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Larch forest growth and climate reconstruction based on tree-ring analysis during the last century in northern Mongolia

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Abstract

Northern Mongolia has experienced in the last century, a sharp increase in air temperature without changes in its annual precipitation regime. Under these conditions the larch forests that distributes in this area, are subjected to continuously drier conditions. In order to explain the response of larch trees to these changing environments and to explain the occurrence of severe forest fires in this region, dendrochronological analysis was carried out. The tree-ring chronology determined for this region of northern Mongolia indicates that from the year 1900 to the present, there are three distinctive periods: high variability at the beginning of the century, where tree growth reached its maximum, followed by a more stable period from the 1920's to late 1950's where moderate peaks indicated that no wet or dry extreme periods took place. Finally the third period is dominated by the presence of frequent occurrence of smaller rings, which in some instances coincide with the largest fire occurrences at the end of the 20th century. The ring width appears to be negatively correlated to air temperature (0.33) in March and positively correlated to precipitation in May (0.39). Precipitation records indicate no variation in precipitation for the beginning of the growing season but temperature continuous rise could decrease the forest area caused by fire or stunted growth caused by water stress.

Keywords: Climate change, Forest fires, *Larix sibirica*, Northern Mongolia, Tree-rings.

1. Introduction

Northern Mongolia's forests form a transition zone between the Siberian boreal forest and the central Asia steppe desert. Changes in temperature and precipitation caused by climate change are expected to have a great effect on forest ecosystems boundaries, as climate change is predicted to shift boreal forests northwards (Hamannn and Wang, 2006). Temperature variability in Mongolia inferred from millennial tree-ring width chronologies from Siberian Pine (*Pinus sibirica*) in Mongolia (D'Arrigo et al., 2001), indicate that the 20th century was the warmest of the last millennium. Evaluation of

Siberian Pine and Siberian larch tree-rings series in other areas of Mongolia showed that the last decades have been the warmest in the last 500 years (D'Arrigo et al., 2000). This later study also shows that Mongolian larch forests have not lost their sensitive to temperature as it has been observed in other boreal regions (Barber et al., 2000; Wilmking et al., 2004). Siberian larch forest has shown high positive response to increased atmospheric CO_2 as well as increased air temperature and soil moisture (Mudrik and Vil'chek, 2001). Concerning precipitation the results of observations, tree-ring analysis and modeling appeared contradictory for Mongolian northern regions. Based on tree-ring analysis, there are more frequent extended wet periods in the twentieth century, with significant precipitation peaks observed between 10.8-12.8 years (Pederson et al., 2001) but this fluctuation appears to be within the long-term range of variations (Jacoby et al., 2003; Nandintsetseg et al., 2007). In contrast, measured records indicate that precipitation has significantly decreased in the 20th century in different parts of northern Mongolia (Batima et al., 2005). This is supported by predictions of further decreases for the 21st century (Sato et al., 2007). As shown in these studies spatial patterns of precipitation are difficult to obtain for northern Mongolia due to variations in elevation, topography and storm tracks. Carbon isotopes measurement in montane larch trees shows that they are well adapted to fluctuations between wet and dry years (Li et al., 2007) as it has been shown for other boreal regions (Lopez et al., 2007). However, Mongolia has experienced one of the highest increases in air temperature, with 2.14 C in the last 70 year, around the globe (MARCC, 2009). Therefore, the objective of this study is to analyze larch growth in the last century under such conditions and clarify its relation with severe forest fires.

2. Methodology

2.1 Study sites and sample trees Sampling

Core samples from larch (*Larix sibirica*) trees took place in the northern border of Darhad valley 51°27'04"N, 99°11'46"E) in Hovsgol region in northern Mongolia. A total of 55 cores were sampled at breast height using non-destructive 10.0 mm diameter increment borer in late September 2010. All samples were checked for missing rings and dating errors using the program COFECHA (Holmes, 1983). This was followed by tree-ring width index series standardization by ARSTAN (Cook, 1985) in order to remove the effect of non-climatic, tree aging and tree geometry trends. A 16-year spline was fitted to the individual records and residuals calculated in ARSTAN. Consistency of year-to-year variations of the tree-ring parameters was estimated by inter-series correlation (RBAR) and the expressed population signal (Wigley et al., 1984) each of them calculated as an average of values obtained for a number of 20-year periods lagged by 10 years. After agreement of all the individual series within a site were confirmed the Master chronology was calculated.

2.2 Meteorological data

Records of precipitation and air temperatures from the Renchinlhumbe meteorological station were used for cross-checking the influence of climate on tree-ring growth. The record extended from the year 1974-2009. The meteorological station is the closest one to the site where the samples were collected.

3. Results and Discussion

3.1 Precipitation

The meteorological data of the last almost 40 years indicates that precipitation, at least, for this region has not increased neither decreased (Fig. 1a) as it has been stated in previous studies (Batima et al., 2005; Sato et al., 2007). It is also evident from the data that almost 90 % of the precipitation falls in summer, mainly in the month of July and August. Winter precipitation contribution to tree water uptake and thus growth is limited. Forest fires in this region occurred mostly in May when the remaining water from snow melting and rain is at its minimum. According to the monthly as well as annual precipitation values there is no variation in the last decades. The meteorological data from Renchinlhumbe thus, coincides with the studies that suggest that drier environments have been the characteristic of northern forest ecosystems (Jacoby et al., 2003; Nandintsetseg et al., 2007).

3.2 Air temperature

In the last decades, air temperature has been steadily increasing as it is shown by the

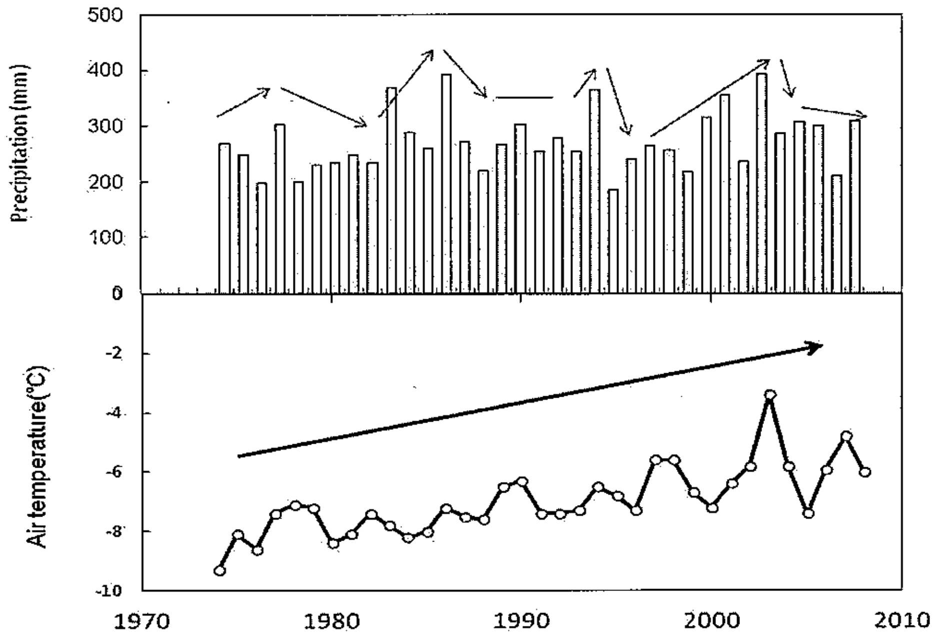

Fig. 1 Meteorological data from Renchinlhumbe (a) Annual precipitation from 1974 to 2009 and (b) mean annual air temperature for the same period.

annual mean values (Fig 1b). The highest increase is reported in winter, as it has been found in other boreal regions. In terms of forest growth, the air temperatures at the beginning of the growing season have been increasing considerably in the last four decades. The differences are of about 5-8 degrees centigrade in April and May, which makes the forest more sensitive to wildfires. Summer temperatures, in turn, have not been increasing at the same pace, with variations of only 2-3 degrees in the last decades. As a result, without the decreasing of precipitation, the evaporation rate has increased largely as a result of increasing temperatures, making the environment drier now than 40 to 50 years ago. The largest fires recorded in history in northern Mongolia were recorded in 1996 and continued in a lower scale in 1997 and 1998.

3.3 Tree-ring index

A tree-ring chronology for Darhad valley was calculated (Fig 2), where the initial year considered was 1900, even though almost one-third of the samples exceeded 150 years of age. The tree-ring series indicate three distinctive periods of larch forest growth in this region. The first one extends from the beginning of the 20th century to the early 1920's, during this period large variations in tree-ring growth are observed during these two decades. The largest tree-growth are observed in these years, which suggests good water supply, especially in early spring and high temperatures in summer. The second period extends from the 1920's to the beginning of the 1950's, a period of moderate upper and lower peaks which represents a stable period of temperature variability. It is, especially a stable period in terms of fire occurrence, if we assume that the moderate fluctuation represents the lack of extreme dry years which could cause severe forest fires. Unfortunately, there is no record of fires during this period but according to oral records from local inhabitants, large fires as those that occurred in the 1990's were not present. The third period extends from the late 1950's to the present and it is dominated by the formation of small rings, which is a strong characteristic found in all tree cores. Years with small rings are 1957, 1963, 1965, 1978, 1981, 1997, 2008 and 2009. This period coincides with the driest period in the last 110 years. It does not mean that every year is dry but the shortage of precipitation in a given year produces extremely dry

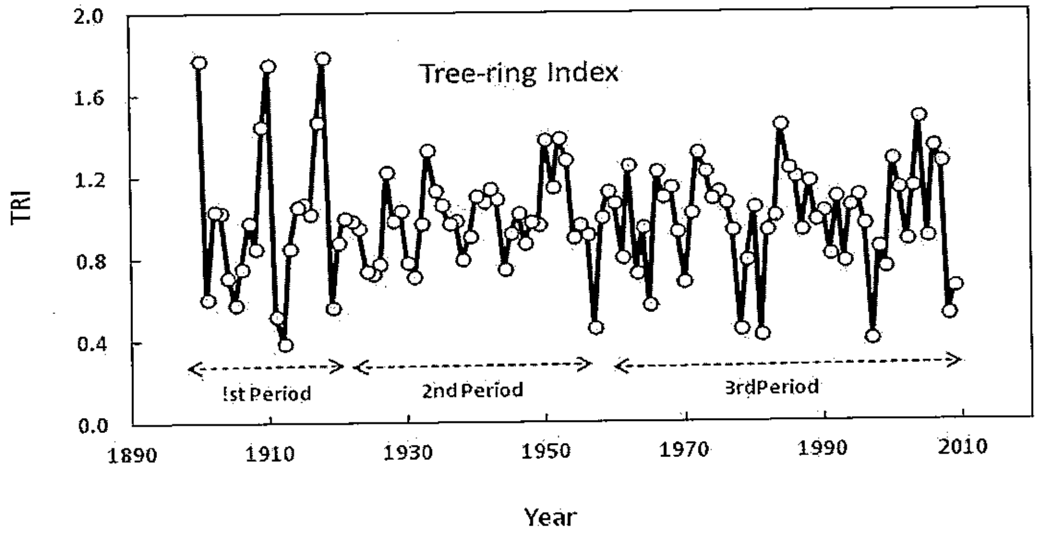

Fig.2 Tree-ring chronology for the larch forest site in northern Darhad valley.
The 110 year chronology is divided in three periods based on the TRI fluctuation.

conditions that are not necessarily reflected in that year but in the next year ring. The relationship forest fires-small ring is not straightforward (except for the 1978, 1981 and 1997) and cannot be used to infer forest fires occurrence in the past. Instead, dry years, especially at the beginning of the growing season could be responsible for small earlywood formation as well as enhanced deepening of the active layer (Lopez et al., 2010). This means that low soil water availability combined with low precipitation contributes to the formation of narrow latewood with only one or two rows of cells, compared to five or six in a normal year. The highest correlation between TRI and precipitation was positive in May (0.39) and negative for air temperature in March (0.33). This indicates that spring conditions in a given year strongly influenced tree growth in that year.

4. Conclusion

Climate change in northern Mongolia in the last decades is reflected in the more frequent formation of smaller rings. The year 1997 is particularly representative of the largest wildfires in recorded history, but more than that represents an accumulation of drought stress in the forest for several decades that burst in 1996 and 2008. Isotopic analysis of these samples could provide better information on the stress levels that larch forests are experiencing now and predict their dynamics in the future.

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