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journal or publication title	Proceedings, International Symposium of the Kanazawa University 22st-Century COE Program
volume	1
page range	424-427
year	2003-03-16
URL	http://hdl.handle.net/2297/6444

Proceedings: International Symposium of the Kanazawa University 21st-Century COE Program Vol. 1 (2003)
Edited by Naoto KAMATA

Estimation of Environmental Changes by Tree Rings

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Abstract - Tree rings are known as one of the best sources of proxy information about environmental changes. This paper introduces some examples of application of dendrochronological analyses for ecological and climatological studies and demonstrated the potential usefulness of tree-ring structures as indicators of environmental changes.

I. Introduction

The tree rings are formed annually as a result of radial growth. The tree growth is controlled by various environmental factors [1]. Thus, tree rings records the changes in their growing conditions. "Dendrochronology" is a study field that investigates the information content in dated tree rings and applies to environmental and historical questions [2].

The dendrochronological techniques have been applied to estimate effects of environmental factors on tree growth, as well as, to estimate environmental changes in the past [3, 4, 5]. The advantages in utility of tree rings in environmental studies are their annual resolution in time scale and continuous data from the past hundreds to thousands years. Thus, tree rings can be used to establish the year in which an event took place. In addition, continuous data from past to present allows statistical investigation on the relationships between tree-ring parameters and climatic data, etc.

The parameters that can be obtained from tree rings are not only their widths but also their anatomical structures and chemical contents. The anatomical indicators including cell dimensions and tree-ring densities provide one of important information on environmental changes [5, 6]. This paper introduces some examples of application of dendrochronological analyses for ecological and climatological studies.

II. Climatic Responses of Tree Radial Growth at Different Altitudes in Mt. Norikura

Dendrochronological analysis have often been used to investigate what climatic factors affect tree-ring widths [6, 7, 8, 9]. Previous studies have shown that high summer temperature increases tree-ring widths at high altitude, as well as at high latitude, and much precipitation increases tree-ring widths at dry sites [6, 7, 10]. Therefore, climatic factors affecting tree growth are detectable by dendrochronological analysis. Increased knowledge of responses to climate of tree species at their distribution limits is important to understand the effects of global warming on their growth and distribution.

We preliminary examined the climatic responses of radial growth of *Abies veitchii* and *Betula ermanii* growing at their lower and upper distribution limits in Mt. Norikura, central Japan [11, 12]. We developed tree-ring width chronologies of the two species at their lower distribution limit (about 1600 m a.s.l.) and higher distribution limit (2400 m a.s.l.). Simple correlation analysis was used to show the effects of monthly mean temperature and total precipitation on the tree-ring widths of the two species. The meteorological data used were temperature data at Matsumoto [610 m a.s.l., about 35 km east of the study site, from 1898 to 2000 (n = 103)] and precipitation data at Nagawato Dam [900 m a.s.l., about 10 km east of the study site, 1969 to 2000 (n = 32)].

Table I
Responses of tree-ring widths to climate

Monthly mean temperature

Sites	Month Species	Previous growth period					Dormant period							Current growth period				
		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Lower distribution limit	*Abies veitchii*																	
	Betula ermanii																-	
Upper distribution limit	*Abies veitchii*						+	+	+								+	
	Betula ermanii								-	-		-				+	+	

Monthly total precipitation

Sites	Month Species	Previous growth period					Dormant period							Current growth period				
		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Lower distribution limit	*Abies veitchii*				+													
	Betula ermanii											+					+	
Upper distribution limit	*Abies veitchii*																-	
	Betula ermanii															-	-	-

+, –: significant correlation coefficient at $p < 0.05$

The tree-ring width of *A. veitchii* at its lower distribution limit was positively correlated with precipitation of the previous August (Table 1). The ring width of *B. ermanii* positively correlated with precipitation and negatively correlated with temperature of the current August. On the other hand, at their upper distribution limit, ring width of both the two species correlated positively with temperature and negatively with precipitation of the current summer.

The results suggest that water deficit in August might reduces the growth of the two species in their lower distribution limit. To the contrary, low temperature and much precipitation, which can be connected with short duration of sunshine, might reduce the growth of the two species in their upper limit of distribution. Therefore, the summer temperature and precipitation are the most important factors regulating growth of the two sub-alpine tree species in both lower and upper distribution limits in central mountains in Japan.

III. Use of Tree-Ring Densities as Indicators of Climatic Changes

Tree rings provide one of the best sources of proxy information about climatic changes. Chronologies of tree-ring widths for some species in Hokkaido have been evaluated for their potential utility in dendroclimatological studies [13].

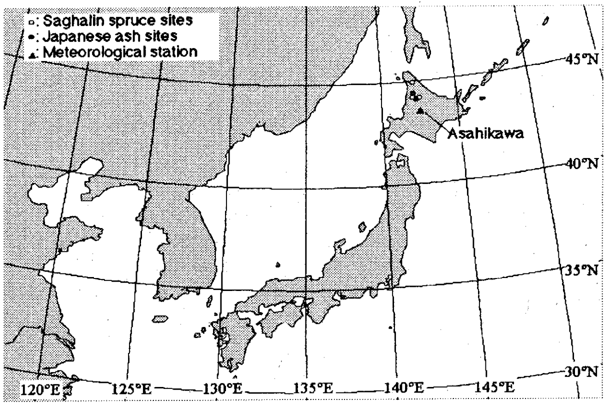

Fig. 1. Map showing the study sites and the meteorological station.

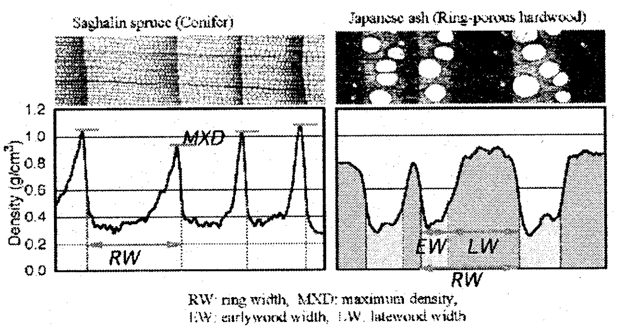

Fig. 2. Tree ring structures (upper photos) and corresponding density fluctuations obtained by X-ray densitometry.

We developed a total of 12 chronologies ranging from 184 to 432 years; six chronologies of ring widths and maximum densities for Sakhalin spruce (*Picea glehnii*) at three sites and six chronologies of ring-width, early- and latewood widths of Japanese ash (*Fraxinus mandshurica* var. *japonica*) at two sites in northern Hokkaido (Figs. 1, 2; [8,9,14,15]). Climatic responses of the chronologies were analyzed by calculation of simple correlation with climatic data. The climatic data that we used were the homogenized monthly mean temperatures and the monthly total precipitation at Asahikawa (1900 – 1990; Fig. 1). The results of correlation analyses revealed that the ring widths of Sakhalin spruce were related mainly to local monthly temperature, but the responses differed among the sites. By contrast, the maximum densities were positively correlated with temperature during the current summer and negatively correlated with precipitation of the current August at all sites. The ring widths and latewood widths of Japanese ash were positively correlated with temperature of current summer. Earlywood widths were negatively correlated with temperature in early summer.

Transfer functions for summer (June to September) temperature and August precipitation were derived from multiple regression equation. The validity of the transfer functions were statistically tested by traditional "verification" statistics (correlation coefficient, sign test, RE, CE; [3]).

The validity of transfer functions for summer temperature for 1807 – 1990 and for 1732 – 1990 were successfully verified. The adjusted square of multiple correlation coefficients (R_{adj}^2) were 0.40 and 0.37, respectively. The transfer functions for August precipitation were also verified for the all periods (from 1807, 1732 or1651 to 1990). R_{adj}^2 were 0.26, 0.26 and 0.24, respectively. Thus the past summer temperature and August precipitation in northern Hokkaido were reconstructed back to AD 1750 and to AD 1651, respectively (Fig. 3). The results emphasized availability of combined density parameters from both conifers and hardwoods for climatic reconstruction.

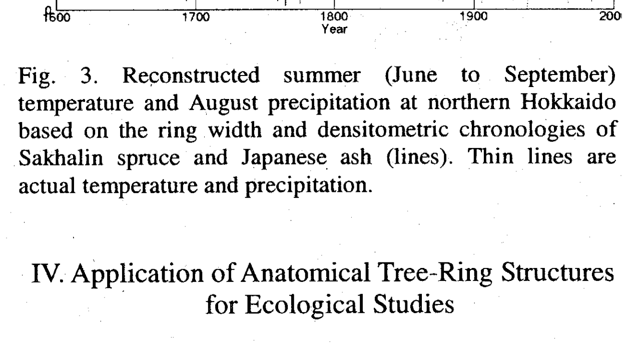

Fig. 3. Reconstructed summer (June to September) temperature and August precipitation at northern Hokkaido based on the ring width and densitometric chronologies of Sakhalin spruce and Japanese ash (lines). Thin lines are actual temperature and precipitation.

IV. Application of Anatomical Tree-Ring Structures for Ecological Studies

The tree rings can provide not only climate related signals but also extreme events that damaged cambial tree growth. Debris flows, floodings and forest fires usually recorded as scars in radial sections in tree trunk that caused by severe physical damages on cambium (Fig. 4). A microscopic observation on the tree-ring structure at the scars make able to detect the season of the occurrence of damages. The other changes in tree-rings structures can also be good indicators of extreme events. A leaning of tree trunk, usually occurred by land slides and debris flow, will cause reaction woods [16]. Tree trunk sinking in water by floodings can also have effect on anatomy of xylems [17]. Therefore, a detailed history of these extreme events can be reconstructed by tree rings.

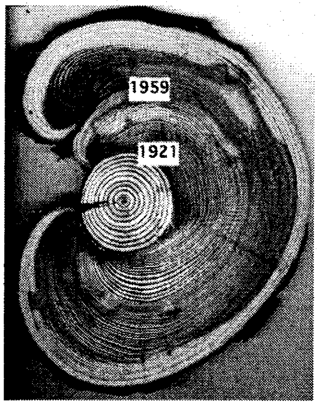

Fig. 4. Flood scars in *Larix gmelinii* growing in river bank of Kochecom River in Tura, central Siberia. The timing and height of past floodings were reconstructed by the scars.

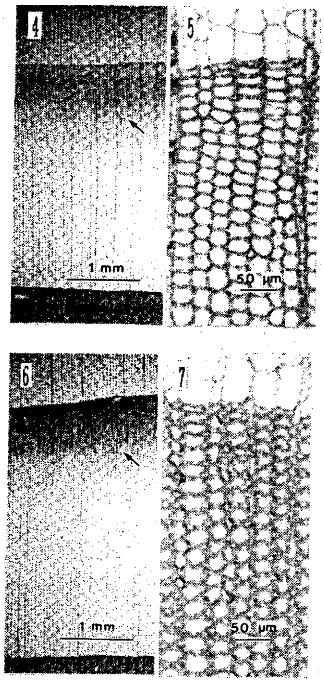

Fig. 5. Microscopic view of transverse sections of the rings of Japanese larch formed the year of pest disease by *Guignardia laricina*. (from Takata and Katayose 1990)
The transition from earlywood to latewood is gradual (Plate 4), the cell wall thickness of latewood trackeids are thin (Plate 5) and oval-shape cells formed in the latewood (Plate 7).

Defoliation by outbreaks of insects and fungi can also affect the tree rings. There have been a lot of reports on sudden decline of ring width by out breaks of insects and fungi [5, 18]. On the other hand, declines of ring width also might be caused by other severe events including climate etc. Characteristic changes in tree-ring structures by outbreaks of insects or fungi will help to distinguish the events. The heavy needle loss of larch trees (*Larix decidua*) in European Alps by outbreaks of larch bud moth leads to growth reduction in early wood cells and thinner cell walls in latewood [5]. On the other hand, it is pointed out the importance of comparison with other species or sites to reconstruct reliable outbreak history [5]. The effects of pest disease by *Guignardia laricina* on tree ring structures of Japanese larch (*Larix kaempferi*) have been reported as reduced density in latewood of the current year and decline of earlywood width of the following year [19]. However, there have still been few reports on the effects of outbreaks on tree ring structure of Japanese trees. The effects of defoliation by out breaks of insects on hardwood species have been reported as abrupt decline in vessel size in annual rings [5] and formation of less lignified rings, called "white rings" [20].

V. Conclusion

Tree rings provide one of the best sources of proxy information about environmental changes. On the other hand, the observed tree rings time series can be considered as aggregation of several effects of factors, such as age related changes, climate effects, competitions with neighboring trees, outbreaks of insects and other forest disturbances. The useful information can be extracted from parameters of tree-ring structures, as well as tree-ring width. A combined information from different tree-ring parameters and comparison between species and sites will help us to clarify the environmental changes in the past.

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