

Influence of the El-niño southern oscillation on cambial growth of *Cedrela fissilis* Vell. in tropical and subtropical Brazil*

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Summary

The width of the increment zones in the xylem of *Cedrela fissilis* Vell. was investigated by dendrochronological methods on a tropical (10°09' S, 59°26' W) and a subtropical site (25°15' S, 50°45' W) in Brazil as to study the relationship between the El-niño southern oscillation (ENSO) and the cambial growth of this species. Tree-ring width chronologies were developed for both sites from cross-dated increment curves. Simple correlations were computed between the southern oscillation index (SOI), meteorological records, and the annual increment of *Cedrela*. On the tropical site the annual increment of *Cedrela* was correlated with the precipitation from March to May of the previous growth period, while on the subtropical site the annual increment was correlated with the air temperature in May of the previous growth period and in November of the current growth period. On the tropical site reduced precipitation from March to May was correlated with low SOI values ("El-niño") in March and April. On the subtropical site increase of air temperature in May and October was correlated with low SOI values in March/April and September/October, respectively. On the tropical site 57 % and on the subtropical site 53 % of the variability of the annual increment of *Cedrela* was due to precipitation and temperature anomalies related to ENSO. This shows that on both sites to a certain amount the variability of cambial growth of *Cedrela* is related to ENSO, but tree ring chronologies of *Cedrela* alone are not secure proxy data for the reconstruction of El-niño events.

Introduction

In many regions of South America the El-niño southern oscillation (ENSO) cycle with a mean wavelength of about three to four years is one of the principal sources of climatic variability (ACEITUNO, 1988; PHILANDER, 1990). Following the classification for El-niño events of TRENBERTH (1997), five out of the seven strongest events between 1950 and 2000 occurred between 1972 and 2000. In addition, an unusual sequence of three El-niño periods, which were not coupled with alternating La-niña periods, occurred between 1990 and 1995. With regard to the strong impact of El-niño periods on the water balance (KOUSKY et al., 1984; MARTIN et al., 1995; GONZALEZ et al., 2002) and agricultural production (BAETHGEN, 1997; CUNHA, 2001) in South America, the question arose as to whether the number and the intensity of El-niño events increased in the last decades compared to former periods.

Due to the lack of long-term meteorological records proxy data might be useful to answer this question. Sedimentary records from Florida (CRONIN et al., 2002) and South America revealed over interannual and decadal time scales a significant relation between geochemical, paleobotanical, and faunal paleosalinity indicators and the climatic variability in the Pacific Ocean/atmosphere system (MARTIN et al., 1995). Due to the strong correlation between climatic factors, namely

temperature (DENNE, 1971; BRIFFA et al., 1990; 1995) and precipitation (HUGHES et al., 1994), in temperate and boreal regions, tree ring records were used successfully as proxy data for the reconstruction of meteorological situations over monthly and annual time scales. Due to the lack of strong seasonality in the humid tropics, the suitability of tropical trees for dendrochronology has been questioned for many years, even though the pioneering investigations by COSTER (1927, 1928) indicated a regular pattern in wood formation of some tropical tree species related to a distinct rainfall periodicity in some tropical areas. Studies on *Tectona grandis* (teak), growing under the Asian monsoon climate, showed that wood formation is correlated with the seasonal course of precipitation. This allowed the elaboration of a tree-ring chronology of *Tectona grandis* for a period of approximately 400 years which first demonstrated the influence of the ENSO cycle on tree growth (BERLAGE, 1931). Further tree ring records from Asia, Africa, and the Amazon floodplains also indicated a relationship between the ENSO cycle and the cambial growth of tropical and subtropical tree species (PRIYA and BHAT, 1999; STAHLER et al., 1999; WORBES, 1999; SCHÖNGART et al., 2003). In spite of these promising results tree ring records from non-inundated tropical and subtropical sites in South America are still rare and the suitability of tree ring records from this region for the reconstruction of meteorological data and the ENSO cycle for periods without instrumental meteorological records is not investigated in detail.

Due to the annual formation of increment zones in the secondary xylem of *Cedrela fissilis* Vell. (besides in other species of the genera *Cedrela* (DÜNISCH et al., 2002; WORBES, 2002)), *Cedrela fissilis* is one of the most promising tree species for dendroclimatological studies in tropical and subtropical South America (BONINSEGNA et al., 1989; MATTOS et al., 1999). In addition, this species has a wide natural distribution, which allows the investigation of the influence of the ENSO cycle on cambial growth under different climatic conditions.

Therefore, this study was designed to investigate the chance for the establishment of tree-ring chronologies of *Cedrela fissilis* as climatic proxies. Special attention was given to the relationship between the tree ring width and the ENSO cycle. A comparative analysis was carried out on a tropical site in the southern part of the Amazon basin, where precipitation decreases during El-niño periods, and a subtropical site in south-east Brazil, where precipitation increases during El-niño periods.

Material and methods

Study sites and experimental trees

The influence of the El-niño southern oscillation (ENSO) and the cambial growth of *Cedrela fissilis* Vell. was investigated on a tropical and a subtropical site in Brazil. On both sites, *Cedrela* is native (LORENZI, 1992; CARVALHO, 2003). The tropical site is located in

* in memoriam Dr. W. Hanagarth

the indigenous forest reserve "Rio Branco" approximately 50 km west of the city of Aripuanã, Mato Grosso (10°09' S, 59°26' W; 190 m above sea-level). The soil is of a xanthic ferralsol type (FAO, 1990). The mean air temperature is 22.6° C and the annual precipitation is approximately 3,000 mm (Fig. 1a; LISBOA et al., 1976). Whereas the mean monthly temperature and the relative humidity of the air show low intra-annual variation, the precipitation is distributed unequally over the year. From May until October the precipitation is significantly reduced compared to the other months of the year (Fig. 1a). The primary forest of the study site has been slightly disturbed by recent logging activities. The actual density of old growth (breast height diameter (BHD) > 0.4 m) *Cedrela fissilis* Vell. in the forest reserve (area: 800 km²) is 171 trees per km².

The subtropical site is located at the Fazenda Bitumirim (area: 11 km²) approximately 130 km west of Curitiba, Paraná (25°15' S, 50°45' W). The soil is also of an acid ferralsol type. The mean air

temperature is 16.6° C, and the annual precipitation is approximately 1,500 mm (Fig. 1b). While the precipitation is distributed relatively equally over the year, the mean air temperature follows a seasonal pattern (temperature less than 15° C from May until September). Approximately 27 % of the area of the Fazenda Bitumirim are disturbed primary forests. The actual density of old growth (BHD > 0.4 m) *Cedrela* in the primary forest fragments is 692 trees per km².

On each site twenty trees were used to determine the period of cambial growth by dendrometer measurements. For the analysis of the width of the increment zones, on the tropical site stem discs were sampled at breast height (1.3 m) directly after felling of 87 *Cedrela* trees (BHD > 0.4 m). On the subtropical site stem cores of 51 trees were collected (stem height 1.3 m) with an increment borer at the north and the south radius of the stem. The stem discs of *Swietenia* and *Cedrela* for tree ring analyses were sampled in an area of 7.2 km² (4 logging plots) and of 5.3 km² (3 logging plots), respectively.

Dendrometer measurements

Strain gauges (accuracy 0.1 mm; UP GmbH, Osnabrück, Germany) were installed in August/September 2001 at breast height (1.3 m). The increase in stem circumference was measured weekly from September 2001 to July 2003.

Wood anatomy and width of increment zones

Wood anatomy and the width of increment zones were studied on polished discs/increment cores along the north-south radius. Annual growth increments in the xylem of *Cedrela* are indicated by alternating fibre and vessel bands embedded in paratracheal parenchyma. (DÉTIENNE and JACQUET, 1983; MAINIERI et al., 1983; WORBES, 2002). In preparation for the increment measurements, the markers of each increment zone were identified by light microscopy of the discs or in microtome cross sections of the xylem blocks (Reichert, Austria; section thickness approximately 20 µm). The width of the increment zones was obtained by means of an digital measuring ocular lens (accuracy 0.1 mm, Corim Maxi, Germany).

Development of increment chronologies

The increment curves were visually cross-dated between trees according to FRITTS (1976). In addition the percentage of parallel run and the linear correlation between the individual increment curves were quantified. The synchronized increment curves were standardized by fitting logarithmic regression lines. The individual standardized increment curves (residuals) were then averaged to establish the corresponding *Cedrela* tree ring width chronologies for the tropical and the subtropical site.

Study of the response of tree growth to meteorological records and El-niño

Long-term meteorological data (since 1866 with missing values) for the tropical region are available from four meteorological stations in Manaus (03°08' S, 59°52' W; 40-70 m above sea-level). The meteorological records of Manaus are strongly correlated with those of the study site Aripuanã (DÜNISCH et al., 2003). For the subtropical site Bitumirim long-term meteorological records are available from three stations in Curitiba (25°25' S, 49°16' W; 890-940 m above sea-level). For the description of El-niño events, the Southern Oscillation Index (SOI) was used. Simple linear correlations were computed between the SOI and the temperature/precipitation of both sites. The increment chronologies of *Cedrela* from the Aripuanã and the

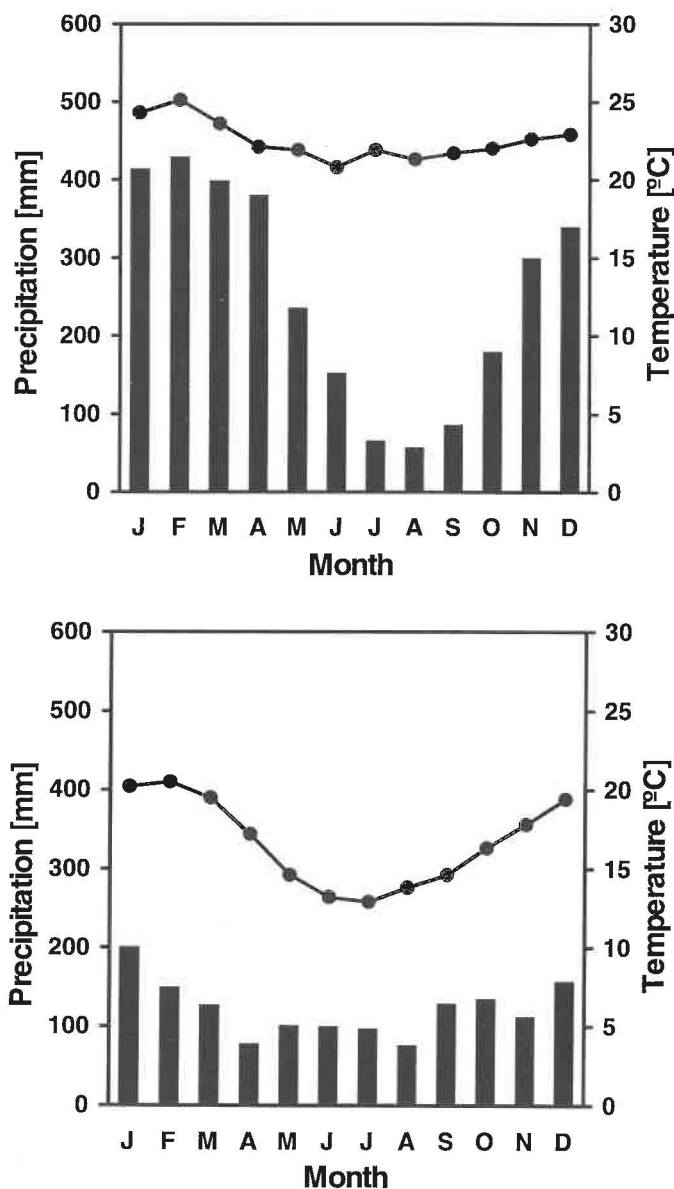


Fig. 1: Mean monthly air temperature [°C] and precipitation [mm] of the study sites (a) Aripuanã, Mato Grosso (10°09' S, 59°26' W) and (b) Bitumirim, Paraná (25°15' S, 50°45' W). Years 1971-2000.

Bitumirim site were correlated with the temperature/precipitation from Manaus and Curitiba, respectively for the years 1890 until 2000 (Manaus: 13 years, Curitiba: 29 years were excluded due to the lack of meteorological data). The relationship between El-niño episodes (definition used in this study: monthly SOI < -1 for a period of 4 months as a minimum) in the relevant months (months for which a significant influence of temperature/precipitation on tree ring width was found) and the tree ring width of *Cedrela* was tested by linear correlation analyses.

Results

Relationship between the SOI and meteorological records of the study sites

Using periods with SOI values less than -1 of 4 or more consecutive months for the definition of El-niño events, 28 El-niño events occurred between 1890 and 2000. 19 out of the 28 El-niño periods were followed by La-niña periods (coupled events). The persistence of the El-niño periods varied between 4 and 49 months (mean 14.8 months). 23 out of the 28 El-niño periods started between January and June. Most negative SOI values were registered between January and March.

Simple correlation between the SOI and the precipitation records of the tropical site (Manaus) revealed a significant influence of the

Pacific surface pressure differences between Tahiti and Darwin (SOI) in January/February, March/April, July to November, and the rainfall in February and May of the actual year and February of the subsequent year (Tab. 1, Fig. 1a). Beside the decrease of precipitation in February and May an increase of the mean annual air temperature in El-niño periods became apparent on the tropical site.

In contrast, on the subtropical site (Curitiba), negative SOI values from January until March and from August until November were correlated with an increase in precipitation in April/May and October/November, respectively (Tab. 1, Fig. 1b). In addition SOI values of March/April, April to July, and September to November were negatively correlated with the air temperature in May, July, and October/November, respectively indicating an increase of the air temperature in El-niño years on this site.

Establishment of master chronologies for *Cedrela fissilis*

After visual cross dating of the increment chronologies of the individual trees the increment curves of 63 out of 87 *Cedrela* trees from the tropical site (Aripuanã) and of 42 out of 51 *Cedrela* trees from the subtropical site (Bitumirim) were included in the increment chronologies (Fig. 2, Fig. 3). Exact dating of the age of the *Cedrela* trees was possible from the whole tree ring records. The age of the trees from the tropical site varied between 78 and 189 years, while the age of the trees from the subtropical site varied between 69 and

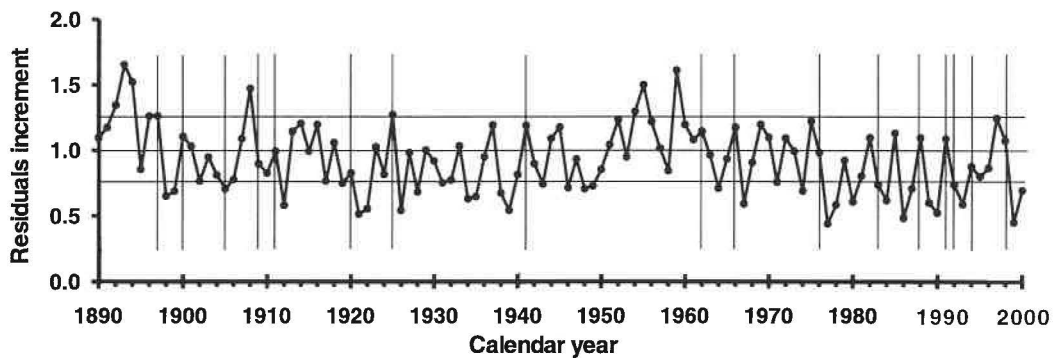


Fig. 2: Residuals of annual growth increments of *Cedrela fissilis* Vell. grown near Aripuanã, Mato Grosso (10°09' S, 59°26' W, N = 63). Years 1890-2000. The calendar year reveals the year of the beginning of the formation of the annual increment zones. Solid vertical lines, Southern Oscillation Index in March/April < -1.0 (low annual increment expected in the subsequent year). The confidence interval (significance level 90 %) is marked by the horizontal lines on either side of mean.

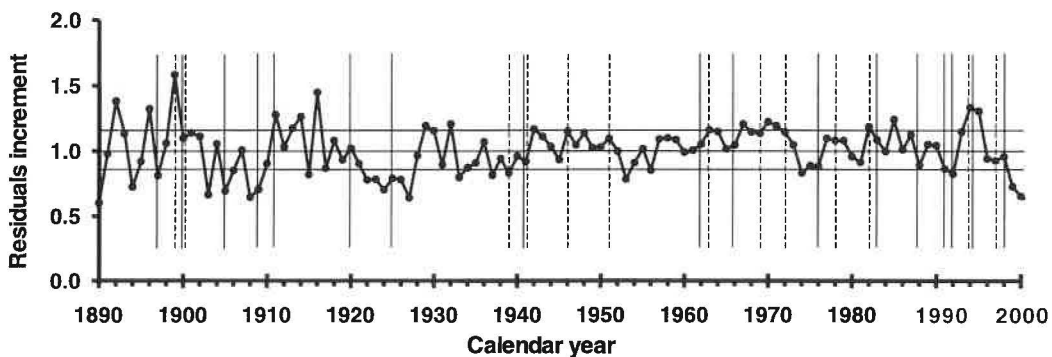


Fig. 3: Residuals of annual growth increments of *Cedrela fissilis* Vell. grown at the Fazenda Bitumirim, Paraná (25°15' S, 50°45' W, N = 42). Years 1890-2000. The calendar year reveals the year of the beginning of the formation of the annual increment zones. Solid vertical lines, Southern Oscillation Index in March/April < -1.0 (high annual increment expected in the subsequent year). Dotted vertical lines, Southern Oscillation Index in September/October < -1.0 (high annual increment expected in the current year). The confidence interval (significance level 90 %) is marked by the horizontal lines on either side of mean.

Tab. 1: Correlation coefficient (r^2) for the relationship of the Southern Oscillation Index (SOI) and the residuals of precipitation and temperature (monthly and annual values) of Manaus (03° S, 60° W) and Curitiba (25° S, 49° W). Correlations are calculated for the period from 1890 to 2000. Manaus: N = 99 (missing meteorological data: 13 years), Curitiba: N = 83 (missing meteorological data: 29 years). Significant correlations ($p < 0.05$) are indicated by frames.

Correlation between SOI and precipitation (residuals): Manaus

SOI	Current yr													Subsequent yr		
	Month	J	F	M	A	M	J	J	A	S	O	N	D	Year	J	F
J		0,19	0,47	-0,05	0,19	0,21	0,24	0,32	-0,09	-0,10	-0,22	0,24	-0,22	0,36	-0,38	-0,27
F			0,36	0,22	0,13	0,03	0,04	0,12	0,03	-0,31	0,04	0,16	-0,25	0,23	-0,40	-0,09
M				-0,02	0,09	0,33	0,21	0,38	-0,22	-0,33	-0,01	0,15	-0,14	0,30	-0,33	-0,10
A					0,03	0,44	0,22	0,31	0,13	-0,17	-0,09	0,27	-0,13	0,29	-0,16	0,14
M						0,33	0,03	0,07	0,09	0,27	-0,17	0,05	-0,04	-0,11	0,07	0,09
J							0,20	0,24	0,12	0,13	-0,04	0,10	-0,25	-0,02	-0,08	0,22
J								0,05	0,13	0,16	-0,17	0,25	-0,15	-0,05	0,05	0,31
A									0,16	0,04	-0,02	0,03	0,07	-0,08	0,19	0,52
S										0,04	-0,01	0,14	-0,04	-0,12	0,11	0,43
O											0,06	0,22	-0,11	0,13	-0,02	0,34
N												0,11	0,12	0,24	0,04	0,50
D													0,13	0,10	0,20	0,63
Year														0,19	-0,13	0,31

Correlation between SOI and temperature (residuals): Manaus

SOI	Current yr													Subsequent yr		
	Month	J	F	M	A	M	J	J	A	S	O	N	D	Year	J	F
J		-0,40	-0,45	-0,11	-0,19	-0,13	0,17	0,22	0,26	0,43	0,38	0,40	0,34	-0,17	0,66	0,51
F			-0,26	-0,07	-0,10	0,24	0,38	0,39	0,24	0,52	0,48	0,38	0,16	-0,27	0,57	0,63
M				-0,20	-0,30	-0,26	0,04	-0,07	0,13	0,23	0,14	0,23	0,19	-0,01	0,28	0,21
A					0,07	0,11	0,36	0,05	0,30	0,46	0,43	0,64	0,59	0,09	0,47	0,43
M						-0,01	-0,07	-0,50	0,00	-0,19	-0,16	0,23	0,29	0,02	0,38	0,38
J							-0,21	-0,22	-0,38	0,02	0,00	0,26	0,42	-0,11	0,03	-0,19
J								0,10	0,56	0,30	0,27	0,39	0,64	0,23	0,14	0,06
A									0,30	0,06	0,07	0,35	0,48	0,27	-0,21	-0,25
S										0,08	0,07	0,30	0,42	0,28	-0,32	-0,25
O											0,29	0,51	0,62	0,23	0,15	0,02
N												0,36	0,37	0,32	-0,07	-0,20
D													0,61	0,29	0,03	0,04
Year														-0,37	0,27	0,17

Correlation between SOI and precipitation (residuals): Curitiba

SOI	Current yr													Subsequent yr		
	Month	J	F	M	A	M	J	J	A	S	O	N	D	Year	J	F
J		0,11	0,25	-0,23	-0,29	-0,49	-0,07	-0,31	-0,07	-0,32	0,22	0,04	0,09	-0,28	-0,19	-0,04
F			0,13	-0,13	-0,40	-0,40	-0,08	-0,39	-0,03	-0,22	0,19	-0,05	-0,01	-0,36	0,12	-0,02
M				-0,20	-0,31	-0,32	0,00	-0,27	-0,17	-0,14	0,07	-0,12	0,00	-0,22	0,07	-0,18
A					-0,16	-0,31	-0,10	-0,17	-0,11	-0,12	-0,17	-0,06	-0,08	-0,29	0,00	-0,15
M						0,11	-0,13	0,17	-0,02	0,04	-0,33	-0,05	-0,16	-0,06	-0,05	-0,09
J							-0,17	0,02	0,13	0,06	-0,04	-0,12	0,15	0,04	-0,01	0,13
J								-0,14	0,08	0,13	0,01	-0,09	-0,14	-0,12	-0,09	0,27
A									0,07	0,15	-0,35	-0,34	-0,14	-0,20	0,08	0,17
S										0,23	-0,31	-0,32	-0,05	0,00	0,14	0,11
O											-0,25	-0,41	0,01	0,07	0,06	0,03
N												-0,52	-0,21	-0,06	0,14	0,25
D													-0,10	0,04	0,16	0,19
Year														-0,21	0,06	0,08

Correlation between SOI and temperature (residuals): Curitiba

SOI	Current yr													Subsequent yr		
	Month	J	F	M	A	M	J	J	A	S	O	N	D	Year	J	F
J		-0,18	-0,04	0,19	-0,15	-0,21	-0,02	-0,15	-0,02	0,22	-0,19	-0,06	-0,17	-0,22	-0,22	-0,04
F			0,05	-0,01	-0,26	-0,09	0,12	-0,12	0,22	0,41	-0,08	-0,21	-0,12	-0,12	0,00	0,06
M				0,17	-0,23	-0,31	0,04	-0,23	0,08	0,17	-0,26	-0,36	-0,20	-0,36	-0,18	-0,07
A					-0,18	-0,31	-0,06	-0,50	-0,04	0,06	-0,27	-0,37	-0,34	-0,54	-0,22	-0,18
M						-0,25	-0,34	-0,47	-0,25	-0,20	-0,17	-0,29	-0,48	-0,54	-0,58	-0,18
J							-0,27	-0,46	0,00	-0,17	-0,37	-0,34	-0,17	-0,40	-0,40	-0,13
J								-0,49	0,11	0,02	-0,24	-0,31	-0,28	-0,45	-0,50	-0,30
A									-0,03	-0,09	-0,24	-0,53	-0,18	-0,40	-0,32	-0,20
S										-0,09	-0,30	-0,51	-0,29	-0,41	-0,25	-0,14
O											-0,38	-0,50	-0,15	-0,53	-0,14	-0,18
N												-0,44	0,02	-0,35	-0,19	0,10
D													-0,06	-0,44	-0,25	0,01
Year														-0,58	-0,38	-0,14

127 years. The mean annual growth increment of *Cedrela* was 2.91 mm on the tropical site and 1.37 mm on the subtropical site.

For both chronologies the parallel run between the standardised increment curves of the individual trees was higher than 90% and the correlation of the standardised tree-ring records of the individual trees was significant ($p < 0.05$; tropical site $r^2 = 0.43$, subtropical site $r^2 = 0.31$). The standard deviation of the chronology from the tropical site was higher than the standard deviation of the chronology from the subtropical site. There was no synchronicity between the chronology from the tropical site and the chronology from the subtropical site.

Relationship between temperature, precipitation, SOI, and the width of the increment zones in the xylem of *Cedrela fissilis*

On both sites, the cambial growth dynamics of *Cedrela* showed one period of dormancy per year. Active cambium was found in *Cedrela* grown on the tropical site (Aripuanã) from the beginning of October until mid June at the utmost (Fig. 4), while cambial activity in *Cedrela* grown on the subtropical site (Bitumirim) was found from late September until mid May of the subsequent year at the utmost (Fig. 5).

Simple correlations between the tree-ring chronologies and the monthly precipitation records revealed a significant influence of the precipitation from March until May of the previous growth season on the width of the increment zones in *Cedrela* trees grown on the tropical site (Fig. 4). No correlation was found between the air temperature and the increment of *Cedrela*. In contrast, the width of the growth increment in the xylem of *Cedrela* grown on the subtropical site was significantly correlated with the air temperature at the end of the previous growth period (May) and the beginning of the current growth period (October, Fig. 5), while no relationship was found between the precipitation and the growth increment.

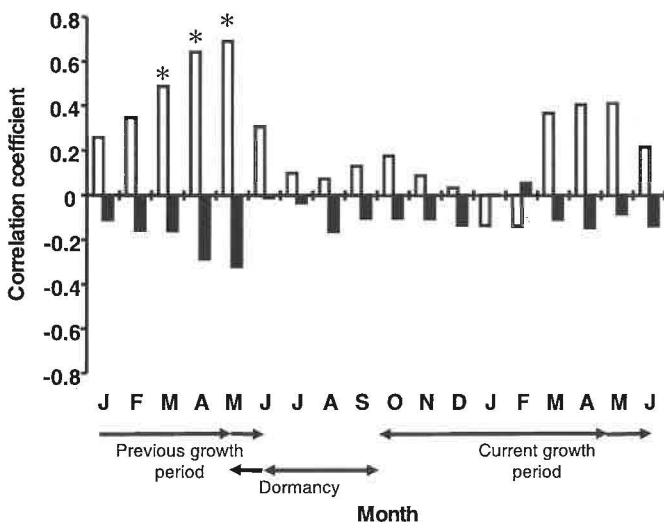


Fig. 4: Correlation coefficient between the standardised monthly temperature (shaded columns) and precipitation (unshaded columns) of Manaus ($03^{\circ}08' S$, $59^{\circ}52' W$) and the standardised growth increment of *Cedrela fissilis* Vell. grown in the north of Mato Grosso (tropical Brazil). Regressions are calculated for the period from 1890 to 2000. $N = 99$ (missing meteorological data: 13 years). Significant correlations ($p < 0.05$) are indicated by *. Meteorological data were standardized by calculating the residuals of the monthly values of each year from the average long-term monthly values.

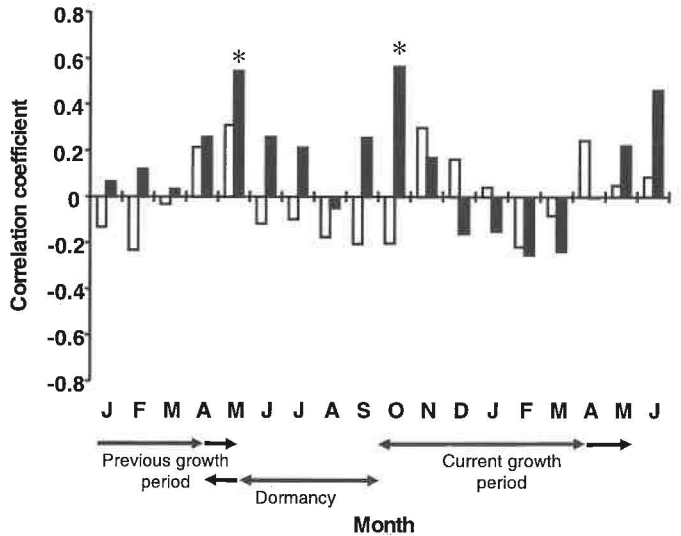


Fig. 5: Correlation coefficient between the standardised monthly temperature (shaded columns) and precipitation (unshaded columns) of Curitiba ($25^{\circ}25' S$, $49^{\circ}16' W$) and the standardised growth increment of *Cedrela fissilis* Vell. grown in Paran (subtropical Brazil). Regressions are calculated for the period from 1890 to 2000. $N = 83$ (missing meteorological data: 29 years). Significant correlations ($p < 0.05$) are indicated by *. Meteorological data were standardised by calculating the residuals of the monthly values of each year from the average long-term monthly values.

In the study on the relationship between El-nio events (SOI values ≤ -1 for 4 or more consecutive months) and the increment of *Cedrela*, only SOI values from months which had a significant influence on the temperature and the precipitation in the periods relevant for the growth of *Cedrela* were considered (tropical site: March/April, subtropical site: March/April and September/October, Tab. 1, Fig. 4, Fig. 5). From 1890 until 2000 in 17 years low SOI values (< -1.0) were registered in March/April and in further 13 years low SOI values were registered in September/October (Tab. 2). On the tropical site 85 % (11 years) and on the subtropical site 92 % (12 years) of the years, which are considered as strong El-nio years the SOI was extremely low within the relevant months. On the other hand between 1890 and 2000 on the tropical site in 23 years the increment of *Cedrela* was significantly low, while on the subtropical site in 19 years the increment of *Cedrela* was significantly high (increment below/above the confidence interval of mean, significance level 90 %). In all years, in which due to El-nio a low increment of *Cedrela* was expected on the tropical site and a high increment of *Cedrela* was expected on the subtropical site, low and high annual increment, respectively was found in the tree ring records. However, on the tropical site in 43 % of all cases abnormal low growth and on the subtropical site 47 % of all cases abnormal high growth of *Cedrela* were not correlated with low SOI values.

Discussion

Although the climatic conditions of the tropical and the subtropical study site differ significantly, on both sites the cambial activity of *Cedrela* followed an annual course and distinct increment zones were formed in the secondary xylem of the trees. The increment curves of the individual trees grown under similar conditions showed high synchronicity, which confirms the high potential of this species for dendrochronological approaches in tropical and subtropical regions (WORBES, 2002). Nevertheless the trigger for the annual growth

Tab. 2: Properties of the relationship between the Southern Oscillation Index (SOI) and the annual increment of *Cedrela fissilis* from the tropical site (Aripuanã, 10°09' S, 59°26' W) and the subtropical site (Bitumirim, 25°15' S, 50°45' W) for the period from 1890 to 2000.

Period 1890-2000	Site Manaus	Site Curitiba
No. of years (Oct.-Sept.) with mean SOI < -1.0	13	13
Relevant months for the relationship between SOI and increment	March, April	March, April, September, October
No. of years with SOI < -1.0 within the relevant months	17	30
No. of years with SOI < -1.0 within the relevant months (out of years with mean SOI < -1.0)	11 (85 %)	12 (92 %)
No. of years in which a decrease (Manaus) / increase (Curitiba) of increment was expected from low SOI (SOI < -1.0)	13 (76 %)	10 (33 %)
No. of years with significant low (Manaus) / high (Curitiba) increment	23	19
No. of years with significant low (Manaus) / high (Curitiba) increment not correlated with low SOI (SOI < -1.0)	10 (43 %)	9 (47 %)

dynamics of *Cedrela* still is not completely understood (RIVERA and BORCHERT, 2001; DÜNISCH et al., 2003).

The response function of the relationship between air temperature, precipitation, and annual increment indicate that on the tropical site the water supply at the end of the previous growth season influences the width of the increment zones. This could indicate that on this site the water supply limits the growth season and influences especially the formation of food reserves, which are mobilised at the beginning of the next growth period (HÖLL, 1985; SAUTER, 2000). Investigations on the assimilate balance of *Cedrela* showed that the growth during the first two months after the dormant period predominantly results from the mobilisation of food reserves (DÜNISCH and PULS, 2003). On the subtropical site significant correlations were found between the air temperature at the beginning and at the end of the growth season and the width of the increment zones. In view of the strong influence of the air temperature in spring and autumn on the width of the increment zones in *Cedrela* a higher increment in warmer years might be due to a longer period of cambial cell divisions. This effect was already observed in other species (GÖTTSCHE-KÜHN, 1988; ANTONOVA and STASOVA, 1993; 1997; DÜNISCH et al., 1996; BORCHERT et al., 2002).

To overcome the problem of the lack of meteorological data measured directly on the study sites, the tree growth was correlated with meteorological parameters recorded in Manaus (tropical site) and Curitiba (subtropical site), respectively. As it was shown by RIBEIRO (1992), ANONYMUS (2001), and DÜNISCH et al. (2003) these long-term records are strongly correlated with the meteorological data of the forest stands. However, in Brazil the low density of meteorological stations with long records is a serious problem, which limits the application of dendrochronological methods in this region.

The increment chronology developed for *Cedrela* grown on the tropical site showed a higher sensitivity compared to the increment chronology developed for *Cedrela* grown on the subtropical site. This reflects the higher interannual variation of precipitation during the relevant months on the tropical site (37 to 193 % of mean, RIBEIRO and ADIS, 1984; RIBEIRO, 1992) compared to the interannual variation of temperature during the relevant months on the subtropical site (89 to 114 % of mean, RIBEIRO, 1992). However, in agreement with ROPELEWSKI and HALPERT (1987, 1989, 1996) this study shows that the impact of El-niño events on temperature and precipitation was stronger on the subtropical site than on the tropical site.

For the definition of El-niño events and the correlation analyses the Southern Oscillation Index (SOI), which is calculated from the surface pressure measured in Tahiti (central Pacific) and Darwin (Australia), was used. Although there are other parameters available for the definition and classification of El-niño events (e.g. sea surface temperature, Puerto Chicama, Perú, CHANGNON (2000)), exclusively the SOI chronology exceeds a time span of at least 50 years, which is the minimum time span for the application of dendroclimatological methods (FRITTS, 1976; SCHWEINGRUBER, 1988). El-niño events show a high variability in terms of the date of their beginning and their end, length, intensity, and their impact on meteorological data. On the other hand, the precipitation and temperature in distinct growth periods only, had a significant influence on the width of the increment growth in *Cedrela*. Consequently, El-Niño periods, which influenced the meteorological conditions of the study sites during the "key"-months for growth had a significant influence on the annual increment of the trees, while other El-niño periods were irrelevant. Therefore, it was concluded that on both study sites to a certain amount the variability of cambial growth of *Cedrela* is related to ENSO, but tree ring chronologies of *Cedrela* alone are not secure proxy data for the reconstruction of El-niño events.

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