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# DENDROECOLOGY OF RELICT CHINESE PINE (*PINUS TABULAEFORMIS* CARR.) IN THE ORTINDAG SAND LAND, NORTH CHINA: IMPLICATIONS FOR ECOSYSTEM MANAGEMENT

# ДЕНДРОЭКОЛОГИЯ РЕЛИКТОВОЙ КИТАЙСКОЙ СОСНЫ (*PINUS TABULAEFORMIS* CARR.) В ПЕСЧАНЫХ ЛАНДШАФТАХ МЕСТНОСТИ ОРТИНДАГ (СЕВЕРНЫЙ КИТАЙ): ВОЗМОЖНОСТИ ДЛЯ РАЦИОНАЛЬНОГО ПРИРОДООЛЬЗОВАНИЯ

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The small patches of relict Chinese pine forests in the Ortindag Sand Land in North China are at their northern distribution limits. Herein we summarized achievements of the recent study of cambial activity as well as tree growth and regeneration dynamics of Chinese pine populations, climate reconstructions from tree rings up to ecosystem dynamics in the Ortindag Sand Land and their implications for ecosystem management.
**Key words:** *Pinus tabulaeformis*, Ortindag Sand Land, dendroecology, cambial activity, precipitation reconstruction, Palmer Drought Severity Index, NDVI, ecosystem management.

Небольшие участки реликтовых лесов из китайской сосны (*Pinus tabulaeformis*) среди песчаных ландшафтов Ортиндаг (Северный Китай) находятся на северном пределе распространения этого вида. В настоящей работе обобщены достижения последних исследований активности камбиального прироста, а также результаты изучения роста деревьев и восстановительной динамики популяций китайской сосны; построены климатические реконструкции динамики экосистем, основанные на кольцах прироста древесины в песчаной местности Ортиндаг. Показаны возможности использования полученных данных для рационального природопользования.
**Ключевые слова:** *Pinus tabulaeformis*, пески Ортиндаг, дендроэкология, камбиальная активность, фитоиндикация климата, индекс Палмера, NDVI, рациональное природопользование.

## INTRODUCTION

Chinese pine is an endemic and widespread conifer species in northern China (Xu, 1990). Its present northern distribution limit coincides with the 400 mm isohyet, which is the fringe area for the effect of the East Asian monsoon (Wang, 1990; Liu et al., 2002). The northern part of its distribution locates in the Ortindag Sand Land, where the landscape is currently dominated by grasslands (Xu and Zou, 1998; Liu et al., 2000). In addition, the Ortindag Sand Land has become one of the source areas for airborne dust and sand in recent decades (Liu et al., 2003).

The relict Chinese pine currently persists as small disjunctive populations in the Ortindag Sand Land (Fig. 1). In the 1960s, the first patch of relict Chinese pine forest was found near the Dali Lake (Yong, Liu, 1982) and later single trees and a few patches of Chinese pine forests were reported for the eastern part of the Ortindag Sand Land (Chen, 1991; Cui, Kong, 1992; Liu et al., 2002). These relict forest communities could be remnants of a previously much wider distribution during favourable growth conditions in the past (Liu et al., 2002). As indicated by a series studies in northern China, Chinese pine exhibits excellent dendroclimatic and dendroecological potential (i.e., Liu, Ma, 1999; Liu et al., 2005; Li et al., 2006; Liang et al., 2006; Liang, Eckstein, 2006). In contrast with the dominant grassland landscape, the relict Chinese pine populations provide a unique opportunity to reconstruct past climate change based on tree-ring analysis.

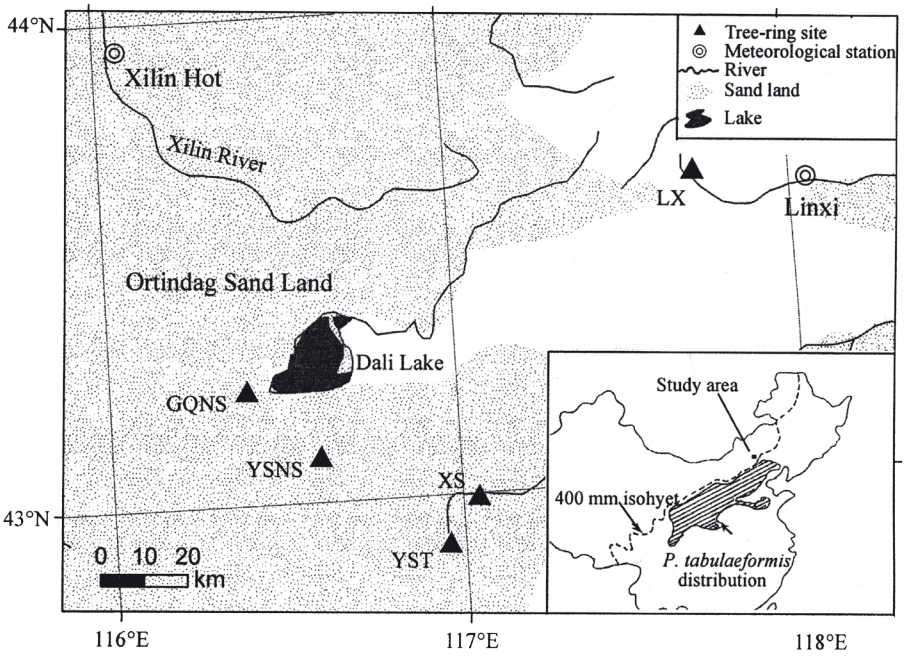


Fig. 1. Map showing study sites and meteorological stations in the Ortindag Sand Land (Liang et al., 2008); insert shows the location of the study area and the distribution of P. tabulaeformis, according to W.D. Xu (1990) and H.Y. Liu et al. (2002))

With the support of the IFS (International Foundation for Science) project, dendroecological studies on relict Chinese pine has been performed in the Ortindag Sandland since 2004 (Liang et al., 2007, 2008, 2009 a, b). The objective of this paper is to sumarrize the main progresses of the above studies and their implications for ecosystem management.

## MAIN PROGRESSES

The studies focused on dendroecological and dendroclimatic studies of patches of relict Chinese pine forests in the Ortindag Sand Land. The details for the study areas, climate and research methods see E. Liang et al. (2007, 2008, 2009a, b).

**1. Seasonal wood formation of Chinese pine**

In order to extract clear and biologically convincing climatic information recorded in a sequence of tree-ring widths, a better understanding of the basic mechanisms of tree-ring development is necessary (Eckstein, 2004; Rossi et al., 2007; Fonti et al., 2010). In this context, seasonal cambial activity of several tree species in the Alps, at northern latitudes as well as in the tropics and subtropics has been studied (see a brief in Liang et al., 2009b), enhancing our understanding on intra-annual growth dynamics and its association with climate factors. A series of dendroecological and dendroclimatic studies have been conducted in China in recent decades. However, seasonal wood formation and its response to climate have not received much attention they deserved.

Since 2006, the weekly cambial activity has been monitoring in the Ortindag Sand Land (Liang et al., 2009b). Due to the complex process for micro-slides of the micro-cores, we just have been reported the primary results based on the seasonal cambial activity in the growing season in 2006. We found that cell division in the cambial zone of these trees started within the third week of May. In June and July, the rate of xylem cell production was the highest and around mid-August cell division is ended. However, cell-wall formation was not yet completed around mid-September. Such work is useful to investigate the intra-annual wood formation dynamics and its driving forces. These preliminary results are important for dendroclimatic studies with Chinese pine in North China and can furthermore be used as a benchmark for future monitoring activities in other forest areas in China.

**2. Dendroecology and dendroclimatology of Chinese pine in the Ortindag Sand Land**

Based on our studies (Liang et al., 2008), we found that tree-ring width variation of Chinese pine is reli-

able recorder of high and low frequency variations of dry/wet environmental conditions in the Ortindag Sand Land. Their age structures within the forest patches prove that they regenerate preferentially in less dry periods. In detail, monthly precipitation and relative air humidity in the previous and current growing seasons are the major limiting factors for the radial growth of Chinese pine. Years with a high frequency of absent tree rings are characterized by particularly extreme dry conditions. These results are supported by negative correlations between radial growth and monthly maximum temperature and evaporation during the growing season. In addition, tree growth shows a high correlation with the East Asian Monsoon index.

The average series of the three long tree-ring width chronologies captured 41.9 % ($p < 0.001$) of the variance of P7-6 (annual precipitation from the previous July to current June) in the calibration interval from 1953 to 2004. Based on our P7-6 reconstruction in eastern Inner Mongolia, wet conditions appeared during the periods 1842–1854, 1868–1878, 1913–1922, 1940–1964 and 1991–1998 and dry conditions during the periods 1855–1867, 1879–1912, 1923–1933, 1965–1990 and 1999–2004 (Fig. 2). All these periods are in general agreement with the dryness-wetness index on the decadal scale. The 163-year regional P7-6 time series displays significant cycles of 2–3, 17.4 and 20.5 years as indicated by a Multi-taper Method TM spectral analysis.

Tree-ring based precipitation reconstruction in east Inner Mongolia captured the declining East Asian Summer Monsoon since the late 1960s (Liang et al., 2008). It is a rare study to bridge tree-ring based precipitation reconstruction and the monsoon index, showing a perspective to retrieve past monsoon dynamics using tree-ring analysis in North China, where climate is primarily controlled by the East Asian Monsoon.

The PDSI (Palmer Drought Severity Index) can be used to determine the onset, end, and severity of a drought period. In a point of view of tree growth, Liang et al. (2007) tested whether the Dai-PDSI is suitable or not to monitor soil drought stress in the Ortindag Sand Land under the recent warming. The enhanced disagreement between tree growth and the PDSI5-7 (the mean Dai-PDSI from May to July) from 1994 to 2004, an extremely warming period in a context of the past 50 years, is evident, as shown by their negative correlation ($r = -0.59$, close to $p < 0.05$) during this period. If the period from 1952 to 1993 was considered, their correlation is higher up to 0.82 ($p < 0.001$). Thus, the Dai-PDSI in the Ortindag Sand Land, east Inner Mongolia, may overestimate the severity of warming-induced droughts. A modification may be necessary for the Dai-PDSI to capture the true of the soil drought conditions in east Inner Mongolia.

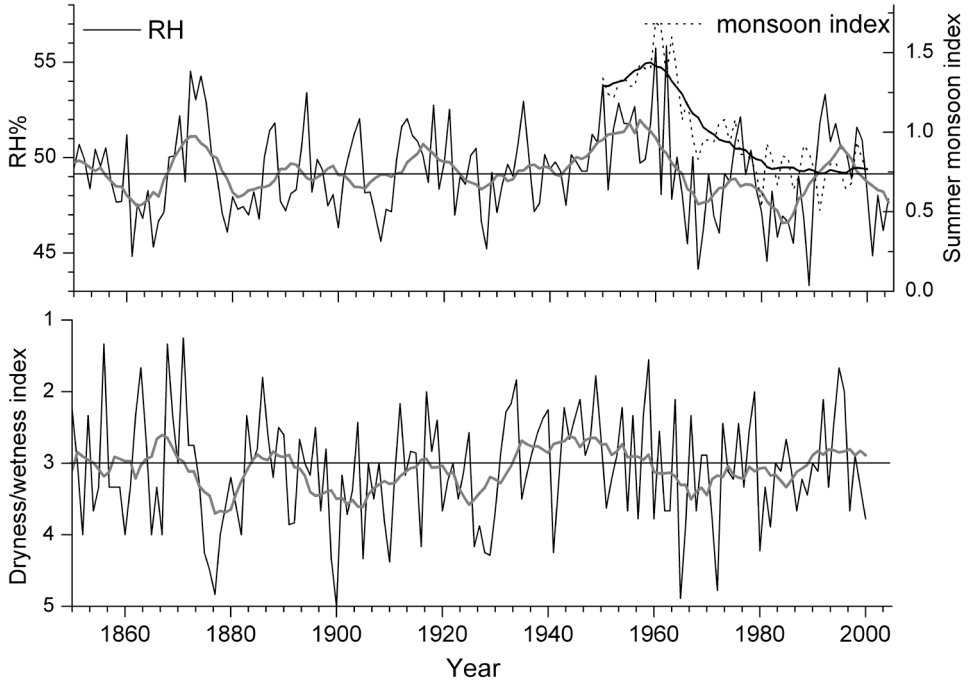


Fig. 2. High and low frequency variation of precipitation from previous July to current June reconstructed from tree rings back to 1842 and, for comparison, June-August mean monsoon index from 1951 to 2000 (dotted line = annual variation; solid line = moving mean) (top); high and low frequency variation of a dryness/wetness index from historical records in North China (bottom) (Liang et al., 2008)

**3. Steppe greenness dynamics inferred from tree rings**

Without a long-term continuous record of grass production in a large scale, the past steppe dynamics is little known. Remote sensing data and climatic models point to an increasing greening since 1982 in the middle and high latitudes of the northern hemisphere (see a brief summary in Liang et al., 2009a). However, no studies have been performed to evaluate such a greening trend in a long-term timescale. In the Ortindag Sand Land, tree-ring width time series of Chinese pine, integrating the underlying process of the typical steppe that is primarily driven by moisture availability, is the fundamental indicator for the vegetation growth dynamics of the ecosystem over time (Liang et al., 2005, 2009a). Thus, it offers a useful opportunity to retrieve past greenness of vegetation in a typical steppe. Tree-ring width time series in the Ortindag Sand Land conveys invaluable information about the steppe greenness dynamics, enabling us to put the recent greening trend in a long-term context. In the context of the past 163 years, the recent greening trend in the typical steppe area in the Ortindag Sand Land is considered to be part of the moisture-driven natural variability and appeared every 17–20 years. There is no reason to overemphasize the recent greening trend. This initial study provides supporting evidence that tree-ring width series, as an indicator of the above-ground biomass of the steppe, can be applied in ecological model.

**Potential applicability of the research results for ecosystem management**

Sand storms from east Inner Mongolia are a major threat to the ecological safety of North China, and actions are desirable to control further desertification. The patches of relict Chinese pine may play a positive role in these processes.

The study clearly answers what climate factors control the growth of relict Chinese pine, in contrast to the steppe landscape, in the Ortindag Sand Land, east Inner Mongolia. This question is critically important for forest conservation. Monthly precipitation and relative air humidity in the previous and current growing seasons are the major limiting factors for the growth of Chinese pine. In a 163-year time series of precipitation, from previous July to current June, reconstructed from the tree rings in east Inner Mongolia, cycles with a wave length of around 20 years are significant. Based on this cycle, the next moisture period will start around 2010. The tree-ring based precipitation reconstruction increases our knowledge about the climate history in east Inner Mongolia.

The age structures within the forest patches prove that Chinese pine regenerates preferentially in less dry periods. It will be critically important to capture another moist period starting around 2010 for regional afforestation and ecosystem restoration. In doing so, the afforestation practice in east Inner Mongolia will be likely more successful.

E. Liang et al. (2005, 2009a) suggested that tree-ring width series can be used as an indicator and estimator for past above-ground biomass of the steppe in east Inner Mongolia. It provides a perspective for future applications in ecological modeling. A recent paper by J. Xiao et al. (2009) have already used one tree-ring chronology in the Ortindag Sand Land to model twentieth-century droughts and their impacts on the terrestrial carbon cycling in China.

Strong human disturbances in association with global warming are threatening the survival of relict Chinese pine in the Ortindag Sand Land, east Inner Mongolia. The occurrence of locally absent rings implies that the prevailing moisture conditions in such years cannot meet the physiological requirements of the trees. Based on the frequency of locally absent tree rings during the past 163 years, extreme droughts occurred most often after 1960 in accordance with an abrupt monsoon decline over East Asia. At one site with severe livestock trapping, we found that several Chinese pine trees did not at all produce annual rings between 2001 and 2004. After the trapping, the fixed sand soil started to move and accelerated the loss of soil water. This provides a strong signal that the relict Chinese pine must be protected against artificial disturbances. Otherwise, the relict Chinese pine forest may be faced with the fate of dieback. It is necessary to take actions to conserve the relict Chinese pine patches in the Ortindag Sand Land.

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