TREE-RING BULLETIN, *Vol. 50, 1990*

ANALYSIS OF BIWEIGHT SITE CHRONOLOGIES: RELATIVE WEIGHTS OF INDIVIDUAL TREES OVER TIME

KURT H. RIITTERS

ManTech Environmental Technology, Inc.
P. O. Box 12313
Research Triangle Park, North Carolina 27709

ABSTRACT

The relative weights on individual trees in a biweight site chronology can indicate the consistency of tree growth responses to macroclimate and can be the basis for stratifying trees in climate-growth analyses. This was explored with 45 years of ring-width indices for 200 trees from five even-aged jack pine (*Pinus banksiana* Lamb.) stands. Average individual-tree relative weights were similar, but most trees had at least one transient occurrence of low relative weight. The standard deviations of individual-tree relative weights suggested that some trees had more variable growth responses than others. The trees were classified by the average and standard deviation of their relative weights, and biweight site chronologies were then calculated for these subgroups. Chronologies derived from trees with low average weights, and from trees with high standard deviation of weights, sometimes appeared to be different from chronologies derived from the remaining trees.

Die relativen Gewichte einzelner Bäume in einer durch 'robuste Mittelung' entstandenen Chronologie ('biweight site chronology') können ein Hinweis auf Zusammenhänge zwischen den Wachstumsreaktionen von Bäumen und dem Makroklima sein und dann als Grundlage zur Stratifizierung der Bäume in einer Klima-Wachstums-Analyse dienen. Dies wurde anhand von 45jährigen Jahrring-Indexzeitreihen von 200 Kiefern (*Pinus banksiana* Lamb.) in fünf gleichaltrigen Beständen untersucht. Die mittleren relativen Gewichte der Einzelbäume waren ähnlich, jedoch kam es bei den meisten Bäumen zu mindestens einem kurzzeitigen Auftreten niedriger relativer Gewichte. Die Standardabweichungen der relativen Gewichte der Einzelbäume legten den Schluß nahe, daß einige Bäume mehr Variabilität in ihren Wachstumsreaktionen aufwiesen als andere. Nach einer Einteilung der Bäume anhand der Mittelwerte und Standardabweichungen ihrer relativen Gewichte wurden für diese Untergruppen 'robust gemittelte' Standortchronologien berechnet. Chronologien von Bäumen mit niedrigen relativen Gewichten und hohen Standardabweichungen der Gewichte schienen sich manchmal von den Chronologien der übrigen Bäume zu unterscheiden.

Les poids relatifs des arbres individuels dans une chronologie de site bipondérée peuvent indiquer la consistance des réponses de croissance vis-à-vis du macrolimat et peut être une base de stratification des arbres dans l'analyse climat-croissance. Cette méthode a été étudiée sur les indices d'épaisseur de 200 arbres provenant de cinq populations équiennes de *Pinus banksiana* Lamb. (jack pine) pour une durée de 45 ans. Les poids relatifs moyens des arbres individuels étaient similaires, mais la plupart des arbres avaient au moins une période passagère de faible poids relatif. Les déviations standards des poids relatifs des arbres individuels suggéraient le fait que certains arbres présentaient des réponses de croissance plus variables que d'autres. Les arbres ont été classés d'aprés la moyenne et la déviation standard de leurs poids relatifs et des chronologies de site bipondérées ont alors été calculées pour ces sous-groupes. Les chronologies dérivées d'arbres présentaient des poids moyens faibles et celles provenent d'arbres munis d'un poids élevé et d'une forte déviation standard apparaissaient parfois différentes des chronologies provenant des arbres restants.

INTRODUCTION

The biweight (Mosteller and Tukey 1977) mean-value function has been used to form site chronologies from individual tree ring-width index series (e.g., Cook 1985; Riitters 1990). The method is gaining popularity because it is resistant (insensitive to outliers) and robust with respect to departures from classical statistical assumptions. The distinctive feature of the biweight is that the relative weight assigned to a given ring-width index value is calculated to reduce the overall influence of outliers on the common site chronology. The procedure is data-driven, and the weights can vary among trees at a given time, or over time for a given tree. The differential weighting scheme opens up the possibility of direct analysis of the relative weights to address the consistency of tree-growth responses to environment.

An individual weight indicates whether a tree's annual growth response is similar to the responses of other trees in that year. If some trees consistently receive relatively low (or high) weights, they may constitute a subpopulation that responds differently to macroclimatic influences. Inconsistency indicates more random deviations from the common site chronology. Thus, the average weights of different trees may suggest a stratification of the sample for modeling climate-growth relationships.

Individual trees may also differ in the year-to-year variability of their relative weights. Trees with a pattern of response to macroclimate that is like the pattern of most other trees will have lower variance, whereas the more sensitive trees should have higher variance. Thus, the standard deviation of individual-tree weights over time may also suggest a grouping of trees with different responses to environment.

THE BIWEIGHT MEAN-VALUE AND WEIGHTING FUNCTIONS

The most common mean-value estimator in dendrochronology is the arithmetic average (Fritts 1976). Although efficient under classic statistical assumptions, it is equally sensitive to all index values, including outliers, and it is not always robust. The best-known robust estimator is the highly resistant median, which is insensitive to outliers and sensitive only to the middle one or two values in an ordered sample. Like the median, the biweight estimator is robust and insensitive to outliers, but it behaves as the arithmetic average near the center of the sample.

The biweight is actually a family of estimators, and the analyst must "tune" the estimation procedure for efficiency in specific applications. In addition, there are different computational strategies for and several approximate formulations of the biweight's variance. Mosteller and Tukey (1977) and Hoaglin et al. (1983) may be consulted for the theory and for practical advice in different situations. In the present study, the computation of the biweight utilized an iteratively reweighted, least-squares algorithm (Goodall 1983). This algorithm is applied each year to a sample of tree ring-width indices. The iteration formula is:

$$T^{k+1} = \frac{\sum_{i=1}^{n} X_i W_i^k}{\sum_{i=1}^{n} W_i^k}$$

where:

T^k = biweight

k = iteration number

X_i = ring-width index of tree i

n = number of trees

W_i^k = weight of tree i at iteration k

$= (1 - [U_i^k]^2)^2$ if $|U_i^k| \leq 1$

$= 0$ if $|U_i^k| > 1$

U_i^k = $(X_i - T^k) / 6s$

s = median $(|X_i - T^k|)$

The function U_i^k expresses the deviations of the ring-width indices from the current estimate of the biweight in units of the tuned "scale factor", s. (The number 6 in the function U_i^k is called the tuning constant.) With this tuning, the weight function (W_i^k) will be zero if X_i is more than about 4 standard deviations away from T^k (Iglewicz 1983). The iterations begin with T^0 taken as the median of the X_i, and terminate when ($T^{k+1} - T^k$) is less than 0.01 times the standard error of T^k. Iglewicz (1983) gives an approximate formula for the standard error of T^k.

The relative tree weight for tree i at the final iteration in a given year is computed as:

$$R_i = W_i^k / \Sigma_{i=1}^n \; W_i^k$$

For any given tree, the average (AVG), the standard deviation (STD), and the range (RNG) of relative tree weight over all years in the chronology summarize the similarity of responses relative to other trees.

ANALYSIS OF RELATIVE WEIGHTS ASSIGNED TO INDIVIDUAL TREES

Sweda and Umemura (1979) reported a study of radial increment growth in even-aged jack pine stands near Fort Smith, Northwest Territories, Canada. Riitters (1990) describes the computation of ring-width indices for samples of large-size trees from each of four sites denoted as FS3, FS6, FS11, and CM8; an additional site denoted as CM2 was included in the present study. For comparison to Table 1 in Riitters (1990), site CM2 is Cherry Mountain 2, with stand age 52 years, basal area 18.7 square meters per hectare, 3790 trees per hectare, and average diameter at breast height 7.6 centimeters at the time of sampling in 1977. Briefly, a gamma-type detrending model (Monserud 1986) was fitted to ring-width chronologies, and the residuals were standardized to form ring-width indices by the usual procedure (Fritts 1976). Ring-width indices for the years 1932-1976 for 40 trees per site were used in this analysis.

Comparisons of Weights Among Individual Trees

The comparisons of weights among individual trees are made in terms of RNG, AVG, STD, as defined above. Frequency histograms of the three summary statistics for sites FS3, FS6, FS11, CM2, and CM8 are shown in Figure 1. Under the null hypothesis of equal weights in a given year, the average weight among trees is $n^{-1} = 0.025$. For most trees, AVG is close to the expected value (i.e., n^{-1}) of 0.025, which suggests fairly homogeneous samples (Figure 1A). The unimodal distribution of AVG suggests no obvious groupings of trees. The tree weights are not constant over time, however, because the RNG is clearly greater than zero for most trees (Figure 1B). These observations together indicate that, over the course of the chronologies, different trees receive relatively little weight in different years; there must be at least one (probably transient) occurrence of relatively low weight for each tree. Examination of the weights for each tree over time (the data are not shown here) indicated abrupt changes in weight that persisted for several years and then disappeared. This does not suggest systematically different responses to macroclimate, but rather responses to random growth disturbances that affect each tree individually. The histograms of STD also do not suggest obvious groups of trees (Figure 1C), but the threefold differences in STD among trees do suggest that some trees are more similar to the common chronology than other trees.

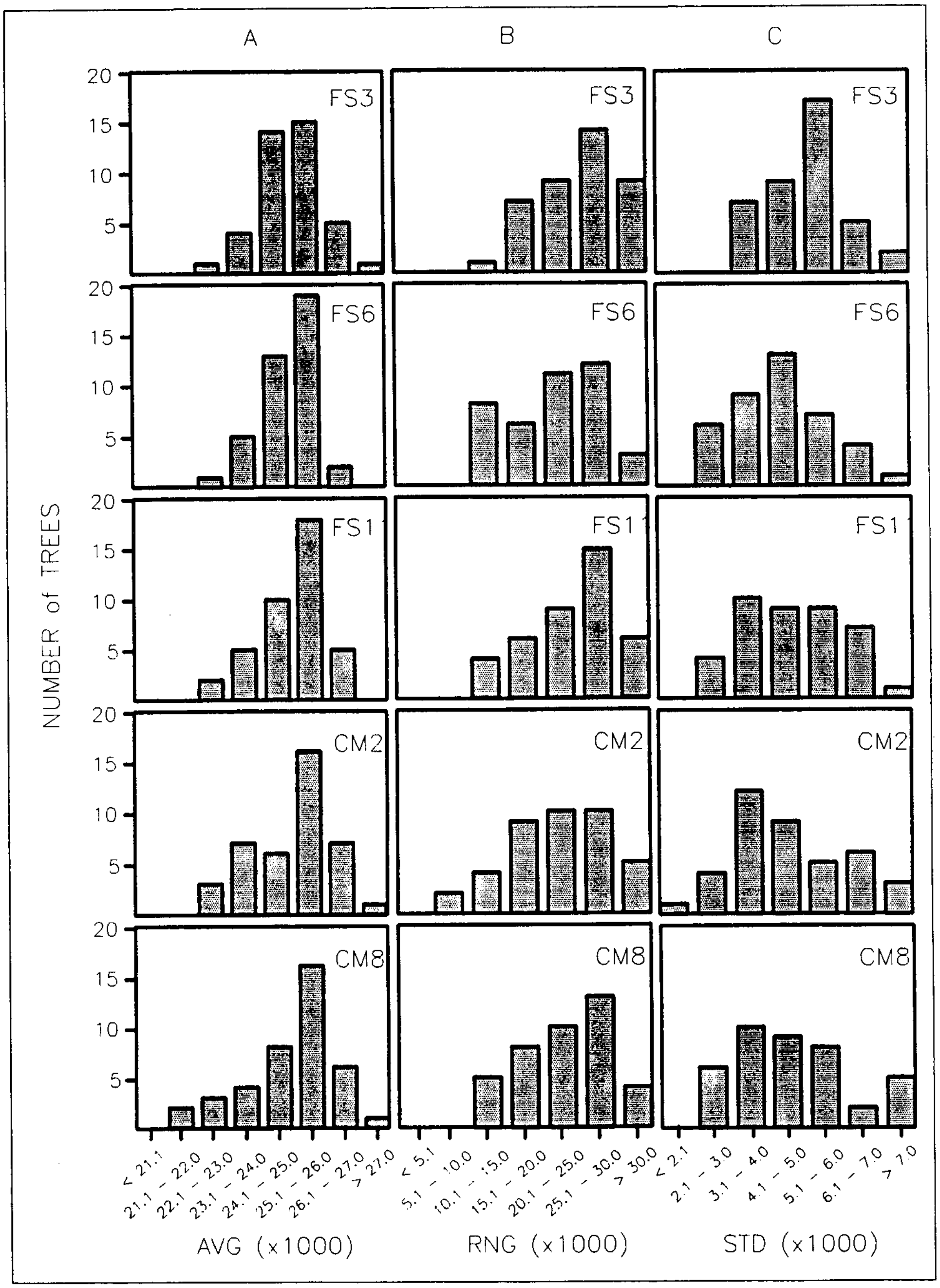

Figure 1. Number of trees classified by AVG (A), RNG (B), and STD (C) for five jack pine sites.

Comparisons of Biweight Chronologies

Little will be gained by excluding low-weight trees from a sample in hopes of finding a better single mean-value chronology, because the biweight accomplishes that automatically. However, if more than one mean-value chronology is sought for a given site, the stratification of trees can be based on the tree weights. Subgroups defined in this way may have similar overall trends but may differ in terms of extreme values. Another possibility is that the overall trends are different. These possibilities would imply quantitative or qualitative differences in growth responses between groups.

The trees from each site were first divided into two groups on the basis of AVG, by using 0.024 as the break point. Five to 10 trees per site were classified as low-AVG trees (Table 1). Biweight site chronologies were then calculated for the low-AVG and high-AVG groups, and for the pooled sample. As might be expected (because of smaller sample sizes), the biweight chronologies of the low-AVG groups were more variable; they also had higher extreme values than the high-AVG groups (Table 1). The biweight chronology means were not much different, although this means little because each tree's indices had been standardized.

The trends of the low-AVG and high-AVG groups appear different for some sites, but similar in others (Figure 2). The visual evidence for deciding the significance of group differences is not compelling. The quantitative evidence is also inconclusive; chronologies are highly correlated for some sites, but not others (Table 1). It would be difficult to conclude that this stratification has identified meaningfully any different subgroups of trees.

The trees from each site were then redivided into two groups on the basis of STD (by using 0.006 as a break point), and biweight site chronologies were calculated for each group. The sample sizes and other statistics for the low-STD and high-STD groups are given in Table 2, and the chronologies are graphed in Figure 3. Because many of the trees classified as high-STD were classified as low-AVG in the previous analysis, the results of the group comparisons are very similar. On site FS3, however, most of the trees classified as high-STD were not those classified as low-AVG. In this case, classifications of the basis of STD yielded groups that appear more similar than the classification based on AVG.

Table 1. Descriptive statistics for biweight site chronologies for all trees (pooled) and for high-AVG and low-AVG groups of trees for five jack pine sites.

Site / Group	Sample Size	Mean	Standard Deviation	Minimum	Maximum	Cross-correlations[1] High	Cross-correlations[1] Low
FS3 / pooled	40	0.989	0.148	0.673	1.231	0.99	0.62
FS3 / high	35	0.989	0.152	0.681	1.252		0.54
FS3 / low	5	0.988	0.180	0.460	1.314		
FS6 / pooled	40	0.983	0.105	0.757	1.214	0.99	0.57
FS6 / high	34	0.984	0.107	0.782	1.199		0.46
FS6 / low	6	0.972	0.137	0.626	1.237		
FS11 / pooled	40	0.979	0.104	0.763	1.300	0.97	0.34
FS11 / high	33	0.983	0.117	0.726	1.357		0.14
FS11 / low	7	0.961	0.165	0.639	1.541		
CM2 / pooled	40	0.998	0.213	0.665	1.619	0.99	0.90
CM2 / high	30	0.994	0.215	0.648	1.616		0.86
CM2 / low	10	1.010	0.230	0.660	1.708		
CM8 / pooled	40	0.984	0.134	0.685	1.248	0.98	0.70
CM8 / high	31	0.994	0.137	0.699	1.310		0.58
CM8 / low	9	0.962	0.181	0.574	1.311		

[1]Among site chronologies for the different groups of trees

DISCUSSION AND SUMMARY

The advantage of the biweight is its efficiency in small samples, and not its optimality in large samples. With large balanced samples such as these, other statistical methods of finding mean-value site chronologies and of classification should be more efficient than the biweight approach. Large sample sizes facilitated this investigation of the weights on individual trees. In practice, sample sizes are commonly much smaller and are often unbalanced, and the biweight is a more attractive alternative in those situations.

The analysis of weights on individual trees in these samples indicated that the weight on a given tree may be large or small in a given year, and that every tree had some years with large weights and some years with small weights. There was no strong evidence for consistency in the weights for an individual tree; abrupt occurrences of relatively low weight persisted for a few years before disappearing. The test of the biweight for stratification was inconclusive. Subgroups of trees could not be conclusively differentiated on the basis of average weight or the standard deviation of weight. But the resulting chronologies sometimes suggested that the groups were composed of trees with different responses to environment.

The grouping of trees on the basis of their biweight weights was demonstrated here, but it was not a very useful interpretive tool for these stands. This may be due to the rather homogeneous sample that was used; the sampled trees were from the larger size classes in uniform, even-aged stands. The grouping techniques would be better tested with samples that are known to contain different populations, for example, in uneven-aged or mixed-species stands. The usual classification procedures are based on multivariate techniques, but they are not always efficient when the tree chronologies are of uneven length, or when the relative responses of individual trees change over time. The biweight method is applied on a year-by-year basis; it does not require the same record length of all trees, and it should perform well for stratifying more heterogeneous samples.

ACKNOWLEDGMENTS

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through Contract 68-02-4444 to ManTech Environmental Technology, Inc., it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Douglas Shadwick's helpful comments are gratefully acknowledged.

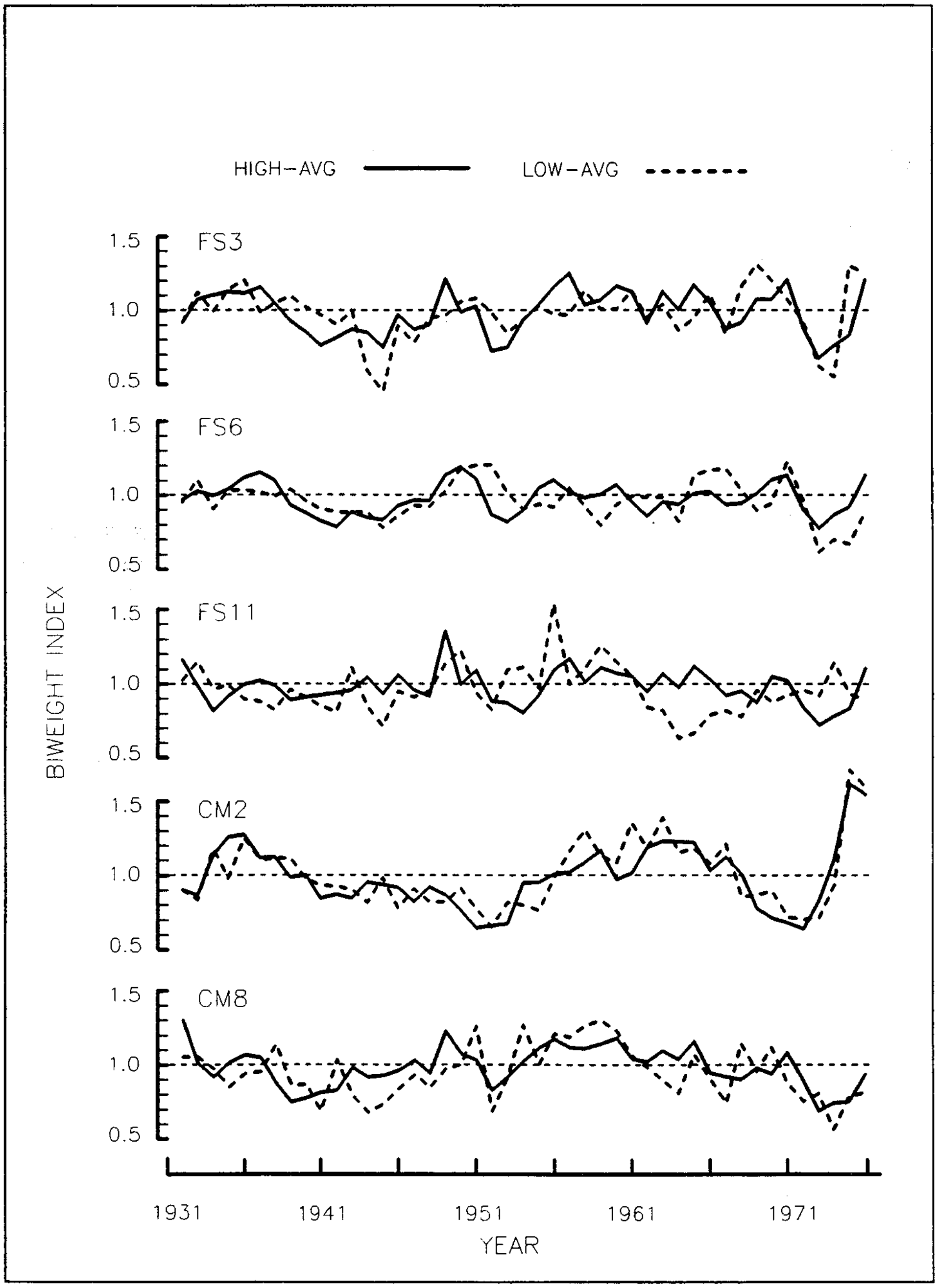

Figure 2. Biweight site chronologies for groups of high-AVG trees and low-AVG trees for five jack pine sites.

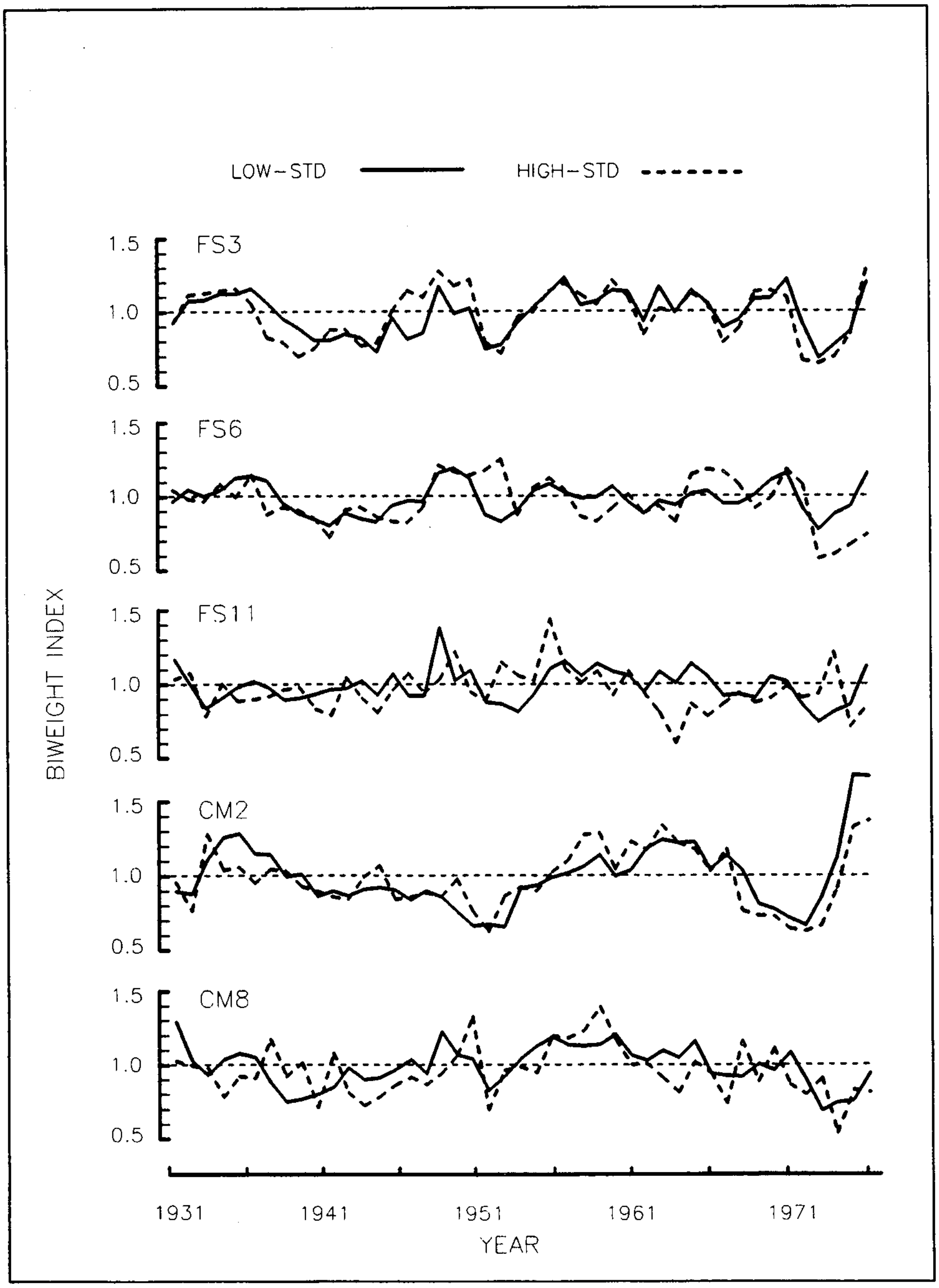

Figure 3. Biweight site chronologies for groups of high-STD trees and low-STD trees for five jack pine sites.

Table 2. Descriptive statistics for biweight site chronologies for all trees (pooled) and for high-STD and low-STD groups of trees for five jack pine sites.

Site / Group	Sample Size	Mean	Standard Deviation	Minimum	Maximum	Cross-correlations[1]	
						High	Low
FS3 / pooled	40	0.989	0.148	0.673	1.231	0.85	0.99
FS3 / high	7	0.986	0.182	0.649	1.297		0.78
FS3 / low	33	0.988	0.149	0.682	1.234		
FS6 / pooled	40	0.983	0.105	0.757	1.214	0.56	0.99
FS6 / high	5	0.967	0.164	0.578	1.254		0.45
FS6 / low	35	0.986	0.107	0.774	1.195		
FS11 / pooled	40	0.979	0.104	0.763	1.300	0.34	0.97
FS11 / high	8	0.956	0.145	0.598	1.441		0.15
FS11 / low	32	0.987	0.117	0.742	1.380		
CM2 / pooled	40	0.998	0.213	0.665	1.619	0.86	0.99
CM2 / high	9	0.983	0.202	0.628	1.373		0.80
CM2 / low	31	1.001	0.224	0.663	1.678		
CM8 / pooled	40	0.984	0.134	0.685	1.248	0.57	0.99
CM8 / high	7	0.956	0.174	0.540	1.395		0.47
CM8 / low	33	0.992	0.140	0.690	1.296		

[1]Among site chronologies for the different groups of trees.

REFERENCES

Cook, E. R.
1985 *A Time Series Analysis Approach to Tree-Ring Standardization.* Ph.D. dissertation, The University of Arizona, Tucson. University Microfilms International, Ann Arbor.

Fritts, H. C.
1976 *Tree Rings and Climate.* Academic Press, New York.

Goodall, C.
1983 M-estimators of location: an outline of the theory. In *Understanding Robust and Exploratory Data Analysis*, edited by D. C. Hoaglin, F. Mosteller, and J. W. Tukey, pp. 339-403. John Wiley and Sons, New York.

Hoaglin, D. C., F. Mosteller, and J. W. Tukey (editors)
1983 *Understanding Robust and Exploratory Data Analysis.* John Wiley and Sons, New York.

Iglewicz, B.
1983 Robust scale estimators and confidence intervals for location. In *Understanding Robust and Exploratory Data Analysis*, edited by D. C. Hoaglin, F. Mosteller, and J. W. Tukey, pp. 404-431. John Wiley and Sons, New York.

Monserud, R. A.
1986 Time-series analysis of tree-ring chronologies. *Forest Science* 32:349-372.

Mosteller, F., and J. W. Tukey
1977 *Data Analysis and Regression.* Addison-Wesley, Reading.

Riitters, K. H.
1990 A comparison of chronologies from tree rings. *Canadian Journal of Forest Research* 20:76-83.

Sweda, T., and T. Umemura
1979 *Growth of Even-Aged Jack Pine Stands.* Department of Forestry, Nagoya University, Nagoya.