easily fail. Some species cope with this weakness thanks to numerous and large wood rays, which through a high radial tensile strength are able to reinforce the earlywood zone (Schniewind 1959; Beery 1983; Mattheck et al. 1994; Badel & Perré 1999; Burgert et al. 1999; Burgert & Eckstein 2001). But this is only partially the case for chestnut wood, which is characterised by small and thin uniseriate wood rays and thus cannot offer great resistance to failures developing in the tangential plane. The high propensity of this species to ring shake may be therefore the result of its extreme weakness in the tangential plane (Ferrand 1980).

Nevertheless, even with a greater tangential weakness, not every chestnut tree is affected by ring shake. Analysis of ring shake occurrence within a single coppice stand has shown that the phenomenon tends to be limited to all stems of a restricted number of stools (Macchioni & Pividori 1996; Fonti et al. 1998), making us believe that there exists an individual propensity of the stool to the defect.

On the basis of these observations we are led to presume that, in the same way as between wood species, variability in anatomical structure within chestnut trees may affect radial tensile strength properties regulating individual ring shake susceptibility. In addition, the annual ring structure and width are expression of several influencing factors such as genetics, soil, climate, history of the stand, etc. Therefore the use of anatomical parameters for discriminating individuals with and without ring shake seems to be a reasonable approach. Therefore, the objectives of this study are to use anatomical parameters in order to a) describe the radial variability of some earlywood vessel lumina features and to b) verify whether ring shake development in chestnut wood is related to some of these anatomical characteristics previously described. Specifically we hypothesise that ring shake easily develops in annual rings or, more general, in chestnut trees characterised by either more numerous, larger or higher amount (line density) of earlywood vessel lumina.

MATERIALS AND METHODS

Plant material

The study material originated from three over-aged chestnut coppice plots located in the southern part of Switzerland. The choice of the plots was affected by the availability in the area of simple coppicing. Stand features are described in Table 1. From each stand discs of about 5 cm in thickness were gathered from the bases (0.5 m above ground) of at least 50 dominant or co-dominant chestnut stems. Given that genetic effects were not considered in our investigation, we selected only one shoot per stool. After collection the discs were first air-dried for about one year to a moisture content of 12-15%, then polished with a 400 grit sand-paper and finally cleaned with a high-pressure water blast to clean out the wood dust from the earlywood vessels. Ten shake-free discs and 10 discs with extreme ring shake (defined as dried discs displaying more than 50 cm of total ring shake failure length), with similar disc diameters, were sampled and compared. Table 2 describes the mean features of the sampled discs. In each stand no significant differences in mean age and mean ring width were found between discs with and without ring shake (t-test, $p<0.05$).

Ring shake incidence

Ring shake incidence was surveyed taking into account all failures noticed on dried wood discs. In fact, during the drying process further ring shake could develop through the relieving of internal wood stresses (Chanson et al. 1989). Because this phenomenon particularly occurs in wood discs that have already displayed ring shake immediately after tree felling (Cielo 1988; Fonti et al. 1998), the drying process further accentuates the proneness of the discs to ring shake.

All failures occurring along the annual ring longer than 1 cm were considered as ring shake. Each single ring shake was then characterised by the length of the failure, the year of the fractured annual ring and the angle of the disc circular sector enclosed by the ring shake (ring shake circular angle).

Earlywood vessel features

The number, size and arrangement of the earlywood vessels lumina are supposed to influence the radial strength capacity of the wood and consequently the susceptibility against ring shake. Therefore we characterised these features through some parameters measured on cross-section of a small portion of single annual rings. The parameters considered are:

- the mean vessel lumen area in mm^2 (MVA), which is the average cross-section lumen area of all the vessel lumina larger than 0.01 mm^2 on the considered single annual ring portion;
- the total vessel lumen area in mm^2 (TVA), which is the sum of the all vessel lumina;
- the vessel lumen line percent (VL%). This parameter indicates the relative proportion of holes to wood along the first row of earlywood vessels. It corresponds to the ratio between the total length of the earlywood vessel lumina that cross a tangential line (drawn along the first row of vessels) and the total length of the line (as shown in Figure 2).

Earlywood vessel lumen parameters were measured on the previously prepared disc cross-section. Measurements were performed ring by ring along an 8 mm wide radius strip. The radius chosen for measurements was positioned midway between the longest and the shortest radii of the disc in order to reduce the undesired effect of stem-eccentricity. Measurements were automatically performed through an image analysis device combining a video camera with an 8x magnification and the "Image Pro Plus" digital analysis program. The data relative to each annual ring were derived from a digitised image that reflected the structure of a cross-section of wood from the microscope on the monitor (Fig. 2). An essential step for the automatic measurement is the discrimination of the vessel lumen from the ground tissue by means of different colour brightness. The image program was set up with filters (morphological 2x2 squares, 1 pass, which erodes the edges of bright objects, and enlarges dark ones) and image enhancer (equalise, best fit) in order to improve the contrast and to better recognise all dark objects (vessel lumen). With the aim of avoiding wrong objects identification, by means of a selecting filter, only dark objects displaying a ratio between horizontal and vertical axes lower than 2 and with a area larger than 0.01 mm^2 were considered. Smaller vessels are presumed not to influence the ring shake development.

RESULTS AND DISCUSSION

Ring shake incidence and distribution

Differences between discs with and without ring shake were distinct (Table 2). Ring shake discs displayed a large number of shakes that on average varied from a minimum of 20.6 for the wood discs of Novaggio to a maximum of 34.5 for those of Bedano, where a mean total failure length of 86.7 cm and 187.1 cm respectively was observed.

The data on ring shake distribution of the discs from the three stands (total ring shake circular angle) were plotted by calendar year, in comparison to the mean radial annual growth (Fig. 3). Failures mainly concentrate in the annual rings belonging to the central part of the radius confirming previous observations on the radial distribution of ring shake (Macchioni & Pividori 1996; Fonti et al. 1998). This distribution could be explained because of an increased growth stresses acting in the radius middle sector (Thibaut et al. 1995). Even though along this area some peaks of ring shake were observed (i.e. in the annual rings 1972-73 for Novaggio's discs), no clear relationship between ring shake incidence and the mean annual radial growth was evident. Only for the discs of Gerra an increase of ring shake was noticed in association to an abrupt change of radial increment resulting from a silvicultural treatment (thinning). This latter result is consistent with the reports that more irregularly grown chestnut individuals produce more ring shakes than more regularly grown ones (Amorini et al. 1998).

Quantitative anatomical parameters of earlywood vessels

The data on earlywood vessel anatomical features relative to each stand (MVA, TVA and VL%) were plotted to show the radial trend (Fig. 4). All the parameters measured along the radius strips displayed a large range of values. The well known phenomenon of juvenile wood (Zobel & van Buijtenen 1989) is clearly expressed only for the MVA, which increases for about the first 20 years from the pith before levelling off (Fig. 4a), but is not plainly evident for TVA and VL% (Fig. 4b, 4c). Given this observation, in order to reduce data variability, further analyses were limited to the mature wood data (ring number from the pith >20).

Considering only the mature wood, MVA at single discs ranged from a minimum of 0.014 mm^2 to a maximum of 0.062 mm^2, TVA ranged from 0.37 mm^2 to 5.88 mm^2 and VL% from 27% to 86%.

Although almost the same pattern was observed in each stand, the three stands revealed dissimilar values in earlywood vessel features. With the exception of the VL%, differences between stands were found significant (using an ANOVA model with "individuals" nested in "stand", $p<0.05$, data not shown). This different vessel anatomical responsiveness between stands may therefore results from effects of environmental factors on wood development, as already observed for some oak species (Villar-Salvador et al. 1997).

Comparative analysis

- Among wood discs with and without ring shake

Because of the significant differences between stands noticed in the quantitative anatomical parameters of earlywood vessels, the comparative analyses between discs with and without ring shake were performed for each site separately. Results from the comparative analyses performed are summarised in Table 3. Significant differences in mean (Wilcoxon signed rank test, $p<0.05$) were observed for MVA, but only for the sites of Gerra and Bedano. As Figure 5 shows, along the radial axes the ring shake discs had continuously smaller MVA than the ones without shake (also in the case of Novaggio), even if for the first annual rings from the pith (in the juvenile wood) differences in vessels size are less manifest. The lack of significance of the Novaggio data could be due to the general low growth rate of the stand. It is therefore possible that the anatomical response was mainly regulated by the unfavourable growing conditions masking the expression of the differences in ring shake proneness.

It is however surprising to observe that the wood discs with ring shake display significantly smaller lumen vessel area than the ones without shakes. This contradicts the initial hypothesis that the development of chestnut ring shake is favoured in trees characterised by larger earlywood cell lumina. Such intriguing result that however shows significantly smaller vessels in discs with ring shake suggests that a relationship between ring shake and earlywood vessel lumen size might exist. But at this stage of analysis it is too soon to draw the cause-effect relationships between these two elements.

- Among annual rings with and without ring shake belonging to shake-prone discs

Considering that ring shake develops mainly in the central part of the radius (Fig. 3), comparative analysis among annual rings with and without ring shake was performed only on rings belonging to this region of the stem. Only data from ring shake discs from the same stands were taken into account. Of course, the surveys on ring shake annual rings were not performed in the failure zones but in the surrounding area. In this analysis the belonging of the annual ring to the individuals was ignored, with the assumption that each of the single annual rings was an independent observation. Results shown in Table 4 indicate that there are no differences in mean between the two groups for all the earlywood features measured. This outcome indicates that among the annual rings of the same wood disc there is no evidence of distinctive vessel anatomical features, as for example very small MVA, that promote the development of ring shake.

CONCLUSION

This study provides a valid body of evidence that wood discs with ring shake are not characterised by a larger and denser area of earlywood cell lumina than the unshaken ones. For two of the three sites, MVA was even found significantly smaller in discs with ring shake, while the TVA and the VL% did not display significant differences. Hence the hypothesis of a promoted development of ring shake favoured by the weakening effect of more numerous, larger and higher amount of earlywood cell cavities is rejected. While considering the shake-prone discs only no significant anatomical differences among shaken and unshaken annual rings have been found.

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TABLES

Table 1: **Stand characteristics**

Characteristics	Units	Novaggio	Gerra	Bedano
Altitude	[mASL]	710	600	530
Exposure	-	West	South East	West – South West
Slope	%	45	50	25-50
Surface	[ha]	0.13	1.57	1.355
Age	[years]	45-50	50	46-60
Silvicultural treatment		None	None	Thinning after 32 years (1986)
Stools per ha	[ha^{-1}]	470	235	447
Stems per ha	[ha^{-1}]	1263	403	719
Mean diameter of dominant stems	[cm]	27.5	29.9	25.6
Mean height of dominant stems	[m]	17.4	15.6	16.7

Table 2. **Descriptive characteristics of the sampled wood discs.** Mean age, mean ring width and mean ring shake incidence of discs among sites and ring shake groups, with and without ring shake (mean ± SE; 1 value for each disc). The disc ring width was calculated as a mean of all its annual ring widths. Mean age and mean ring width between groups were not significantly different (p<0.05, t-test)

Site	**Discs group**	**Mean age [year]**	**Mean ring width [mm]**	**Total number of ring shakes on each disc**	**Total ring shake circular angle [gon]**	**Total ring shake failure length [cm]**
Novaggio	Without ring shake	43.9 ± 1.2	2.251 ± 0.261	-	-	-
	With ring shake	45.8 ± 1.4	2.096 ± 0.170	20.6 ± 3.8	900 ± 137	86.7 ± 14.4
Gerra	Without ring shake	44.7 ± 0.2	2.399 ± 0.142	-	-	-
	With ring shake	45.0 ± 0.0	2.926 ± 0.267	23.6 ± 2.7	1168 ± 145	150.1 ± 22.1
Bedano	Without ring shake	52.0 ± 1.4	3.316 ± 0.303	-	-	-
	With ring shake	52.8 ± 2.1	3.160 ± 0.176	34.5 ± 4.2	1331 ± 136	187.1 ± 22.2

Table 3. **Results of the comparative analysis among discs.** MVA, TVA and VL% of discs distinguishing among sites and ring shake groups (mean ± SE; 1 value for each disc). Single disc values are calculated as a mean of the value measured on the mature wood annual rings (ring number from the pith > 20). Comparison of means was performed using a non-parametrical statistical test (Wilcoxon signed rank test)

Characteristic	Sites	Discs without ring shake (n = 10)	Discs with ring shake (n = 10)	p-value[1]
	Novaggio	27.52 ± 1.81	26.20 ± 0.92	0.676
MVA [μm^2]	Gerra	38.22 ± 2.06	29.64 ± 1.81	0.010*
	Bedano	45.04 ± 0.84	37.21 ± 1.74	0.001*
	Novaggio	1.373 ± 0.279	1.176 ± 0.114	0.671
TVA [mm^2]	Gerra	1.867 ± 0.118	1.581 ± 0.181	0.096
	Bedano	2.473 ± 0.307	1.984 ± 0.162	0.199
	Novaggio	58.4 ± 2.2	58.2 ± 1.7	0.909
VL% [%]	Gerra	49.1 ± 2.1	55.8 ± 1.7	0.023*
	Bedano	49.6 ± 1.9	54.0 ± 1.9	0.151

* =P<0.05

Table 4. **Results of the comparative analysis among annual rings.** MVA, TVA and VL% of annual rings (mean ± SE) belonging to the central part of the radius (20 < ring number from the pith < 35; ca. 14 values for each disc) of discs with ring shake, distinguishing among sites and annual rings with and without ring shake. Comparison of means was performed using a non-parametrical statistical test (Wilcoxon signed rank test)

Characteristic	Sites	Annual rings without ring shake	Annual rings with ring shake	p-value[1]
	Novaggio	26.35 ± 0.49	25.99 ± 0.57	0.722
MVA [μm^2]	Gerra	30.01 ± 0.73	30.11 ± 0.96	0.946
	Bedano	36.91 ± 1.07	36.65 ± 0.94	0.852
	Novaggio	1.286 ± 0.066	1.163 ± 0.061	0.583
TVA [mm^2]	Gerra	1.253 ± 0.073	1.486 ± 0.086	0.020*
	Bedano	2.032 ± 0.118	2.466 ± 0.143	0.205
	Novaggio	56.2 ± 0.9	57.0 ± 1.1	0.638
VL% [%]	Gerra	53.3 ± 1.0	53.3 ± 1.2	0.767
	Bedano	53.5 ± 1.0	52.7 ± 1.0	0.498

* =P<0.05

Figures

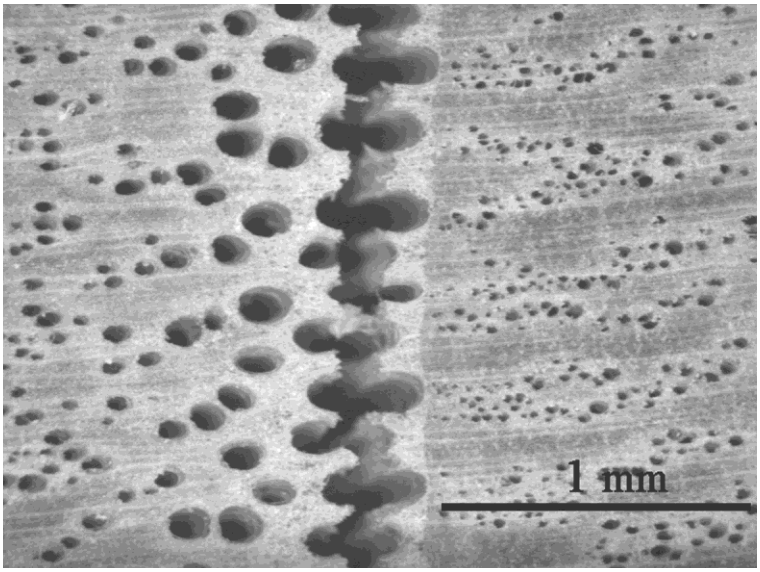


Fig. 1: **Enlarged cross section of ring shake in chestnut wood**. The earlywood zone, which has plenty of large holes (earlywood vessels lumen) disposed in rows along the annual ring boundary, represents a weak zone if any load is applied in the radial direction and therefore fails brashly (perpendicular to the cell axis) giving rise to the ring shake.

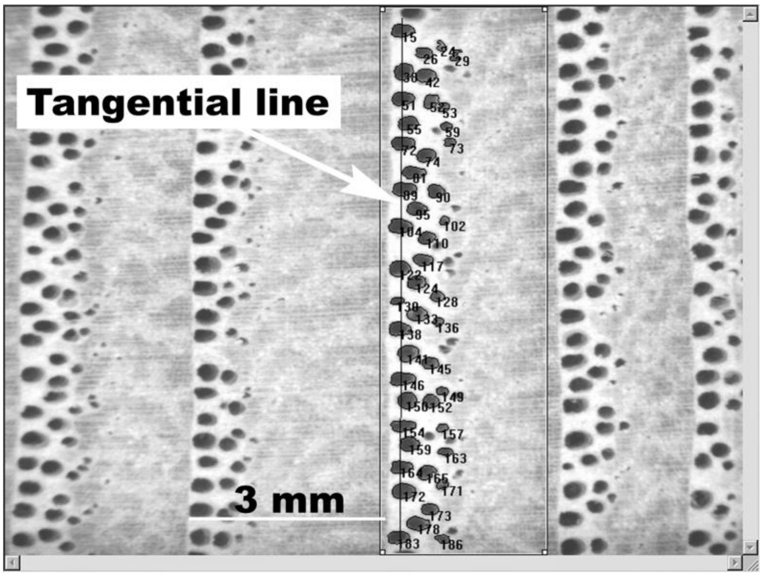


Fig. 2: **Example of a digitised image that has been analysed.** Transverse sections were viewed with a compound microscope using the 8x objective and images were captured through a video camera. Images were analysed with the "Images Pro Plus" (version 4.0.0.13 for window 95/NT/98) digital analysis program. Labelled objects have been recognised and ring width measured. The tangential line crossing the first row of earlywood vessels is used to measure the line-proportion of vessel lumen (VL%).

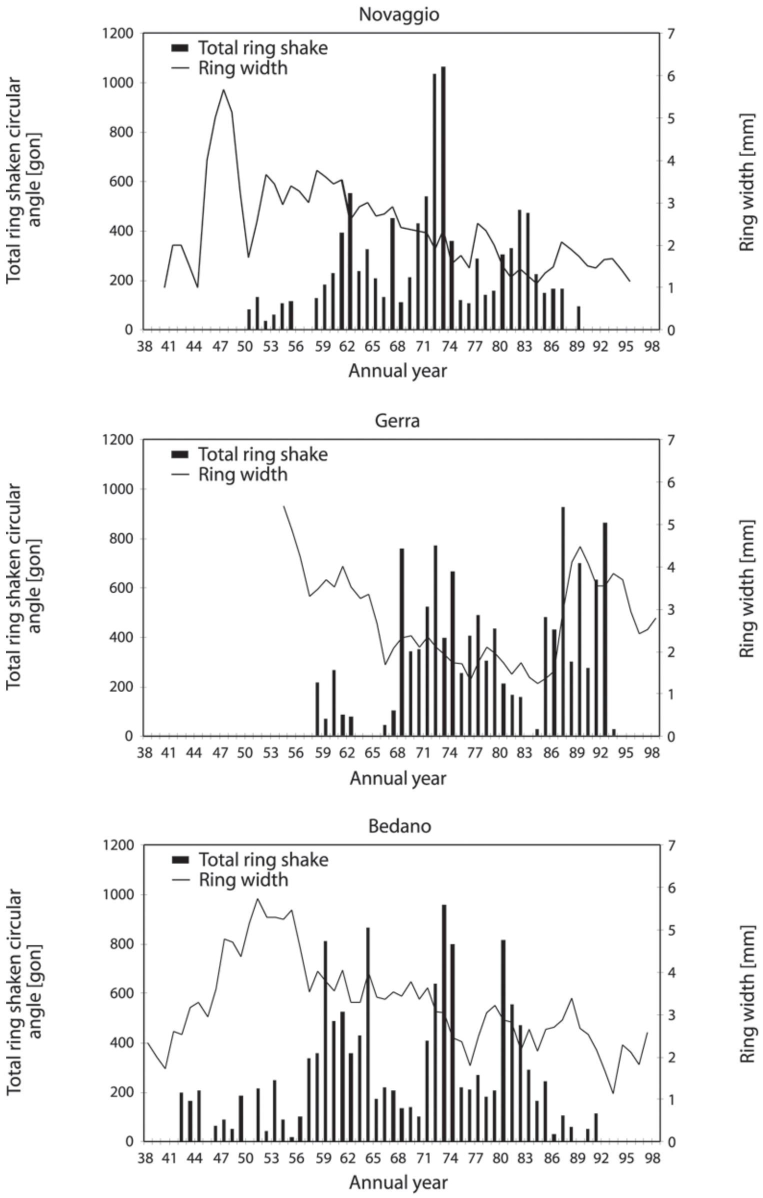
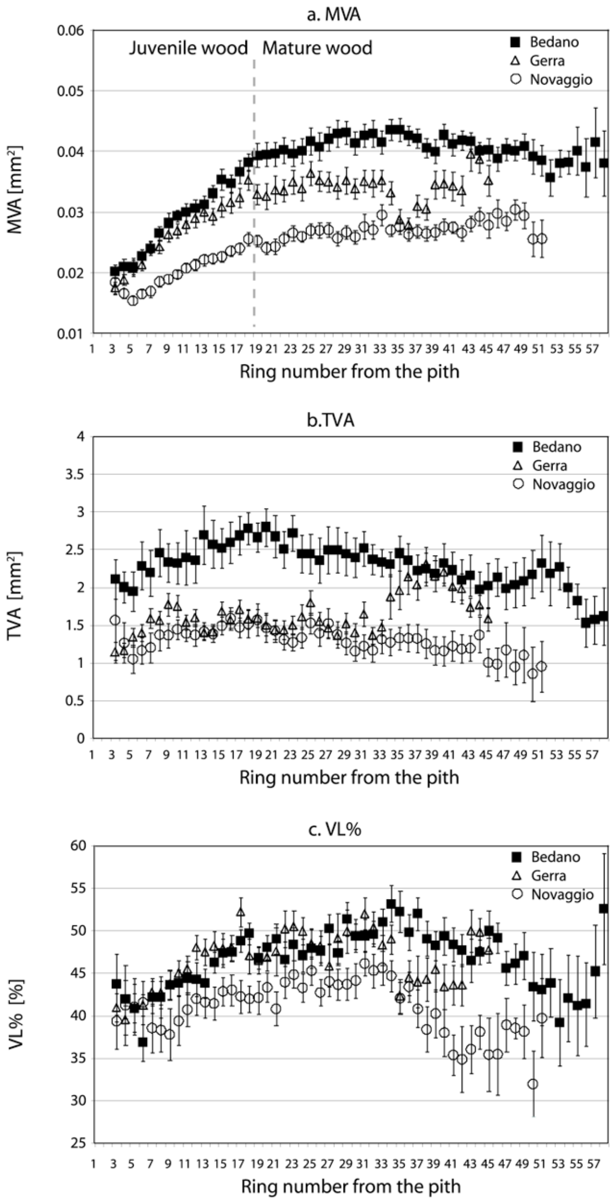


Fig. 3: **Annual ring shake incidence expressed in total ring shake circular angle by calendar year, in comparison to the mean radial annual growth.** Each graph summarises the data for the 20 discs of each stand (only 10 of which have ring shake).



285 Fig. 4a--c: **Radial pattern for a. MVA, b. TVA, and c. VL%.** Each point represents the mean values relative to a site (□ Bedano, ▲ Gerra, ○ Novaggio). Bars indicate the standard error of mean.

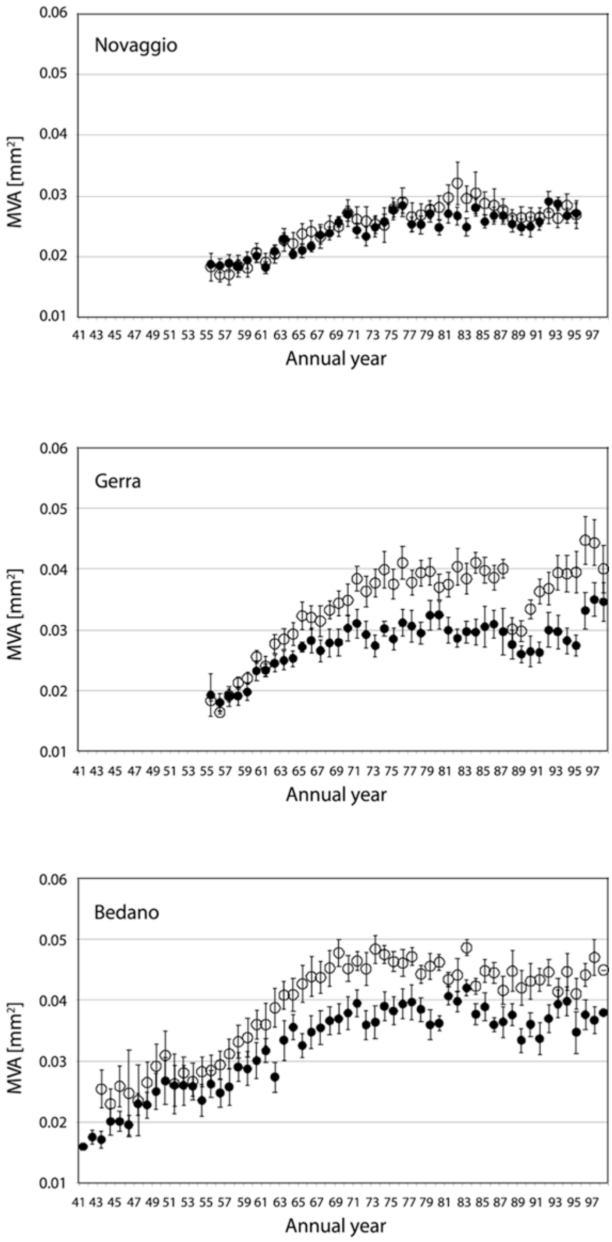


Fig. 5: **MVA area against the year of the annual ring for each site distinguishing among discs with and without ring shake.** Closed circles (●) correspond to discs with ring shake and the open circle (○) to the unshaken ones. Bars indicate the standard error of mean.