NOTES

GROWTH PERIODICITY OF *PINUS PATULA* IN SOUTHERN TANZANIA

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Relatively few studies are available on the periodicity or seasonal characteristics of wood formation of tropical trees (Nobuchi *et al.* 1995), especially when compared with the large number of tropical tree species that are used for economic purposes. Even though tropical trees can form growth rings, it is frequently uncertain whether the rings are annual or related to seasonal events.

If the species is known to form annual rings, it greatly simplifies the task of determining tree age and growth rate. If a tree species does not form annual rings, the available options for growth and yield studies are limited as it is difficult, if not impossible, to analyse growth retrospectively using the methods of tree ring analysis. Although yield can be studied on stands with known stand age and stand history, monitoring of growth by periodic measurements on permanent experiments is the most usual choice. Even that may be problematic in the tropics, since one frequently does not have accurate information on the intra-annual growth variation of the species. Ideally, one would like to measure experiments during a period of cambial dormancy. If the species does not have a regularly occurring dormancy period, one would prefer a period of relatively slow growth. Measurements of short-term (daily) changes of stem dimensions are used for determining the seasonal characteristics of tree growth.

Pinus patula has been a popular choice for wood production on plantations in East Africa. The species, which was first introduced to South Africa from Mexico in 1907, has been planted on commercial scale since the 1940s (Wormald 1975). Today *P. patula* is the most widely planted tree species in Tanzania (Isango & Saramäki 1999) and the second most important exotic softwood species in Kenya (Ngugi 1996). Local names for the species in English speaking countries include Mexican weeping pine, spreading-leaved pine and Patula pine (Wormald 1975).

The growth and yield of *P. patula* growing in East Africa have been analysed in a rather large number of studies. Several authors have developed growth models and volume and taper functions for the species (Klitgaard & Mikkelssen 1976, Alder 1977, Pikkarainen 1986, Malimbwi & Philip 1989, Tennent 1990, Isango 1994, Ngugi 1996). A comprehensive review of the models for *P. patula* in the region of East Africa is given by Valkonen *et al.* (2000).

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P. patula does form rings in the xylem, but apparently it has not been verified how the rings are related to seasonal weather variation in the conditions of East Africa. The modelling studies are mostly based on data from permanent sample plots. However, very little information is given about the timing of repeated measurements on the plots. Only Ngugi (1996) stated a principle, that sample plots should be remeasured at the same time of year each time. The lack of information about the timing of the sample plot measurements indicates that there is no commonly enforced standard for it. Therefore, results on the intra-annual growth rhythm of *P. patula* could be useful for creating such standard methodology.

This paper presents results from continuous measurements of the circumference increment of *P. patula* in southern Tanzania. Automatic, high precision girth bands were used for a period of slightly more than a year and a half. The results were compared with daily precipitation measurements.

We measured the daily growth of *P. patula* at the plantation of Kiwira, which is situated in the Southern Highlands of Tanzania (9° 3' S, 38° 42' E) (Figure 1). The plantation is located at high altitude (2225 to 2412 m asl). Average annual rainfall is high (1846 mm), most of it falling in November till May. The area has been described in more detail by Isango and Saramäki (1999).

A dense *P. patula* stand was chosen. The stand had regenerated naturally after a fire in 1988. Thinnings had been conducted on this stand. Circumferential increment was measured with dendrometer bands (type ELPA). The accuracy of the circumference measurements was 0.03 mm. The bands were connected to a data logger, which automatically registered the circumference of each tree once each hour.

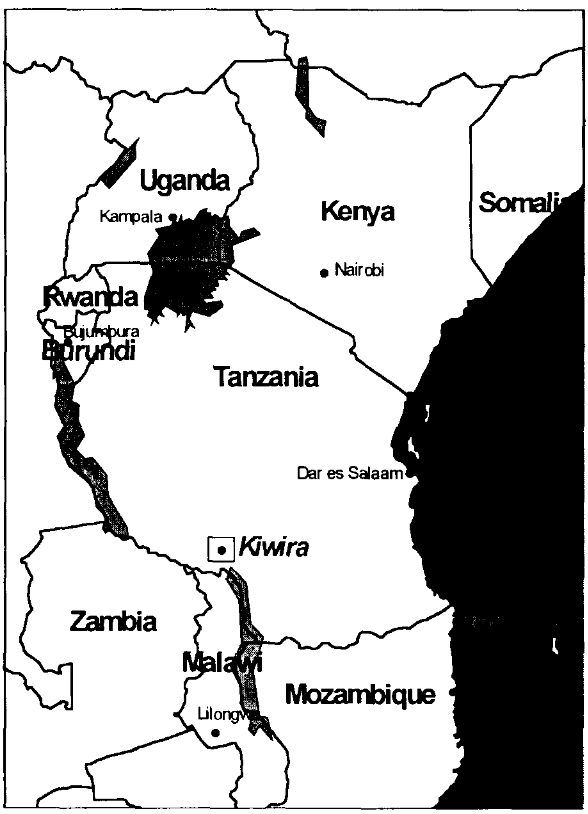

Figure 1 Location of the study area at Kiwira

Measurements were taken from 26 January 1999 till 8 August 2000, providing results for a period of slightly more than a year and a half. We started the measurements with seven bands, but only three of them produced reasonable data from 26 January 1999 till 18 January 2000. At that point six out of seven bands were serviced and the measurements continued. However, the problems continued after the maintenance. Only two bands produced continuous data from 18 January 2000 till 8 August 2000. The most obvious reason for the malfunctioning of the dendrometers was abundant resin flow.

In addition to dendrometer band measurements, daily precipitation data were available from 1 January 1999 till 16 December 1999. The measurements were made at the weather station of the Kiwira Forest Project, which is situated less than 100 m away from the monitored trees. In addition, we were provided with monthly precipitation from December 1999 until September 2000 from the same station. Long-term monthly precipitation averages for the station at Mbeya (Anonymous 1996), which is situated 20 km from Kiwira, were used for our analysis.

The shape of the cumulative increment curves (Figure 2) suggests that there was a large variation in increment rate within a year. After being installed, the dendrometer bands measured no increment for a period of about two weeks (26 January till 10 February 1999). Given the fast increment growth rate in January 2000, this result probably did not reflect the true change of circumference. Rather, it was probably due to the fact that, after installation, the bands around the tree stems were not adjusted tight enough—a common problem in dendrometer studies (Keeland & Sharitz 1993).

A period of fast increment followed from mid February until late April. In May 1999 a gradual decrease began and in June till August increment was slow. In September till October 1999 increment gradually reached a faster rate, which continued until April 2000. As in 1999, the level of increment was low in June till July 2000.

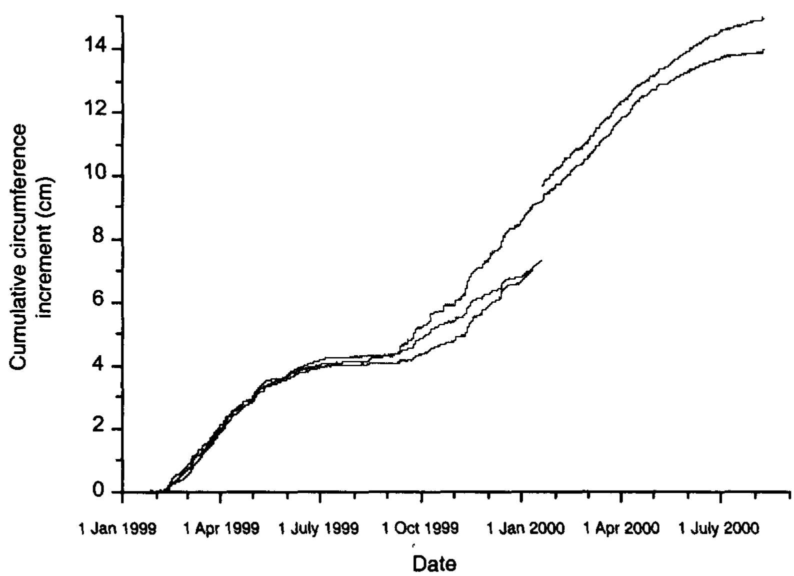

Figure 2 Cumulative circumference increment of *Pinus patula* sample trees at Kiwira, Southern Tanzania. The girth band measurements cover the period 26 January 1999 till 8 August 2000.

Figure 3 shows the monthly change of circumference of the sampled trees together with the monthly precipitation measured at the same site. The long-term monthly precipitation averages for the meteorological station at Mbeya are also given (Anonymous 1996). As is typical for the region, the long-term averages show that rainfall varies sharply between months. Very obvious dry seasons took place from May till August both in 1999 and 2000. The long-term monthly precipitation averages measured at Mbeya are much lower than those measured at Kiwira. However, the pattern of variation is rather similar: a dry season in June till August and a high precipitation in December till March. Thus the distribution of rainfall measured at Kiwira in 1999 till 2000 appears to be typical for the area.

The pattern of variation for monthly precipitation is notably similar to the pattern of the monthly increment. During the dry period of 1999 the monthly circumference increment of the sample trees diminished from the maximum of 1.27 cm in March to 0.11 cm and 0.09 cm in July and August respectively. In year 2000 the dry period started earlier and there was very little rainfall in May. Circumference follows a similar pattern to 1999; the July mean increment for the year 2000 was 0.15 cm.

In 1999 the monthly rainfall increased in August (39.0 mm) and September (90.6 mm), while the October precipitation was again low (24.5 mm). All these figures still represent low levels of precipitation compared with the 501 mm in March 1999. However, the monthly mean circumference increment increased considerably to 0.55 and 0.61 cm in September and October 1999 respectively. Relatively high increments were also measured for November and December 1999, which were months of relatively high precipitation. As in 1999, the highest monthly growth for the year 2000 was recorded in March.

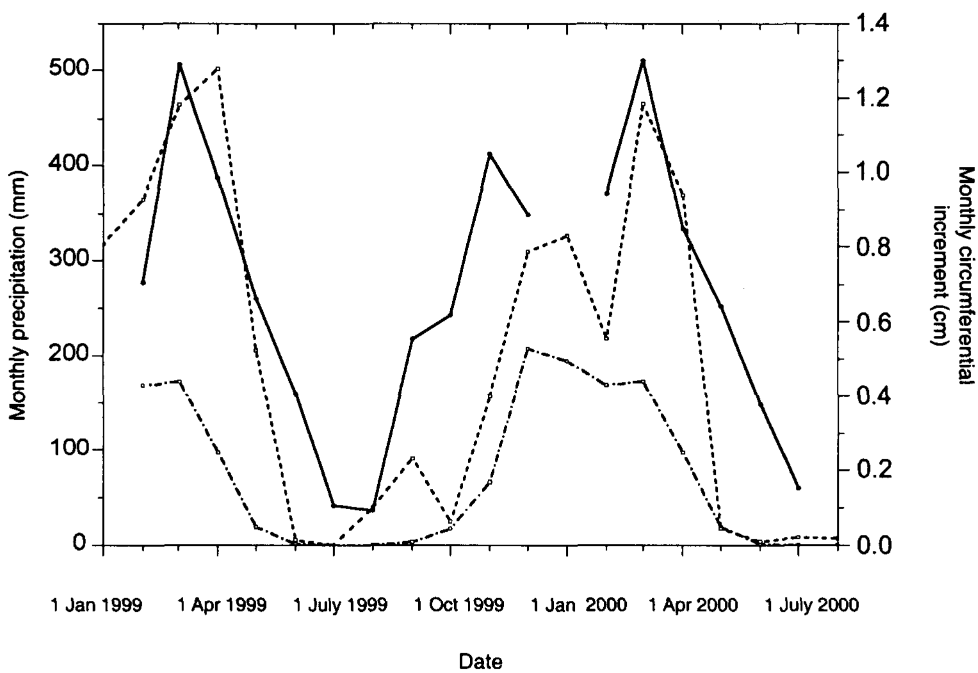

Figure 3 Monthly precipitation (dashed line) measured at the study site from February 1999 until July 2000, long-term averages of monthly precipitation from Mbeya (dotted line) and the mean monthly increment of the sample trees (solid line)

In Figure 4 the data on increment and precipitation is shown in greater detail by using three-day moving averages. Unfortunately, our data on daily rainfall were only available from 1 January till 16 December 1999. There is obvious similarity in the timing of rainy episodes and periods of especially fast increment. During the dry period, the increment steadily decreased from June until early August. After the first rains in September a faster increment level was again reached. In October till December, when rains occurred less regularly than in February till April, there was greater fluctuation in the short-term increment.

The three-day moving averages of increment very rarely had a negative value. Those few episodes that did, occurred mainly during the period of slow increment in August. Even then the occasional shrinking of the tree stems was rather small compared with the increase during the following rainy episodes. The monthly increment was well above zero, even in August (Figure 3).

Naturally all changes of tree circumference are not caused by formation of new cells. There are also different types of reversible changes of stem dimensions that are often related to depletion and replenishment of internal water reserves of the tree (Kozlowski & Winget 1964). These can be sizeable. For Norway spruce (*Picea abiest*) in Switzerland, the water induced shrinkage of the bark up to two times the annual growth-induced increase of the stem radius (Zweifel 1999).

Our study site experienced an extremely severe reduction in rainfall both in June till August 1999 and in May till July 2000. These dry periods most likely cause a reduction of internal water reserves of the trees. Thus, if *P. patula* had had a period of cambial dormancy during those dry periods a clear reduction of stem diameters is expected. However, we measured positive monthly increments during all months. Therefore, the results tend to suggest that *P. patula* did not reach a state of cambial dormancy during the study period.

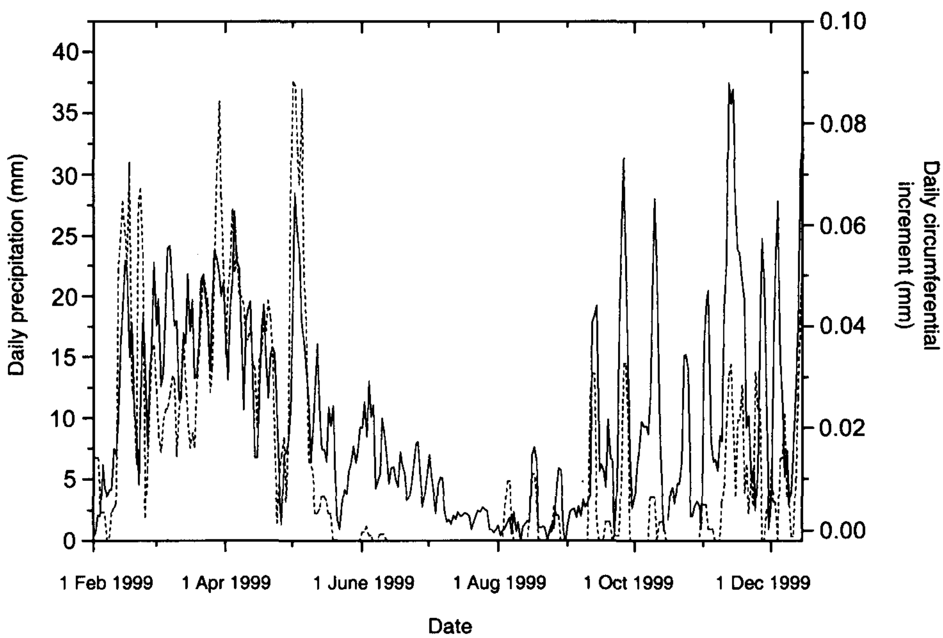

Figure 4 Three day moving averages of daily increment (solid line) and daily precipitation (dashed line) for 1 February 1999 till 16 December 1999. Notice that on few occasions the three-day moving average of daily increment goes below zero.

The results also suggest that the circumferential increment of *P. patula* respond strongly to precipitation. Monthly circumferential increment fell from a maximum of 1.27 cm in March 1999 to only 0.09 cm in August 1999. The variation of monthly increment follows a notably similar pattern as the variation of monthly precipitation (Figure 3).

Previous studies have shown that precipitation commonly has a strong effect on the growth of trees in the tropics. In fact, cambial dormancy and formation of annual rings in tropical trees are frequently induced by regularly occurring dry periods (Worbes 1995). Thus, it is plausible that similar patterns of variation for monthly increment of *P. patula* and monthly precipitation indicate a strong causal relationship between the two.

Since there was such a drastic reduction in precipitation, part of the observed variation of monthly increment is most likely due to shrinkage of the stems, caused by a depletion of internal water reserves of the trees. It is hard to estimate how large the effect of such shrinkage could be. Sheil (1995) estimated that a hydrostatic flex of ± 0.5 to 1.0% of tree size is normal for tropical trees. For our sample trees, a 1% hydrostatic flex would mean a maximum diameter change of about 2 mm, which corresponds to a circumferential shrink of approximately 6 mm. Zweifel (1999) reported a radii shrinkage of 1 to 2 mm for Norway spruce between the largest radius expansion in summer and the most contracted state the following winter. A 2-mm radii shrinkage corresponds to a circumferential shrinkage of 1.2 cm, which incidentally is roughly equal to the difference between the highest and lowest monthly increments at Kiwira (Figure 3). However, the shrinkage reported by Zweifel (1999) is mainly caused by extremely low temperatures that are unlikely to occur in the tropics. Also, at Kiwira the severe growth depression lasted several months. Thus, even if water-induced stem flexibility caused circumferential shrinkage of 1.2 cm for *P. patula* in the dry period, it would only account for a minor part of the increment depression.

It is worth noting that the period of slow increment in July till August coincides with a period of low temperatures and frost events. Increase in temperature might partly explain the enhanced growth in September till October 1999, both of which were months of relatively low precipitation (Figure 3). Significant relationships between growth variations of two pine species (*P. kesiya, P. merkusii*) and both temperature and precipitation in Thailand have been reported (Buckley *et al.* 1995). In particular, weather in November, i.e. the transitional month from wet to dry season, was strongly correlated with growth.

Variation of the daily growth of *P. patula* may also have practical value in planning of field experiments and in analysing existing data sets. While one of our main findings is that there is no total cessation of increment, it is nevertheless evident that if a similar growth pattern occurs in most years, the best time to make periodic measurements on permanent experiments is in July till August. Long-term monthly precipitation averages at Mbeya show that drought occurs repeatedly this time of year (Anonymous 1996). According to Isango & Saramäki (1999), this is also the coldest time of the year. It is, therefore, likely that growth rates will also be low during these months.

Since our data cover only a short period, the results must be considered very preliminary. As increment appears to be linked with precipitation, our findings cannot be applied to regions where the onset of dry and rainy seasons is different. Climatic conditions can be varying even within small geographic regions in the tropics (Anonymous 1996). The regions in East Africa, where *P. patula* has been planted, belong to this category. Thus, it would be useful to study the intra-annual growth of *P. patula* in differing climatic conditions. Also, with a longer time series, it would be possible to model the relationship between weather parameters and short-term increment.

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