Source: Haneca K, Verheyden A, Beekmann H, Gärtner H, Helle G, Schleser G (eds.) (2007) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 5: Proceedings of the DENDROSYMPOSIUM 2006, April 20th – 22nd 2006, Tervuren, Belgium. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 74, p. 73 - 79.

Dendrochronological investigations on *Juniperus procera* from Ethiopian dry afromontane forests

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Introduction

Within the dry afromontane forests of the Ethiopian highlands, *Juniperus procera* dominates from 2300 to 3200 m asl, where the mean annual rainfall ranges from 500 to 1100 mm. This tall (up to 50 m), evergreen forest tree is the only tropical African juniper and is indigenous to the East African tropical highlands. Its timber is strong and highly valuable; after seasoning the wood is very durable, immune to fungal attacks, termites or wood-borers (Gardner 1926, Pohjonen and Pukkala 1992). Therefore, juniper is the most preferred multipurpose tree in Ethiopia for construction, furniture, firewood, fencing and medicinal uses (Chaffey 1982), and holds as well a strong symbolic and religious meaning. The juniper dominated woodlands once covered a large part of the country. However, as a consequence of long-lasting and persistent human influence, they have been considerably depleted and are now reduced to some isolated patches (Negussie 1995, Nyssen et al. 2004).

To support conservation, restoration and sustainable use of the remaining woodlands more information is needed on growth pattern and population dynamics of *Juniperus procera*. Moreover, in the context of an increasing concern about global climate change, this study was an opportunity to assess the potential of *Juniperus procera* for dendroclimatic investigations in this poorly documented region of the tropics (Verheyden et al. 2005). Classical dendrochronological methods were used to build up tree-ring chronologies for *Juniperus procera* trees from two Ethiopian highland forests, and to check whether these chronologies have the potential to serve as proxies to study past changes in climate.

Study sites

The two investigated sites are located 300 km apart from each other in the Ethiopian highlands (Fig.1). The Menagesha-Suba forest stretches on the southwest facing slopes of Mount Wechecha (8°97'N to 9°00'N, 38°35'E to 38°38'E; 2300 - 2900 m asl), an extinct volcano 45 km southwest of the capital city Addis Ababa. The Adaba-Dodola forest lies on the northern side of the Bale Mountains (6°50'N to 7°00'N, 30°07'E to 39°22'E; 2400 - 3100 m asl).

Figure 1: Map of Ethiopia with the two study sites.

Both woodlands are remnants of dry evergreen mountain forests dominated by *Juniperus procera*. Despite their conservation status as National Forest Priority Areas, repeated human interferences have led to heavy degradation and nowadays closed forest is only restricted to difficultly accessible areas. The climate is tropical alpine, with an average temperature of 10 °C to 16 °C, depending on the altitude, and a mean annual precipitation of 1200 mm. The climate records from the Holeta and Dodola stations, located in direct vicinity of the study sites, show a slight difference in the total amount of rainfall but a similar pattern in the annual distribution of precipitation (Fig. 2).

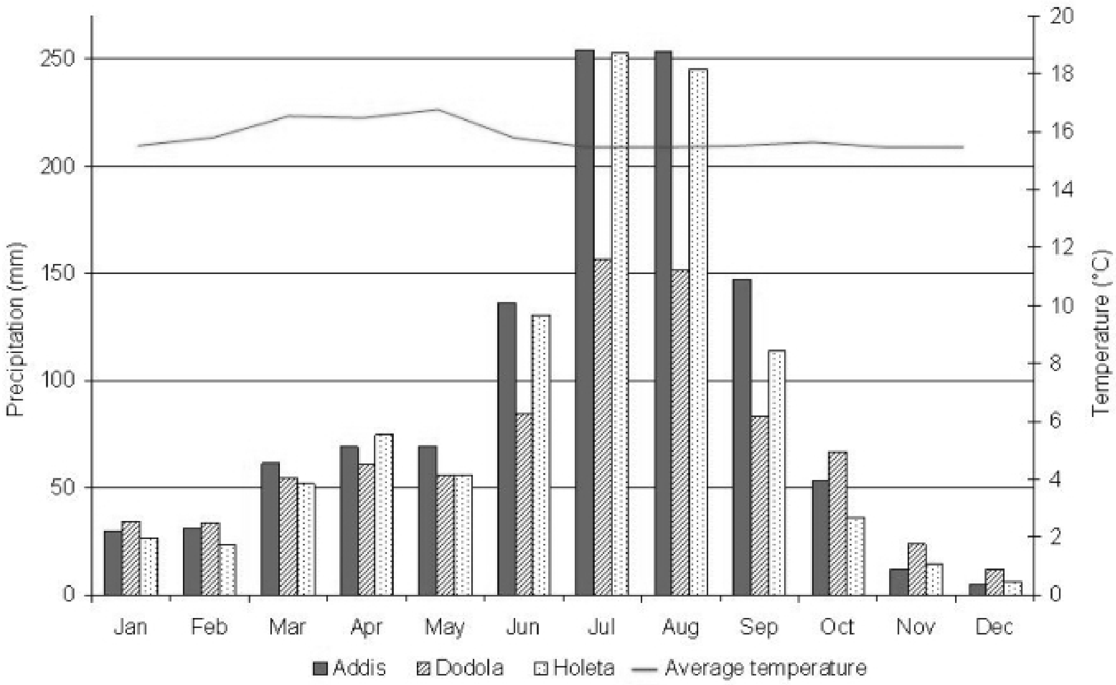

Figure 2: Climate diagram for Addis Ababa (09°03' N, 38°42' E; 2400 m asl), Adaba-Dodola and Holeta (closest weather station from Menagesha). Average values for the 13 common years with available data in the three sites (1972, 1975-1979 and 1996-2002).

Both records reflect a bimodal distribution in rainfall with a main rainy season from June/July to September/October and a minor one from January/February to April/May.

Material and methods

Since juniper species are known to be problematic for dendrochronological studies (Esper 2000, Sigl et al. 2005), we mainly worked with whole stem sections from fallen trees or remains of recently cut trees: 11 stem discs were collected in Adaba-Dodola, from which two were planted at a known date. 11 stem discs and 26 increment cores from 13 living trees were collected in Menagesha-Suba. The stem discs were taken from stumps with a known felling date, between 30 and 50 cm above the ground; the two cores per tree were collected at breast height. The diameters of the sampled trees ranged from 16 to 46 cm.

All samples were air-dried. The stem discs were sanded until grit size of 800 and the 26 increment cores were mounted on wooden holders and hand-trimmed with a Stanley knife. From a first macroscopic inspection, distinct concentric growth bands were visible.

Tree ring widths were measured with a precision of 0.01 mm along four radii of the stem sections, using LINTAB (RinnTec) associated with TSAP (Rinn 1996). The time series were visually and statistically cross-dated to obtain mean tree-ring series for each juniper tree (Cook & Kairiukstis 1990, Stokes and Smiley 1996). We estimated the age of single trees after correction for missing rings due to sampling height. From this estimation and the measured ring widths, we developed diameter-age relationships for each individual. Linear regression was fitted to each of the accumulated growth curves to calculate mean growth rates for each tree. Tree-ring chronologies for the two sites, Adaba-Dodola and Menagesha-Suba, were constructed following a standard dendrochronological protocol: a 30-year spline was fitted to the single tree-ring records to remove any age-related trend in the series. Tree-ring indices were then produced by dividing each of the original tree-ring widths by the value of the fitted spline (Cook 1985, program ARSTAN http://www.ldeo.columbia.edu/res/fac/trl/public/publicSoftware.html). Subsequently, the 11 and 24 index series were averaged into two single site chronologies for *Juniperus procera* in Adaba-Dodola and Menagesha-Suba forests, respectively.

To evaluate the signal strength of both sites we calculated the Expressed Population Signal (EPS) for both chronologies, based on the average correlation between each site's tree-ring series (Wigley et al. 1984, Verheyden et al. 2005).

Response-function analysis (program DendroClim 2002, Biondi and Waikul 2004) has been carried out to assess the impact of changes in monthly mean temperature and the monthly sum of precipitation from September of the previous year till October of the observed year on the annual variation of tree-ring width during the period from 1905 to 2002.

Results and discussion

Wood of *Juniperus procera* appears light brown or golden, with clearly distinguishable, more reddish, heartwood (Fig. 3). Concentric tree rings are macroscopically visible: the late wood consisting of small and thick-walled tracheids appears darker than the early wood made of wider and thin-walled tracheids. The boundary between rings is marked by a flattening of the tracheids, which become almost rectangular (Fig. 4a). Even so, measurement was hampered by the occurrence of wedging or partly missing rings, mostly due to low growth rates. Intra-annual variations appear in some growth layers, almost exclusively in the widest ones (Fig. 4b). They could often be related to a particularly clear bimodal pattern in the distribution of precipitations in the corresponding years, with a minor rainy season followed by a major one. However, these “double rings” do not appear in all trees simultaneously, which can possibly be related to different sensitivities of trees and/or site conditions. Studies focusing more specifically on this wood-anatomical pattern would clarify the relationship between juniper wood formation and environmental conditions with a high temporal resolution.

Figure 3: Stem disc of Juniperus procera with distinct growth layers.

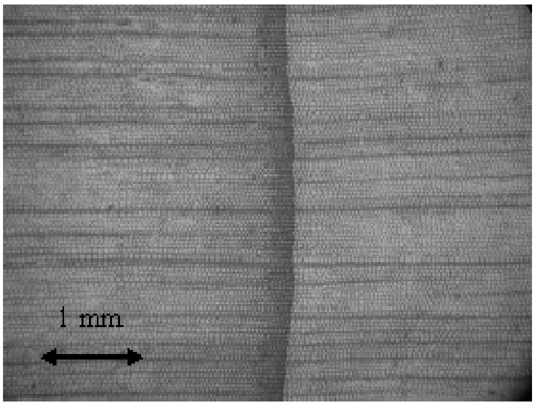

Figure 4a

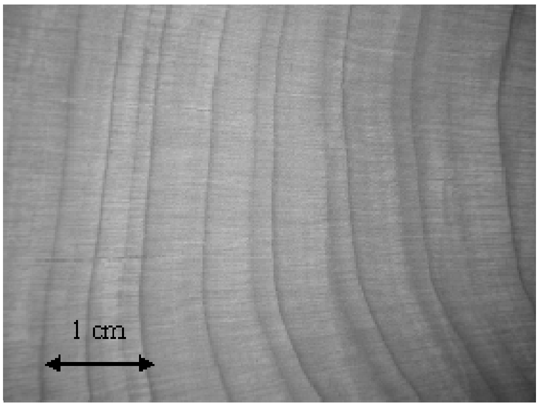

Figure 4b

Figure 4: Ring boundary under binocular (4a) and “double-ring” pattern (intra-annual density variation) (4b).

The single radii of the 11 trees from Dodola and the 24 trees from Menagesha-Suba could be visually and statistically cross-dated and averaged into two site chronologies, running from 1900 till 2003 for Dodola and from1869 till 2004 for Menagesha. This is a first indication for the annual nature of growth rings (Worbes 1995, Stahle 1999).

The EPS values for Dodola and Menagesha are 0.74 (for the period 1939-2000) and 0.81 (for the period 1963-2000), respectively. They are slightly below the commonly accepted threshold of 0.85 (Wigley et al. 1984), but already suggest a fair level of synchronicity between the chronologies and the existence of a common factor influencing growth.

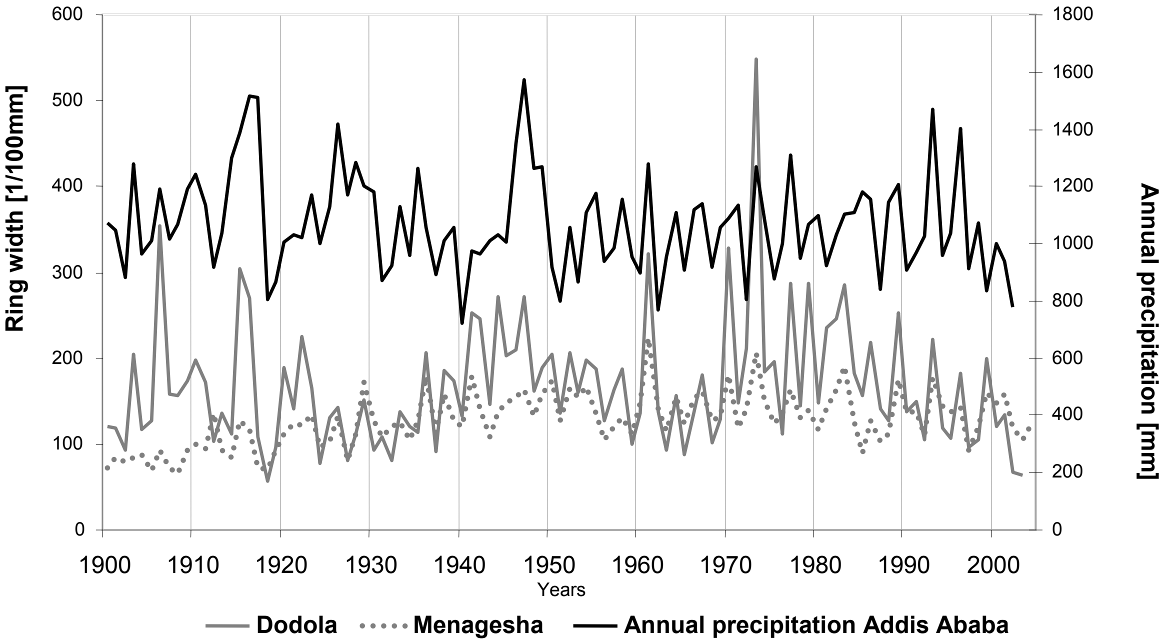

Figure 5: Master chronology of the sampled trees in both sites and record of annual precipitations from Addis Abeba.

Mean ring widths, expressing the growth rates of the trees, showed a huge variability. In Dodola, the mean annual growth rate amounts to 0.4 cm/year (minimum: 0.29, maximum: 0.51), being significantly higher than in Menagesha where it only reaches 0.26 cm/year (minimum: 0.13, maximum: 0.48). This can be the consequence of a higher amount and more equal distribution of rainfall in Dodola.

The high correlation between the two site chronologies (r=0.63), indicates that growth of the junipers in both areas is influenced by a common external factor (Fig. 5). In both sites the response-function analysis revealed that the annual growth was strongly related to the amount of precipitation, especially during the major rainy season when most of the rain falls, from July to September/October. Moreover, extremely wet or dry years could be clearly identified in tree growth. Once more, this points to a large-scale precipitation signal in the growth pattern of *Juniperus procera* in the Ethiopian dry afromontane forests (Fritts 1976). Temperature did not evolve as influencing factor. Other studies with the genus *Juniperus* were already successful for climate reconstruction (Bilham et al. 1984, Esper 2000, Bräuning 1999, 2001, Esper et al. 2002, Zhang et al. 2003). Juniper chronologies from the Ethiopian highlands are hence extremely promising for reconstructing climate history and to evaluate the impact of future climate changes in this region. It is of high relevance in this area where extreme climatic events such as drought periods can have disastrous economic and social consequences.

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