A DENDROECOLOGICAL ASSESSMENT OF WHITEBARK PINE IN THE SAWTOOTH SALMON RIVER REGION IDAHO

by

Dana Lee Perkins

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APPROVAL BY THESIS DIRECTORS

This thesis has been approved on the date shown below:

Thomas W. Swetnam	12/14/95
Dr. Thomas W. Swetnam Associate Professor of Dendrochronology and Watershed Management	Date
J M Cushing	12/13/95
Dr. Jim C. Cushing Professor of Mathematics	Date
	12/14/95
Dr. Malcolm K. Hughes Professor of Dendrochronology and Watershed Management	Date

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ABSTRACT

Whitebark pine (Pinus albicaulis Engelm.) tree-ring chronologies of 700 to greater than 1,000 years in length were developed for four sites in the Sawtooth-Salmon River region, central Idaho. These ring-width chronologies were used to 1) assess the dendrochronological characteristics of this species, 2) detect annual mortality dates of whitebark pine attributed to a widespread mountain pine beetle (Dendroctonus ponderosae Hopk.) epidemic during the 1909 to 1940 period, and 3) establish the response of whitebark pine tree ring-width growth to climate variables.

Crossdating of whitebark pine tree-ring width patterns was verified. Ring-width indices had low mean sensitivity (0.123–0.174) typical of high elevation conifers in western North America, and variable first order autocorrelation (0.206–0.551). Mortality of dominant whitebark pine caused by mountain pine beetle had a maxima at 1930 on all four sites. Response functions and correlation analyses with state divisional weather records indicate that above average radial growth is positively correlated with winter and spring precipitation and inversely correlated with April temperature. These correlations appear to be a response to seasonal snowpack. Whitebark pine is a promising species for dendroclimatic studies.

CHAPTER 1

Introduction

This research was initiated to study the dendroecology of whitebark pine (Pinus albicaulis Engelm.). Our objectives were to assess the dendrochronological characteristics of this long-lived pine, to evaluate the timing of a mountain pine beetle (Dendroctonus ponderosae Hopk.) epidemic that occured in the early part of this century and to investigate the potential of whitebark pine for dendroclimatic research.

Concern over whitebark pine decline caused by exotic white pine blister rust (Cronartium ribocola J.C. Fisch.), infestations of mountain pine beetle, fire suppression and subsequent succession by shade-tolerant conifers (Arno and Hoff 1989, Keane et al 1989, Morgan and Bunting 1989, Keane and Arno 1993) has stimulated research on whitebark pine populations. Widespread mortality of whitebark pine and potential replacement by other tree species suggest changes in distribution and abundance of whitebark pine in the northern Rockies. Research on this species has concentrated in the intermountain region of western Montana and in the Greater Yellowstone ecosystem. (Arno 1986, Arno and Hoff 1989, Keane et al 1989) Environmental conditions favorable to the propagation of blister rust have resulted in severe pine mortality and reduced whitebark pine cone crops in northwestern Montana (Keane and Arno 1993, Kendall and Arno 1990, Mattson and Jonkel 1990).

The Sawtooth Salmon River region, near the southern edge of whitebark pine distribution (Arno and Hoff 1989), appears to be a stronghold against the spread of white pine blister rust, but stands have sustained widespread mortality from bark beetle infestations. This area represents a large geographic gap in whitebark pine research and in current tree-ring chronology networks. Schulman (1956) sampled 1,600 year old limber pines (Pinus flexilis James) near Ketchum, Idaho, but no other sites with 1,000-year tree-ring chronologies have been developed for the northern Rockies in the United States. Consequently, we began this research to evaluate whitebark pine tree-ring chronologies as a source of long-term information on the historic ecological and climatic processes affecting subalpine ecosystems.

Whitebark pine is a slow growing, long-lived, stone pine (subsection Cembrae) of high elevation forests and timberlines of the northwestern United States and southwestern Canada. It occupies harsh, cold sites characterized by rocky, poorly developed soils and snowy, windswept exposures. Throughout its range whitebark pine may occur as an alpine species including a krummholz form in communities above tree line, as a seral species, or co-dominant with subalpine fir(Abies lasiocarpa (Hook) Nutt.) (Arno and Hoff 1989). Other common associates are lodgepole pine (Pinus contorta Dougl.), Engelmann spruce (Picea engelmannii Parry ex Engelm.), and mountain hemlock (Tsuga mertensiana (Bong) Carr.) (Arno and Hoff 1989).

Whitebark pine is a monoecious conifer with indehiscent cones that bear large wingless seeds. Clark's nutcracker (Nucifraga columbiana Wilson) is the primary dispersal agent of whitebark pine seeds and therefore is a critical component in their regeneration dynamics (Hutchins and Lanner 1982; Lanner 1982; Tomback 1982). Whitebark pine seeds are also important foods for red squirrels (Tamiasciurus hudsonicus), black bear (Ursus americana), and endangered grizzly bear (Ursus arctos). Natural mortality of whitebark is attributed to mountain pine beetle outbreaks and fire. These subalpine forests are valued as important wildlife habitats, watershed catchments, recreation areas and sensitive environmental indicators (Arno and Hoff 1989)

High elevation whitebark pine forests in central Idaho are composed of large diameter, old whitebark pine snags mixed with stands of live whitebark pine and subalpine fir. Mass mortality of mature age class trees has been attributed to a mountain pine beetle outbreak transmitted from lower elevation lodgepole forests to high elevation stands of whitebark pine(Arno and Hoff 1989, Bartos and Gibson 1990). This outbreak reached epidemic proportions from 1920 to 1940, and was reported from southern Canada to Wyoming (Arno and Hoff 1989; Ciesla and Furniss 1975). However, timing and patterns of mortality within and between whitebark pine stands are largely unknown. Specific questions arise from this lack of knowledge: Did the numerous dead overstory trees within stands succumb in a short period of a few years, or did they die over longer periods? Are mortality events synchronous among stands in the region? What were the climate conditions before, during and after the mortality? What are the interactions between climate variables and beetles? Is the mortality event unprecedented? While this study does not fully address or answer all these questions, it demonstrates the potential utility and value of tree-ring data for doing so.

Whitebark pine is a relatively new species of interest to dendrochronologists. Its ring-width series are known to crossdate and chronologies have been produced from the Canadian Rockies, and eastern Oregon (Luckman 1993, 1994, Peterson 1990, Parker and Graumlich unpublished data). However, dendrochronological characteristics and response to temperature and precipitation variables have not been described. The semiarid conditions of homogeneous, open canopied, high elevation stands in central Idaho favor the dendroecological study of whitebark pine in a setting nearly free from exotic blister rust fungus. This area is influenced by north Pacific weather patterns and is located in a transition zone between continental and inland-maritime climates (Arno and Hammerly 1984). Variability of continental atmospheric patterns in the transition zone affects ecophysiological requirements of whitebark pine and mountain pine beetle. The dynamical feedbacks among these variables: trees, beetles and climate, is important for understanding changing environments. The vast pristine high elevation forests are relatively free of human disturbances such as logging and fuelwood collection. However, these areas have been affected by mountain pine beetle attacks, fires on some sites, fire suppression at most sites, and increasingly by recreational impacts. Assessment of natural disturbance patterns and climatic factors affecting whitebark pine is essential to provide baseline reference for current and future changes in these subalpine habitats.

CHAPTER 2

Methods

Site Descriptions

Four whitebark pine study sites were selected in central Idaho within the geographic region north of the headwaters of the Salmon River, south of the Middle Fork of the Salmon River, west of the East Fork of the Salmon River and east of the North Fork of the Boise River (Figure 1). Two sites, Sandpass (SDP) and Upper Sandpass (UPS) are within the Sawtooth Wilderness area on the windward (west) side of the northwest trending Sawtooth Mountains. The Railroad Ridge site (RRR), is in the lee (east side) of the northwest trending White Cloud Mountains, and the Twin Peaks site (TWP) is on the east flank of the Salmon River Mountains, in the southeastern region of the Frank Church River of No Return Wilderness near Challis Idaho.

Whitebark pine stands in this region are typical of light-demanding conifers near timberline. They show increasing stand openness with elevation, often lack sharp stand boundaries and occur in an uneven mosaic pattern (Walter 1968, Tranquillini 1979). Tree distribution at the study sites appears to be limited by edaphic factors and wind rather than elevational constraints and associated temperature limitations. Ground cover is virtually non-existent on Sandpass, Upper Sandpass and Twin Peaks. The broad flat ridgetop of the Railroad Ridge site has ground cover composed primarily of Artemesia tridentata and Carex spp. Habitat types are the PIAL/ABLA or PIAL series according to Steele et al. (1981).

We selected "classic dendroclimatic" sites (Douglass 1941; Schulman 1956; Fritts 1976) characterized by steep exposed slopes, open grown stands, coarse well drained soils and southerly aspects to determine if whitebark pine in this region had sufficient climatic sensitivity to display a common response in ring-width pattern. These physical site characteristics maximize climatic responsiveness of tree-ring width chronologies, while minimizing the influence of within-stand dynamics, such as competition and interference. We also selected these sites because of the standing dead component that could be attributed to mountain pine beetle infestation.

Site elevations range from 2,800 to 3,000 meters. Site areas range from 1.5 to 4.0 hectares. The SDP and UPS sites occur on the divide between the Payette and Salmon River basins on the granitic contact between the Sawtooth and Idaho batholiths. These two sites are subject to the prevailing westerly weather patterns. The Twin Peaks site is rhyolitic substrate and the Railroad Ridge site is granitic. Physical site characteristics are summarized in Table 1.

This region is semiarid with 30 – 80 cm of precipitation a year, most of which falls as snow and rain during winter and spring. At elevations above 2,700 meters, most precipitation falls as snow. Precipitation may range from lows of 20 cm in the valleys to over 150 cm on mountain peaks (Steele et al. 1981).

Annual temperatures range from average minima of −8° C to average maxima of 10° C. Extreme cold temperatures from −34 to −47° C are recorded from December through February. Winds redistribute snow around whitebark pine trees to form snowdrifts that may linger until July and occassionally August. In open areas, near clumps of trees and associated snowdrifts, remnant dead and subfossil wood is abundant. The semiarid nature of this region precludes rapid decay of these fallen trees.

Field Collections

Tree-Ring Width Chronologies

Field collections were made to develop master ring-width chronologies on each of the four sites using standard dendrochronological procedures (Fritts 1976, Swetnam et al 1985). Fifteen to thirty live and/or dead trees were sampled on each site during the growing season 1992-1993. Intermediate, codominant and dominant size classes were sampled with emphasis on old trees characterized by flat tops, heavy drooping limbs, exposed roots, and limb and leader dieback. Photographs were taken of all trees sampled. At least two cores were extracted from each tree using a 51 cm (20") increment borer. Diameter at breast height (DBH) and estimated heights were recorded.

Mortality and Size-Class Sampling

A sampling strategy based on distance methods (Pollard 1971, Smeins and Slack 1978) was used to determine the relative frequency of trees killed by mountain pine beetle and to characterize stand structure. Relative frequency, F_i, is expressed as $F_i = (\frac{n_i}{n})100$ where n_i is the number of occurrences of the phenomena of interest (size or mortality class), and n is the the total number of occurrences (total trees sampled). Transects were systematically established on 61 meter (200 ft) topographic contours (level curves) across each site. On each transect, plot centers were located at random distances. From each plot center we recorded the distance (meters) to the nearest two trees. We used both trees at each sample plot to record mortality and size-class frequencies.

A consequence of seed dispersal by Clark's Nutcracker is that whitebark pine have a spatially clumped distribution (Lanner 1980, Sudworth 1980, Tomback 1982). Clumps are composed of genetically distinct stems (several trees) or genetically identical, multistemmed individuals (one tree). To meet random distribution assumptions, we consider the clumps, rather than tree stems, to be randomly distributed.

Mortality patterns were described by recording whether the tree was live (L), dead by an unknown cause (U), or dead due to beetle kill (B). The latter was determined if adult mountain pine beetle galleries, which appear as distinctive vertically aligned 'J' shaped marks (Wood 1982), were observed on the bole. These galleries were constructed in the the phloem tissue under the bark the year of infestation (Wood 1982). Dead trees and subfossil wood without beetle galleries were coded unknown dead. At least two increment cores were extracted from all beetle-killed trees.

To describe stand structure patterns, we recorded diameter at breast height (DBH), estimated height and coded cohorts according to the following criteria: seedling (s), those trees less than 1 inch (2.54 cm) in DBH and under a foot (30.5 cm) tall, sapling (S), less than 1 inch (2.54 cm) to 4 inches (10.2 cm) DBH and greater than a foot (30.5 cm) tall, intermediate (i), 4 to 8 inches (10.2 – 25.8 cm) DBH, co-dominate (c), 8 to 19 inches (25.8 – 48.3 cm) DBH and dominant (d), greater than 19 inches (48.3 cm) DBH. Although this categorization scheme is not exhaustive, all trees observed on our sites fall into these categories.

Laboratory Analysis

New Chronology Development and Assessment

Increment cores were mounted in wooden holders and surfaced with sandpaper to reveal ring boundaries and diagnostic ring structures. (Stokes and Smiley 1968; Swetnam et al 1985), Measurements of ring widths were made with a sliding-stage micrometer interfaced with a microcomputer (Robinson and Evans 1980).

Crossdating consisted of combined traditional techniques of skeleton plotting, a graphical technique of ring-width comparison, (Stokes and Smiley 1968; Swetnam et al 1985), and the use of quality control crossdating program, COFECHA, to ensure measured series were accurately dated (Holmes 1983). Crossdating is the fundamental principle of dendrochronology. It is the property that cores sampled from different trees within a stand, and cores from the same tree, share a common pattern of wide and narrow annual rings. The synchroneity of these patterns allows assignment of an exact calendar year to each tree-ring. (Douglass 1941, Fritts 1976). The COFECHA algorithm calculates running correlation coefficients between a single series and the master composite that excludes the series being tested. Crossdating was confirmed if the highest significant correlation occured at the dated position. If COFECHA suggested an alternative position, the core was visually examined to confirm the suggested re-postioning. After crossdating was assured by the above methods, each series was standardized to remove biological age and stand-related (endogenous) trends (Fritts 1976, Cook and Holmes 1984).

The mathematical standardization function that has the most widespread application for semiarid open-grown conifers is the decreasing exponential function, $y = ae^{-bx} + k$ (Fritts 1969). For each series, $x = x(t)$ is the observed ring-width in a given year, t. The constants a, b and k are estimated for each series and y is the expected ring-width in year t. Each series is normalized by dividing each ring width by y.

The theoretical justification for this detrending method is that a negative exponential function idealizes the addition of wood volume to a cylinder, which biologically reflects the geometric growth of a tree bole (Fritts 1969). All series with this type of monotonically decreasing growth trend were standardized in this manner. If the coefficients b, a are negative then a line was fitted to the series. Division of the observed ring-width values by the expected values calculated from the selected detrending function produces the index value for the series.

For series with oscillatory growth trends, we chose a 100-year smoothing spline (Cook and Peters 1981; Reinsch 1967) that preserves 50% of the amplitude frequency response at the 100-year wavelength. Generally this detrending method removes the inter-decadal to sub-century length trends in the ring-width series caused by non-climatic endogenous stand dynamics (Cook and Peters 1981, Cook 1985). For instance, growth releases following the creation of canopy gaps, after insect attack or fire, are usually removed by this type of detrending.

After division of each series by a decreasing exponential function, linear function or 100-year smoothing spline, the series were averaged to produce a master index chronology for the site. Selection of the detrending options and development of the final master chronologies was performed with procedures in computer program ARSTAN (Cook 1985). Sandpass and Upper Sandpass were standardized with a combination of the decreasing exponential, linear or 100-year smoothing spline and all series at the Twin Peaks and Railroad Ridge sites were standardized with the the 100-year smoothing spline.

Correlation analyses, and standard descriptive statistics were used to compare dendrochronological characteristics between whitebark pine master chronologies for the four sites. For correlation analyses both pre-whitened, i.e. autocorrelation effects removed, (Cook 1985) and standard chronologies were used. The new chronologies were also compared to other chronologies on sites with same or similar species type, similar site elevation, and geographic proximity. These include a Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) chronology from near Ketchum, Idaho, a Douglas-fir chronology near Salmon, Idaho, three whitebark pine chronologies from near Joseph, Oregon and one Rocky Mountain Juniper (Juniperus scopulorum). chronology near Jarbidge, Nevada. A Fast Fourier Transform (FFT) algorithm (Press et al 1988), which preserves the spectral trends of time series, was derived for each chronology and overlain on the master chronology for visual comparison of trends. The interval chosen for this analysis was 8 years.

Mortality Assessment

Increment core samples from the mountain pine beetle-killed trees were skeleton plotted and visually crossdated with the master chronologies. Two criteria were considered to record the year of mortality of a whitebark pine: (1) observed adult beetle galleries on the bole and (2) dating of outer ring of against crossdated series and chronology. Measured ring-widths were processed through program COFECHA, to verify crossdating and and the outside ring date.

Dendroclimatic Assessment

Simple correlations and response functions (Fritts 1971, 1976) were calculated to assess whitebark pine annual ring growth response to monthly average temperature and total precipitation factors. Response function analysis regresses principal components (eigenvectors) of climate variables upon the master index chronology to calculate a set of coefficients (weights) that correspond to the original set of climate variables. A computer routine samples many times with replacement to generate empirical estimates of the entire sampling distribution, from which confidence intervals are computed for the response coefficients (Fritts 1993). Meteorologic data for the central mountain region of Idaho, compiled by the National Climatic Data Center, NOAA, Asheville, North Carolina for the 95 year time period, 1896-1991 were used for this analysis. This is a composite data set, based on homogeneity of weather patterns within a geographic region. Divisional data set, Idaho 1003, was selected because nearby weather stations were scarce, were situated at low elevations, and data sets had many missing values. Monthly total precipitation and monthly average temperature values for a fourteen month period starting in July through the following August were selected as the climatic variables. Three years prior growth was also used to assess autocorrelation affects.

CHAPTER 3

Results and Discussion

Tree-Ring Width Chronologies

Whitebark pine tree-ring chronologies from central Idaho constitute the first millennium-length chronologies constructed from the northern Rocky Mountain region in the United States. The discovery of the oldest living whitebark pine known in North America was made in the Sawtooth Salmon River region during this study. This tree exceeds 1,270 years in age. The innermost ring of an increment core that did not include the pith was A.D. 726. Whitebark pine is now eleventh on the longest-lived tree species list, after Douglas-fir (Brown 1994). The largest whitebark pine on the National Register of Big Trees, also occurs in this region; it exceeds 260 cm (8.5 feet) diameter at breast height.

Crossdating Characteristics

Crossdating of these trees was successful, but not easy. Narrow-ring signature years common to most sites aided crossdating efforts, but lack of high frequency variation of ring-widths made the task difficult with some cores. Old, large-diameter trees crossdated well with each other and comprise the master chronology. On all sites, the crossdating of the intermediate and codominant trees with the dominant and old trees was poor. The strength of crossdating between trees was highest for Sandpass and Twin Peaks as reflected by an interseries correlation above 0.6 (Table

2). Upper Sandpass and Railroad Ridge had interseries correlations above 0.5. Trees with interseries correlations near and below 0.43 were problematic to crossdate and were not included in the master ring-width chronologies.

The complacent nature of many segments of the ring-width series, the occurrence of heart rot, and the low sample depth before A.D. 1300, prevented us from including some live, some standing dead and several remnant down and dead samples in the master ring-width chronologies. Sample depth, the number of trees or series included in the chronology in a given calendar year, dropped off rapidly before A.D. 1300 and after 1930 (Figure 2). Increased sampling efforts, particularly of dead and remnant wood, may allow future development of chronologies with good sample depth in the 700 to 1300 year period.

Master Chronologies

Master chronologies for the time period, A.D. 760 to 1991, overlain with the FFT smoothed curve, revealed low frequency variation from A.D. 1300 to the present (Figure 2). The large amplitude of ring width variations between 970–1300 was likely a consequence of few samples and juvenile growth patterns. (Figure 2). Generally, as young trees mature, annual ring increment increases to a maxima, then decreases exponentially to an asymptotic ring-width level.

Mean sensitivity, defined as the average absolute difference between two adjacent ring-width measurements divided by their mean measurement (Douglass 1936), ranges between 0.12 on the UPS site to 0.17 on TWP, RRR and SDP sites and is representative of the low year to year variance typical of Rocky Mountain conifers at high elevation sites (LaMarche and Stockton 1974, Fritts and Shatz 1975). First order autocorrelation coefficients range from 0.21 at the Twin Peaks site to 0.55 at the Sand Pass site. This is a measure of the average dependence of a ring width value at year t relative to the ring width value at year $t-1$. High autocorrelation coefficients are typical of high elevation tree-ring chronologies (LaMarche and Stockton 1974, Fritts and Shatz 1975). We note that the Sandpass and Railroad Ridge sites are typical in this response whereas Upper Sandpass and Twin Peaks are less autocorrelated (Table 2).

Visual comparisons of master skeleton plots and correlation analysis with Idaho, Douglas-fir, Oregon, whitebark pine and Nevada, Rocky Mountain juniper chronologies, revealed no crossdating with the exception of one whitebark pine chronology, from near Joseph, Oregon (CHJOE2). Possible explanations for lack of crossdating include site differences (e.g. elevation, substrate, aspect), distance from region of study, differential species response to climate variables and climatic pattern variation. Strong positive correlations among the four Sawtooth Salmon River region whitebark pine chronologies for the 1300-1991 period, and positive association with the eastern Oregon chronology (Parker unpublished data, 1543–1964 period) are shown in a correlation matrix (Table 3). SDP and TWP exhibit the strongest correlation. RRR is the least well correlated with the other Idaho sites but shows the highest correlation with the eastern Oregon whitebark pine site.

Mountain Pine Beetle Caused Mortality

Calendar dates were determined for the mountain pine beetle outbreak of the early twentieth century. The distribution of crossdated beetle kill trees starts in the early 1920s and clusters around a single peak maximum at 1930 on all four sites (Figure 3). These observations were made independently of historical documentation of mountain pine beetle infestation in central Idaho. In a 1929 letter to the District Forester in Ogden Utah, the Challis Forest Supervisor reports that infestation reached epidemic stage in lodgepole pine, in the summer of 1926. He noted that although the chief host was lodgepole pine, whitebark pine and limber pine were also infected and appeared less resistant to beetle attack than lodgepole (Renner 1929).

Laboratory analysis of all trees with adult mountain pine beetle galleries, revealed the presence of blue stain fungus (Ophiostoma clavigerum) in the outer sapwood. This fungus is associated with several species of bark beetles, (Harrington 1987) and is not a sufficient criterion alone to indicate mountain pine beetle presence. Blue stain fungus, however, may be viewed as a secondary indicator of bark beetle presence. In addition to the beetle-killed tree mortality dates shown in Fig. 3, two dead trees with blue stain fungus looked like probable beetle kill trees in the field. Death dates were 1730 and 1887. The weathering of the bole prevented us from confirming the presence of adult galleries on these trees. One tree on the UPS site died in 1819 and had observable mountain pine beetle galleries on the stem. This is the only tree in our sample base that we suggest was killed by mountain pine beetle before the 20th century epidemic.

The magnitude of the 1930 outbreak is apparent from the relative frequency of mountain pine beetle killed whitebark pine. On four sites, live codominant and dominant trees comprised less than or equal to 8% of the total sample, and young size class trees, seedlings, saplings, and intermediates comprise 56-74%. (Table 4). From the dead tree subset of the total sample, the relative frequency of beetle killed trees was 20% on SDP, 61% on UPS, 70% on TWP and 58% on RRR. The ratio of beetle-killed snags to large diameter size class snags was 67, 57, 100, 52% for the respective sites. Interpretation of the dead tree subset data is statistically tenuous because the ratio of random variables may result in a nondifferentiable distribution function. However, the relative frequency of size class data, dramatic decrease of dominant whitebark pine trees near 1930 (Figure 2) and synchronous crossdated beetle-kill dates over the Sawtooth Salmon river region, exemplify the magnitude and scope of the mid 1920's-early 1930's mountain pine beetle epidemic (Figure 3).

SDP and TWP master chronologies from 1850 to the present show general synchronous patterns punctuated by narrow ring marker years, 1885, 1895, 1915, 1928, 1934, 1939, and 1969. The mountain pine beetle infestation occurred at the start of the longest sustained low growth period for the last 200 years (Figure 4). The duration of the epidemic in whitebark pine was approximately 8 - 12 years (Figure 3) and was typical of the range of infestation in the most common host, lodgepole pine. (Roe and Amman 1970, Cole and Amman 1980).

Climate-Tree-Growth Relationships

Whitebark pine is a promising species for dendroclimatic studies of the transitional climate zone of the northern Rockies. All four sites showed the same response to climate variable analysis. However Sandpass and Twin Peaks tree-ring width chronologies revealed significant correlations at the $p < 0.05$ level. Results for those sites are reported here (Figure 5).

Response functions for the Sandpass standardized chronology revealed 48.0% of the variance (r^2 adjusted) in ring width is explained by climate variables, while 8.0% was explained by prior growth. This was a total of 56.0% variance explained by the abiotic and biotic components of this system (Figure 5).

For the Twin Peaks site, standardized chronology, 39.0% of the variance in ring width was explained by climate variables, and 12.0% was explained by prior growth, for a total variance of 51.0% (Figure 5). The third and second years previous growth was significant on the SDP and TWP sites respectively (Figure 5). This is a low contribution by previous growth relative to other tree-ring chronologies used in dendroclimatic work (Fritts 1992), particularly high elevation conifers (La Marche 1974, LaMarche and Stockton 1974) The low importance of autocorrelation in these results was confirmed by computing correlation and response functions using chronology residuals from autoregressive models (i.e. whitened series). Residual chronologies revealed 50% of the variance explained by climate for Sandpass, and 45% for Twin Peaks, 36% for Upper Sandpass and 13% for Railroad Ridge.

Correlation and response function analyses revealed ring width growth was positively correlated with winter and spring precipitation, and inversely correlated with April and May temperature (Figure 5). Our interpretation is that above average growth occurs with abundant snowpack and cool spring temperatures. The onset of June and July heat with continued cool nights, produces gradual snow melt and adequate soil water availability for whitebark root systems.

On high elevation sites in North America, correlations of tree growth with climate variables typically respond positively to winter and spring precipitation and summer temperature. (Kienast and Schweingruber 1986, Graumlich and Brubaker 1986, Peterson et al 1990, and others). Whitebark pine is similar in this response, with June temperature, positively correlated and statistically significant ($p < 0.05$) on the SDP site, but not statistically significant on TWP. The feedbacks among spring precipitation and temperature variables likely produce nonlinear interactions affecting snowpack. Results from this work suggest that increased sampling of open grown stands of high elevation living whitebark pine and further time series analysis is needed to clarify relationships between climate and whitebark pine tree-growth variables.

CHAPTER 4

Conclusions

Attempts to understand processes governing forest ecosystems are plagued by short data sets and compounded by the long generation time of trees. Preliminary dendroecological analysis of high elevation homogenous whitebark pine stands on classic dendroclimatic sites generated time series greater than 700 years. We have shown that whitebark pine tree-ring chronologies reveal patterns associated with the biotic and abiotic factors affecting the their growth. These long time series are essential for recording the cyclicity of disturbance events and are candidates for dendroclimatic research. As such, whitebark pine tree rings may serve as a type of subalpine clock. The southern Idaho semiarid climate favors preservation of high elevation remnant wood. It is therefore possible to increase the sample size and replication in earlier time periods included in our current chronologies, so that ecological and climatic investigations could be extended back into the first millennium A.D. The observation of the nineteeth century (1819) beetle-killed tree with galleries preserved in the sapwood is encouragement to look further for evidence of pre-twentieth century infestations. These chronologies have filled a large geographic gap in the North American tree-ring network, particularly of high elevation sites.

The ability to map a mountain pine beetle epidemic in the time domain was demonstrated. A logical continuation of this research would generate spatial maps of the mountain pine beetle outbreak using the methods established here. Decay and loss of sapwood may limit the accurate dating of time of death to subsets of trees and sites. The potential to expand this sampling to other locations could resolve spatial and temporal patterns of mountain pine beetle infestations on stand level to regional scales.

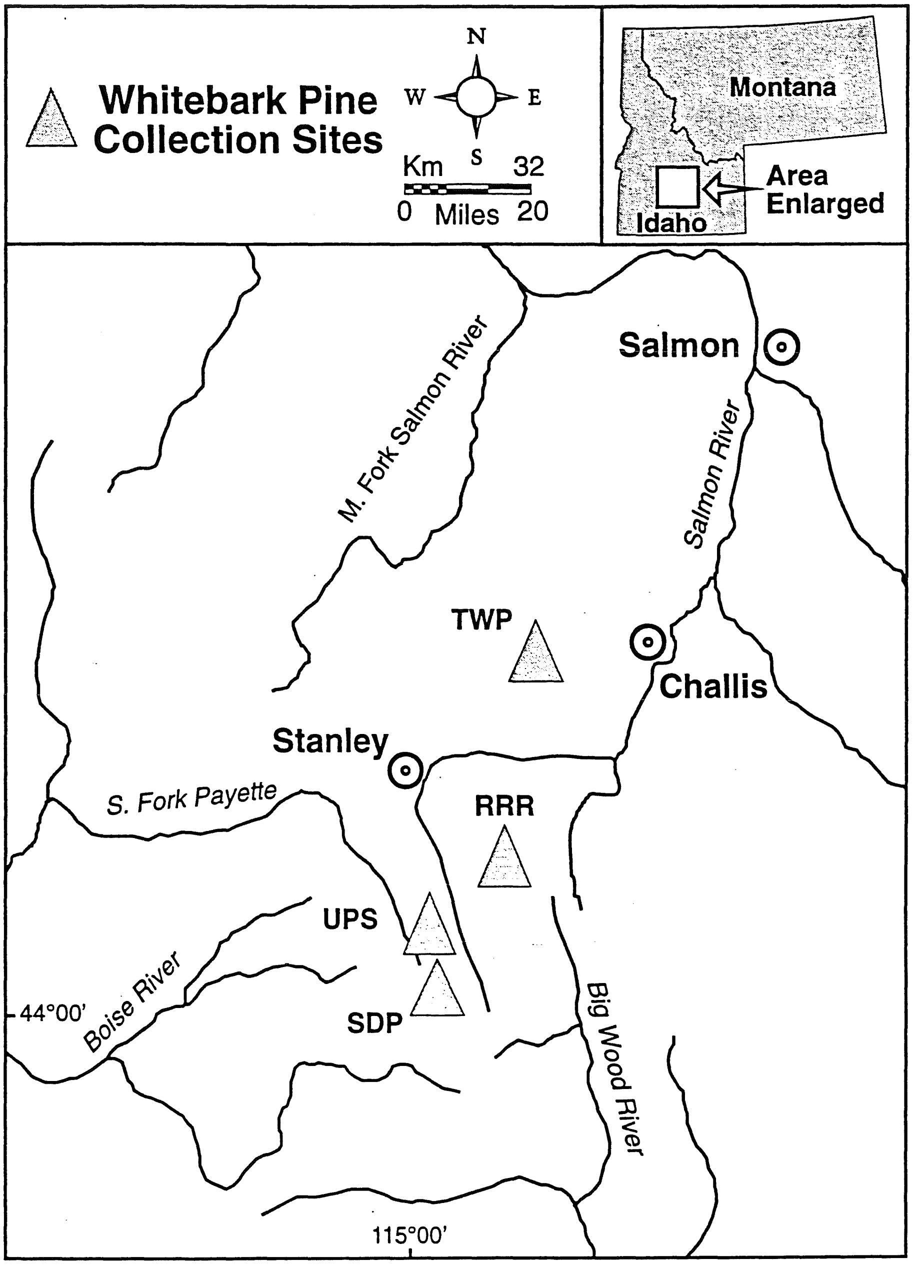

Figure 1: Whitebark pine study sites, Sawtooth Salmon River Region, Idaho

Table 1: Whitebark pine site descriptions.

	Sandpass	Upper Sandpass	Twin Peaks	Railroad Ridge
Latitude	43°58′15″ N	43°58′28″N	44°36′03″N	44°08′25″N
Longitude	114°58′06″ E	114°58′02″ E	114°27′46″ E	114°33′07″ E
Elevation	2800 m	2800 m	2800 m	2930 m
Aspect	S–SE	WSW–W	S	S-SE
Slope	5 – 30°	20 – 35°	15 – 30°	5 – 30°
Soil	granite	granite	rhyolite	granite
Site Area	3.0 ha	2.2 ha	1.5 ha	4.0 ha

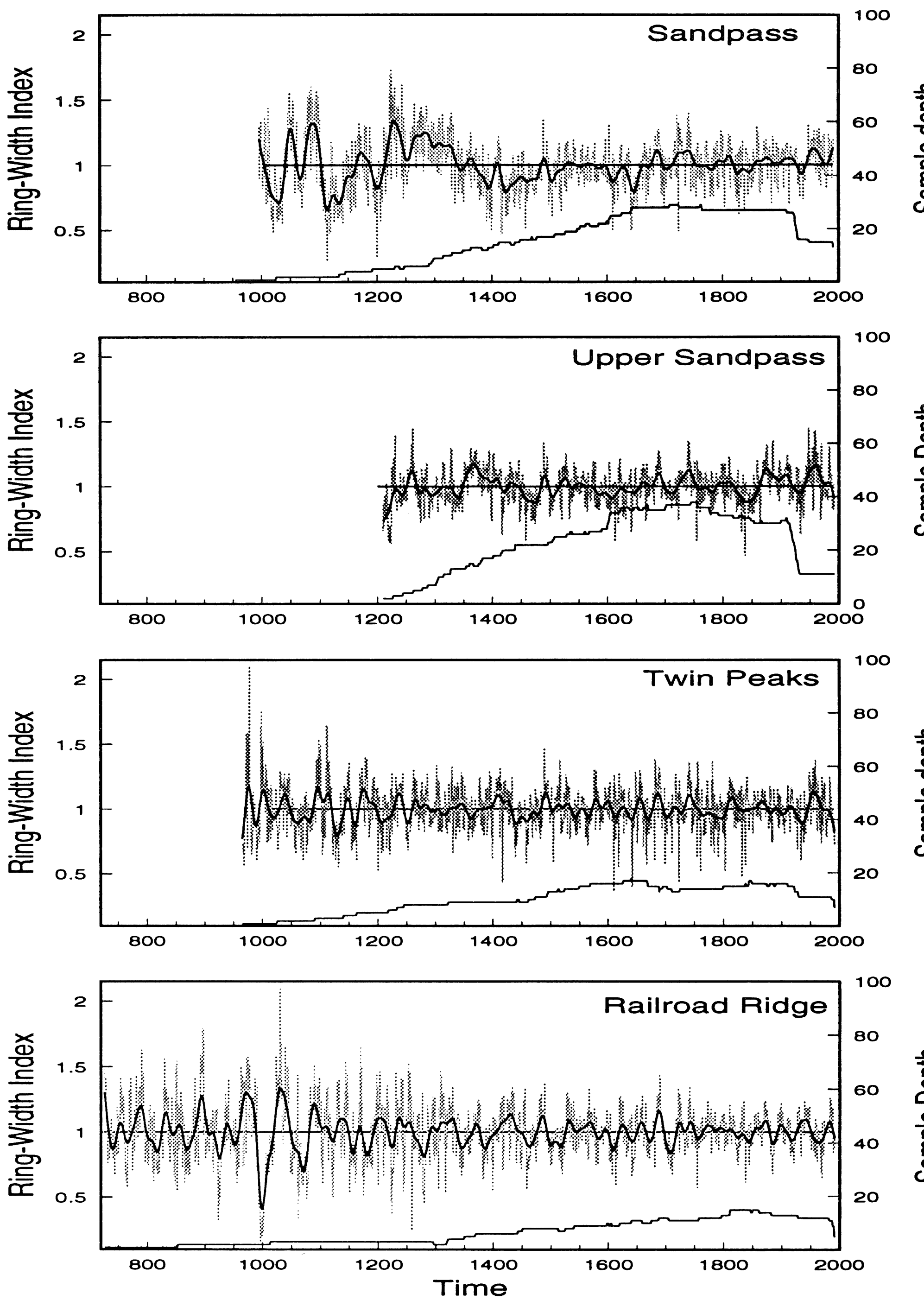

Figure 2: Whitebark pine master ring-width chronologies, scaled to a common interval and overlain with a Fast Fourier Transform smoothing function to accentuate inter-decadal trends. Sample depth, the number of series represented in the chronology at a particular year, is plotted on the right hand axis.

Table 2: Whitebark pine chronology statistics.

	Sandpass	Upper Sandpass	Twin Peaks	Railroad Ridge
Length [yrs]	1037	783	1028	1267
Number of trees	19	28	12	11
Number of cores	37	52	29	22
Mean Ring-Width [mm]	0.46	0.33	0.39	0.49
Inter-Series Correl.	0.63	0.56	0.62	0.57
Mean Sensitivity	0.17	0.12	0.17	0.17
First Order Autocorrel.	0.55	0.29	0.21	0.48

Table 3: Correlation matrix for whitebark pine tree-ring chronologies, central Idaho and eastern Oregon. Time periods for comparison are 1300–1991, except for correlations with the eastern Oregon site, CHJOE2, which were 1543–1964. Correlations in parentheses are for pre-whitened chronologies. All correlations are significant at the $p \leq 0.01$.

	SDP	UPS	TWP	RRR	CHJOE2
SDP	1.0				
UPS	0.64 (0.67)	1.0			
TWP	0.65 (0.72)	0.59 (0.64)	1.0		
RRR	0.48 (0.52)	0.51 (0.60)	0.46 (0.54)	1.0	
CHJOE2	0.38 (0.46)	0.32 (0.54)	0.35 (0.51)	0.47 (0.58)	1.0

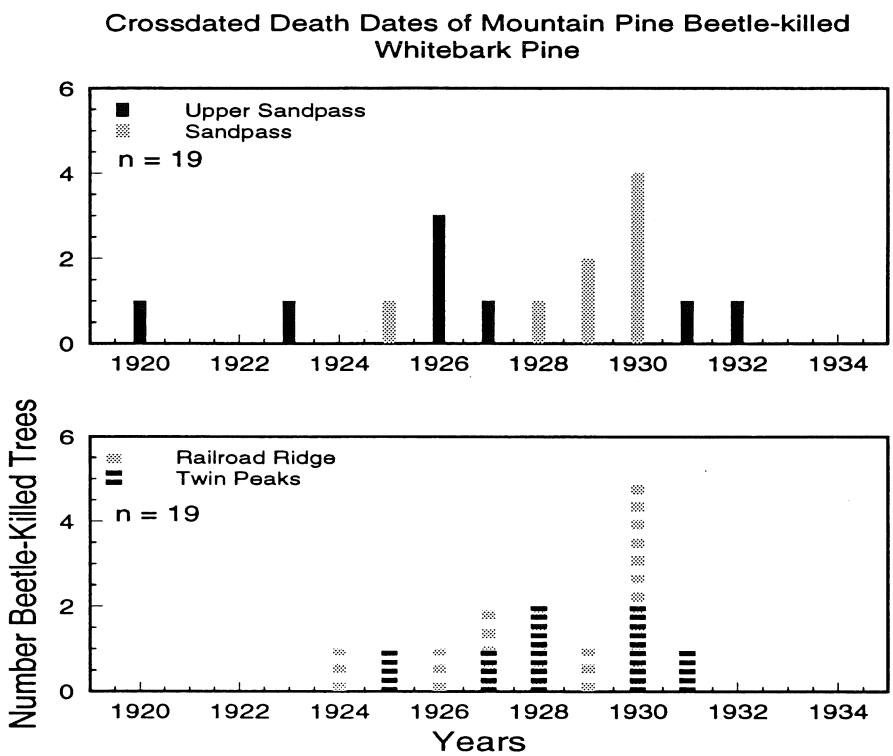

Figure 3: Crossdated death dates of thirty-eight whitebark pine killed by mountain pine beetle. Mortality reaches a maximum at 1930.

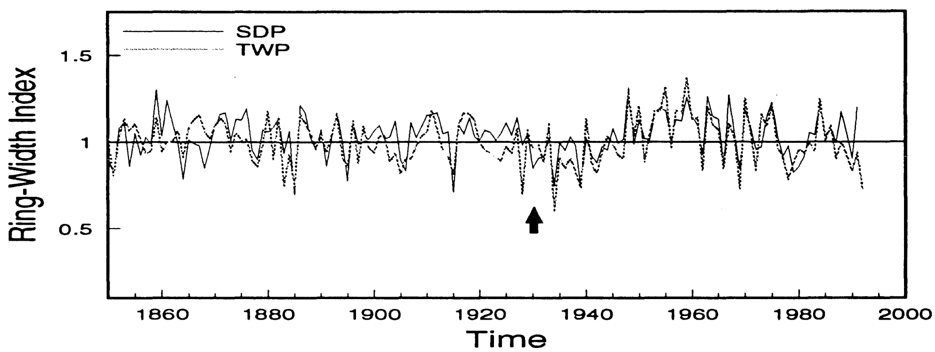

Figure 4: SDP and TWP master chronologies for 1850 to 1991. Arrow indicates peak of mountain pine beetle-kill in whitebark pine.

Table 4: Whitebark pine stand structure summary. Trees killed by mountain pine beetle had distinct J-shaped adult galleries on the stem. Trees were coded unknown dead when galleries weren't observable. Numbers in parentheses are relative frequencies of occurrence.

	SDP	UPS	TWP	RRR
Number of plots	47	25	18	35
Number of trees inventoried	94	50	36	71
Live trees	73(78)	32(64)	23(64)	47(66)
Dead trees	21(22)	18(36)	13(36)	24(34)
Live trees				
Seedlings	27 (29)	4(8)	8(22)	7(10)
Saplings	32 (34)	19(38)	11(30)	24(34)
Intermediates	10(11)	5(10)	4(14)	9(13)
Codominants	3(3)	1(2)	0	6(8)
Dominants	1(1)	3(6)	0	1(1)
Subset of dead trees				
Beetle-killed trees	4(20)	11(61)	9(70)	14(58)
Unknown dead	17(80)	7(39)	4(30)	10(42)

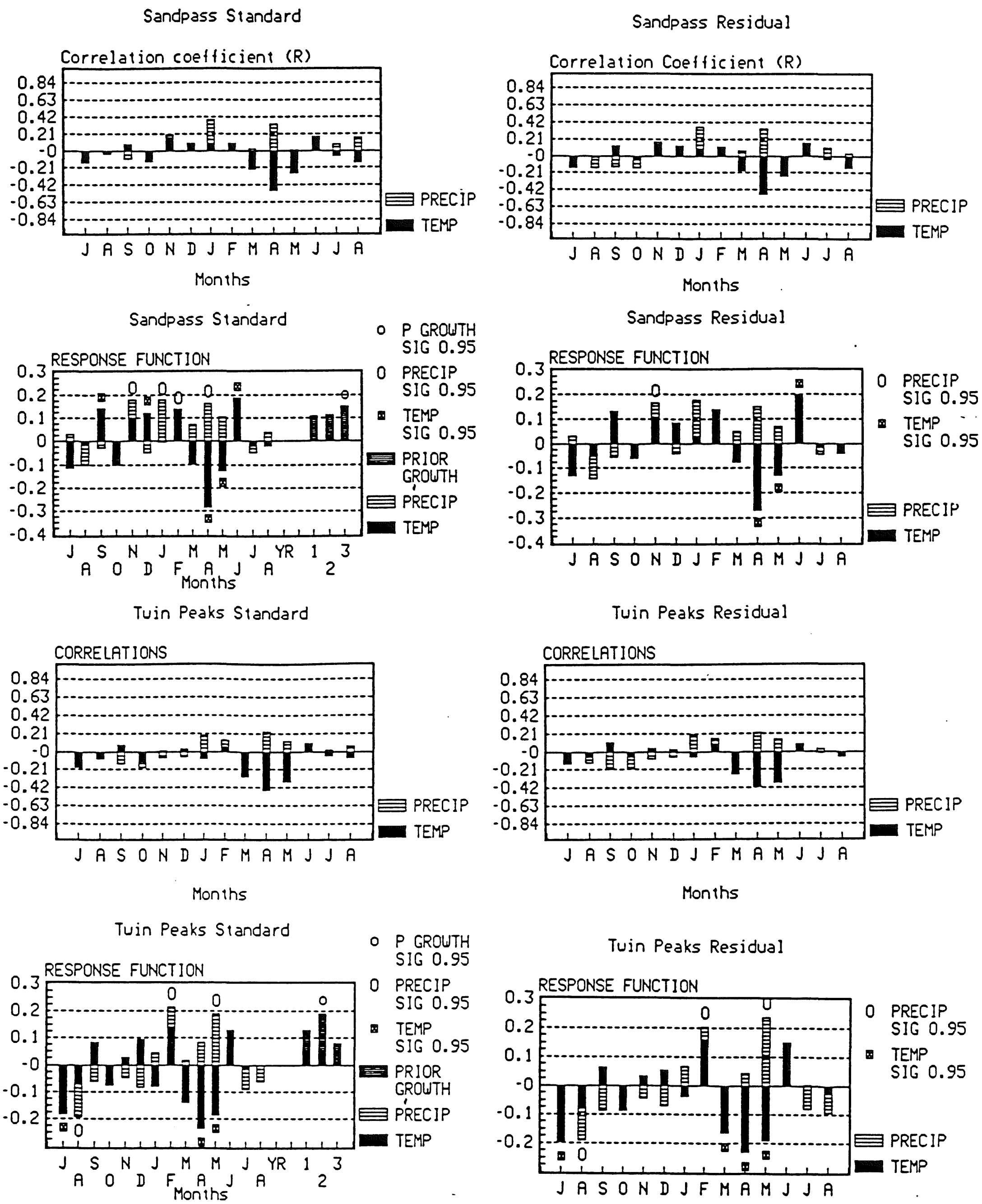

Figure 5: Correlations and response functions. Correlation coefficients are significant ($p < 0.05$) for $|r| = 0.210$ for Sandpass and Twin Peaks.

CHAPTER 5

Appendix A

Sandpass Master Indices

Date	Tree-Ring Indices 0	1	2	3	4	5	6	7	8	9	Number of samples 0	1	2	3	4	5	6	7	8	9
955						191	207	219	194	154						1	1	1	1	1
960	131	131	136	159	145	115	155	188	143	132	1	1	1	1	1	1	1	1	1	1
970	211	270	190	146	106	99	83	78	66	64	1	1	1	1	1	1	1	1	1	1
980	64	69	52	78	95	83	78	121	104	95	1	1	1	1	1	1	1	1	1	1
990	76	107	76	57	100	91	117	81	100	119	1	1	1	1	1	1	1	1	1	1
1000	105	103	82	74	82	91	101	122	89	63	1	1	1	1	1	1	1	1	1	1
1010	63	70	75	130	68	77	87	63	53	53	1	1	1	1	1	1	1	1	1	1
1020	63	44	51	92	85	90	74	71	53	71	1	1	1	1	1	1	2	2	2	2
1030	61	55	66	86	59	63	67	52	76	101	2	2	2	2	2	2	2	2	2	2
1040	90	108	87	109	116	89	101	134	143	150	2	2	2	2	2	2	2	2	2	2
1050	132	107	130	129	143	135	94	113	77	87	2	2	2	2	2	2	2	2	2	2
1060	100	114	131	86	80	91	85	87	78	84	2	2	2	2	2	2	2	2	2	2
1070	66	76	80	109	91	126	87	119	97	123	2	2	2	2	2	2	2	2	2	2
1080	137	146	116	118	150	114	92	153	121	118	2	2	2	2	2	2	2	2	2	2
1090	107	132	116	144	137	150	81	147	126	138	2	2	2	2	2	2	2	2	2	2
1100	124	91	79	77	76	103	62	96	81	62	2	2	2	2	2	2	2	2	2	2
1110	86	54	56	44	25	75	66	66	46	58	2	2	2	2	2	2	2	2	2	2
1120	74	115	78	84	89	79	54	54	79	89	2	2	2	2	2	2	2	2	2	2
1130	65	78	59	57	60	60	73	70	68	60	2	2	2	2	3	3	3	3	3	3
1140	55	99	81	73	83	82	110	111	87	72	3	3	3	3	3	4	4	4	4	4
1150	107	95	97	101	68	61	117	106	82	83	4	4	4	4	4	4	4	4	4	4
1160	68	101	117	66	108	90	99	114	129	128	4	4	4	4	4	4	4	4	4	4
1170	86	121	116	120	101	97	104	87	101	128	4	4	4	4	4	4	4	4	4	4
1180	119	129	81	105	98	67	96	104	128	113	4	4	4	4	4	4	4	4	4	4
1190	100	95	99	86	76	86	62	89	84	91	4	4	5	5	5	5	5	5	5	5
1200	29	84	86	100	103	96	67	56	100	81	5	5	5	5	5	5	5	5	5	5
1210	71	118	125	105	96	76	125	98	103	90	5	5	5	5	5	5	5	5	5	5
1220	98	104	152	173	164	88	125	148	151	129	5	5	5	5	5	5	5	5	5	5
1230	120	151	114	138	90	138	118	137	138	123	5	6	6	6	6	6	6	6	6	5
1240	116	117	71	127	96	73	119	126	120	93	5	5	5	5	5	5	5	6	6	6
1250	88	88	77	84	92	97	92	121	96	102	6	6	6	6	6	6	6	6	6	6
1260	122	124	115	108	140	116	105	122	90	126	6	6	6	6	6	6	6	6	6	6

1270	132	108	134	122	128	100	136	119	107	108	6	6	6	6	6	6	6	6	6	6
1280	133	90	123	120	118	140	140	138	125	103	6	6	6	6	6	6	6	6	6	6
1290	111	126	113	104	131	125	98	111	132	102	7	7	7	7	7	8	8	8	9	9
1300	98	114	124	119	101	92	130	97	136	134	9	9	9	9	9	9	9	9	9	9
1310	116	119	91	138	109	124	121	112	108	111	9	9	9	9	9	10	10	10	10	10
1320	98	101	110	131	104	114	116	131	141	135	10	10	10	10	10	10	10	10	10	10
1330	80	111	112	132	109	71	84	101	109	100	11	11	11	11	11	11	11	11	11	11
1340	115	120	78	84	88	107	113	113	78	95	11	11	11	11	11	11	11	11	11	12
1350	71	102	104	92	93	109	109	98	108	111	12	12	12	12	12	12	12	12	12	12
1360	94	109	127	116	83	110	102	99	110	109	12	12	12	13	13	13	13	13	13	13
1370	93	104	113	97	97	83	99	109	94	75	13	13	13	13	13	13	13	13	13	13
1380	96	78	91	100	87	117	77	103	92	100	13	13	13	12	12	12	12	12	12	12
1390	80	98	57	81	87	111	61	90	83	50	12	12	12	12	13	13	13	13	13	13
1400	81	86	95	100	103	106	108	100	97	107	13	13	13	14	14	14	14	14	14	14
1410	107	124	85	120	112	116	92	48	81	94	14	14	15	15	15	15	15	15	15	15
1420	90	78	85	86	80	62	94	62	86	86	15	15	15	15	15	15	15	15	15	15
1430	73	93	78	96	90	91	95	109	79	68	15	15	15	14	14	14	14	14	14	14
1440	99	72	82	83	95	100	109	95	69	93	15	15	15	15	15	15	15	15	15	16
1450	92	79	112	108	88	112	90	101	52	84	16	16	16	16	16	16	16	16	16	16
1460	99	76	91	79	88	104	102	94	91	101	16	16	16	16	16	16	16	16	16	17
1470	104	91	83	82	86	76	94	98	83	93	17	16	16	16	16	16	16	16	17	17
1480	99	101	95	92	107	90	91	96	102	138	17	17	17	17	17	17	17	17	17	17
1490	117	107	106	101	108	121	111	101	107	70	17	17	17	17	17	17	17	17	17	17
1500	87	100	86	80	76	61	89	90	97	105	17	17	17	17	17	17	17	17	17	18
1510	99	85	106	101	96	103	120	113	70	89	18	18	18	18	18	18	18	18	18	18
1520	65	97	103	105	101	105	85	114	119	81	18	18	18	18	18	18	18	19	19	19
1530	108	121	109	108	92	106	97	111	92	98	19	19	19	19	19	19	19	19	19	19
1540	95	101	123	108	100	115	111	96	102	103	19	19	19	19	19	19	19	19	20	20
1550	85	86	92	95	95	114	110	95	119	106	20	20	20	21	21	21	21	21	21	21
1560	93	85	105	111	101	89	110	117	107	101	21	21	21	22	22	22	22	22	22	22
1570	100	87	98	97	107	106	111	108	88	118	21	21	21	21	21	21	21	21	21	21
1580	109	89	87	101	99	89	96	98	97	104	21	21	21	21	21	22	22	22	22	22
1590	100	95	98	110	92	108	110	121	92	93	22	22	22	22	22	22	22	22	22	23
1600	87	98	92	130	89	84	91	83	91	104	22	22	22	24	24	24	25	25	25	25
1610	51	111	89	69	100	88	85	98	73	100	25	25	25	25	25	25	25	25	25	25
1620	94	107	95	116	104	117	97	84	100	89	25	25	25	25	25	26	26	26	26	26

1630	88	104	79	110	105	90	114	110	97	91	26	26	26	26	26	26	26	26	26	26
1640	104	69	50	76	74	65	72	83	93	90	26	27	27	28	28	28	28	28	28	28
1650	93	66	79	94	97	103	80	97	95	103	28	28	28	28	28	28	28	28	28	28
1660	104	80	109	98	111	117	108	71	111	108	28	28	28	28	28	28	28	28	28	28
1670	88	77	107	90	99	114	99	97	97	105	28	28	28	28	28	28	28	28	28	28
1680	93	93	116	121	117	117	105	101	126	127	28	28	28	28	28	28	28	28	28	28
1690	116	122	101	113	79	77	110	111	107	68	28	28	28	28	28	28	28	28	28	28
1700	106	106	101	82	99	101	100	107	97	100	28	28	28	28	28	28	28	28	29	29
1710	88	90	101	95	100	103	113	115	118	92	29	29	29	29	29	29	29	29	29	29
1720	102	90	140	49	132	115	129	116	114	113	29	29	29	29	29	28	28	28	28	28
1730	120	104	104	103	113	96	85	107	100	116	28	28	28	28	28	28	28	28	28	28
1740	127	141	114	129	110	126	78	109	98	99	28	28	28	28	28	28	28	28	28	28
1750	81	108	103	108	106	74	113	117	91	109	28	28	28	28	28	28	28	28	28	28
1760	104	88	94	110	86	100	90	98	99	98	28	29	29	29	29	27	27	27	27	27
1770	73	113	102	118	112	106	93	96	89	84	27	27	27	27	27	27	27	27	27	27
1780	74	107	102	80	75	113	113	95	97	111	27	27	27	27	27	27	27	27	27	27
1790	117	82	109	80	108	99	101	114	125	95	27	27	27	27	27	27	27	27	27	27
1800	88	122	98	67	100	100	101	103	110	107	27	27	27	27	27	27	27	27	27	27
1810	102	126	121	122	80	115	106	111	93	94	27	27	27	27	27	27	27	27	27	27
1820	102	82	84	106	70	80	108	108	62	94	27	27	27	27	27	27	27	27	27	27
1830	111	111	80	102	93	116	98	63	75	82	27	27	27	27	27	27	27	27	27	27
1840	111	109	111	104	77	96	103	87	88	88	27	27	27	27	27	27	27	27	27	27
1850	92	79	107	109	83	103	91	101	97	131	27	27	27	27	27	27	27	27	27	27
1860	101	124	110	99	78	103	100	99	83	97	27	27	27	27	27	27	27	27	27	27
1870	110	117	118	101	110	110	120	94	88	105	27	27	27	27	27	27	27	27	27	27
1880	106	106	111	91	106	68	120	118	99	93	27	27	27	27	27	27	27	27	27	27
1890	107	83	102	117	99	75	112	99	99	103	27	27	27	27	27	27	27	27	27	27
1900	104	108	101	104	113	87	81	111	101	110	27	27	27	27	27	27	27	27	27	27
1910	115	116	114	102	103	68	111	105	114	102	27	26	26	26	26	26	26	26	26	26
1920	101	107	107	99	101	113	101	116	96	103	26	26	26	25	25	22	21	20	19	17
1930	81	89	93	103	74	98	92	98	98	70	16	16	16	16	16	16	16	16	16	16
1940	104	87	83	98	91	103	95	96	127	93	16	16	16	16	16	16	16	16	16	15
1950	113	98	96	116	117	117	99	113	113	122	15	15	15	15	15	15	15	15	15	15
1960	110	108	93	124	110	115	82	128	102	85	15	15	15	15	15	15	15	15	15	15
1970	119	111	98	97	117	123	102	93	98	81	15	15	15	15	15	15	15	15	15	15
1980	85	86	107	103	122	101	108	98	118	103	15	15	15	15	15	15	15	15	15	15

1990 85 118 15 13

Upper Sandpass Master Indices

	Tree-Ring Indices										Number of samples									
Date	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1210	66	89	74	93	77	84	103	88	69	64	2	2	2	2	2	2	2	2	2	2
1220	58	69	58	57	114	110	103	101	122	98	2	2	2	2	2	2	2	3	3	3
1230	93	139	87	87	82	89	88	94	87	110	3	3	3	3	3	3	3	3	3	3
1240	100	84	93	85	102	108	90	89	97	92	3	3	3	3	4	4	4	4	4	4
1250	98	88	114	102	101	101	101	116	110	132	4	4	4	4	4	4	4	4	4	4
1260	127	144	103	118	97	104	94	98	112	96	4	4	5	5	5	5	5	5	5	5
1270	83	87	106	83	97	72	114	100	98	107	5	5	5	5	5	5	5	5	6	6
1280	93	76	98	114	94	118	112	103	91	83	6	6	6	6	6	6	6	7	7	7
1290	76	96	87	90	94	97	83	99	101	100	7	7	7	7	7	7	7	7	7	7
1300	93	98	95	107	87	81	100	92	95	96	7	7	8	8	9	9	10	10	10	10
1310	92	98	91	118	115	105	117	93	85	101	10	10	10	10	10	11	11	11	11	11
1320	100	93	90	88	94	105	87	114	129	117	11	11	11	11	11	11	11	13	13	13
1330	74	95	98	105	89	80	86	92	90	85	13	13	13	13	13	13	13	13	13	13
1340	101	96	82	96	87	94	105	102	80	91	13	13	13	13	13	13	13	13	13	13
1350	98	112	119	110	105	115	116	94	117	113	13	13	13	13	14	14	14	14	14	14
1360	110	110	129	118	107	120	117	109	123	128	15	15	15	15	15	15	15	14	14	14
1370	115	113	127	114	119	101	110	120	102	105	14	14	14	14	14	14	15	15	15	15
1380	114	114	93	99	97	119	97	110	110	115	16	16	16	17	17	17	17	17	17	17
1390	109	118	97	95	105	128	97	102	95	74	17	17	17	17	17	17	17	17	17	17
1400	109	98	125	102	109	99	114	111	98	109	17	17	18	18	18	18	18	18	18	18
1410	109	110	97	114	107	113	113	64	91	89	18	18	18	18	18	19	19	19	20	20
1420	81	95	93	107	105	94	106	86	109	87	20	20	20	20	20	20	20	20	20	20
1430	99	118	107	114	110	90	112	108	87	89	20	20	20	20	20	20	20	20	20	20
1440	102	90	112	101	106	104	120	102	73	103	22	22	22	22	22	22	22	22	22	22
1450	81	99	104	109	90	103	98	96	59	76	22	22	22	22	22	22	22	22	22	22
1460	98	81	92	92	97	95	97	86	74	92	22	22	22	22	22	22	22	22	22	22
1470	95	90	75	94	87	72	101	91	84	88	22	22	22	22	22	22	22	22	22	22
1480	88	91	92	85	111	105	102	99	96	134	22	22	22	22	22	22	22	22	22	22
1490	112	110	111	113	97	124	104	106	104	91	22	22	22	22	22	22	22	23	23	23
1500	77	99	93	87	84	82	92	93	88	100	23	23	23	23	23	24	24	24	25	25
1510	100	102	100	99	96	100	112	104	83	96	26	26	26	26	26	26	26	26	26	26
1520	75	115	113	116	101	115	104	114	126	99	26	26	26	26	26	26	26	26	26	27
1530	113	110	97	101	75	105	92	106	88	99	27	27	27	27	27	28	28	28	28	28
1540	93	92	118	100	98	114	96	97	108	100	28	28	28	28	28	28	28	28	28	28
1550	104	93	103	100	95	107	107	107	112	106	28	28	28	28	28	28	28	28	28	28

1560	97	84	106	98	102	81	110	104	102	101	29	29	28	28	28	28	28	28	28	28
1570	94	89	108	94	103	119	101	100	84	118	28	28	28	28	28	28	28	28	28	28
1580	101	83	89	96	86	83	82	100	94	104	28	28	28	28	28	28	28	28	28	28
1590	98	97	94	91	90	105	108	101	91	84	29	29	29	29	29	29	29	29	29	29
1600	82	86	92	118	82	78	90	98	98	104	31	31	32	33	35	35	35	35	35	35
1610	86	103	87	58	103	84	95	99	72	115	35	35	35	35	35	35	35	35	35	35
1620	91	121	106	109	102	102	89	77	100	102	35	35	36	37	37	37	37	37	36	36
1630	94	103	75	99	96	98	102	102	108	104	37	37	37	37	37	37	37	37	36	36
1640	113	66	72	100	96	96	95	92	114	101	36	36	36	36	36	36	37	37	37	37
1650	95	82	99	98	97	102	106	91	96	113	37	37	37	37	37	37	37	37	37	37
1660	102	99	116	107	114	104	91	74	118	111	37	37	38	38	38	38	38	39	39	39
1670	104	91	108	92	105	104	104	109	96	98	39	37	37	37	37	37	37	37	37	37
1680	90	87	105	105	112	117	100	100	125	128	37	37	37	37	37	37	37	37	37	37
1690	113	122	113	114	91	98	97	105	104	93	37	37	37	37	37	37	37	37	37	37
1700	103	95	90	90	93	102	104	98	90	104	38	38	39	39	39	39	39	39	39	39
1710	92	84	100	93	89	90	97	104	106	86	39	39	39	39	39	39	39	39	39	39
1720	95	97	108	74	111	112	110	102	111	112	39	39	39	39	39	39	39	39	39	39
1730	109	103	102	108	107	108	101	97	104	122	39	39	39	39	39	39	39	39	39	39
1740	125	135	116	128	102	116	93	110	104	104	39	39	39	39	39	40	40	40	40	40
1750	97	120	102	102	103	58	120	105	86	111	40	40	40	40	40	40	39	38	38	38
1760	112	81	97	111	86	101	88	106	89	95	38	38	38	38	38	38	38	38	38	38
1770	93	111	102	105	104	93	106	97	96	78	38	38	38	38	38	38	38	37	36	36
1780	93	111	92	82	86	103	105	88	101	110	36	36	36	36	36	36	36	36	36	36
1790	105	93	103	100	107	107	100	102	117	95	36	36	36	35	35	35	35	35	35	35
1800	96	117	99	81	117	103	92	104	108	92	35	35	35	35	35	35	35	35	35	35
1810	100	122	111	110	90	108	97	105	96	102	35	35	35	35	35	35	35	35	34	34
1820	105	91	97	103	81	93	112	98	85	96	34	34	34	34	34	34	34	34	35	35
1830	95	100	66	99	88	108	80	83	48	103	35	35	35	35	34	34	34	34	34	34
1840	99	99	95	92	76	86	97	81	88	84	34	34	34	34	34	34	34	34	33	33
1850	95	78	92	108	79	101	88	87	89	119	33	33	33	33	32	32	32	32	32	32
1860	92	107	93	102	74	105	105	100	111	115	32	32	32	32	32	33	33	33	32	32
1870	120	121	117	109	127	108	132	110	102	103	32	32	32	32	32	32	32	32	32	32
1880	114	94	110	109	105	103	135	113	108	106	32	32	32	32	32	32	32	32	32	32
1890	102	103	108	108	94	95	114	89	120	97	32	32	32	32	32	32	32	32	32	32
1900	113	106	108	105	98	109	101	112	114	112	33	33	33	33	33	33	33	33	33	34
1910	112	123	106	98	117	87	115	102	112	95	34	33	32	32	32	32	30	29	29	27
1920	90	90	99	97	98	103	95	114	81	103	26	23	23	22	22	21	19	18	18	17
1930	94	113	87	103	63	100	89	104	100	76	15	14	13	13	13	13	13	13	13	13
1940	107	93	99	102	116	114	98	100	145	104	13	13	13	13	13	13	13	13	13	13

1950	121	105	98	109	118	130	82	108	114	143	13	13	13	13	13	13	13	13	13	13
1960	135	121	103	126	115	103	114	117	110	75	13	13	13	13	13	13	13	13	13	13
1970	132	103	89	107	106	101	105	92	98	95	13	13	13	13	13	13	13	13	13	13
1980	95	90	107	114	130	107	109	108	100	90	13	13	13	13	13	13	13	13	13	13
1990	82	101	83								13	13	11							

Twin Peaks Master Indices

	Tree-Ring Indices										Number of samples									
Date	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
965						70	73	67	56	71						1	1	1	1	1
970	102	94	159	157	69	158	120	117	210	107	1	1	1	1	1	1	1	1	1	1
980	98	71	64	77	109	113	99	105	90	89	1	1	1	1	1	1	1	1	1	1
990	59	68	71	93	104	74	90	105	176	104	1	1	1	1	1	1	1	1	1	1
1000	116	152	124	111	120	97	119	136	75	74	1	1	1	1	1	1	1	1	1	1
1010	123	76	94	116	98	76	118	111	85	83	1	1	1	1	1	1	1	1	1	1
1020	98	98	92	92	116	96	81	68	77	84	1	1	1	1	1	1	2	2	2	2
1030	95	130	127	116	117	119	106	85	127	116	2	2	2	2	2	2	2	2	2	2
1040	102	117	112	77	123	118	96	129	96	98	2	2	2	2	2	2	2	2	2	2
1050	86	90	109	104	103	86	71	86	65	86	2	2	2	2	2	2	2	2	2	2
1060	94	101	97	78	100	95	105	68	101	94	2	2	2	2	2	2	2	2	2	2
1070	102	60	105	111	94	113	65	105	72	91	2	2	2	2	2	2	2	2	2	2
1080	104	94	92	82	99	100	83	83	101	92	2	2	2	2	2	2	2	2	2	2
1090	101	111	90	138	127	140	107	154	124	107	2	3	3	3	3	3	3	3	3	3
1100	149	115	110	64	102	70	88	109	79	78	3	3	3	3	3	3	3	3	3	3
1110	114	165	163	111	98	137	123	114	100	118	3	3	3	3	3	3	3	3	3	3
1120	98	76	64	85	85	84	87	61	90	81	3	3	3	3	3	3	3	3	3	3
1130	85	53	89	78	89	114	80	78	84	80	3	3	3	3	3	3	3	3	3	3
1140	91	119	80	117	98	115	104	128	113	122	4	4	4	4	4	4	4	4	4	4
1150	137	101	114	110	68	69	99	96	74	88	4	4	4	4	4	4	4	4	4	4
1160	91	77	105	60	87	88	85	99	128	110	4	4	4	5	5	5	5	5	5	5
1170	110	107	133	133	114	107	97	87	141	124	5	5	5	5	5	5	5	5	5	5
1180	133	139	99	111	97	77	85	89	106	108	5	5	5	5	5	5	5	5	5	5
1190	119	91	123	104	126	109	90	98	116	117	5	5	5	5	5	5	5	5	5	5
1200	53	83	109	97	82	92	65	77	109	68	5	5	5	5	5	5	5	5	5	5
1210	81	111	101	111	103	70	104	94	106	84	5	5	5	5	5	5	5	5	6	6
1220	64	69	115	89	129	81	96	110	100	91	6	6	6	6	6	6	6	6	6	6
1230	94	126	120	115	86	116	116	118	120	120	6	6	6	7	7	7	7	7	7	7
1240	103	103	108	127	95	101	102	106	92	75	7	7	7	7	7	8	8	8	8	8
1250	91	85	69	80	82	83	81	107	88	99	8	8	8	8	8	8	8	8	8	8
1260	119	122	131	95	123	101	95	121	95	113	8	8	8	8	8	8	8	8	8	8
1270	88	84	108	92	114	92	121	102	90	111	8	8	8	8	8	8	8	8	8	8
1280	96	81	117	100	96	128	113	113	102	86	8	8	8	8	8	8	8	8	8	8
1290	100	102	86	93	91	89	98	102	106	92	8	8	8	8	8	8	8	8	8	8

1300	96	111	133	94	88	83	124	83	109	100	8	8	8	8	8	8	8	8	8	8
1310	82	95	82	103	99	98	113	96	85	104	8	8	8	8	8	8	8	8	8	8
1320	83	81	102	120	92	88	106	105	132	118	8	8	9	9	9	9	9	9	9	9
1330	66	85	108	117	108	77	82	121	119	86	9	9	9	9	9	9	9	9	9	9
1340	117	101	81	96	110	128	109	126	84	93	9	9	9	9	9	9	9	9	9	9
1350	83	119	103	102	102	109	96	77	76	107	9	9	9	9	9	9	9	9	9	9
1360	85	93	111	100	78	87	98	83	107	107	9	9	9	9	9	9	9	9	9	9
1370	87	96	92	96	94	95	116	125	114	88	9	9	9	9	9	9	9	9	9	9
1380	108	83	95	106	79	105	81	114	116	109	9	9	9	9	9	9	9	9	9	9
1390	80	117	86	98	106	129	94	125	98	61	9	9	9	9	9	9	9	9	9	9
1400	103	87	109	114	107	100	123	109	122	116	9	9	9	9	9	9	9	9	9	9
1410	124	116	79	131	119	120	107	43	102	121	9	9	9	9	9	9	9	9	9	9
1420	106	102	123	113	114	96	117	87	115	103	9	9	9	9	9	9	9	9	9	9
1430	90	112	97	124	108	86	98	99	83	63	9	9	9	9	9	9	9	9	9	9
1440	89	71	75	82	103	92	104	106	85	103	9	9	10	10	10	10	9	9	9	9
1450	89	98	96	93	92	106	90	104	59	84	9	9	9	9	9	9	9	9	9	9
1460	84	73	93	98	93	112	108	101	95	77	9	9	10	10	10	10	10	10	10	10
1470	104	91	90	99	116	83	110	103	92	107	10	10	10	10	11	11	11	11	11	11
1480	85	96	77	84	113	86	93	110	107	147	11	11	11	11	11	11	11	11	11	11
1490	126	107	116	119	120	122	109	101	103	88	11	11	11	11	12	12	13	13	13	13
1500	96	95	116	97	100	58	84	104	109	108	13	13	13	13	13	13	13	13	13	13
1510	109	97	118	112	98	105	138	111	81	94	13	13	13	14	14	13	13	13	13	13
1520	82	87	90	114	107	92	100	126	121	81	13	13	13	13	14	14	14	14	14	14
1530	118	115	112	116	76	97	99	101	91	97	14	14	14	14	14	14	14	14	14	14
1540	94	88	107	87	79	104	94	80	114	93	14	14	14	14	14	14	14	14	14	14
1550	102	85	94	103	109	111	103	103	110	103	15	15	15	15	15	15	15	15	15	15
1560	100	78	95	102	95	71	99	95	88	90	15	15	15	15	15	15	15	15	15	16
1570	97	90	103	95	99	106	130	117	84	130	16	16	16	16	16	16	16	16	16	16
1580	130	98	97	113	106	103	84	101	91	104	16	16	16	16	16	16	16	16	16	16
1590	102	90	97	107	104	117	111	110	101	95	16	16	16	16	16	16	16	16	16	16
1600	108	116	91	121	107	108	106	90	92	118	16	16	16	16	16	16	16	16	16	16
1610	36	126	88	76	114	91	89	107	56	128	16	16	16	16	16	16	16	16	16	16
1620	95	93	102	118	108	106	113	81	115	98	16	16	16	16	16	16	17	17	17	17
1630	96	94	89	100	98	93	116	97	95	100	17	17	17	17	17	17	17	17	17	17
1640	109	69	40	94	100	86	98	97	128	111	18	18	17	17	17	17	17	17	17	17
1650	111	73	111	93	118	129	101	128	111	119	17	17	17	17	17	17	17	17	17	17
1660	111	70	106	91	107	105	77	57	108	106	17	17	17	17	17	17	17	17	17	15
1670	96	81	102	88	88	85	99	103	113	110	15	15	15	15	15	15	15	15	15	15

1680	100	60	138	118	123	117	97	94	127	133	15	15	15	15	15	15	15	15	15	13
1690	124	127	96	103	85	105	100	93	116	57	14	14	14	14	14	15	15	15	15	15
1700	97	96	95	80	98	106	101	100	88	98	15	15	15	14	14	14	14	14	14	14
1710	105	67	111	103	95	100	99	127	127	104	14	13	13	13	13	13	13	13	13	13
1720	88	92	112	44	122	103	111	92	91	104	13	13	13	13	13	14	14	14	14	14
1730	105	89	89	95	89	106	98	93	116	127	14	14	14	14	14	14	14	14	14	14
1740	116	137	124	122	110	122	82	105	97	87	14	14	14	14	14	14	14	14	14	14
1750	95	95	117	99	118	64	137	122	91	112	14	14	14	14	14	14	14	14	14	14
1760	95	53	96	115	99	101	82	80	93	92	14	14	14	14	14	14	14	14	14	14
1770	81	111	94	121	111	103	92	90	88	71	14	14	14	14	14	14	14	14	14	14
1780	82	137	108	101	66	111	93	85	89	105	14	14	14	14	14	14	14	14	14	14
1790	103	63	89	81	111	98	101	106	107	83	14	14	14	14	14	14	14	14	14	14
1800	81	104	90	53	105	92	90	107	114	100	15	15	15	15	15	15	15	15	15	15
1810	115	124	122	117	99	121	106	118	86	109	15	15	15	15	15	15	15	15	15	15
1820	115	85	98	112	89	91	113	114	91	111	15	15	15	15	15	15	15	15	15	15
1830	114	117	48	109	94	111	93	84	57	114	15	15	15	15	15	15	15	15	16	15
1840	120	126	108	108	83	86	103	96	99	99	15	15	15	15	17	17	17	17	17	16
1850	104	81	103	113	106	111	101	94	95	115	16	16	16	16	16	16	16	16	16	16
1860	95	100	100	107	91	109	113	116	107	102	16	16	16	16	16	16	16	16	16	16
1870	109	114	110	95	106	101	102	90	85	98	16	16	16	16	16	15	15	15	15	15
1880	118	90	115	75	93	75	116	111	105	97	16	16	16	16	16	16	16	15	15	15
1890	104	95	104	116	91	85	112	87	109	96	16	16	16	16	16	16	16	16	16	16
1900	94	103	104	88	94	81	91	90	98	103	16	16	16	16	16	16	16	16	16	16
1910	105	119	107	95	92	81	110	117	117	113	16	15	15	15	15	15	15	15	15	15
1920	101	95	94	91	89	97	93	108	69	107	15	15	15	13	13	13	13	13	13	12
1930	96	99	88	111	60	91	84	91	83	73	11	11	11	11	11	11	11	11	11	11
1940	114	88	81	94	104	99	92	90	128	103	11	11	11	11	11	11	11	11	11	11
1950	121	88	105	118	117	132	97	119	116	138	11	11	11	11	11	11	11	11	11	11
1960	113	114	83	121	109	107	84	111	102	73	11	11	11	11	11	11	11	11	11	11
1970	126	106	83	116	109	121	97	91	78	88	11	11	11	11	11	11	11	11	11	11
1980	96	94	99	95	125	101	109	90	100	92	11	11	11	11	11	11	11	10	10	10
1990	83	94	72								10	10	7							

Railroad Ridge Master Indices

	Tree-Ring Indices										Number of samples									
Date	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
726							148	134	142	111							1	1	1	1
730	100	93	77	79	82	103	86	96	110	84	1	1	1	1	1	1	1	1	1	1
740	101	79	84	68	96	101	89	82	119	84	1	1	1	1	1	1	1	1	1	1
750	88	91	109	121	142	118	113	125	129	104	1	1	1	1	1	1	1	1	1	1
760	108	71	78	66	56	61	79	102	93	133	1	1	1	1	1	1	1	1	1	1
770	106	142	105	92	71	89	96	118	86	95	1	1	1	1	1	1	1	1	1	1
780	129	144	104	95	95	131	135	104	111	142	1	1	1	1	1	1	1	1	1	1
790	163	116	145	125	114	76	81	92	95	100	1	1	1	1	1	1	1	1	1	1
800	79	73	91	110	122	90	111	78	111	105	1	1	1	1	1	1	1	1	1	1
810	60	74	115	84	98	96	70	77	68	87	1	1	1	1	1	1	1	1	1	1
820	68	92	94	94	106	101	80	94	122	158	1	1	1	1	1	1	1	1	1	1
830	105	131	134	122	131	91	126	107	76	102	1	1	1	1	1	1	1	1	1	1
840	76	95	102	128	109	83	92	59	99	120	1	1	1	1	1	1	1	1	1	1
850	154	55	103	122	86	119	94	130	90	130	1	1	1	2	2	2	2	2	2	2
860	73	105	115	102	106	61	87	88	68	79	2	2	2	2	2	2	2	2	2	2
870	99	63	89	66	105	88	93	100	109	117	2	2	2	2	2	2	2	2	2	2
880	92	103	143	76	81	97	94	123	74	124	2	2	2	2	2	2	2	2	2	2
890	113	107	158	151	144	146	179	168	97	107	2	2	2	2	2	2	2	2	2	2
900	81	94	80	88	111	97	110	85	87	109	2	2	2	2	2	2	2	2	2	2
910	109	101	101	117	68	94	104	109	118	99	2	2	2	2	2	2	2	2	2	2
920	110	119	70	33	46	65	49	73	96	87	2	2	2	2	2	2	2	2	2	2
930	91	103	103	101	117	88	131	93	120	89	2	2	2	2	2	2	2	2	2	2
940	106	141	93	96	96	80	102	100	91	108	2	2	2	2	2	2	2	2	2	2
950	94	85	91	111	85	60	75	97	72	73	2	2	2	2	2	2	2	2	2	2
960	124	103	118	150	130	143	134	72	138	126	2	2	2	2	2	2	2	2	2	2
970	139	84	139	156	149	157	98	140	150	150	2	2	2	2	2	2	2	2	2	2
980	99	95	100	98	128	118	137	141	117	124	2	2	2	2	2	2	2	2	2	2
990	72	136	102	43	46	36	27	16	20	21	2	2	2	2	2	2	2	2	2	2
1000	34	24	39	46	52	67	74	85	69	83	2	2	2	2	2	2	2	2	2	2
1010	83	78	68	101	83	80	87	84	74	94	2	2	2	2	3	3	3	3	3	3
1020	91	90	83	121	157	133	130	119	144	120	3	3	3	3	3	3	3	3	3	3
1030	132	209	152	128	128	89	104	104	127	108	3	3	3	3	3	3	3	3	3	3
1040	165	132	125	118	151	133	124	117	68	83	3	3	3	3	3	3	3	3	3	3
1050	68	66	96	102	79	87	80	87	93	105	3	3	3	3	3	3	3	3	3	3

1060	100	143	34	64	75	87	93	74	67	59	3	3	3	3	3	3	3	3	3	3
1070	60	67	78	82	68	72	49	63	61	95	3	3	3	3	3	3	3	3	3	3
1080	117	102	120	134	123	118	113	121	121	115	3	3	3	3	3	3	3	3	3	3
1090	151	102	123	115	101	134	103	109	142	104	3	3	3	3	3	3	3	3	3	3
1100	119	125	71	78	60	96	112	117	96	93	3	3	3	3	3	3	3	3	3	3
1110	122	132	134	94	79	115	101	112	96	105	3	3	3	3	3	3	3	3	3	3
1120	80	47	74	77	99	91	97	87	116	138	3	3	3	3	3	3	3	3	3	3
1130	129	111	140	110	106	111	81	95	110	96	3	3	3	3	3	3	3	3	3	3
1140	93	122	79	154	118	111	146	117	122	100	3	3	3	3	3	3	3	3	3	3
1150	62	53	99	75	77	78	115	81	74	90	3	3	3	3	3	3	3	3	3	3
1160	88	59	96	80	92	97	110	110	146	97	3	3	3	3	3	3	3	3	3	3
1170	165	129	99	81	49	86	65	81	87	94	3	3	3	3	3	3	3	3	3	3
1180	83	74	76	96	85	84	75	86	106	70	3	3	3	3	3	3	3	3	3	3
1190	107	75	111	108	96	112	124	91	144	97	3	3	3	3	3	3	3	3	3	3
1200	59	113	142	146	96	118	102	123	119	99	3	3	3	3	3	3	3	3	3	3
1210	65	111	117	86	114	102	137	117	112	88	3	3	3	3	3	3	3	3	3	3
1220	97	90	106	36	72	68	68	84	103	94	3	3	3	3	3	3	3	3	3	3
1230	87	147	118	125	83	113	118	118	94	141	3	3	3	3	3	3	3	3	3	3
1240	129	91	142	123	54	72	79	95	114	101	3	3	3	3	3	3	3	3	3	3
1250	105	110	111	152	125	146	102	128	26	80	3	3	3	3	3	3	3	3	3	3
1260	117	103	87	99	89	91	87	100	114	110	3	3	3	3	3	3	3	3	3	3
1270	77	115	74	85	79	80	111	130	56	44	3	3	3	3	3	3	3	3	3	3
1280	44	63	87	91	82	120	100	108	81	99	3	3	3	3	3	3	3	3	3	3
1290	75	105	110	109	127	126	91	79	127	128	3	3	3	3	3	3	2	2	2	2
1300	81	104	103	86	80	56	118	94	116	148	2	2	2	2	2	2	2	2	2	2
1310	111	115	129	120	130	90	117	52	70	118	2	2	2	2	2	2	2	2	2	3
1320	97	111	109	126	108	121	112	106	133	136	3	4	4	4	4	4	4	4	4	4
1330	82	117	105	107	93	82	88	112	112	114	4	4	4	4	4	4	4	4	4	4
1340	111	87	72	87	92	67	82	87	72	86	4	4	4	4	4	4	4	4	4	4
1350	87	103	91	98	97	96	118	83	98	93	5	5	5	5	5	5	5	5	5	5
1360	83	98	94	96	93	115	100	98	113	112	5	5	5	5	5	5	5	5	5	6
1370	100	104	109	115	126	91	104	123	90	94	6	6	6	6	6	6	6	6	6	6
1380	104	94	74	62	82	87	76	97	103	86	6	6	6	6	6	6	6	6	6	6
1390	76	97	95	89	106	103	99	100	102	55	6	6	6	6	6	6	6	6	6	6
1400	111	88	107	109	99	108	98	93	96	100	6	6	6	6	6	6	6	6	6	6
1410	93	116	101	122	104	116	127	71	87	128	6	6	6	6	6	6	6	6	6	6
1420	111	110	106	109	116	126	120	98	123	78	6	6	6	6	6	6	6	6	6	6
1430	103	121	127	134	113	112	130	101	99	108	6	6	6	6	6	6	6	6	6	6

1440	99	77	102	94	107	117	117	101	72	85	6	6	6	7	7	7	7	7	7	7
1450	79	96	109	124	105	134	101	107	57	79	7	8	8	8	8	8	8	8	8	8
1460	73	71	81	78	81	101	101	96	98	106	8	8	8	8	8	8	8	8	8	8
1470	105	89	103	88	86	77	112	93	90	105	8	8	8	8	8	8	8	8	8	8
1480	119	126	102	100	129	115	117	116	106	138	8	8	8	8	8	8	8	8	8	8
1490	125	93	98	98	94	101	84	92	90	94	8	8	8	8	8	8	8	8	8	8
1500	74	75	96	99	86	95	91	91	96	102	8	8	8	8	8	8	8	8	8	8
1510	95	101	105	82	80	82	103	92	77	68	8	8	8	7	7	7	7	7	7	7
1520	80	104	88	100	82	101	92	120	131	98	7	7	7	7	7	8	8	8	8	8
1530	113	127	113	111	91	121	95	120	94	87	8	8	8	8	8	8	8	8	8	8
1540	125	101	106	88	83	111	103	94	108	87	8	9	9	9	9	9	9	9	9	9
1550	112	96	107	109	94	104	108	108	111	98	9	9	9	9	9	9	9	9	9	9
1560	96	90	108	112	117	78	133	119	104	98	9	9	9	9	9	9	9	9	9	9
1570	116	117	103	96	103	108	119	96	75	111	9	9	9	9	9	9	9	9	9	9
1580	101	92	75	92	93	95	100	100	104	100	9	9	9	9	9	9	9	9	9	9
1590	93	91	100	104	102	104	101	111	117	107	9	9	9	9	9	9	9	9	10	10
1600	105	94	78	114	83	78	92	68	89	96	10	9	9	9	9	10	9	9	9	9
1610	85	95	82	58	102	81	92	97	88	126	9	9	9	9	9	9	9	9	9	9
1620	113	129	103	105	106	125	96	89	108	107	10	10	10	10	10	10	10	10	10	10
1630	92	106	81	102	105	86	111	101	106	109	10	10	10	10	10	10	10	10	10	10
1640	113	66	69	81	77	78	88	110	117	120	11	11	11	11	11	11	11	11	11	11
1650	103	98	93	104	95	108	117	119	101	127	11	11	11	11	11	11	11	11	11	10
1660	105	90	105	97	114	123	97	81	101	95	10	10	10	10	10	10	10	10	10	10
1670	79	94	79	91	98	95	96	99	109	102	10	10	10	10	10	11	11	11	11	11
1680	83	73	111	112	116	129	117	117	126	143	11	11	11	11	11	11	11	11	12	12
1690	121	127	100	113	106	102	99	89	103	87	12	12	12	12	12	12	12	12	12	12
1700	86	86	92	85	76	97	99	90	72	75	12	12	12	12	12	11	11	11	11	11
1710	83	67	85	92	81	81	97	103	110	98	11	11	11	11	11	11	11	11	11	11
1720	102	97	133	85	129	129	104	102	110	108	11	11	11	11	11	11	11	11	11	11
1730	98	98	94	83	96	95	104	93	88	119	11	11	11	11	11	11	11	11	11	11
1740	109	136	110	122	101	113	91	104	117	107	11	11	11	11	11	11	11	11	11	11
1750	89	107	96	89	104	58	104	90	88	102	11	11	11	11	11	11	11	11	12	12
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1770	97	102	107	124	109	102	109	104	119	84	12	12	12	12	12	12	12	12	12	12
1780	91	111	103	103	101	116	102	91	100	105	12	12	12	12	12	12	12	12	12	12
1790	104	86	100	105	108	99	105	108	114	113	12	12	12	12	12	12	12	13	13	13
1800	102	114	86	92	107	92	89	96	103	101	13	13	13	13	13	13	13	13	13	13
1810	97	123	103	107	92	102	105	114	107	105	13	15	15	15	15	15	15	15	15	15

1820	104	87	86	90	75	81	99	99	89	108	15	15	15	15	15	15	15	15	15	15
1830	108	118	94	104	96	124	96	93	62	91	15	15	15	15	15	15	15	15	15	15
1840	91	101	97	106	76	87	107	89	89	92	15	15	15	15	15	15	15	14	14	14
1850	93	90	95	113	113	115	105	102	99	115	15	15	15	15	15	15	15	15	15	15
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1870	123	108	124	112	116	118	114	102	106	104	14	14	14	14	14	14	14	14	14	14
1880	108	84	92	70	79	67	98	94	92	98	14	14	13	13	13	13	13	13	13	13
1890	93	92	104	115	94	106	115	98	124	100	13	13	13	13	13	13	13	13	13	13
1900	113	116	105	92	96	91	94	99	103	101	13	13	13	13	13	13	13	13	13	13
1910	112	109	99	92	109	82	100	95	86	91	13	13	13	13	13	13	13	13	13	13
1920	84	77	89	94	95	103	101	115	104	120	13	13	13	13	13	13	13	13	12	12
1930	117	120	92	111	82	110	106	106	98	104	12	12	12	12	12	12	12	12	12	12
1940	125	112	115	118	108	118	115	104	121	95	12	12	12	12	12	12	12	12	12	12
1950	97	85	93	99	94	100	86	97	82	111	12	12	12	12	12	12	12	12	12	12
1960	103	91	78	103	98	96	87	94	80	65	12	12	12	12	12	12	12	12	12	12
1970	108	103	81	97	109	102	101	103	106	100	12	12	12	12	12	12	12	12	12	12
1980	108	108	99	104	127	122	110	105	118	99	12	12	11	11	11	11	11	11	9	9
1990	84	97	90								9	5	5							

CHAPTER 6

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