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**A Dendrochronological Investigation of *Pinus radiata*
from Silvermine Nature Reserve**

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**Botany Honours Thesis 2002
University of Cape Town**

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A Dendrochronological Investigation of *Pinus radiata* from Silvermine Nature Reserve

Abstract:

Whole trunk cross sections of *Pinus radiata* were collected from Silvermine Nature Reserve, Cape Town. The site was located on a hill in the nature reserve where precipitation was assumed to be a limiting factor in tree growth. Ring widths along 82 radii on 41 samples were measured to the closest 0.1mm. Samples displaying the highest correlation between ring width values were selected to create a growth index chronology for the site. The resulting chronology was compared to various aspects of precipitation and temperature. Correlation coefficients between tree growth and annual, winter and growth season precipitation levels, minimum and maximum growth season temperatures, mean summer and mean winter temperatures were calculated with the use of a regression analysis. None of the correlation coefficients were above 0.1, leading to the conclusion that the growth of trees was possibly disturbed by humans while the stand was under Cape Nature Conservation management. An alternative explanation could be that the height at which trees were sampled is likely to cause lowered correlation between samples as proposed by Fletcher (1974b). Although it is not statistically significant, trees displayed similar patterns to precipitation levels since 1955. The conclusion of this study is that *Pinus radiata* could provide a useful proxy record of climate in South Africa, but an undisturbed site where trees are limited by precipitation needs to be located before attempting the development of another ring index chronology.



Introduction:

Dendrochronology is a term that refers to all scientific studies of tree rings, where annual growth is assigned specific calendar years. A subfield of research in dendrochronology, known as dendroclimatology, has come about because tree rings have characteristics which make them a valuable source of proxy data on palaeoclimates (Fritts, 1976). Few other sources of proxy data can provide both the level of continuity and precise datability available from tree rings. Understanding the natural variability in climate could help man to better anticipate future climatic changes as well as to better understand those of the past (Gates and Mintz, 1975)

The application of dendrochronological studies has presented more problems in South Africa than any other region in the Southern Hemisphere. This is mainly due to problems associated with poorly defined, locally absent and converging rings (February and Stock, 1998). *Podocarpus* species have been at the center of dendrochronological research in South Africa with many claims for a relationship between ring width and certain climate variables (February and Stock, 1998). Lilly's (1977) survey of 115 tree species indigenous to South Africa is probably the most extensive with African tree species. She concluded that few were as well suited to such studies as those from Europe and North America. Tropical woods are typically diffuse in their anatomical structure and exhibit more visually dominant parenchyma. The latter compounds the already difficult task of detecting growth bands (Gourlay, 1995). In *Widdringtonia cedarbergensis*, the development of well dated ring width index chronologies is hampered by the lack of an abrupt termination of late wood in many samples (February and Stock 1998). However, Dunwiddie and La Marche (1980) successfully developed a chronology for *Widdringtonia cedarbergensis* in the Cape Province. Development of tree ring chronologies in other areas of South Africa would have substantial potential benefits to climatology, forest ecology and forest management.

Aims and objectives:

The main objective of this project was to apply the science of dendrochronology to whole trunk cross section samples from Cape Town. If the trees were sensitive to the climate, the application of dendroclimatology could produce a reconstruction of climate in Cape Town for the past 57 years. *Pinus radiata* was chosen above indigenous species as trees from the Northern Hemisphere (eg: *Araucaria*, *Artemesia*, *Fagus*, *Juniperis*, *Libocedrus*, *Abies*, *Picea*, *Pinus*, *Pseudotsuga*, *Tsuga*, *Quercus*, *Sequoia* and *Larix*) are better suited to the application of dendrochronological analyses.

why - if empirical, refs?

A suitable site was located at Silvermine Nature Reserve, where a stand of *Pinus radiata* trees had been felled in 1998. The tree stumps were located on the crest of a hill and whole trunk cross section samples were taken from the top of the hill where the topography changed drastically to a steep cliff. It was hypothesized that the growth of these trees would be limited by precipitation as the sites substratum was unable to retain enough water to allow trees a permanent source throughout the year. This means that trees should reflect periods of drought as abnormally narrow rings. Conversely, trees would grow faster during years when precipitation was higher during the warm months. These years would be reflected as abnormally wide rings in the samples. Therefore, with a large sample size, I attempted the first dendrochronological study in South Africa that relates precipitation to ring width in *Pinus radiata*. A successful study would culminate in the production of a tree ring chronology of precipitation patterns in Cape Town since 1955.

to methods

Materials and methods:

In dendrochronological studies, criteria for sampling include trees that 1) are not too close to other trees, as competition may overshadow climatic response; 2) have no subsurface supply of water, for example, an adjacent spring or perennial stream; and 3) have no outward appearance of injury or disease. Even when working with a species of established quality, often it is necessary to sample young trees which may be used to validate interpretation or to solve the problems in the tree-ring chronology. Thus all available age classes should be included within the species and site transects. (Ferguson, 1970). Bearing these factors in mind, 41 whole trunk cross sections were cut from stumps of previously felled trees with a chainsaw. The site was within the Silvermine Nature Reserve (34' 05" S, 18' 25" E). Before trees were felled, they had been growing on the edge of a cliff formed on the Muizenberg mountain. Currently, Table mountain fynbos species (*Cliffortia*, *Erica*, *Protea* etc.) are dominant at the site.

Climate in Cape Town is described as "Mediterranean" which implies hot, dry summers and cool, rainy winters. Climate data since 1955, in the form of monthly precipitation, maximum and minimum temperatures were obtained from the South African Weather Bureau. Rainfall at Silvermine is seasonal (Graph 1) with a monthly mean of 45.5mm in summer, 144mm in winter and an annual mean of 1237mm. The range of annual precipitation since 1955 is 927mm to 1639mm (Graph 2).

did intro

47 yrs ago!
- why?

defined as ?

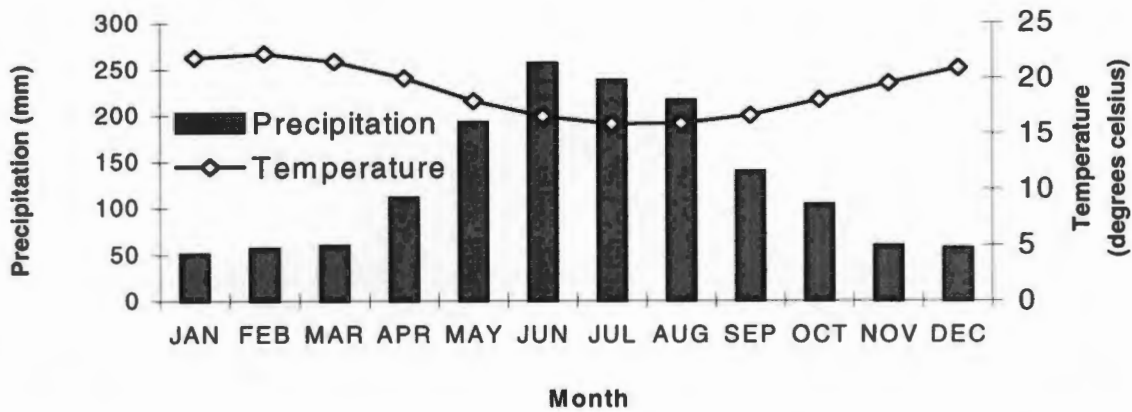
defined as ?

Fig-2 shows
a low of ~50 mm
in 2000.

Fig.

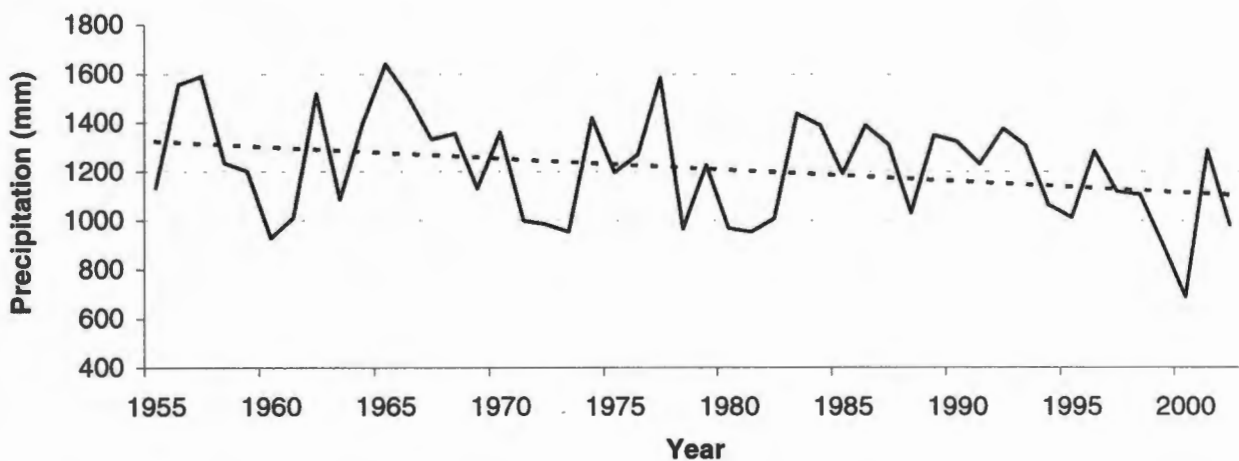
Fig

Mean Monthly Temperature and Precipitation at Silvermine



Graph 1: Mean monthly temperature and precipitation at Silvermine shows seasonality in both variables.

Total Annual Precipitation at Silvermine since 1955



Graph 2: Total annual precipitation at Silvermine since 1955 shows that mean precipitation (trendline) has decreased by 200mm.

In the laboratory, a belt sander (Makita 4" Japan) was used to prepare the specimens for microscopy. Progressively finer grained sandpaper, starting at 40-grit and ending with 600-grit, was used to prepare samples. Additional polishing was performed in the same manner with a rotary sander utilizing 320, 360 and 400-grit paper.

Cross dating:

Skeleton plots were produced for some samples. This method of analysis does not attempt to show the absolute width of rings, but rather their relative width with reference to those adjacent to them, drawing attention in particular to the narrowest ones. These are represented by vertical lines which become longer as rings get narrower, but not proportionally. Rings which are the same width or wider than the neighbouring groups are not shown. This process allows the tendency for rings to decrease in width due to age or competition to be eliminated. The simple ocular comparison of skeleton plots allows recognition of sequences of particularly narrow rings called signatures (Trenard, 1982). Accurate cross-dating was impossible due to substantial variation in growth form between radii, therefore ring widths were measured with a computer linked with an incremental measuring stage in conjunction with a Leica stereoscopic microscope (10X) with cross hairs and PJKV2 software on an Apple Macintosh operating system. COFECHA (Holmes, 1983) is a computer program that correlates variations in ring width measurements between samples and it was used to select samples that grew with similar responses to climate. A total of 28 out of 82 radii were selected in this manner.

Standardization (De-trending):

Rings vary not only with fluctuations in environmental conditions, but also with systematic changes in tree age, height within the stem and conditions affecting productivity of the site (Fritts, 1976). The transformation of ring width measurements by de-trending results in a sequence of ring width indices. Their mean value is one and they generally have no linear trend. The larger variability in ring width of the younger, faster growing portions of the tree is made comparable to the lesser variability in the ring width of the older, slower growing portions of the tree. The indices from a group of trees are averaged to obtain the mean chronology or mean standardized indices for a site. These calculations were performed by a software package known as Arstan (Cook, 1985). The term "growth" in graphs 3, 5, 6 and 7 refer to the ring width indices produced by Arstan.

The chronology that resulted from the de-trending of ring width measurements and the averaging of ring width indices was compared with temperature and rainfall data that I

obtained from the South African Weather Bureau. Regression analyses between mean growth and various climatic variables were performed with Microsoft Excel. The correlation coefficients derived from these analyses are measures of whether or not a chronology is statistically comparable with a climatic variable.

Results:

Table 1: Regression Statistics between Growth and Climatic Variables

<i>Climate Variable</i>	<i>R²</i>
Minimum Temperature in the Growth Season	0.06
Maximum Temperature in the Growth Season	0.02
Temperature in Summer	0.06
Precipitation in the Growth Season	0.08
Precipitation in Winter	0.01
Annual Precipitation	0.04

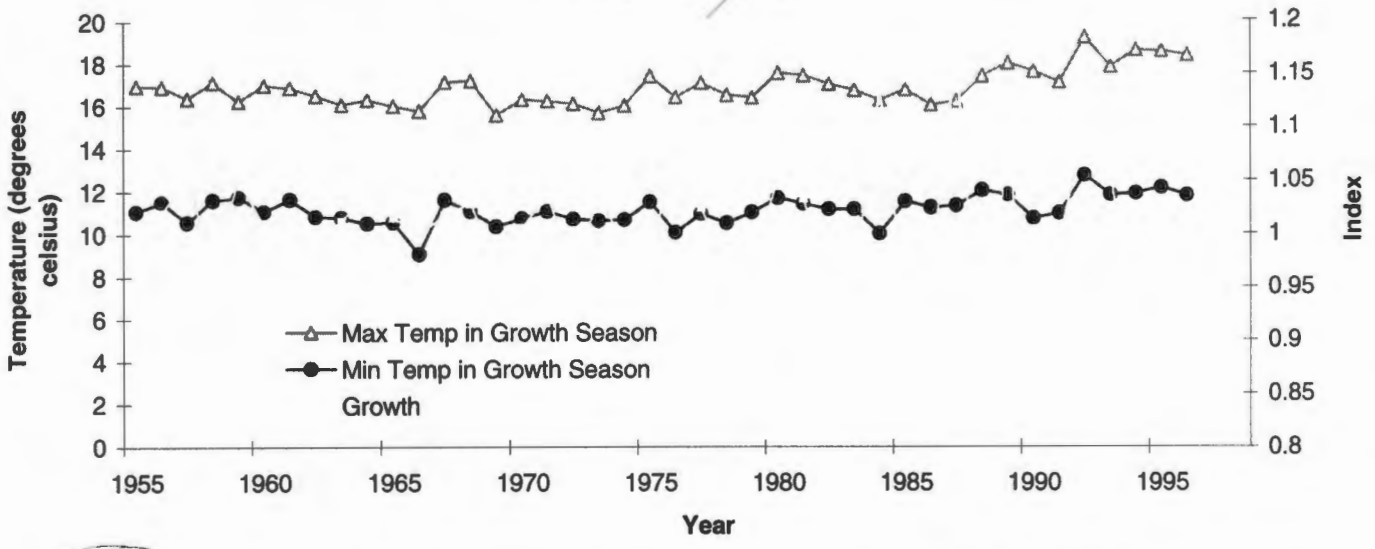
The period designated as "Summer" was between November and March, while "Winter" refers to the months of April to October. method

can't see this growth line in Fig 3. correlation not clear elsewhere either
It is clear that growth followed precipitation and temperature patterns fairly closely (Graph 3, 4, 5, 6 and 7), but the correlation coefficients between growth and each variable were all below 0.1 (Table 1; Appendix 1). Fig. 2

The growth of *Pinus radiata* at Silvermine was not statistically comparable with any combinations of seasonal temperature of precipitation patterns. This makes accurate climate reconstruction impossible from the samples used in this study. ✓

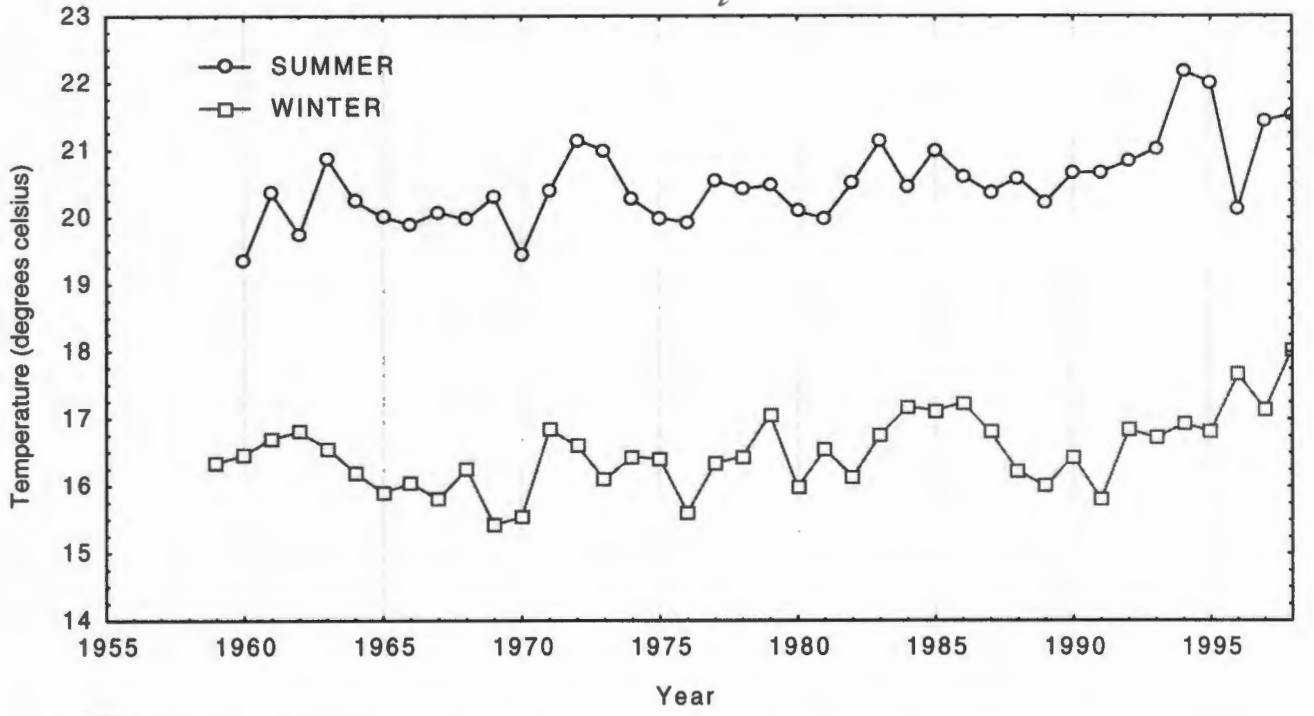
Growth and Average Maximum and Minimum Temperatures in the Growth Season since 1955

can't see growth line!



Graph 3: Growth and average maximum and minimum temperatures in the growth season since 1955.

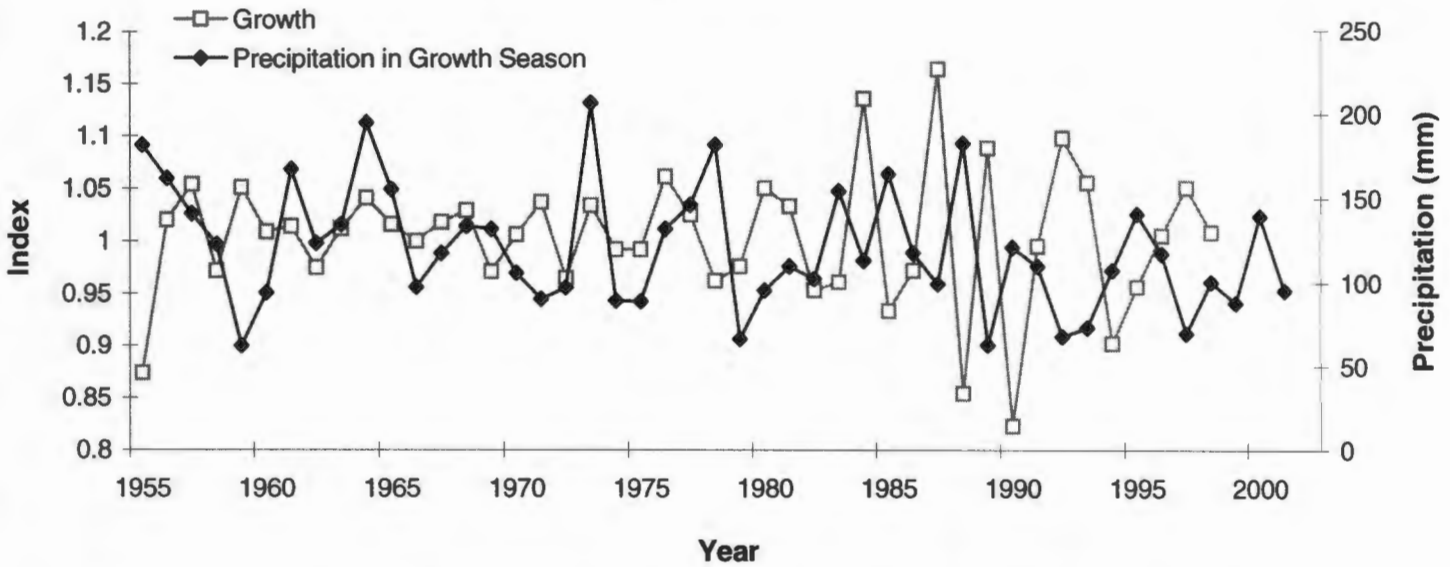
Graph of Mean Summer and Winter Temperatures at Silvermine since 1959



growth

Graph 4: Mean summer and winter temperatures at Silvermine since 1959.

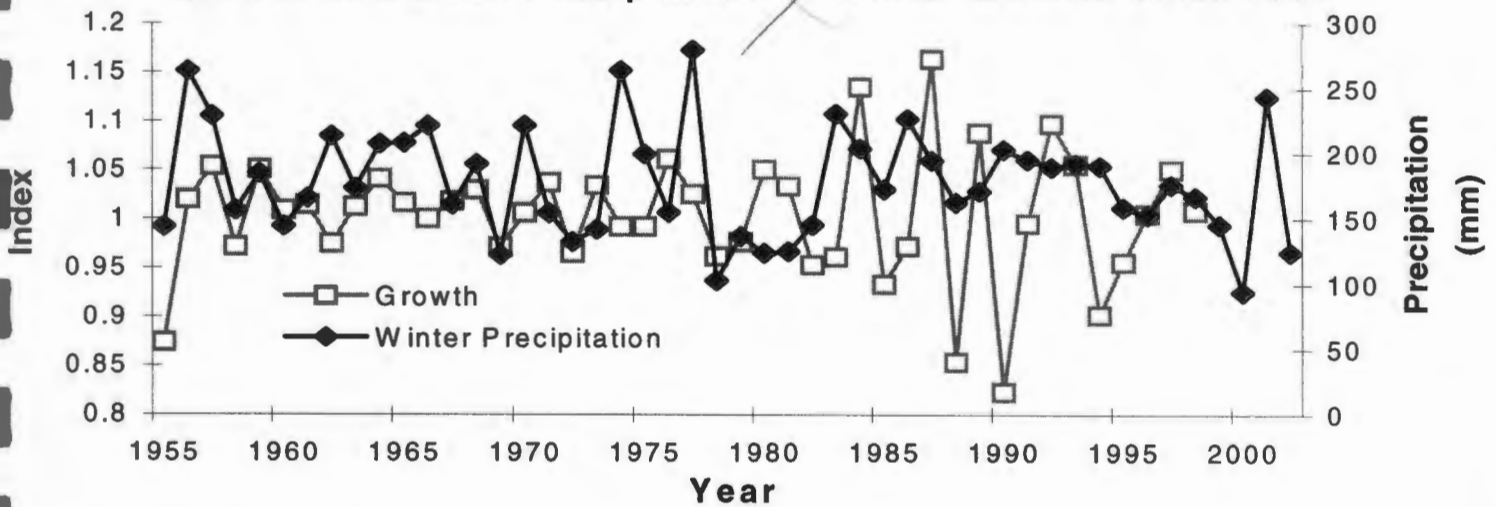
Growth and Mean Monthly Precipitation in the Growth Season since 1955



Graph 5: Growth and mean monthly precipitation in the growth season since 1955.

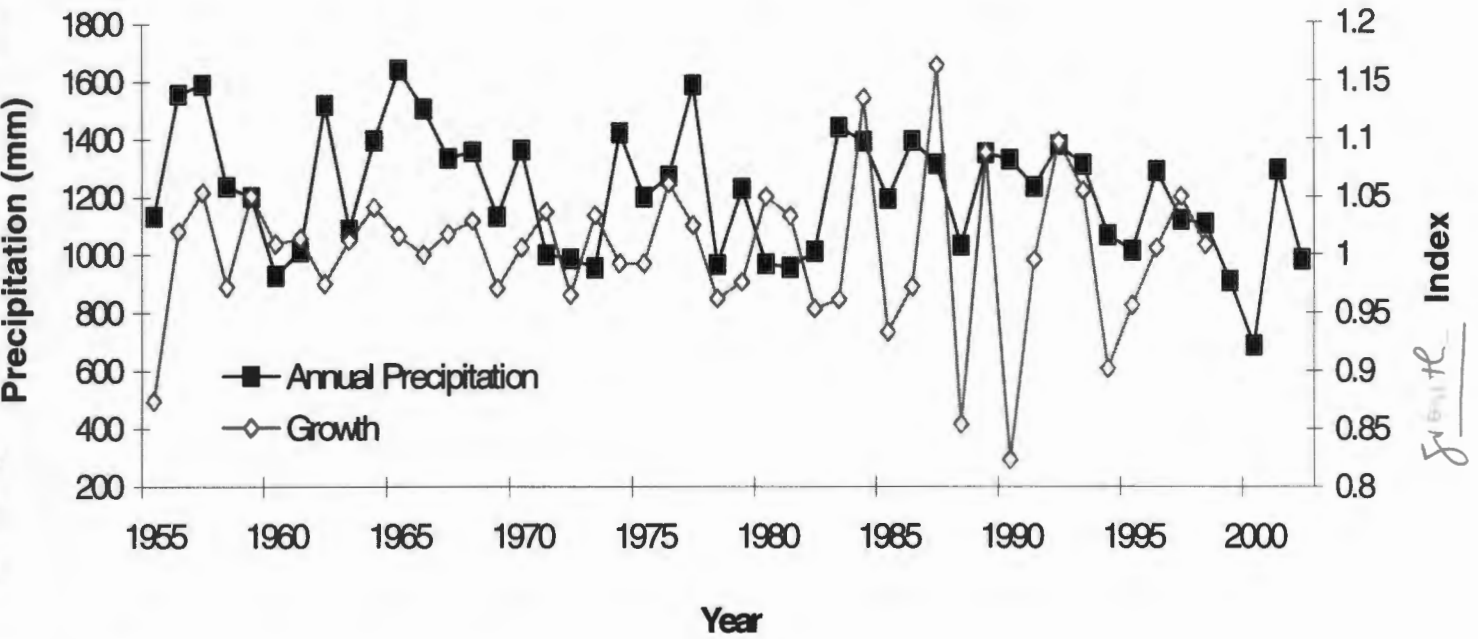
Looks like growth lags behind rainfall by 1 yr. Did you try regressing growth against previous yr's rainfall?

Growth and Mean Precipitation in Winter Months since 1955



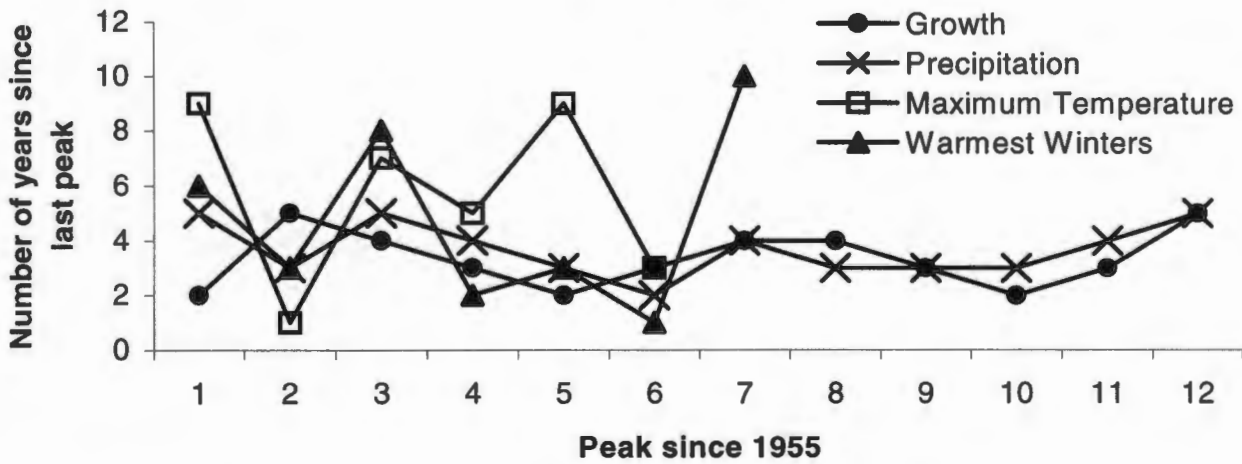
Graph 6: Growth and mean precipitation in winter months since 1955.

Growth and Annual Precipitation since 1955



Graph 7: Growth and annual precipitation since 1955.

Number of Years Between Peaks in Various Climatic Factors



Graph 8 Number of years between peaks in various climatic variables.

Discussion:

The choice of species to which dendrochronology can be applied is only limited by the need for confidence that they form one ring each year. Theoretically, this could apply to all coniferous and broadleaved species in temperate regions. In practice, several considerations restrict this choice. Fir, spruce, larch, pine, beech and alder frequently have rings missing on all or part of the circumference of the stem (Brehme, 1951; Hollstein, 1970a; Eckstein, 1970a). The severity of the climate notably increases these gaps (Lobzhanidze, 1972) and this obviously increases the chances of distorting the synchronizations between several individuals, and preventing the production of a definite chronology. Regardless of the negative factors experienced using pine in dendrochronological studies in the past, it was selected above other species as it has been grown in South Africa for more than 300 years and is found over a large geographical range. If it can be shown that an accurate growth index chronology could be produced with this species, then the climatic record could possibly be extended further into the past. Chronologies could also be developed for a larger geographical area in South Africa as Pines are well distributed throughout the country.

d.c.

The patterns of maximum and minimum temperatures (Graph 3) and maximum summer and winter temperatures (Graph 4) are not comparable with the tree growth patterns. This supports the hypothesis that trees were not limited by extreme temperatures and that precipitation should be the only limiting factor in the climate.

OK, though even the correlation with precipitation are weak.

Growing season of pines is from spring to mid-summer. The climatic data for the months of August, September, October and November were averaged and compared with the annual growth of trees. To ensure that growth was not affected by any other factor, climate data from all seasons was compared with annual growth indices. There was only a slightly greater correlation between growth and climatic factors during the growth season, than at other times of the year (Table 1).

method
results

Mean growth indices remain relatively uniform, peaking at around 1.05 in 1957, '59, '64, '68, '71, '73, '76, and '80, while fluctuating almost concurrently with precipitation in the growth season (Graph 5), precipitation in winter (Graph 6) and annual precipitation (Graph 7) until the early 1980's, when sharp fluctuations in growth rates were experienced. Peaks in growth indices at around 1.15, indicating higher precipitation rates, were experienced in 1984, '87, '89, '92 and '97. This may be due to the management strategy of Silvermine

write full results.

No, not necessarily. Further on you attribute this to management.

Nature Reserve. Direct human intervention on a stand of trees can lead to competitive release for some trees if the stand is artificially thinned (Kolchin, 1962). As soon as competition for a limiting factor is reduced, growth is stimulated. This could explain the low correlation between growth and climatic factors. ✓

For reasons of convenience, samples were taken at breast height (1.3m above ground level). However, Fletcher (1974^b) thinks that this is the height at which one gets the worst correlation between trees. He recommends taking samples at a height of four metres. Barefoot *et al* (1974) worked on several heights and even on stumps. Pilcher (1973) also makes measurements on stumps. However, it appears that broadleaves and conifers do not react in the same way, and that as a rule a height of about 1.50 m is reasonable for broadleaves, while a greater height, near to 4 metres, would be preferable for conifers (Trenard, 1982). Perhaps the low levels of correlation between samples were due, at least in part, to the height above ground from which samples were taken. The felled tree trunks are still lying around on the site, so new samples could be analysed from regions in the trunk where higher correlation between trees is expected. "b" ?

The pattern formed by plotting the number of years between peak growth years (Graph 8) may provide insight into the longer term climatic cycles. The number of years between peak growth years seems to fluctuate between 2 and 5 years, in a very uniform distribution. Every fifth gap between peak growth years seems likely to be the same, or almost the same number of years. A longer sequence of data and a deeper understanding of atmospheric and ocean circulation patterns in the Southern Hemisphere are required to draw firm conclusions about the frequency of extreme climatic events and the variation in observed patterns. of ?

The investigation of the application feasibility of dendrochronology and dendroclimatology has produced negative results from the site at Silvermine. Sites should be sought with pines that have had no direct human influence during their lifetime. ✓

Some observations from the data are that annual precipitation seems to be on a slow decline (Graph 7), while mean temperatures are increasing (Graph 2). To be certain that these trends are as a result of the global warming effect, a well dated chronology from the Cape Town area is still required. This chronology would have to depict at least 100 years worth of data for any conclusions to be drawn. enough ?

Acknowledgements:

I would like to thank Dr Edmund February, Dr Zewdu Eschetu, Mrs Rose Newton at the University of Cape Town and Gavin Bell at Silvermine Nature Reserve for their assistance in this project.

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1976 in text (p2)

?

cited in discussion.

Ekstein 1970a
Brohm 1951
Hollstein 1970a
Lobzhanidze 1972
Koldin 1962
Fletcher 1974b
Barclay et al. 1974
Pilcher 1973

Appendix 1:

Regression Statistics

Growth vs Minimum temperature in Growing Season

R= 0.258167

R Squared: 0.06665

Adjusted R Squared: 0.041425

Standard Error: 0.083834

N= 39

Growth vs Maximum temperature in growth season

R= 0.1424

R Squared: 0.020278

Adjusted R Squared: -0.0062

Standard Error: 0.085892

N= 39

Growth vs Winter Precipitation

R= 0.106521

R Squared: 0.011347

Adjusted R Squared: -0.01277

Standard Error: 0.082833

N= 43

Growth vs Precipitation during the growth season

R= 0.283228

R Squared: 0.080218

Adjusted R Squared: 0.057784

Standard Error: 0.060785

N= 43

Growth vs Precipitation growth season

R= 0.177473

R Squared: 0.031497

Adjusted R Squared: 0.007874

Standard Error: 0.062374

N= 43

Growth vs Minimum temperature during the growth season

R= 0.239297

R Squared: 0.057263

Adjusted R Squared: 0.031784

Standard Error: 0.063631

N= 39

Growth vs Maximum temperature during the growth season

R= 0.144879

R Squared: 0.02099

Adjusted R Squared: -0.00547

Standard Error: 0.064843

N= 39

Growth vs Summer Temperature

R= 0.257549

R Squared: 0.066331

Adjusted R Squared: 0.040396

Standard Error: 0.064193

N= 38

Growth vs Winter Precipitation

R= 0.121935

R Squared: 0.014868

Adjusted R Squared: -0.00916

Standard Error: 0.062907

N= 43

Growth vs Annual Precipitation

R= 0.214915792

R Squared: 0.046188798

Adjusted R Squared: 0.02292511

Standard Error: 0.061899323

N= 43