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Reconstruction of defoliating insects outbreak frequency in Bogd Khan Mountain, Mongolia by dendroecological method

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Abstract

Tree-ring cores (samples) were collected to reconstruct frequency of insect outbreaks in the larch forest of eastern part of Bogd Khan Mountain, Ulaanbaatar, Mongolia. Using tree ring measurements, master chronologies of four conifer species were built. The response functions of *Larix sibirica, Pinus sibirica, Pinus sylvestris* and *Picea obovata* chronologies with monthly mean temperature and monthly total precipitation for the interval from 1940 to 2000 showed that their radial growth are mainly controlled by spring precipitation and negatively affected by high summer temperatures. Comparisons of the tree ring chronologies among the four species showed growth suppressions which climate variations and the probable occurrence of insect outbreaks from 1800 to 1900. According the recorded outbreaks, Siberian moth (*Dendrolimus sibiricus* Tschetw) invasion noted in 1925-1929 and in 1955-1957, vapourer moth (*Orgyia antiqua* Linn) in 1941-1944, Siberian moth, Jacobson's geometrid moth (*Erannis Jacobsoni* Djak) in 1971-1972 and Siberian moth and geometrid moths were infested in 1989 in Bogd Khan Mountain, Ulaanbaatar. Recently Siberian moth, vapourer moth and gypsy moth (*Ocneria dispar* Linn) attacks occurred in 2000, 2003 and 2005 in this region. All these outbreaks reduced radial growth of trees in this region, which were confirmed by this study. Moreover, we identified major disturbances which are most probably linked to insect outbreaks for the years 1902-1903, 1879 - 1880, 1850, 1847 and 1829 which may could indicate a roughly 30 year frequency.

Rekonstruktion von Waldschadensepisoden durch nadelfressende Insekten in den Bogd Khan Bergen, Mongolei, mittels dendroökologischer Methoden

In Waldbeständen der Bogd Khan Bergen, Ulaanbaatar, Mongolei, wurden Bohrkernproben aus dem Stammholz gezogen, um die Häufigkeit von Schadinsektenkalamitäten zu rekonstruieren. Die Korrelation der *Larix sibirica, Pinus sibirica, Pinus sylvestris* und *Picea obovata* Chronologien auf Monatsmittelwerte der Temperatur sowie der Niederschlagsmengen zeigte, dass der jährliche Durchmesserzuwachs wesentlich von der Menge der Frühjahrsniederschläge bestimmt wird und von heißen Sommern negativ beeinflusst wird. Darüber hinaus waren während des Zeitraumes von 1800 bis 1900 bei den vier untersuchten Baumarten Wuchsstörungen erkennbar, die hypothetisch durch Klimaschwankungen oder Insektenkalamitäten verursacht sein könnten. Die rekonstrierten Daten aus dem 19 Jahrhundert wurden mit den im zwanzigsten Jahrhundert beobachteten und dokumentierten Massenvermehrungen des Sibirischen Arvenspinners (*Dendrolimus sibiricus* Tschetw) zwischen 1925-1929 und 1955-1957, des Schlehen-Bürstenspinners (*Orgyia antiqua* Linn) in 1941-1944, sowie des Sibirischen Arvenspinners und des Spanners *Erannis Jacobsoni* Djak in 1971-1972 und des Sibirischen Arvenspinners und von *E. Jacobsoni* im Jahr 1989 in den Bogd Khan Bergen verglichen. Die jüngsten Massenvermehrungen des Sibirischen Arvenspinners, des Schlehen-Bürstenspinners und des Schwammspinners (*Ocneria dispar* Linn) traten in den Jahren 2000, 2003 and 2005 in dieser Region auf. Alle Massenvermehrungen waren an den Bohrkernen als verminderte Radialzuwächse erkennbar. Die Bohrkerne ließen auch drastische Zuwachseinbrüche in den Jahren 1902-1903, 1879 - 1880, 1847-1849 and 1825-1829 erkennen, die insgesamt einen annähernd dreißigjährigen Zyklus der Massenvermehrungen erkennen lassen.

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1. INTRODUCTION

This study was undertaken in order to identify insect outbreak frequency in the forests of Bogd Khan Mountain, Mongolia. This forest ecosystem is sensitive to environmental factors due to its unique location where most southern point of Siberian taiga borders to great Mongolian highlands and Gobi Desert (Adiyasuren, 1997).

Siberian moth (*Dendrolimus sibiricus*) and gypsy moth (*Lymantria dispar*) are severe disturbance factor in these forest ecosystems, causing widespread mortality in larch forest stands since Bogd Khan Mountain had been protected in 1778. Since 1957, there were four outbreaks occurred which Siberian moths and gypsy moths, and recently in 2003 almost 15000 ha of forest were defoliated by these moth species in this mountain area. These defoliations weakened forest health and reduced resistance to invasion of other forest pests and diseases, which led to their mortality. For management activities against insect invasions in this area, the necessity of understand long-term outbreak frequency was required.

As consequences of insect feeding on foliages of trees, radial growth of these host trees reduced which clearly illustrated on tree ring sequences. According to the several studies (Swetnam and Lynch, 1989; Weber, 1997; Schweingruber, 1996; Zhang, 1999), tree ring analysis is quite efficient way to provide knowledge of forest insect outbreaks on both a temporal and spatial scales.

The major goals of study were to reconstruct the past defoliating outbreaks in living host trees of this study area and to try finding relationships between climate and outbreak occurrences.

In this study, we developed ring width chronologies of Siberian larch (*Larix sibirica*), Siberian pine (*Pinus sibirica*), Siberian spruce (*Picea obovata*) and Scots pine (*Pinus sylvestris*) located in Bogd Khan Mountain, Ulaanbaatar, Mongolia. In order to define climate-growth relationships at study area, the climate data compared with tree growth by using special dendroclimatological program based on response function analysis. Growth dynamics of each species for last two centuries were examined, and major climate anomalies and probable defoliating insect outbreaks were reconstructed and discussed.

Based on this study, one poster presentation with preliminary results had presented at EURODENDRO 2008 conference which held in Hallstadt, Austria, and one presentation with abstract submitted to Second Asian Dendroecological Association Conference in Mongolia, which will be held on 25-28 September 2009.

Background information

Mongolian forests exist between the great Siberian taiga and the Mongolian highland of steppe. As closed forests cover only 8.1 % (conifer forest is around 6.1%) of total area of Mongolia, which shows low forest resources country according to the category by FAO.

These forest resources have been increasingly degraded over the past few years, due to timber cutting, forest fires (both natural and human made), pests and diseases (Tsogtbaatar, 2004). These severe ecological stresses complicated by global warming and drought in some regions (Jacoby *et al*., 1996).

According to the fourth national report on conservation of biodiversity of Mongolia, forest pest and disease injury are key factors which negatively affecting forest ecosystems of Mongolia (2009). Since 1998-1999, each year excessive populations of Siberian moth - *Dendrolimus superans sibiricus*, Gypsy moth – *Lymantria dispar,* Vapourer moth - *Orgyia antiqua Linn* and Jacobson's spanworm - *Erannis jacobsoni Diak* (Figure 1.1) have overrun particular areas.

Knowing and understanding long-term pattern of outbreaks is not only important for resource management, but also forest ecological studies. Unfortunately, the historical record of insect outbreaks in the region is scarce.

Like many other countries, the global warming started to affect negatively in Mongolia recently. Such a climate change is influencing explicitly vegetation, water resources, forest boundaries, snow coverage, location, and area of permafrost in Mongolia (Mijiddorj and Yadamsuren, 1989). For instance, precipitation amount have decreased by over 10 percent compared with long-term dynamics in almost all parts of Mongolia in recent years. In addition, rising air temperature is making comfortable conditions for insect propagation, and from another perspective, the insect's high biological reproductive capability will influence outbreaks of some species of harmful forest insects in forested areas of Mongolia (Enkhbat, 2009).

Dendrolimus superans sibiricus (adult) *Lymantria dispar* (adult)

Dendrolimus superans sibiricus (larva) *Lymantria dispar* (larva)

Figure 1.1 Recently documented insect species, which are heavily defoliated forest area in Mongolia.

Source: www.insectimages.org by John H. Ghent, USDA Forest Service, Bugwood.org

Scientists named about 40 species from 400 forest pests recorded in Mongolia, that are most harmful to forests such as the Siberian silk moth (*Dendrolimus superans*), Gypsy moth (*Lymantria dispar*), vapourer (*Orgyia antiqua*), Jacobson's spanworm (*Erannis* *jacobsoni*), larch budmoth (*Zeiraphera diniana)*, longhorn beetle (Cerambycidae), jewel beetle (Buprestidae) and the Bark beetle (Scolytidae) (Enkhbat, 2009).

Since 1980s, mitigation measures against forest pests has started after establishing Forest Research Institute by Ministry of Nature Environment in Mongolia. Unfortunately, due to lack of human resources, less developed infrastructures accessing to steep terrain mountain regions, mitigation measures did not succeed well (figure 1.2).

Siberian moth and gypsy moth maybe considered the most problematic defoliators in boreal forests of many countries such as North America, Russia and Mongolia (Muzika and Liebhold, 1999; Kucherov, 1988; Tegshjargal, 1991; Tsagaantsooj, 2003, Hauck *et al.*, 2007). Siberian moth (*Dendrolimus superans sibiricus* Tschtv) belongs to family of Lepidoptera: Lasiocampida). It is the most destructive defoliator of the coniferous taiga forest in Siberia and the Russian Far East. Outbreaks of this pest species are the primary biological factor influencing change in forest cover in the southern taiga subzone with enormous ecological and social consequences (Baranchikov *et al*., 2001). The species has a range that extends from the Pacific Ocean (Russian Far East, Japan and Northern Korea) across Siberia, Northern China and Mongolia to the Ural Mountains (Rozhkov, 1963). Known heavy defoliating outbreak frequency for this species is from 8-11 years (Anonymous, 2009).

Gypsy moth (*Lymantria dispar* L.) ascribed as main defoliator of broadleaved trees however its feeding menu included larch and pine forests in Siberian Taiga when population of this species are great (Muzika and Liebhold, 1999). Gypsy moth in northeastern Asia, where the species has evolved, is genetically distinct from western populations in Europe (Reineke and Zebitz, 1999). In Asian populations, both female and male have wings and infest a wide range of tree species. European populations have a strong preference for oak and their females are incapable of flight. Gypsy moth was introduced to North America in the 19th or 20th century, respectively, from Europe and the Russian Far East (Muzika and Liebhold, 1999).

Figure 1.2 Dead larch (Larix sibirica) forest stand after Siberian moth massive outbreak in 2000

Source: photo from www.insectimages.org by John H. Ghent, USDA Forest Service, Bugwood.org

Outbreaks of gypsy moth in northern Mongolia and southern Siberia (Gninenko and Orlinskii, 2003) are more frequent and more persistent than in Europe. One reason for this is the dispersibility of the females. Furthermore, resistances to low winter temperatures and promotion by forest susceptibility to herbivore attack probably contribute to the frequency of gypsy moth invasions in Mongolia and southern Siberia (Hauck *et al*, 2007). High forest susceptibility can be assumed because larch trees (Larix sibirica) occur in this area at their drought limit (Dulamsuren *et al*., 2008). The outbreak frequency of gypsy moth did not inform clearly, but according to the recorded outbreaks, it could also 11-12 years (Anonymous, 2009).

Tree ring applications can be useful in assessing the effect of insect outbreaks, but have been used primarily to reconstruct historic patterns of outbreaks (Fritts and Swetnam, 1989). In western North America, western spruce budworm (*Choristoneura occidentalis* Freeman) outbreak histories have been developed through many studies (Swetnam and Lynch, 1989, 1993, and 2003; Weber, 1997; Zhang, 1996). Extensive chronologies have been developed to determine the long-term impact of defoliation, such as radial growth losses of trees and forests in these studies.

Therefore, in this study we wanted to provide valuable information resources about these two defoliators based on growth changes of conifer forests in Bogd Khan Mountain using this dendroecological method.

Acknowledgement of previous works

The literature review was done in two directions; (1) defoliating insects' influences on tree growth and (2) dendroecological studies dealing with insect outbreaks.

Insect and tree relation: Many studies had done related to radial growth change as consequences of defoliation by forest insects. The changes were various regarding to which species, age of woody plants, individual characteristics of trees during the outbreak of defoliating insects and their population growth with outbreak intensity (Dajoz, 2000) and site conditions. Trees in poor condition may have high mortality rates (Weber, 1997).

Ecophysiological studies explained why insect outbreaks could occur in forest. It connected resistance of trees to insect herbivore with environmental changes and other natural disturbances such as drought, forest fire and air pollution or human made activities (Kozlowski *et al*, 1990). The main clue behind this vulnerability related with chemical defense of trees. This resistance mechanism of tree could be weakened by environmental stress. For instance, drought leads to increase air and soil temperature, insolation and decrease precipitation and humidity. Consequently, growth, resistance mechanisms and water content of host trees will decrease. In contrast, this condition will improve nutrition, thermal environment, development rates as well host finding and acceptance of phytophagous insects and will favor their outbreaks (Kozlowski *et al.*, 1990).

As regarding to the resistance to the defoliation by insects trees divided into two groups: (1) Evergreen conifer trees and (2) deciduous conifer and broadleaves.

In general, broadleaves have more stored starch than conifers providing them to produce new growth of leaves easily. Therefore, they are more resistant to defoliation (Dajoz, 2000). Evergreen conifers (genera of *Pinus, Picea* and *Abies* etc): are very sensitive to losing photosynthetic apparatus. Losing all needles may lead to dead of these trees (Kucherov, 1988; Dajoz, 2000), however young trees react less to defoliation than older trees (Schweingruber, 1996). Heavy needle loss at the time of the most intense earlywood formation (late June to mid July) leads to growth reductions and cell wall changes in the latewood throughout the stem (Kucherov, 1988).

Among conifers, larch species are unique; more tolerate defoliation than other conifers. This species survives even though 50-75% of needle loss due to defoliators (Schweingruber, 1979). Moreover, if outbreak occurred early summer, both early and latewood growth is reduced and if it in late summer only latewood growth is reduced.

Larch growth only recovered when latewood formation is completed (Vaganov, 1977). Therefore, larch species are good indicators of defoliation occurred in the past centuries.

Dendroecological studies dealing with insect outbreaks: Trees are reacting to various environmental impacts with corresponding changes in their annual growth rings. Therefore, history of radial growth of trees, which recorded these changes, can expose through tree ring applications (Fritts and Swetnam, 1989).

Dendrochronology made possibility of fact that in many trees their annual rings are visible in cross section exhibit characteristic patterns (Stokes and Smiley, 1968). Trees are almost unique in being able to provide information about past and probable future environmental change can affect human populations. (Jacoby *et al.*, 2000).

Dendroecological research or ecological research using tree ring application derived from the Germany early nineteenth century at school of Theoder and Robert Hartig (Schweingruber, 1996). However, it had become so popular later in 1980s when this application had enormous success in archeological research using cross dating method, introduced by A.E.Douglass.

Insect infestations play key role in modifying forest structure, and severe outbreaks can cause tree mortality, reduction of growth rates, reduced lumber quality, and proliferation of the understory (Veblen et al., 1991). Questions about the economic loss in increment are common after a massive insect outbreak, but tree ring analytical studies are rarely made (Schweingruber, 1996). Several studies well did in Northern American (Swetnam *et al.,* 1985; Swetnam and Lynch, 1993; Veblen *et a.l*, 1991; Zhang *et al.,* 1999) and European countries: Switzerland especially Alps, Sweden, Czech, Sweden and Russia

(Schweingruber, 1979; Eckstein *et al.,* 1990; Weber, 1997; Vins and Materina, 1969; Vaganov *et al.,* 1972; Litvinenko, 1972; Kucherov, 1988).

Connecting to drought and insect outbreak frequency there is possibility to use data as reference from dendroclimatological studies in Mongolia. The radial growth responses of trees have been extensively studied for conifer trees in order to reconstruct fluctuation of temperature and precipitation across Mongolia since 1996 (Jacoby *et al.*, 1996 and D'Arrigo *et al.*, 2001, Pederson *et al.*, 2003, Davi *et al*., 2006) which conducted by project called MARTIP (Mongolian American Tree Ring Project). Based on these references, examine the ecological changes in the past periods are started since 2006 at Tree Ring Laboratory of National University of Mongolia. There are several projects completed by using tree ring analysis to identify air pollution influence on forest and forest fire regimes (Baatarbileg *et al.*, 2006, Tardif *et al*., 2009 and Oyunsanaa *et al*., 2003). Several studies had been conducted to investigate effects of fire-insect interactions on ecological succession and vegetation dynamics in general, use of prescribed fire for insect pest control, and effects of fire on insect diversity from northern and boreal forests in North America mostly (McCullough *et al.,* 1998 and Fleming *et al.*, 2002). Therefore, our study is starting part of these dendrochronological studies, which is dealing with reconstructing frequency of insect outbreaks in Mongolia, which may lead to other new studies in this field of sciences.

Objective of the study

There are many and mixed environmental factors, which include climate, insect infestations, fire, and competition among trees and other species, soil characteristics, and others influencing the growth of forest ecosystem.

The radial growth responses of trees to climate have been studied for conifer species in Mongolia since 1980s (Mijjidorj and Yadamsuren, 1989). The ring growth of Siberian pine (*Pinus sibirica*), Siberian larch (*Larix sibirica*) and Scots pine (*Pinus sylvestris*) on Northwest to Northeast of Mongolia are sensitive to spring and summer precipitation (Jacoby *et al*., 1996; Pederson *et al.*, 2003). Insect outbreaks are modifying forest structure and severe outbreaks cause tree mortality, reduction of growth rates and proliferation of the understory (Veblen *et al*., 1991)

Dendroentonochronology is the science that uses tree rings to date and study the past dynamics of insect populations. Tree defoliation causes a reduction in radial growth and is therefore visible in tree rings. Measurements of growth reduction and mortality may be the most important information in assessing damage caused by the insect. Based on these periodically recurring changes, outbreaks can be reconstructed by making a comparison of tree ring chronologies of host trees with species, which were not affected by the insect or non-host trees in same regions (Schweingruber, 1996). Therefore referring these previous studies, we started new field of study in Mongolia, reconstructing the outbreak frequency of defoliating insects in Bogd Khan Mountain, Mongolia.

The objective of this study is to use dendroecological techniques to identify the magnitude and extent of insect outbreaks in the past centuries in Bogd Khan Mountain, Ulaanbaatar, Mongolia. In this frame, I had following aims to be achieved:

1. Develop tree ring width chronologies of Siberian larch (*Larix sibirica*), Siberian spruce (*Picea obovata*), Siberian pine (*Pinus sibirica*) and Scot’s pine (*Pinus sylvestris*)
2. Identify climate-growth relationships of these species by comparing with climate data and using response function analysis
3. Reconstruct possible insect outbreak frequency and major environmental changes using tree ring chronologies by comparing host (larch) and non-host tree species (pine).
4. Confirm probable outbreak years by comparing meteorological data, in our case it would be precipitation.

2. STUDY AREA

Bogd Khan Mountain is located at 47°43' - 47°54' N latitude; and 106°46' - 107°10' E longitude. The mountain occupies 22.9 thousands ha of forest, which means about 55.8% of the total area. Forest species composed of larch (*Larix sibirica,* 56.8%), Siberian pine (*Pinus sibirica,* 22.2%), Siberian spruce (*Picea obovata*, 15.4%), Scots pine (*Pinus sylvestris*, 1.4%), birch (*Betula* spp, 2.6%) and small shrubs (1%). The lower tree line started at 1400 m above sea level in north side, in contrast southern side, and tree lower line started from almost 1800m above sea level. On eastern side, it started at 1600m and upper tree line is located from 2100-2150m above sea level. Siberian pine forest is mostly dominating on upper treeline and west, northwest side of the Mountain. Along the tree line, southwest and south part of the mountain is covered by Siberian spruce and Scots pine, while north and southeast part is covered by Siberian larch forest.

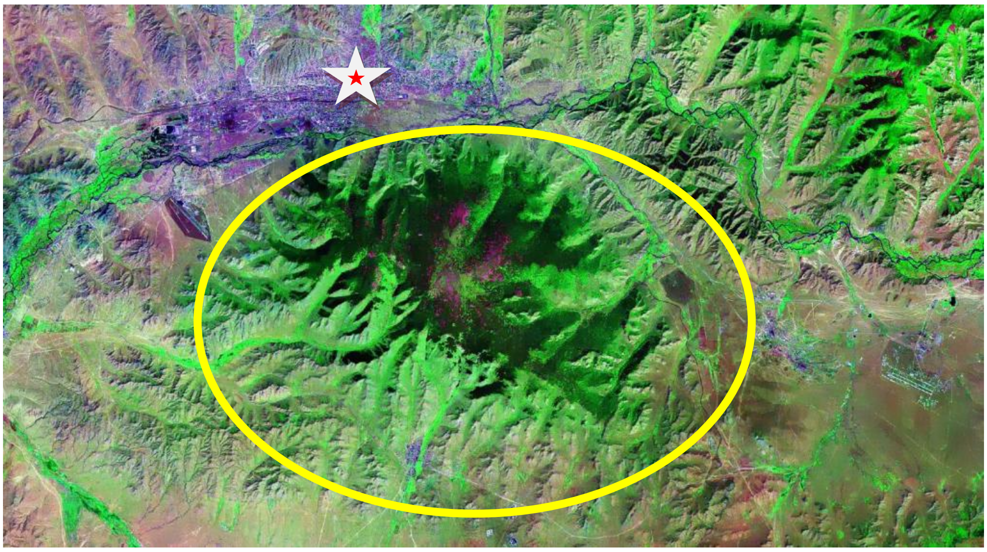


Figure 2.1 Location of Bogd Khan Mountain, Ulaanbaatar is marked by star
Source: Google earth satellite picture, 2009

According to climatic data (1940-2000) from the Ulaanbaatar weather station, mean temperature in January is -25,8 ^{0} C and +17 ^{0} C in July. Mean annual precipitation ranges from 250-350 mm (Figure 2.1).

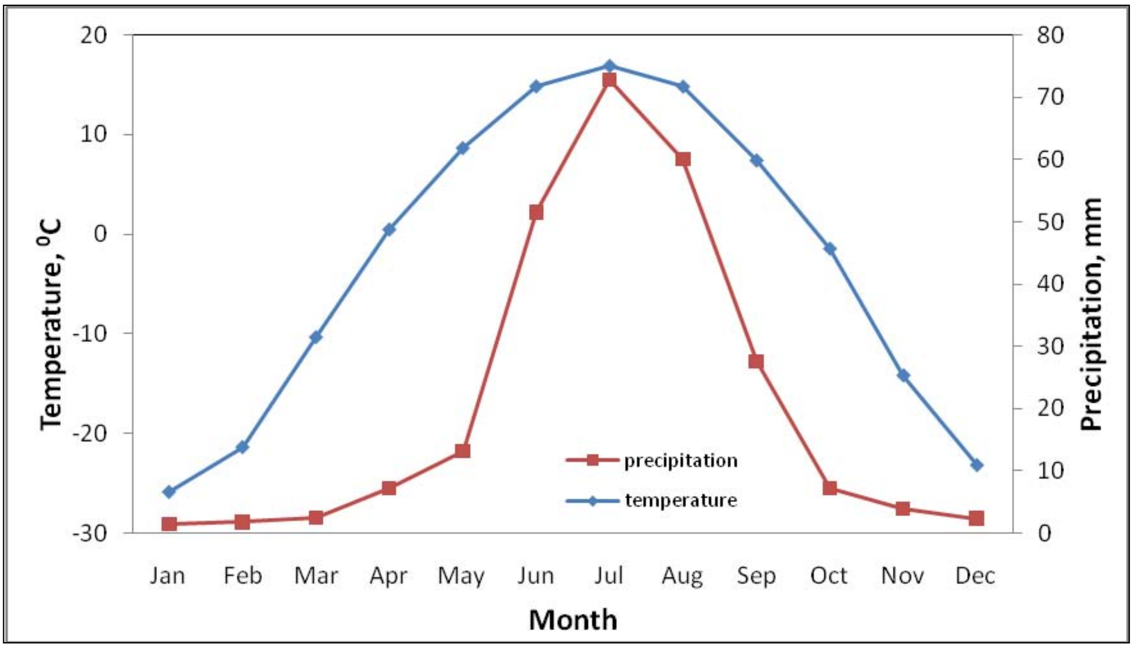


Figure 2.2 Diagram representing the climate for Bogd Khan Mountain (averaged for 1940-2000 using records from the weather station 292 at Ulaanbaatar, Mongolia)

According to the tradition of protecting nature, flora, and fauna, the Bogd Khan Mountain has a long history. It is one of the three big mountains being proposed for inclusion into protected areas. All represent sacred values first identified by Chinggis Khan in the 13th centuries and later included in the laws of "Khalkh Juram" which were emplaced between 1709 and 1799 (Adiyasuren, 1997). They are the most important of the 16 sacred mountains of Mongolia protected by tradition, common law, and royal decree. The designation of these sites as sacred natural areas meant that they have been conserved and treated with respect for centuries (Anonymous, 2009). As world's oldest officially protected area as the Emperor of Manchu passed resolutions to formalize the sacred values of Bogd Khan Mountain and provide for official protection of the site (UNESCO

World Heritage List, 1996 Figure 2.3) in 1778. The Tree-Ring Laboratory at the National University of Mongolia has confirmed the protected status of the mountain by a forest-fire study in this mountain. All fire records from tree-ring sampling from the mountain dated before 1778 (Tardif *et al.*, 2009). That means there was no major fire since the protection. Therefore forest disturbances in this area would occur naturally, which gives us confident to reconstruct insect outbreak frequency.

Forest fire and insect outbreak, illegal logging and collecting Siberian pine (*Pinus sibirica*) cones for selling their nuts are general disturbances that affect forest structure and composition in this study area. During the fieldwork in this study, we found out that locals had damaged two plots (ART and ARN) which were dominated by Siberian pines in order to harvesting and selling seeds with cone as pine nuts illegally (Figure 2.4).

Since 1970s, forest pest and mitigation measures have been started. According to a literature survey of previous studies, which Russian scientists and other foreign travellers have recorded, and amateurs from early 19th centuries, several insect attacks were recorded in this region, as noted by some entomologists (Jantsantomboo, 2003 and Gerel, 2003). As regarding to the recorded insect outbreaks showed in table 2.1, we could say that Siberian moth outbreak frequency was about 28-30 years and in between there were 15-16 year intervals. In contrast, gypsy moth outbreak may have shorter intervals in 11-12 years.

According to the forest pest surveys, Gypsy moth (*Ocneria dispar* Linn), Sibirian moth (*Dendrolimus sibiricus* Tschetw), Jacbson's spanworm (*Erannis Jacobsoni* Djak), Vapourer moth (*Orgyia antiqua* Linn) are the most damaging insects and can kill many mature larch trees during an outbreak (Jantsantomboo, 2003; Tegshjargal 1999, and Gerel 1985).

Since 1980s, the Institute of Forest Research (IFR) and Ministry of Nature and Environment, has started forest pest study and mitigation measures in Mongolia. Bogd Khan Mountain was one of the study sites for its pest outbreak (Anonymous, 2003).

Table 2.1 Recorded insect outbreaks in Bogd Khan Mountain

Recorded species	Recorded year of outbreak	People who documented this outbreaks
Siberian moth (*Dendrolimus sibiricus* Tschetw)	1925-1929	Kazanskii K.A.
Vapourer moth (*Orgyia antiqua* Linn)	1941-1944	Prozorov C.C
Siberian moth	1955-1957	Tsendsuren A
Jacobson's spanworm (*Erannis Jacobsoni* Djak)	1971-1972	Yanovskii and Tsendsuren
Siberian moth	1971-1972	Yanovskii and Tsendsuren
Siberian moth	1979-1981	Tegshjargal
Jacobson's spanworm	1987-1989	Tsagaantsooj
Siberian moth, vapourer moth and gypsy moth (*Ocneria dispar* Linn)	1999-2003	Gerel and Dorj

Main pest species were Siberian moth (*Dendrolimus sibiricus* Tschetw), Jacbson's spanworm (*Erannis Jacobsoni* Djak), gypsy moth (*Ocneria dispar* Linn), and Vapourer moth (*Orgyia antiqua* Linn). The latest study was conducted by the Institute of Forest Research at Bogd Khan Mountain in 2003 (Report of forest pest and its mitigation measures in Bogd Mountain, 2003). Using this reference, we chose the plots from these gaps and collected our tree ring samples (see table 2.2 and figure 2.5). According to this report, 60-70% of larch needles had been eaten by *Dendrolimus sibiricus* (Tschetverikov) – Siberian coniferous silk moth; *Ocneria dispar* (L) – Gypsy moth in 90-95% of study area.

Local wind conditions in the glacial fore field can cause variances in the outbreak boundaries (Weber, 1997) which could see clear in Bogd Khan Mountain. The south to eastern gaps of the mountain covered by larch stands had infected by gypsy moth and Siberian moth and many stands had been dead after the massive invasion of gypsy moth and Siberian moth since 1989. North to western gaps of the mountain less defoliated because dominating species were Pines and spruce. Therefore, field sampling in done two main directions, south to eastern valleys and south to western valleys (Table 2.3).

Site factors such as slope, elevation and tree limits also could modify the periodicity of the outbreaks in case study in Valais, Switzerland by Weber and Schweingruber, 1995 (Weber, 1997; Schweingruber, 1996). Hence, trees in poor condition may have high mortality rates (Kozlowski *et al*., 1991; Schweingruber, 1996), I recorded site factors such as elevation, slope of each sites (Table 2.3).

Among conifers, pines are more resistant than spruce and larches (Dajoz, 2000). Therefore, I chose conifer trees in Bogd Khan Mountain, Ulaanbaatar for this study The forest stand in northeast is dominated by larch (*Larix sibirica*) with a small number of Scot's pine (*Pinus sylvestris* L) trees. The north side of the mountain is covered by Scots pine (*Pinus sylvestris* L) with Siberian pine or Siberian Stone pine (*Pinus sibirica*) on the higher altitudes. As it getting to northwest and west side, more Siberian spruce (*Picea obovata*) and Scots pine are dominating.

Figure 2.3 Bogd Khan Mountain (forest stand attacked by Siberian moth recently)

Figure 2.4 Damages caused by pine nut collector on forest stand, Bogd Khan Mountain. *Source: Photo by Biligbaatar N, 2008*

Table 2.2 The distribution of pests in study plots at Bogd Khan Mountain

Gaps of Mountain (sampling plots)	Pest distribution area (ha)	Recorded pest species
Hurheree (HRS and HDS)	26	Sibirian moth, gypsy moth
Chuluut (CHU and CHL)	1917	Sibirian moth, gypsy moth
Khargana (SP)	1850	Sibirian moth, gypsy moth
Tor Khurakh (THS)	1024	Sibirian moth, gypsy moth
Shajin Khurakh (SHH)	1027	Sibirian moth, gypsy moth
Artsat (ARN and ART)	47	Gypsy moth
Huush (HU)	250	Gypsy moth

Source: Report of studies of forest pest and its mitigation measures at Bogd Mountain, 2003

Figure 2.5 Tree ring sampling sites at the Bogd Khan Mountain
Source: Google earth software

Table 2.3 Sampling plot information

plot ID	Gap names	GPS location		Elevation, m	Collected species	Aspect
		N	E			
HDS	Khurkheree (dead stand)	47.50893	108.26573	1271	*Larix sibirica*	west facing slope
HRS	Khurkheree (rocky slope)	47.50893	107.02216	1620	*Larix sibirica*	west facing slope
SP	Bumbat (non host)	47.49233	107.04056	1881	*Pinus sibirica*	east facing slope
THS	Tor Khurah	47.49229	107.04051	1867	*Picea obovata*	south facing slope
CHL	Chuluut (lower slope)	47.52876	107.01373	1409	*Larix sibirica*	north facing slope
CHU	Chuluut (upper slope)	47.52644	107.01633	1500	*Larix sibirica*	north facing slope
ART	Artsat (non host)	47.51386	106.52895	1872	*Pinus sylvestris*	north west facing slope
ARN	Artsat (non host)	47.51316	106.52586	1883	*Pinus sylvestris*	north east facing slope
HU	Huush (non host)	47.51317	106.52567	1884	*Pinus sibirica*	north west facing slope
SHH	Shajin Khurah	47.449	107.07583	1665	*Larix sibirica*	west facing slope

3. METHODS

In this study, dendrochronological methods, a scientific dating method based on the analysis of tree-ring growth patterns, were used (Schweingruber, 1993). The astronomer A. E. Douglass developed this technique around 1930s.

3.1 Field sampling

Due to sampling restrictions in the National Park, we were only allowed to take core samples from trees and not disks (which would require cutting down a tree). Samples were collected from Siberian spruce (*Picea obovata*), Scots pine (*Pinus sylvestris*), Siberian pine (*Pinus sibrica*) and Siberian larch (*Larix sibirica*) by research students of the Tree Ring Laboratory, National University of Mongolia including myself in the late summer of 2008. The cores (2 cores per tree) were extracted at breast height with an increment borer (Figure 3.1 table 3.1). Then cores kept in straws until next day to dry and mounted on sticks for the laboratory procedure.

We tried to find sites with the least evidence of human disturbance. There was evidence of fire in ARN and ART plots where we sampled Scots pine. We sampled by avoiding areas on the trunk near burn scars and there seemed to be no effect in most of the cores and resulting ring-width series. The larch specimens in SHH plot also have some problems. There is a serious heart-rot problem and at some sites with old-aged trees, it is difficult to find trees that yield solid cores extending to the central rings. That is why core length of this site only reached from 1910 to 2007.

Table 3.1Number of increment core samples collected at each site in the Bogd Khan Mountain, during the summer of 2008

Site ID	Name of Sites	collected species	Number of cores
HDS	Hurkheree dead stand	*Larix sibirica*	30 cores (15 trees)
HRS	Hurkheree rocky slope	*Larix sibirica*	30 cores (15 trees)
SP	Bumbat	*Pinus sibirica*	30 cores (15 trees)
THS	Tor Khurah	*Picea obovata*	30 cores (15 trees)
CHL	Chuluut lower slope	*Larix sibirica*	30 cores (15 trees)
CHU	Chuluut upper slope	*Larix sibirica*	30 cores (15 trees)
ART	Artsat	*Pinus sylvestris*	30 cores (15 trees)
ARN	Between Artsat and Huush	*Pinus sylvestris*	30 cores (15 trees)
HU	Huush	*Pinus sibirica*	30 cores (15 trees)
SHH	Shajin Hurah	*Larix sibirica*	30 cores (15 trees)
		Total	**300 cores**

Figure 3.1 Coring the tree using the increment borer

In addition, we have observed anatomical symptoms in larch that may indicate tree damage due to insects. The xylem cell patterns are similar to those described by Weber (1997) for damage by larch budmoth to trees in Switzerland. This potential problem is being investigated further to see the effect on trees and the ring-width series.

3.2 Laboratory procedure

300 cores from all sampled plots were mounted on grooved wooden sticks and then sanded by hand with a series of sandpaper grits 220 to 600 in order to enhance visibility of tree-ring pattern under the microscope before the cross dating (Figure 3.2).

Figure 3.2 Core samples after sanding.

Tree ring growth returns in to normal just after climatically poor year. In contrast, after insect attack it takes 3-4 years for the tree ring growth to return to normal shape, which means it could detect while the skeleton plotting and cross dating visually.

During the cross dating, tree rings widths of each sample were plotted and the patterns of wide and narrow rings were cross-dated among trees according to Douglass, 1941 (Figure 3.3). This procedure known as “skeleton plotting” helps to identify possible false rings, missing rings to avoiding faulty measurements. The high-resolution microscope was used to examine and note the width of each individual tree ring from each tree core. Radial growth can be different from tree to tree, even were growing in the same growing conditions.

Ring widths from each core (from the same plot) were marked on a standard graph. This graph is called a skeleton plot, which illustrates key (either narrow or wider) growth years. Skeleton plot methods are the best tool for determining the minimum growth year. Skeleton plots help visualize tree-ring growth patterns and help to compare to with other years and other cores (Schweingruber, 1993).

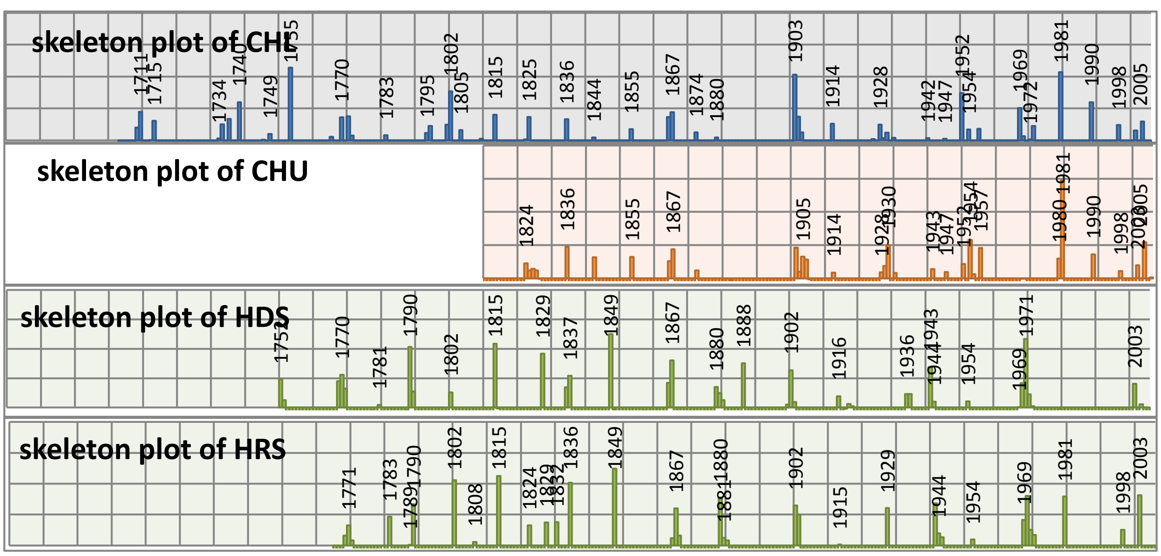


Figure 3.3 Skeleton plots of some sites from Bogd Mountain

Then tree-ring width measurements had done by using a Velmex-Measuring system with the precision scale of 0.01 mm (Figure 3.4) at Dendrolab of Institute of Wood Science and Technology, BOKU (University of Natural Resources and Applied Life Sciences, Vienna).

After measurement, the quality of cross dating was examined using the program COFECHA (Holmes 1983), which checked ring patterns by calculating correlation coefficient among tree-ring sequences. There were three parts of the output file from COFECHA program (Grissino-Mayer, 2009, figure 3.5):

1. the statistical measures and summary information for the chronology (Header)
2. the "correlation matrix" that shows the correlations of each series segment with the master chronology (Correlation of Series by Segments)
3. the summary statistics provided for each series in the chronology, and averaged over all series (Descriptive Statistics)

Figure 3.4 Velmex Measuring system

```
Untitled - Notepad
File  Edit  Format  View  Help
Time span of Master dating series is  1672 to  2007   336 years
 Continuous time span is               1672 to  2007   336 years
 Portion with two or more series is    1682 to  2007   326 years

                                        ****************************************
                                        *C* Number of dated series        14 *C*
                                        *O* Master series 1672 2007  336 yrs *O*
                                        *F* Total rings in all series   3354 *F*
                                        *E* Total dated rings checked   3344 *E*
                                        *C* Series intercorrelation    0.764 *C*
                                        *H* Average mean sensitivity   0.282 *H*
                                        *A* Segments, possible problems    0 *A*
                                        *** Mean length of series      239.6 ***
                                        ****************************************
PART 5:  CORRELATION OF SERIES BY SEGMENTS: arn
------------------------------------------------------------------------------------------------
 Correlations of  50-year dated segments, lagged  25 years
 Flags:  A = correlation under  0.3281 but highest as dated;  B = correlation higher at other t

 Seq Series  Time_span   1675 1700 1725 1750 1775 1800 1825 1850 1875 1900 1925 1950 1975
                         1724 1749 1774 1799 1824 1849 1874 1899 1924 1949 1974 1999 2024
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 arn09s   1885 2007                                              .73  .77  .73  .87  .87
   2 arn09n   1775 2007                          .78  .83  .75  .75  .83  .72  .54  .67  .75
   3 arn11n   1682 2007   .78  .76  .63  .60  .78  .84  .83  .77  .74  .83  .80  .81  .81
   4 arn11s   1752 2007                     .59  .50  .57  .92  .85  .74  .75  .62  .78  .83
   5 arn06m   1798 2007                          .68  .68  .77  .77  .58  .63  .80  .89  .91
   6 arn06s   1794 2007                          .73  .80  .76  .77  .74  .77  .76  .77  .76
   7 arn02s   1850 2007                                         .81  .77  .77  .80  .86  .85
   8 arn02n   1672 2007   .84  .82  .77  .59  .38  .67  .88  .80  .72  .75  .73  .80  .84
   9 arn05e   1748 2007             .63  .63  .63  .79  .82  .84  .55  .57  .81  .84  .84
  10 arn05w   1738 2007             .63  .63  .47  .73  .79  .81  .85  .67  .68  .75  .76
  11 arn04n   1838 2007                                    .83  .83  .77  .71  .69  .89  .90
  12 arn04s   1811 2007                               .81  .83  .82  .82  .85  .77  .82  .81
  13 arn03s   1709 2007        .87  .80  .74  .76  .84  .88  .81  .81  .82  .83  .80  .74
  14 arn03n   1706 2007        .85  .77  .77  .86  .89  .79  .71  .78  .81  .88  .84  .77
 Av segment correlation  0.81 0.82 0.70 0.65 0.65 0.77 0.82 0.80 0.75 0.74 0.74 0.81 0.82

 [*] All segments correlate highest as dated with correlation with master series over  0.3281
♀PART 7:  DESCRIPTIVE STATISTICS: arn
------------------------------------------------------------------------------------------------

                                                   Corr   //-------- Unfiltered --------\\  //----
                           No.    No.    No.       with   Mean    Max     Std   Auto   Mean    Max
 Seq Series   Interval    Years  Segmt  Flags    Master  msmt    msmt    dev   corr   sens   value
 --- -------- ---------   -----  -----  -----    ------  -----  -----  -----  -----  -----  -----
   1 arn09s   1885 2007    123      5      0     0.786   0.60   1.18  0.192  0.708  0.200   2.66
   2 arn09n   1775 2007    233      9      0     0.730   0.48   1.66  0.214  0.758  0.230   2.46
   3 arn11n   1682 2007    326     13      0     0.758   0.55   1.72  0.281  0.786  0.252   2.44
   4 arn11s   1752 2007    256     10      0     0.715   0.41   1.08  0.162  0.703  0.266   2.56
   5 arn06m   1798 2007    210      9      0     0.754   0.92   2.13  0.374  0.735  0.242   2.56
   6 arn06s   1794 2007    214      9      0     0.749   0.69   2.63  0.317  0.761  0.245   2.60
   7 arn02s   1850 2007    158      6      0     0.811   0.48   1.08  0.224  0.768  0.252   2.46
   8 arn02n   1672 2007    336     13      0     0.748   0.62   1.52  0.278  0.771  0.259   2.45
   9 arn05e   1748 2007    260     11      0     0.746   0.39   1.15  0.196  0.678  0.313   2.54
  10 arn05w   1738 2007    270     11      0     0.700   0.46   1.33  0.294  0.791  0.336   2.57
  11 arn04n   1838 2007    170      7      0     0.805   0.74   2.04  0.343  0.718  0.298   2.61
```

Figure 3.5 COFECHA output file showing quality of the chronology which are cross dated

The program ARSTAN (Cook, 1990) produces chronologies from tree-ring measurement series by detrending and indexing (standardize) the series, then applying a robust estimation of the mean value function to remove effects of endogenous stand disturbances. The resulting yearly values in the chronology, called ring-width indices, represent the growth variations affected by environmental factors. The index values are unitless, with a nearly stable mean and variance, allowing indices from numerous trees to be averaged into a site chronology. The chronology represents the departure of growth for a given year vs. the series mean representing the long-term mean. Higher or lower values for a given year represent proportionally higher or lower tree growth for that year. A researcher can combine knowledge of the individual site and tree species to interpret the growth variations in terms of climate or other environmental factors. The chronologies recorded here are those calculated by the original investigator. The raw ring widths were also archived to allow reprocessing of the chronologies. These standardized chronologies were used for checking climate-growth relationship.

3.3 Dendroecological analysis

According to the tree-ring studies, high precipitation in the late fall has a positive effect on growth of larch, suggesting that warm and moist days in the late fall favor active photosynthesis and continuous food storage, which leads to large ring widths in the following year. If any chronologies show negative correlations between growth and precipitation, it is likely that non-climatic factors, insect infestation, and competition among trees, may have degraded the climate-growth relationships (Swetnam *et al.*, 1985).

The program Dendroclim 2002 (This program was developed at the Department of Geography, University of Nevada, Reno, based upon work partly supported by the Paleoclimate Program in the Division of Atmospheric Sciences at the National Science Foundation) were used for the analysis of climate/tree growth relationships. Input data for this program are a tree-ring and up to three climatic variables, such as temperature and precipitation, for a given number of years (Biondi and Waikul, 2004). The tree-ring chronology were selected is the residual chronology of each plot, which was computed by the ARTSAN program. The meteorological data (both temperature and precipitation) are from 1940-2000 (station index for Ulaanbaatar city, Mongolia is 292).

The analysis of climate-growth relationships will provide information on the effects of climate on tree growth. Growth suppressions in these species maybe caused either by climate factors (temperature and precipitation) or by insect defoliators. Activities of defoliators such as Gypsy moth, Siberian moth, Vapourer moth, Jacobson's spanworm has been documented in the area in since 1925 (Jantsantomboo, 2003; Tsagaantsooj, 2003; Tegshjargal, 1991). This recorded data was used as a reference confirming growth reduction due to defoliation.

Several studies showing that identifying growth reduction caused by defoliating insects requires comparing annual growth measurements of damaged species (host) with a species that has not been attacked by insect (non host) (Weber, 1997; Muzika and Liebhold, 1999; Schweingruber, 1996; Zhang *et al.*, 1999). Therefore Larch as host species vs. Siberian pine as non-host species will be compared as regarding their resistance to the defoliating insects.

In order to confirm probable outbreak years in the past, reconstructions of annual precipitation with 345 years in length (AD 1651-1995) were used. This chronology is presenting for northeastern Mongolia based on tree-ring width data (Pederson *et al.*, 2003), where Bogd Khan Mountain includes in this region.

4. RESULT

4.1 Skeleton plots

After comparing each trees skeleton plot, one master skeleton plot was derived from each plot (Figure 4.1). It showed growth reduction or suppressed growth of years clearly matching with recorded years with gypsy moth in 1989 and 2000 years, and Siberian moth outbreak in 2005, 2003, 2000, 1955-1957 and 1925-1929 quite well.

All samples had narrower ring widths in 2007, 2005 2003, 1981, 1969, 1954, 1952, 1944, 1925, 1867-1866 and 1836 which would be match to precipitation data so that we could confirm either these growth reduction caused drought or defoliation. Growth reduction before 1900s, give us hint to probable outbreak influence on growth. Therefore, after ring width measurements we developed chronologies for each plot and compared the radial growth changes in given time.

4.2 Ring – width chronologies

Tree ring chronologies of each site of this study showed in Figure 4.2. Scot's pine (*Pinus sylvestris*) from the plot ARN has longest chronology from 1672 to 2007 and lowest mean ring width due to its longetivity and reflecting its unaffected growing condition by human activities at higher elevation than other species. Siberian larch (*Larix sibirica*) has shortest chronology in SHH plot comparing with other four plots with same species (CHL, CHU and HRS, HDS) due to wood decay (during the coring, could not reach pith). In addition, chronology of SHH plot has highest mean ring width and standard deviation reflecting to its younger age than other stands.

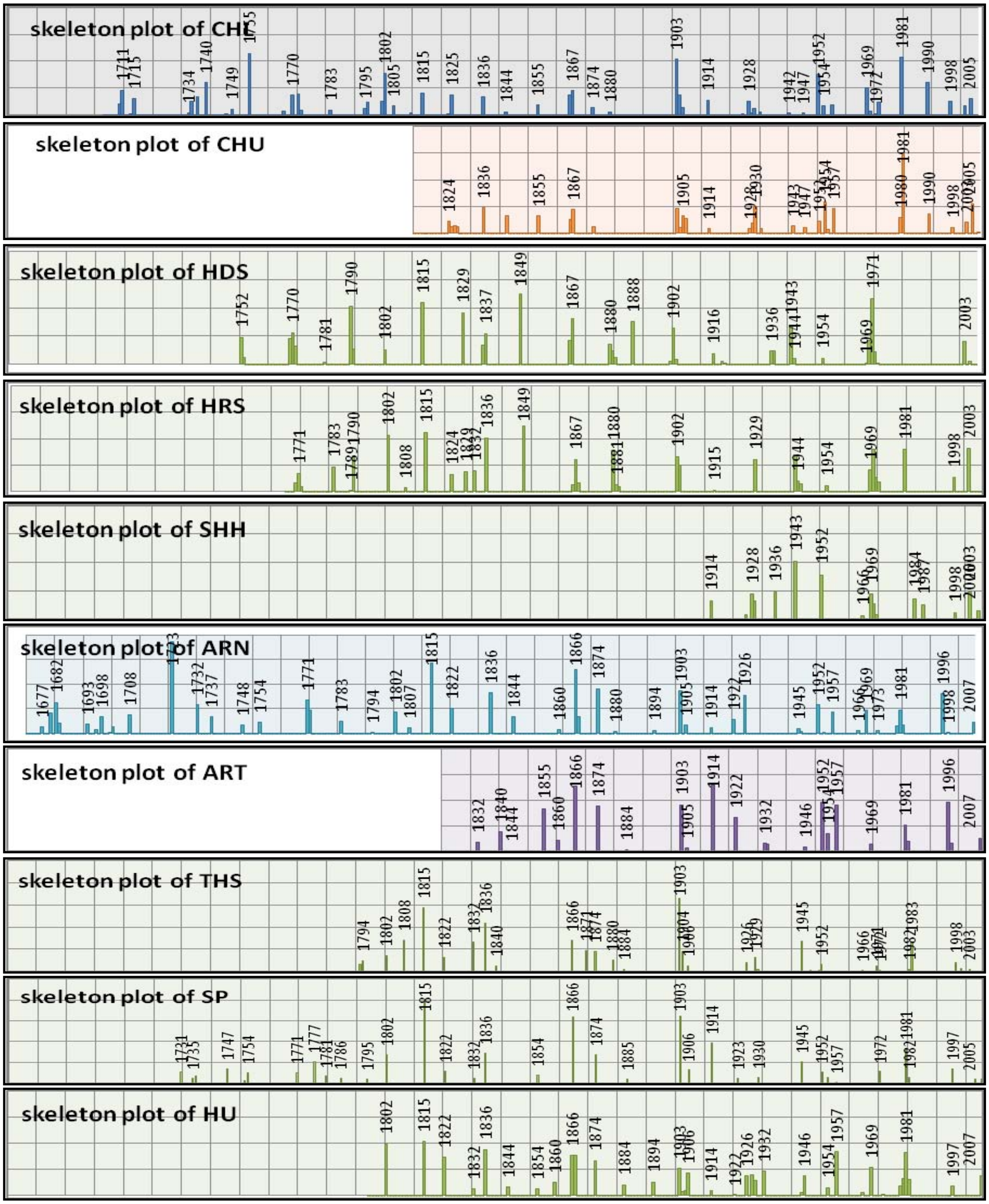
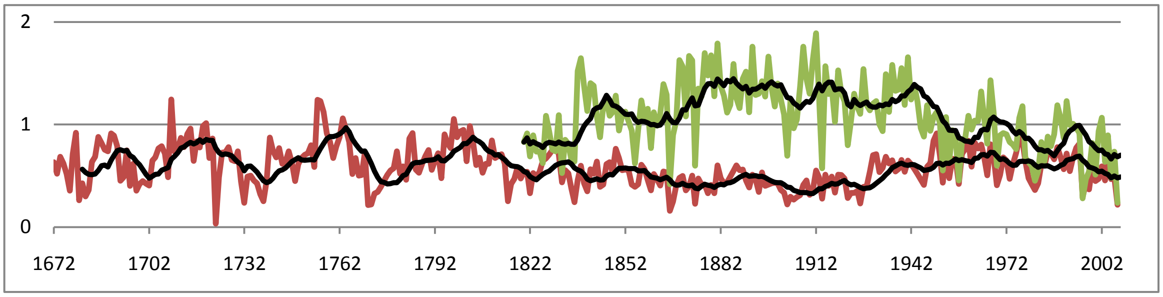
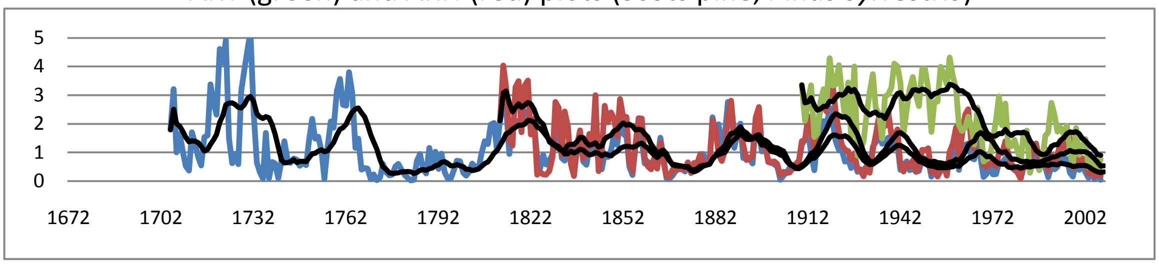


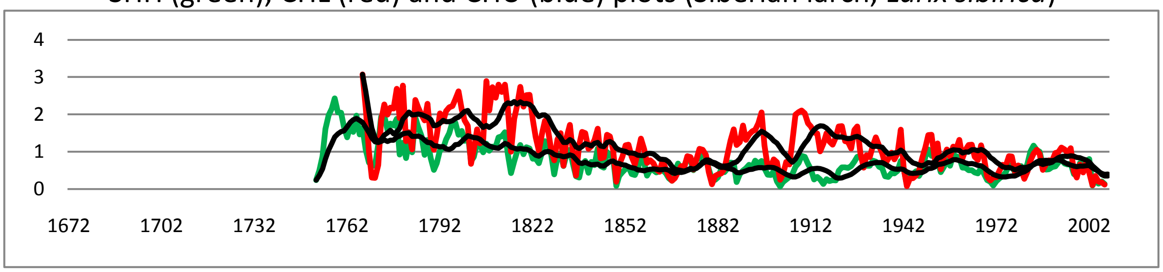
Figure 4.1 Skeleton plots of study sites, Bogd Khan Mountain



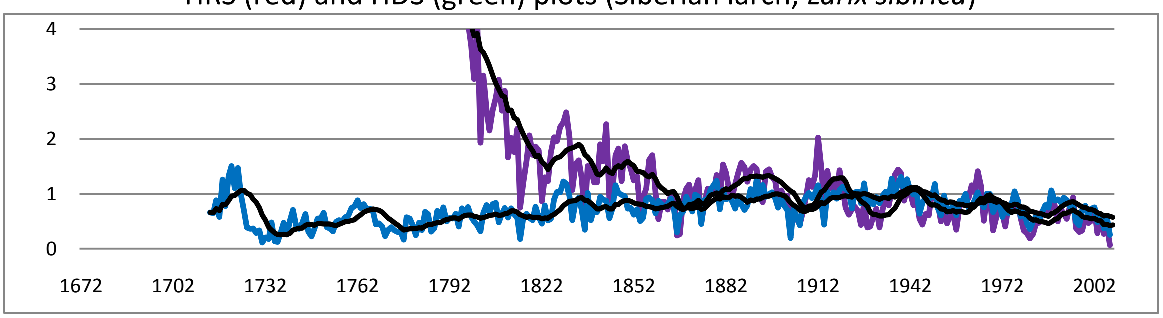
ART (green) and ARN (red) plots (Scots pine, *Pinus sylvestris*)



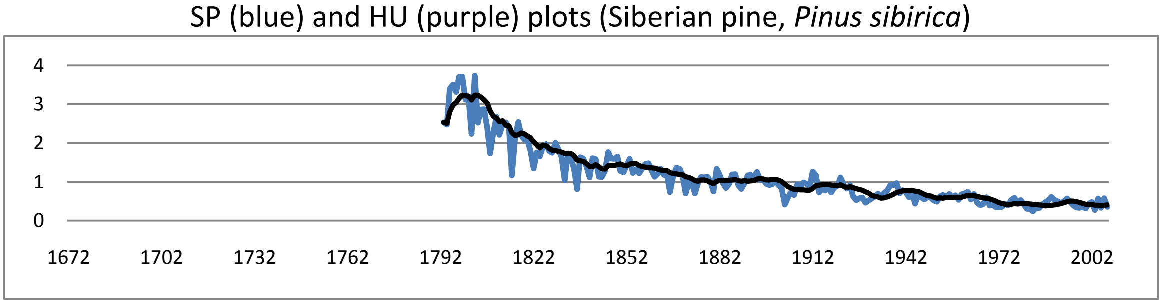
SHH (green), CHL (red) and CHU (blue) plots (Siberian larch, *Larix sibirica*)



HRS (red) and HDS (green) plots (Siberian larch, *Larix sibirica*)



SP (blue) and HU (purple) plots (Siberian pine, *Pinus sibirica*)



THS plots (Siberian spruce, *Picea obovata*)

Figure 4.2 Tree ring chronologies of each site, Bogd Mountain.

Black smoothing lines were derived from a 10-year moving average.

Table 4.1 Statistics for tree ring chronologies of plots of Bogd Mountain

Plots	*Entire chronology length*	*Length with minimum ten trees*	*Length with minimum five trees*	*Mean series inter-correlation*	*Mean ring width (mm)*	*Standard deviation*	*Mean sensitivity*	*First order auto-correlation*
ART	1820-2007	1870-2007	1837-2007	0.798	1.1	0.441	0.294	0.601
ARN	**1672-2007**	1798-2007	1738-2007	0.764	**0.58**	**0.277**	0.282	0.733
CHL	1705-2007	1831-2007	1819-2007	0.828	1.3	1.214	**0.557**	0.651
CHU	1812-2007	1849-2007	1838-2007	0.851	1.49	1,230	**0.539**	0.643
HDS	1752-2007	1813-2007	1775-2007	0.763	0.7	0.426	0.374	**0.748**
HRS	1767-2007	1810-2007	1806-2007	0.781	1.08	0.716	0.336	**0.803**
HU	1796-2007	1821-2007	1814-2007	0.806	1.03	0.635	0.345	0.748
SHH	1910-2007	1931-2007	1917-2007	0.820	**2.11**	**1.284**	0.42	0.72
SP	1714-2007	1878-2007	1828-2007	0.759	0.86	0.344	0.273	0.65
THS	1793-2007	1820-2007	1800-2007	0.736	1.28	0.741	**0.227**	**0.85**

Accuracy of these reconstructions may be limited in the earlier time intervals between 1820 - 1672 due to length of samples were less than five tree cores. Therefore, further analysis we used only length until year 1820, which included at least ten cores and they were compared.

The statistical figures of each chronology showed in table 4.1, which directly produced from COFECHA software. Mean sensitivity, which measures the relative difference in width from one ring to the next, was similar for all plots except CHU and CHL, which were quite high. It indicates they had high inter-annual variability in the ring widths and were sensitive to environmental changes yearly.

The first-order autocorrelation, which measures the correlation between a ring width at time *t* and its predecessor at time *t-1,* was high for all species. These results are clearly visible in the chronologies: Siberian pine and Scots pine tend to have multi-year periods where growth is either constant or slowly increasing or decreasing, whereas Siberian larch is much more prone to sudden year-to-year increases or decreases in growth.

Siberian pine (*Pinus sibirica*) from SP and HU plots has lower mean ring width and standard deviation could explain by its longetivity and its resistance to defoliators.

Siberian spruce (*Picea obovata*) from THS plot has lowest mean sensitivity means less inter-annual variables in ring widths and less sensitive to the environmental factors.

4.3 Climate-tree growth relations

The response functions of chronologies of Siberian pine, Siberian spruce, Scots pine and Siberian larch with monthly mean temperature and monthly total precipitation for interval from 1940 to 2000 using DENDROCLIM-2002 program were presented in figure 4.3. Tree ring growth of Siberian pine was correlated positively with precipitation in May and June of the growth year and showing negative correlation with temperature in June and July and previous year's June and July. Growth of Scot's pine has negative correlation with temperature in June, July and previous August.

All species correlated negatively with growth and high summer temperature. It suggested that due to high temperature, evapotransporation and water loss increased and radial growth had reduced. Positive effect of spring precipitation (March to June) of all species could be explain that precipitation during the growing season is the limiting factor of radial growth. This gives us clue that we could compare annual precipitation data with radial growth measurements to identify whether growth reduction caused by drought or other environmental disturbances in our case it could be insect outbreaks. In order to compare species by species, each plot chronology used for build master chronology. Chuluut chronology presented CHU and CHL plots as well as Hurheree chronology is for HRS and HDS plots for Siberian larch and Siberian pine chronology derived from SP and HU plots.

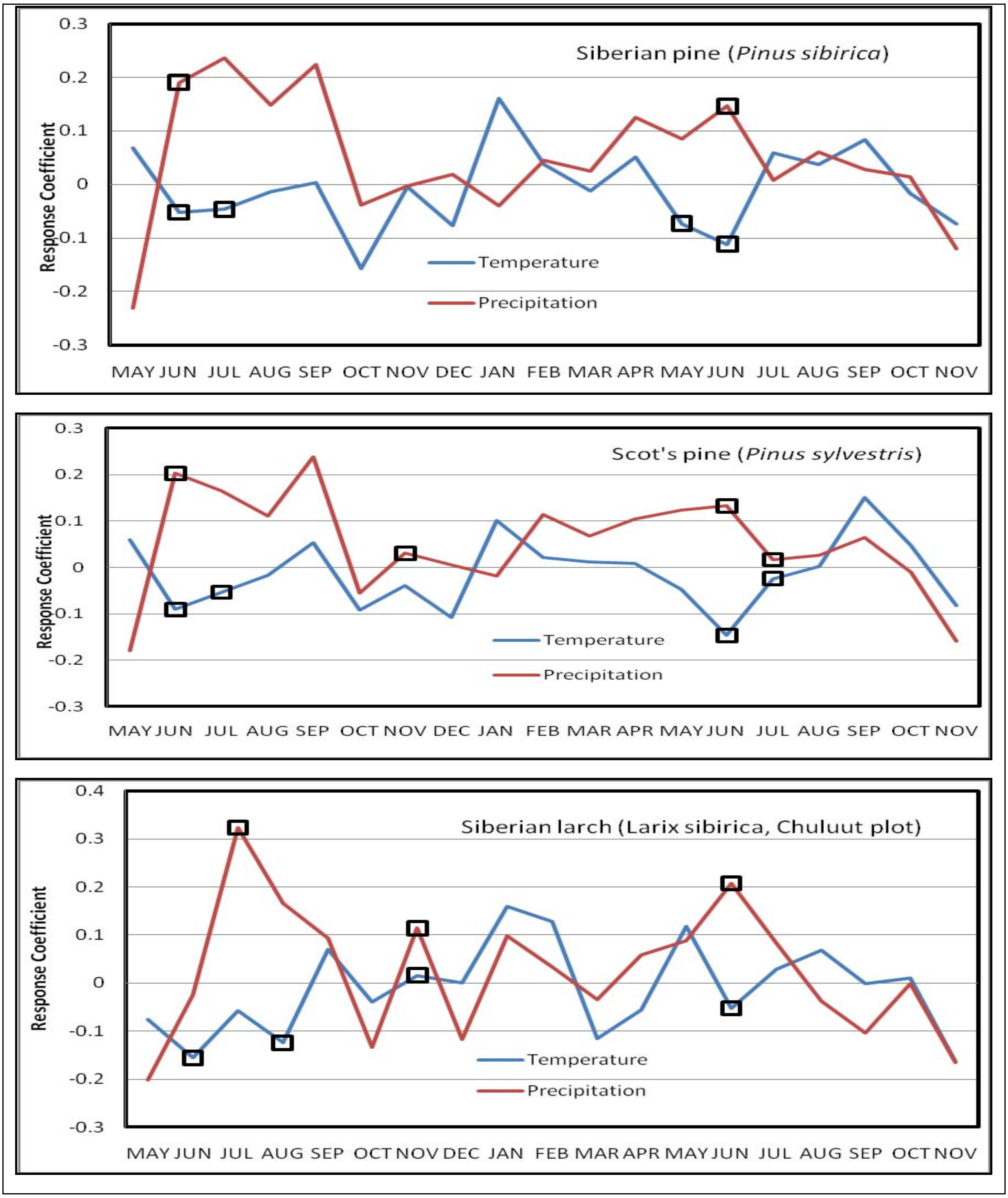


Figure 4.3 Response functions of tree ring chronologies.

Monthly climate data from 1940-2000 are used to explain the variance in the tree rings. The square marked points represent a significant (95% level) effect of either temperature or precipitation on growth

4.4 History of forest growth anomalies

Comparison of growth curves from Siberian larch (*Larix sibirica*) as host and Siberian pine (*Pinus sibirica*) as non-host species had shown in figure 4.4 and 4.5. The time span of comparison is limited by the non-host species (Siberian pine) which has a length of the chronology with minimum ten trees from 1820 to 2007.

As a host species, we had four different plots CHL, CHU and HRS, HDS. Using residual Chuluut chronology (Figure 4.4) which was built from both chronologies of CHL and CHU plots. Then we had confirmed that radial growth reduction in recorded years of insect outbreaks, which were in 2005, 2003, 2000, 1989, 1957, 1954, 1942 and 1929. Before 1930s, possible outbreak may be occurred in 1903, 1892, 1879, 1847 and 1825. The radial growths in these years were shown quite visible reduction while comparing Siberian pine chronology with larch chronology.

Residual chronology called Hurheree (Figure 4.4), which were derived from HRS and HDS chronologies were showing drops in radial growth in 2003, 1971, 1957, 1943 and 1929. In addition, it could be shown probable outbreak occurred years could be 1902, 1880, 1859, and 1829, which also compared with pine radial growth in these respective years.

Chronologies of Siberian spruce (*Picea obovata*) and Scot's pine (*Pinus sylvestris*) have no significant difference than Siberian pine chronology (Figure 4.6 and 4.7). moreover, Siberian spruce and Scot's pines chronologies which assumed fairly resistance species to defoliating insects did not show any clear growth reduction while comparing with chronology Siberian pine as highly resistant (like non host) species.

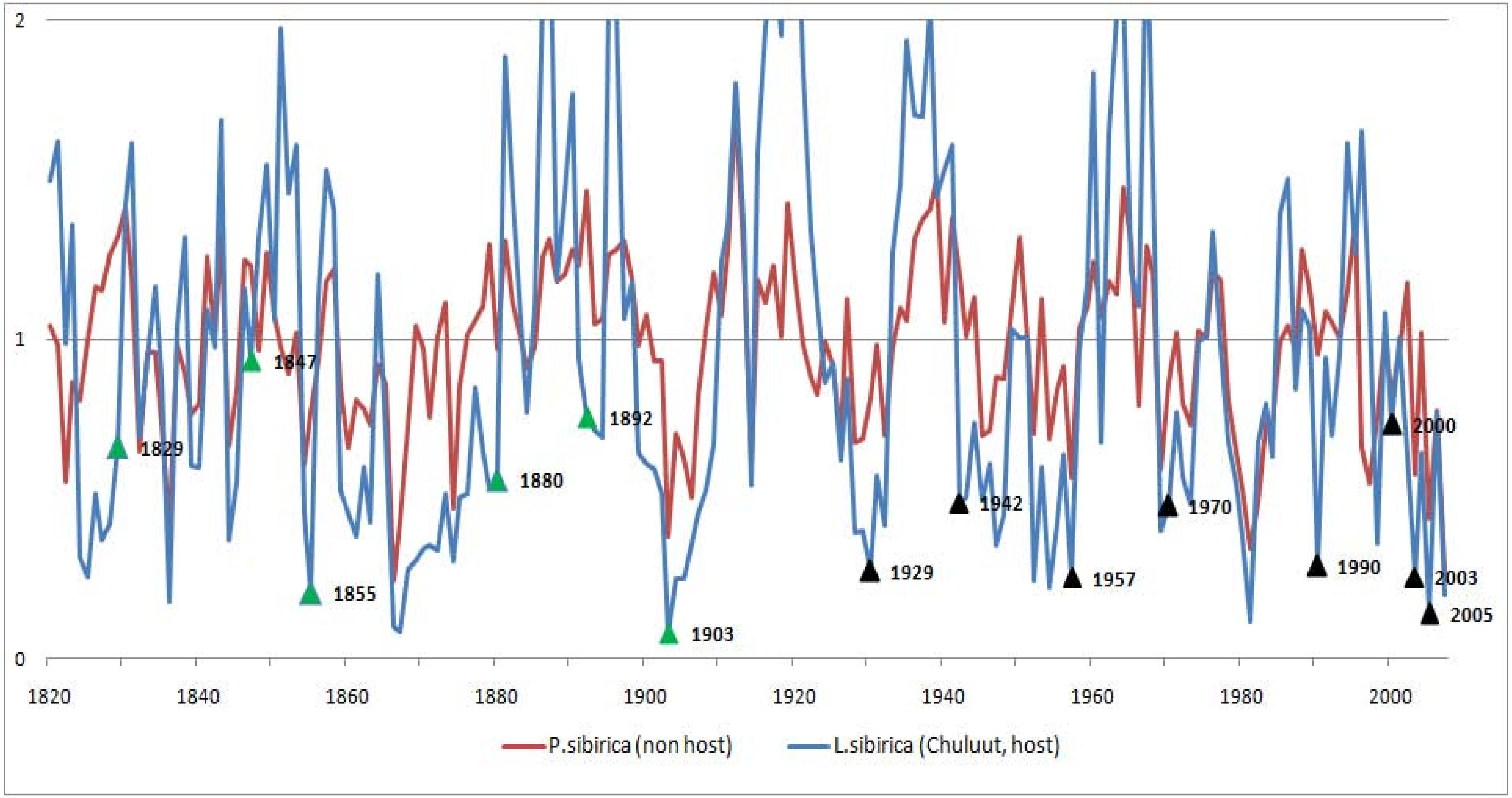


Figure 4.4 Comparison of host and non host species growth

Δ - insect outbreak years (black-recorded year; green-probable years)

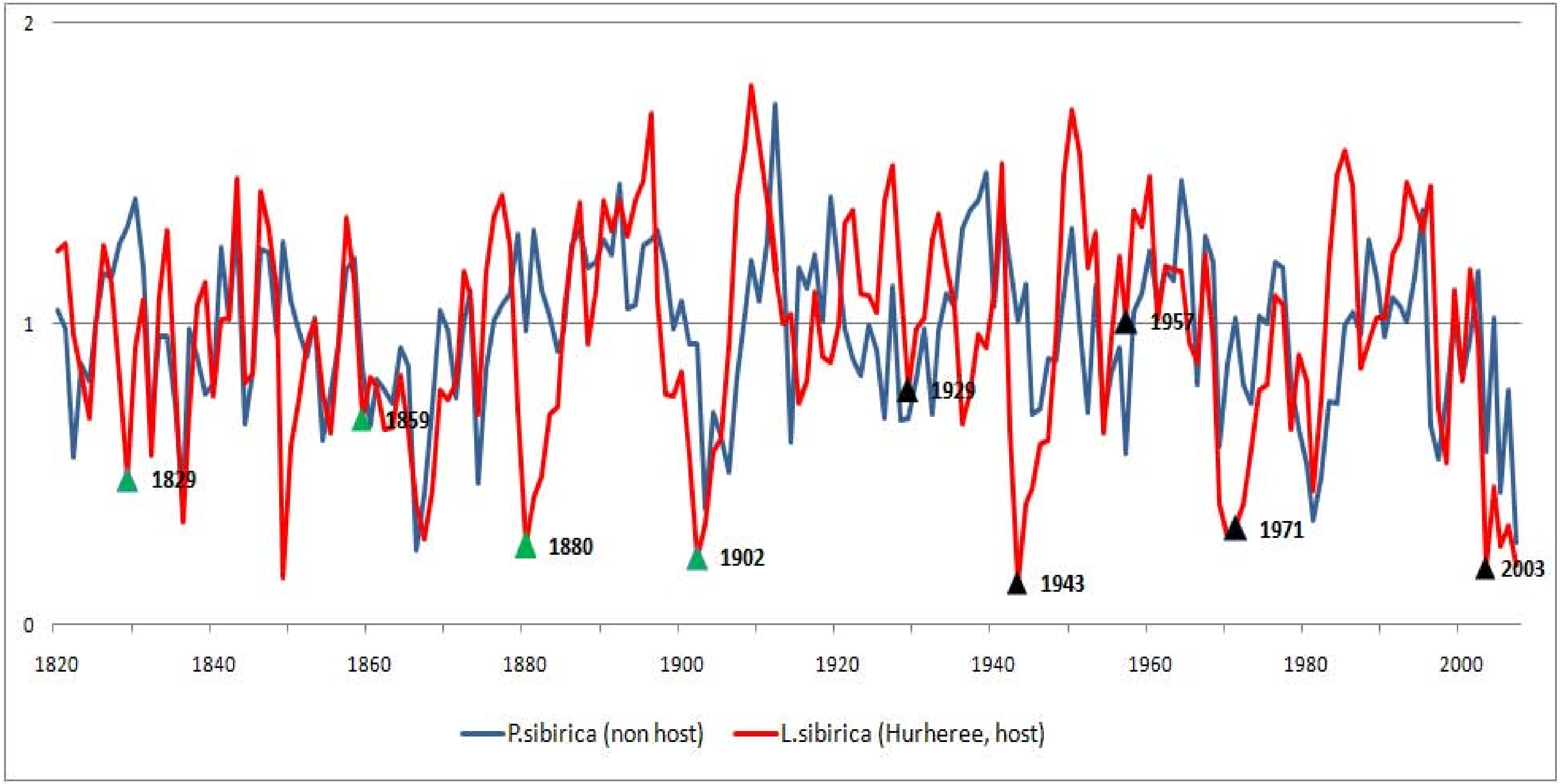


Figure 4.5 Comparison of host and non host species growth

Δ - insect outbreak years (black-recorded year; green-probable years)

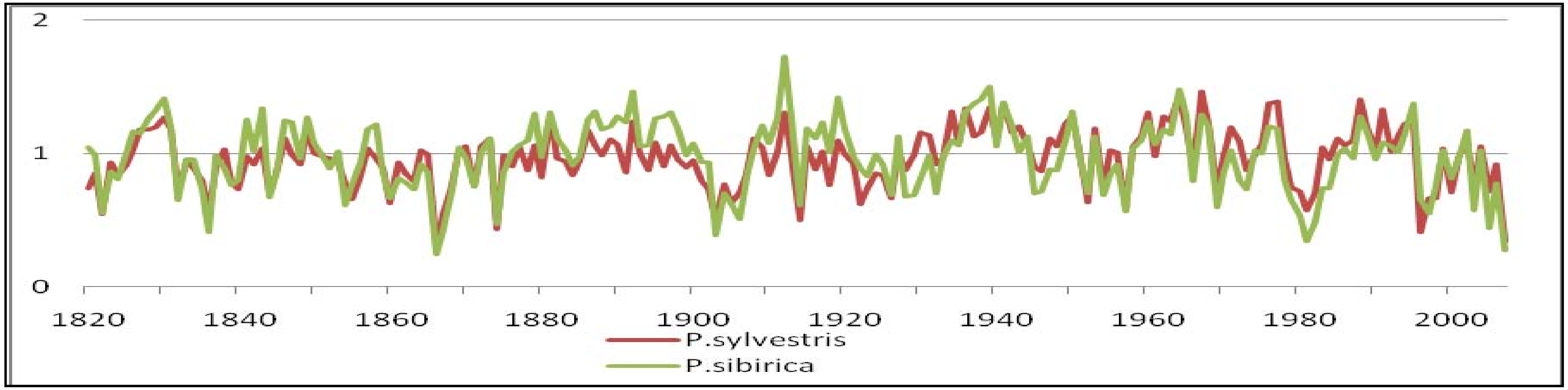


Figure 4.6 Comparison of growth of Scot's pine and Siberian pine.

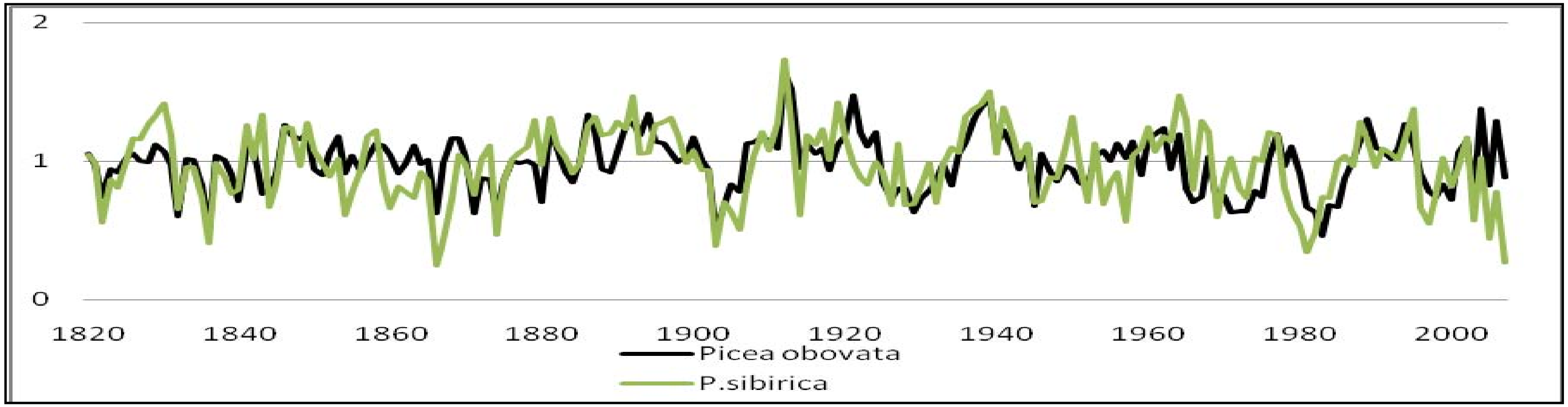


Figure 4.7 Comparison of growth of Siberian spruce and Siberian pine

However, both species (larch and pine) had radial growth drop in same years while some years the growth is quite in opposite. For instance, in figure 4.4, the radial growth of both pine and larch had shown similar pattern as dropped in 2000, 2003 and 2005, 1971 and 1957. Apparently, Hurheree and pine chronologies had shown in the figure 4.5, congruent decline in 2003, 1957, and 1929. In this case proving sudden growth reduction caused by insect outbreak, chronologies were crosschecked with annual precipitation data. On this occasion, reconstructed annual precipitation using tree ring chronologies of northeast region (where Bogd Khan Mountain belong to) by Pederson *et al.* was used to compare with Chuluut and Hurheree chronologies (Figure 4.8 and 4.9) during the year of 1995 to 1820.

While confronting Chuluut chronology and precipitation, radial growth had reduced not because of drought but the insect outbreaks in 1970, 1957, 1942 and 1929 (marked by black arrow in figure 4.8). In addition, it confirmed that probable outbreak years in 1903, 1880, 1855, 1847 and 1829 (marked by green arrow in figure 4.8). In these years, precipitations were higher but radial growths were dropped. In contrast, recorded outbreak year in 1990 also could be influenced by lower precipitation in same year (red arrow in figure 4.8). Similarly, assumed outbreak in 1892 may not be reduced by insect defoliation. Because precipitation in this year was quite lower than average, which maybe drought (marked by red arrow in figure 4.8).

As it shown in figure 4.9, radial growth reduction was not affected by precipitation in 1971, 1957 and 1929 (marked by black arrow in figure 4.9). However, radial growth drop in 1954 also overlapped lower precipitation values, which means it, may also suppress the growth in this year (marked with red arrow in figure 4.9). Probable outbreak years in 1902, 1880, 1859 and 1829 were contradicted quite well with precipitation data (marked by green arrow in figure 4.9). This approved occurrence of insect outbreak led to radial growth reduction in these years.

From skeleton plots of all samples showed narrower ring widths in 2007, 2005 2003, 1981, 1969, 1954, 1952, 1944, 1925, 1867-1866 and 1836. All these years matched to precipitation data so that it confirmed that by radial growth of all trees limited by less precipitations in these years.

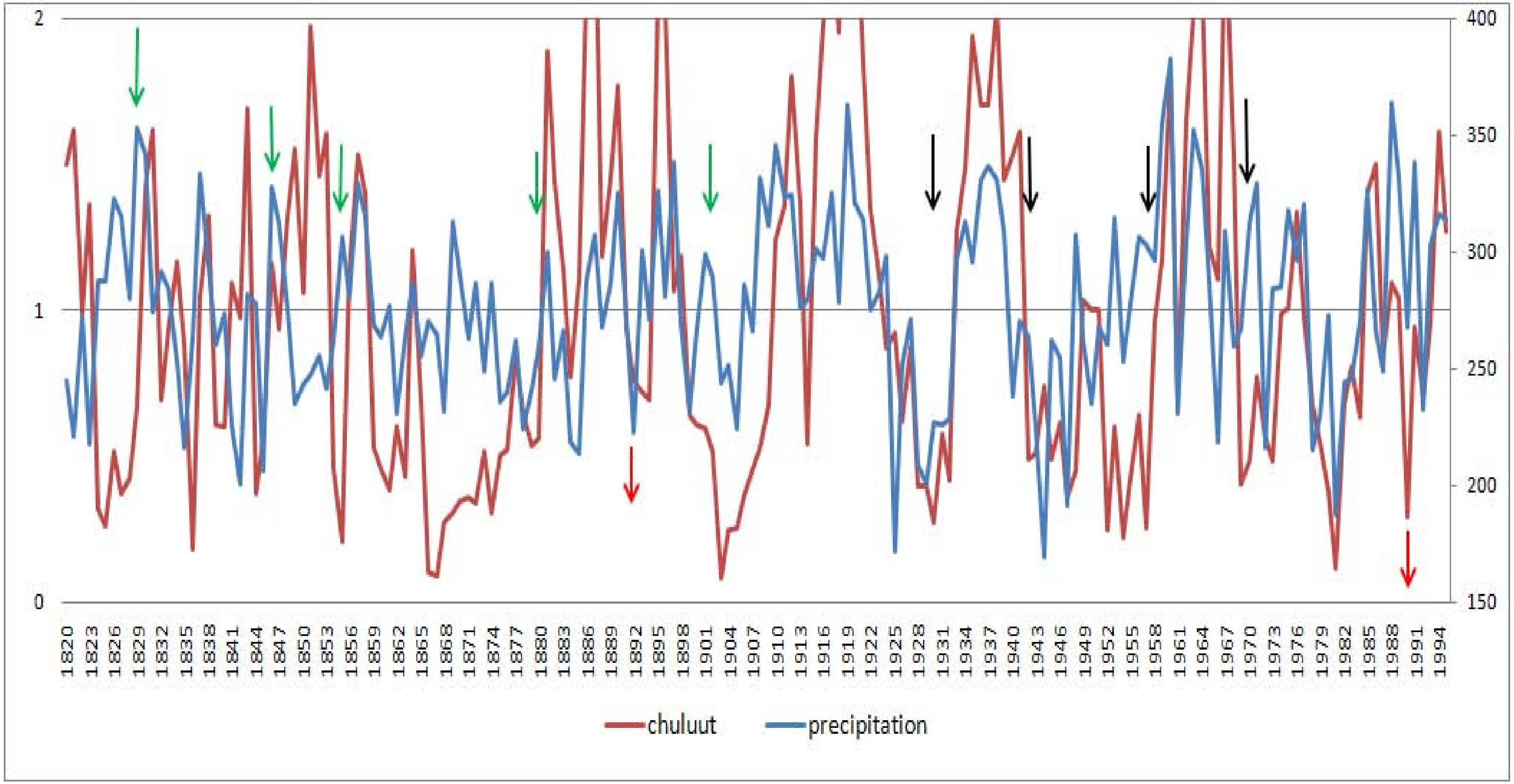


Figure 4.8 Comparison of precipitation and Chuluut chronology
Arrow shows insect outbreak years
(red – growth reduction due to drought; black – recorded outbreak years; green – probable outbreak years)

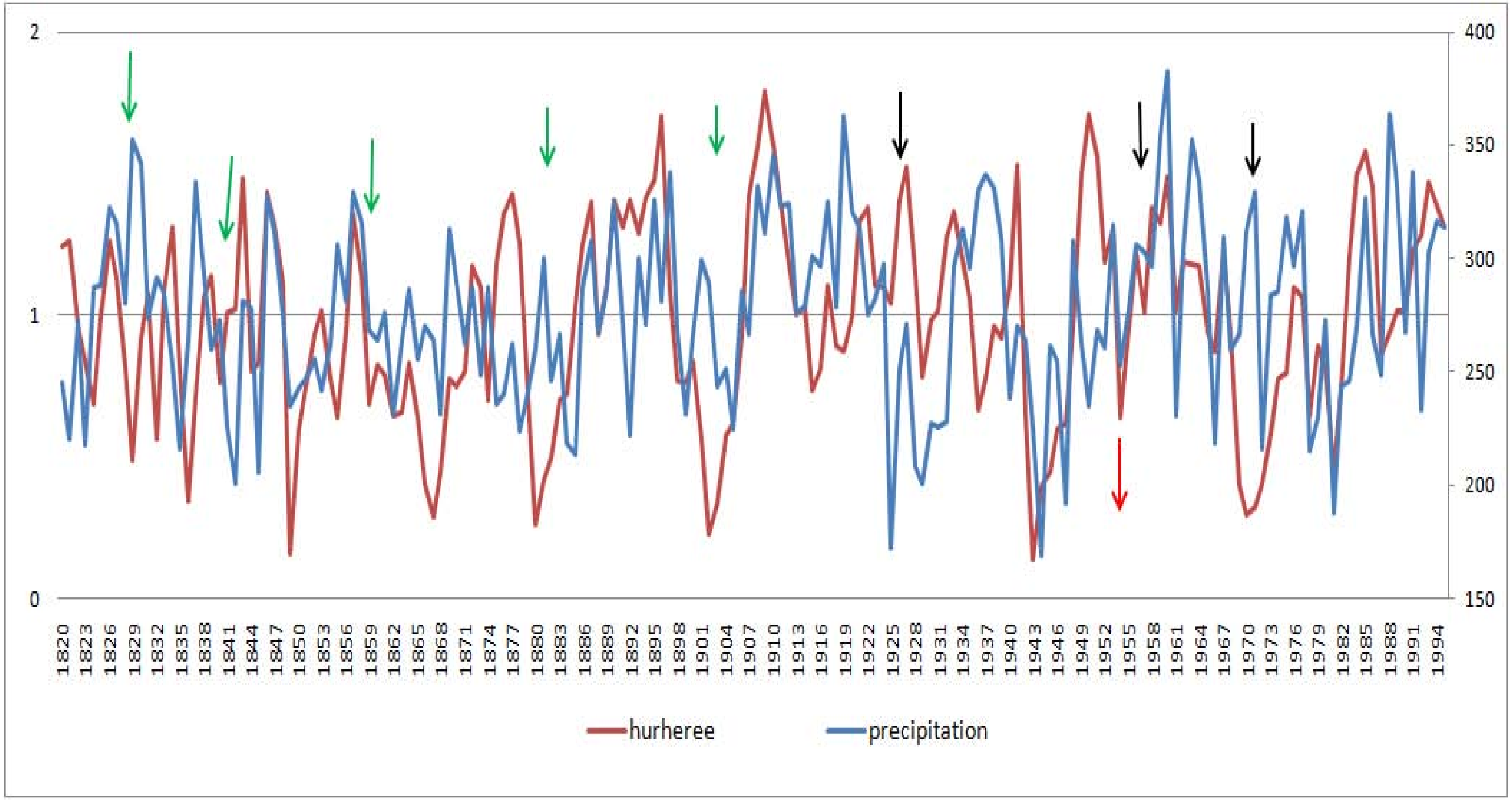


Figure 4.9 Comparison of precipitation and Hurheree chronology
Arrow shows insect outbreak years
(red – growth reduction due to drought; black – recorded outbreak years; green – probable outbreak years)

5. DISCUSSION and CONCLUSION

The tree ring width of Siberian pine, Siberian spruce, Scot's pine and Siberian larch showed distinct characteristics to environmental factors, so confronting chronologies among these four species provide useful information on past major climate and forest disturbances such as insect outbreaks apparently.

Siberian larch was the most sensitive species in terms of environmental changes such as climate and ecological changes. In this study, only major climate events on tree growth were illustrated in order to trace back severe insect outbreaks and to reconstruct by using tree ring chronologies of different conifer species at Bogd Khan Mountain.

In order to reconstruct occurrence of insect outbreak and climatic changes in long term from the samples effectively, comparing tree ring chronologies of host and non-host species with their climate sensitiveness were very successful from previous similar studies (Swetnam and Lynch, 1993; Zhang *et al.*, 1999). Our study confirmed recorded occurrence in 2005, 2003, 2000, 1971, 1957, 1942 and 1929. From here, we also could conclude that in long term massive insect defoliation occurred in each 13-15 from 1970s to 1930s. However, almost each 3-year outbreaks had occurred in each sites of this forested area since 2000 that could be connected to recent dramatic climatic changes.

Additionally, in 1903, 1880, 1847 and 1829 in Chuluut plot and in 1902, 1880, 1859 and 1829 in Hurheree plot from Siberian larch chronologies had shown that suspected occurrence. It could be clear that if we could say 30-28 and 18 year frequency in last two centuries (1900-1800) in the north east (Hurheree) and north facing slopes (Chuluut) of Bogd Mountain due this part was covered by Siberian larch forest. Unfortunately expected outbreak year in 1990 and 1954 (from both Chuluut and Hurheree chronologies) and probable outbreak in 1892 (from Chuluut chronology) could not confirmed by this comparison due to precipitation amount of these years were quite lower than average. By comparing them back Siberian pine chronology (as non-host species) radial growth in 1990 and 1954 were also slightly reduced than its average. It means either drought or outbreak maybe reduced radial growth, moreover maybe both these factors (drought and insect defoliation) had influenced.

As a first time study, I was not confident to make concrete conclusion about relationship between weather and insect outbreak. Therefore more extended sampling of old growth host and non-host species needed to find out long term and rock steady accurate data of outbreaks and climate fluctuations. These records help us to ameliorate our knowledge of frequency of outbreak as well as their relationships with climate.

This study introduced a new ecological application using tree-ring chronologies of common conifer species in Bogd Khan Mountain. Using this method, we could read and discover hidden historic information about forest dynamics, climate fluctuations in different sites even more in detail, the insect outbreak influence on radial growth. Chronologies were used for reconstructing the microclimate changes by compared with previous dendroclimatological studies in this region to confirm that past insect outbreak suppressed growth of those reconstructed years.

Using dendroecological methods which described by many authors could be used for reconstruct more detailed and accurate dendroclimatological and dendroecological data in many other different regions of Mongolia where this kind of studies never done before. Forest pest managers can use this information to decide on appropriate responses and timing of management actions. The extent of infestation, tree mortality, and height-growth reduction can usually be determined from aerial surveys and onsite observations, however to conduct these kind of studies, requires a big expenses and more human resources. Comparing with these expensive studies, tree ring application is much easier to collect data, even though measuring radial-growth reduction requires detailed analysis in advanced level by professionals. Therefore this method has quite potential to use in forest sectors whereas lack of budget and human resources especially.

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