## A PRACTITIONER'S GUIDE FOR USING DENDROECOLOGICAL TECHNIQUES TO DETERMINE THE EXTENT AND FREQUENCY OF AVALANCHES

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ABSTRACT: Mountain resorts, highway departments, real estate offices and others often require information on the extent and frequency of avalanches in paths that may affect values at risk, or for future planning. The general extent of an avalanche path is often obvious from vegetative indicators or terrain features. However, the frequency of large, infrequent avalanches with the potential to affect mountain operations may be unknown. The historical record or past direct observation may yield some information, but it is often unreliable and/or incomplete.

Dendroecological techniques (i.e. vegetative and tree ring analysis) can provide a means for reliably dating avalanches and calculating frequency where sufficient woody vegetation exists for sampling. Several avalanche papers describe the basis for dendroecological techniques and the methods for collecting and analyzing tree samples. No study, however, provides a comprehensive explanation of the methodology required to design, implement and conduct a dendroecological study of avalanches.

We used the Hell's Canyon avalanche path at Snowbasin, Utah, USA as a case study to present a detailed methodology for dendroecological analysis. Information is presented on avalanche path delineation, sampling design, sample collection and preparation as well as analysis, interpretation and presentation of results.

This paper is designed as a basic guide for practitioners desiring to use dendroecological techniques to date historic avalanche events.

Keywords: snow avalanches, tree-ring analyses, disturbance ecology

## 1. INTRODUCTION

Snow avalanches commonly occur in mountainous terrain of the intermountain region in the western United States (Figure 1). Like other disturbances, snow avalanches vary in kind, frequency, magnitude, intensity, and severity. Interactions between local topography, weather, and the existing snow pack structure largely influence these parameters (Fredston and Fesler 1999, Hebertson and Jenkins 2003). The complexity of these interactions inherently makes understanding avalanche occurrence difficult, especially for major avalanches that occur infrequently and/or over large spatial scales. In the absence of historical records, few methods provide a reliable means for deriving

chronologies of naturally occurring avalanches.



Figure 1. Forest damage caused by a major avalanche in Big Cottonwood Canyon, Utah, USA.

Trees respond to damage in several ways, thus providing a record of avalanche events. Dendroecological methods utilize tree-ring analyses that involve the examination of scars, reaction-wood formation, suppressed growth, and other indicators of avalanche damage to date avalanche events. Scars result from wounds to the inner bark of trees caused by snow and debris. In response to wounding, trees produce annual rings of callous tissue to seal the injured tissues. By counting the number of callous rings to the scar surface. one can derive a reliable date for the avalanche event. Severe avalanche damage also results in atypical growth responses that are reflected in tree-ring patterns. Root system disruption for example can result in the formation of relatively narrow growth rings. Trees tilted by avalanches produce a special tissue called reaction wood in an effort to regain upright growth. Years connoting the initiation of these atypical growth patterns provide a means to date avalanche events. Aging new vertical stems or sprouts can provide additional evidence of avalanche occurrence during a specific period of time (Burrows and Burrows 1976). The ability to date avalanche events allows one to calculate avalanche frequencies, return intervals, and maximum runout distances.

We have used dendroecological methods to construct avalanche chronologies in order to date avalanche events for several undocumented paths (Jenkins and Hebertson 1994, 1998, unpub. reports, Hebertson and Jenkins 2003). Mountain planners working in avalanche terrain often desire information on the methodology used for dendroecological analysis. In this paper we use a case study to illustrate how these techniques can be employed to aid planners in determination of some avalanche parameters.

#### 2. STUDY SITE

The case study was conducted in the Hell's Canyon avalanche path at Snowbasin a Sun Valley Resort in northern Utah, USA. The path is outside the patrolled and controlled resort boundary, but is being increasingly used for "yo-yo" skiing. The Snow Safety Department is interested in this path because of the need to control the terrain that will eventually be incorporated into the resort.

The path is northeast facing with a starting zone elevation of 2700 meters. The several tracks that feed into the main starting zone range in steepness between 35 and 40 degrees.

Woody plant species characteristic of the avalanche path include Douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), bigtooth maple (*Acer grandidentatum*) and quaking aspen (*Populus tremuloides*).



Figure 2. The Hell's avalanche path at Snowbasin, Utah, USA.

#### 3. METHODS

# 3.1 Avalanche path selection

Terrain and vegetative features present on topographic maps and aerial photographs can be used to approximate avalanche path boundaries. Factors to consider when determining if a path is appropriate for sampling include sufficient woody vegetation, accessibility, and the apparent absence of other disturbances, e.g., landslides, rock avalanches, fire, and timber harvesting. In addition to vegetative indicators, the location of maximum run out can also be determined using the alpha and beta relationships described in McClung and Schaerer (1993). The expected maximum extent of avalanche run out is delimited on topographic maps and aerial photographs for the sample path (Appendix 1).

#### 3.2 Sample tree selection

Focused sampling is one method of selecting sample trees within the path.

Transects are run through the flanks and terminal portions of each path perpendicular to the fall line to the maximum extent of the run out zone. Trees with avalanche scars, broken tops, flagged and new vertical stems, etc. are sampled as they are encountered along each transect. This technique is suitable for dating avalanche events that affected a particular individual tree. This method is biased since trees are not randomly selected and limited in its reliability for estimating parameters for avalanche path-wide events.

A more statistically reliable and powerful method for sample tree selection is the grid method. Sample points or locations are systematically distributed in a grid pattern superimposed on the previously delimited path boundaries (Appendix 1). In our study, we further subdivided the runout zone into lower (A), middle (B), and upper (C) areas to determine how avalanche parameters may differ between different portions of the Hell's avalanche path.

A question that often arises is what sample size (in our case, how many sample points) will allow one to estimate an avalanche parameter with a desired level of confidence. For the Hell's avalanche path, we were interested in reliably estimating the proportion of avalanche events to affect a sample point, or run out area during a given period of time. The sample size for a single proportion and other statistics such as a mean can be predetermined using simple formulas described in most statistical books (Moore and McCabe 1999). However, the desired sample size often exceeds what is practical. Based on prior work, we have found that a sample size > 30 will generally provide an acceptable level of confidence for most simple avalanche path analyses. If obtaining this sample size is still too prohibitive, we have provided an alternative method one can use to easily derive a 95% confidence interval for single proportion using Microsoft Excel<sup>®</sup> in section 3.7.

## 3.3 Sample collection

Trees can be sampled by extracting increment cores from similar heights on four sides of the tree (Figure 3). Since atypical growth responses can occur in different radii of the tree, up to four cores are taken from each sample tree, one from each cardinal location. The cores are placed in straws and labeled with tree and grid point location. Avalanche scars are sampled by cutting a wedge from the scar, or by taking a core sample using the technique described by Arno and Barrett (1988) (Figures 4A, B). Tree ages can be determined from disks that are cut from the base of a tree (Figures 5A, B). An increment core or disk can be removed from the base of new vertical stems to determine their age. Trees exhibiting evidence of damage or stress induced by agents other than snow avalanches should not be sampled.



Figure 3: Extracting an increment core.



Figure 4: (A) Sampling a tree scar (B) The scar sample that was removed.



Figure 5: (A) Using a chainsaw to remove an aspen cross section (B) Samples of aspen cross-sections.

Gaining reliable dates for avalanche events can be confounded by climate factors such as drought. Therefore, the process of cross dating is desirable. For the purpose of cross dating, samples are collected from damage-free trees growing outside the path boundaries. Cross dating involves comparing common tree-ring patterns and atypical growth responses among sample trees with a master climate plot. The master climate plot is constructed from samples extracted from damage-free conifers growing on climatically sensitive, or harsh sites in forests adjacent to avalanche paths.

## 3.4 Sample preparation

Increment core, scar, and crosssectional samples must be prepared prior to tree-ring analysis. Remove increment cores from straws and allow all samples to dry. Once dry, mount the cores using wood glue on grooved boards (Figure 6). Apply weight to the mounted cores to prevent warping until the glue dries. Be sure to label cores with sample information. All samples are then sanded using consecutively finergrained paper (60 to 200 grit) to reveal the annual growth rings (Figure 7). Many samples will have rings that can be viewed macroscopically. Viewing samples with narrow rings may require magnification. Some species especially hardwoods, e.g. aspen and maple, may need to be stained in order to view annual rings. A technique for staining rings is provided in Appendix 2.



Figure 6: Mounting increment core samples onto a grooved board with wood glue to prepare them for sanding.



Figure 7: Sanding an aspen sample to help reveal the annual growth rings.

## 3.5 Construction of chronologies

Prepared samples of each sample tree are examined for years of atypical growth responses including reaction-wood formation, narrow ring series, and scars (Figure 8). Years of potential avalanche events are determined by counting the annual rings, beginning with the outermost ring, inward to rings exhibiting the initiation of atypical growth responses or scars. Scar samples are dated by examining tree rings along one to several radii extending from the inner bark, through callous tissue to the ring corresponding to the wound face. The age of new vertical stems is determined by counting the annual rings inward to the pith.



Figure 8: Cross section of a scar sample showing various growth responses.

Avalanche event responses from samples are then graphed using a modified skeleton plot (Schroder 1978) (Appendix 3). A modified skeleton plot is drawn on graph paper (10 squares/2.54 cm) with years on the x-axis and tree identification number on the y-axis. Symbols denoting the various kinds of avalanche event responses are placed in the square corresponding to the sample and year of event initiation.

## 3.6 Dating avalanche events

Methods of cross replication are used to validate potential avalanche events for both within-tree samples and samples collected from the path. For example, an avalanche event is considered valid if scar dates and/or the initiation of atypical growth responses matched along the different radii of a sample (Figure 9). Samples that do not have sufficient event replication, or are too difficult to decipher are eliminated from further analyses.



Figure 9: Samples collected from two different trees showing reaction wood (A) and a corresponding narrow-ring series (B) both initiated in 1982.

Potential avalanche event responses are next compared with the master climate plot to eliminate atypical treering patterns such as narrow ring series, and false and missing rings caused by climate factors such as drought. Growth responses attributed to climate are disregarded as possible avalanche events. With the completion of cross dating procedures, replicated avalanche events are summed across all samples collected from a path to date avalanche years.

## <u>3.7 Determination of common avalanche</u> parameters

3.7.1 Once avalanches have been dated, a single proportion of the event responses

detected for a given sample point can be calculated using formula:

$$\hat{p} = \frac{\chi}{n}$$
(3.7.1a)

where *X* is the number of samples at that point affected, and *n* is the total number of samples collected at that point. For example, if you sampled a total of 50 points within the lower runout of an avalanche path and dated 30 event responses, the proportion would equal 30/50, or 0.60. For large sample sizes (> 30), a simple formula to derive a 95% confidence interval is

$$\hat{p} \pm 1.96 \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$

(3.7.1b)

where p is the proportion of samples affected at a sampling point, and n is the total number of samples collected at that point. In this example,

$$0.60 \pm 1.96 \sqrt{\frac{0.60(1-0.60)}{n}} =$$
$$0.60 \pm 0.135$$
(3.7.1c)

with a 95% confidence interval of (0.47, 0.74). This suggests that our estimated proportion of 0.6 falls within an acceptable range of confidence for many applications.

For small sample sizes, equation 3.7.1(b) may not be accurate. Equations for an exact method are complex (Clopper and Pearson 1934). A special function in many statistical software programs and spreadsheets, however, allows one to easily calculate an accurate confidence interval.

Using Excel for example, enter the number of points affected in cell A2. The total number of points sampled is entered in cell B2, and the value for the desired confidence level (i.e. 95%, or  $\alpha$  = 0.05) in cell C2. The lower and upper confidence limit is derived by entering the following formulas into cells D2 and E2, respectively.

LL=IF(A2=0,0,BETAINV(C2/2,A2,B2-A2+1))

UL=IF(A2=B2,1,1-BETAINV(C2/2,B2-A2,A2+1))

(3.7.1d)

For four affected sample points out of five total points, and a 95% confidence interval, the resulting Excel spreadsheet would be:

|   | Α | В | С     | D    | E   |
|---|---|---|-------|------|-----|
| 1 | # | n | alpha | LL   | UL  |
| 2 | 4 | 5 | 0.05  | 0.28 | .99 |

These formulas also provide accurate confidence limits when the number of points affected is 0, or the number of affected points equals the total number of points sampled.

3.7.2 Avalanche return intervals (RI) are calculated using the formula:

$$RI = \frac{L}{n}$$
(3.7.2)

where L is the number of years in the period of study and n is the number of avalanche events dated during L. For example if 15 avalanches were dated during a 45-year period the return interval is equal to 3 years.

3.7.3 The frequency of avalanche events is the reciprocal of the return period. In the example above, the frequency is 15/45 = 0.33.

# 4. RESULTS

We sampled trees at 20 points within the runout zone of the Hell's avalanche path. Our results illustrate the use of the techniques described above. The longest tree-ring chronology derived from the skeleton plots dated from 2003 to 1851 providing a 152-year record. Using the cross dating techniques described in section 3.6, we dated numerous avalanche years during the period of record. Avalanche years, and the proportion of samples affected in each year for areas A, B, and C within the runout zone, are given in Appendix 4. The proportions of samples affected within a given year were higher in area C (upper runout zone), and decreased lower in the runout zone. However, relatively higher proportions throughout the path were calculated during several years. These years included 1998, 1982, 1975, 1970, 1965, 1962, 1956, 1952, 1948, 1945, 1938, and 1936.

Early event responses were also evident in several tree samples corresponding to 1918, 1904, 1898, 1876, 1874, 1864, 1858, 1854, and 1851. However, the number of chronologies available for reliably dating event responses decreased significantly for years before 1940. Consequently, we derived avalanche parameters for the period of 2003 to 1940 only. Using formula 3.7.2, the avalanche return interval within area C was on average 3 years (63 years/20 avalanche years). Area B also had an avalanche return interval of about 3 years. Not surprisingly, area A had the longest return interval of 16 years.

We used formula 3.7.1(a) to estimate the proportion of event responses in area A over the past 100 years. Within area A, five sample points were affected out of a total of nine points sampled giving a proportion 0.60 (5/9). Because our sample size was small, we used the Excel procedure described in Section 3.7.1(d) to derive exact lower and upper 95% confidence limits for this proportion. The resulting confidence interval was (0.21,0.86) indicating that we could be 95% certain the actual proportion was between these values.

#### 5. DISCUSSION

One application of dating avalanche events is to make inferences about the nature and frequency of avalanche activity in paths of interest. For example, a higher proportion of event responses were observed in the upper portion of the Hell's path. A higher frequency of avalanches typically does occur in the upper portions of the path. Also more trees are available to record events due to the confined nature and reduced impact pressures typical of the upper runout zone. Because trees in the upper path often record more events they are of value for validating events occurring farther down the path.

Major avalanche years often result in region-wide avalanche event responses affecting many paths. Several years with relatively high proportions of event responses during the period of record were coincident with several major avalanche years recorded for the neighboring No Name avalanche path and other paths throughout northern Utah (Hebertson and Jenkins 2003, Jenkins and Hebertson, unpub. reports).

During the early 1900's, major avalanche events dated in Hell's, No Name and other Utah avalanche paths included 1918, 1926,1929, and 1936. The Hell's and No Name avalanche chronologies also indicated that large, generally widespread avalanche events occurred at Snowbasin during the winters 1946, 1948, 1952, 1958, 1962, 1965, and 1992. Avalanche years dated in Hell's, but not common to No Name were 1985, and 1982. These years, however, were dated in other northern Utah chronologies (Jenkins and Hebertson 1994, Hebertson and Jenkins 2003, Jenkins and Hebertson, unpub. reports).

Avalanche practitioners are often interested in maximum runout distances. In this study, we were interested in knowing whether a major avalanche event had reached area A in last 100 years. Our estimated proportion of event responses for this area was 0.60. The width of the interval however, indicates low confidence in our estimate. We do not know if the actual probability is closer to 0.21, or 0.89. Therefore, we would need to sample a greater number of points within area A to obtain a narrower confidence interval and a more precise estimate of the actual avalanche probability. Although statistical confidence for this area was low, evidence of event responses coincident with avalanche damage to woody vegetation is often sufficient to indicate maximum runout distances.

We made several other observations of interest. An event response in 1978 was evident from one point sampled in area A. This year was not evident in other areas of the path. Trees at this point may have been affected by a major avalanche that ran in the No Name avalanche path during that same year. Climate responses evident in some samples in area A (wide ring series) indicated wet years, providing some evidence consistent with avalanche years 1975, 1965, 1964, 1958, and 1936. Several samples collected from the lower Hell's runout zone indicated that an extensive forest disturbance occurred in 1904. The establishment of aspen within this area also corresponds with a major 'turn of the last century' disturbance event, however, none of the other avalanche chronologies replicated this date. This period is consistent with settlement and early logging activities in Utah including the area encompassing Snowbasin. Therefore, we did not attribute this date to an avalanche event.

We used avalanche return intervals to determine the frequency that avalanches affected various portions of the path. In areas B and C of the Hell's path, we determined that avalanches ran 680 vertical meters about once every 3 years. This is an important finding for snow safety personnel and others responsible for public safety in this terrain.

The dates of avalanche years can be used in more complex analyses. We have used dendroecological techniques to associate major avalanche years with historic climate factors for the Wasatch Plateau in central Utah (Hebertson and Jenkins 2003). We have also used these techniques to determine the effect that avalanche control has had on avalanche frequency and extent. Finally, we have attempted to correlate patterns of avalanche activity with revegetation efforts in ski resorts.

#### 6. SUMMARY

Patterns present in the tree rings of woody forest vegetation contain information on environmental factors affecting plant growth. Careful examination of tree ring samples can provide avalanche practitioners with data necessary to evaluate important avalanche path parameters. This paper provides a step-by-step approach useful for collecting, analyzing and interpreting samples in a systematic and statistically valid manner.

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Appendix 1. A map showing the Hell's avalanche path boundary and points where trees were sampled within the lower (area A), middle (area B), and upper (area C) portions of the path.

Appendix 2. Recipe for staining tree samples.

A staining solution of 1% phloroglucinol in 95% ethyl alcohol (i.e. one gram of phloroglucinol in 1000 milliliters of 95% ethyl alcohol) and a rinse solution of 50% aqueous hydrochloric acid make growth rings more distinct, facilitating the task of counting and measuring the annual rings.

Staining procedure:

- 1. Soak sample cores in phloroglucinol solution
- 2. Place cores in hydrochloric acid solution
- 3. Remove the cores from the acid solution when they begin to turn red (approximately one minute), then rinse carefully in tap water
- 4. Allow cores to dry
- 5. Examine under fluorescent light. Growth rings will become more distinct as the core samples dry

Appendix 3. A modified skeleton plot derived from tree samples collected in the upper portion of the Hell's avalanche path. Tree samples are identified on the y-axis, and year of tree-ring on the x-axis. Symbols used are UH = upper Hell's; R = reaction wood response; W = exceptionally wide ring; N = narrow ring; VN = very narrow ring; S = scar; D = dark latewood; / = a continued response. Arrows indicate cross-replicating events used for dating avalanches. For example, reaction wood and narrow ring series are evident in 2001, 1989, 1982, 1975, 1965, and 1962. A scar and reaction wood response are both evident in 1986.



| Appendix 4. Table showing years within the period of record, and the proportion of event responses for each year in the lower (A) middle (B) and upper (C) portions of the Hell's avalanche path |             |      |      |          |             |      |      |                 |             |      |                 |      |             |      |      |
|--|-------------|------|------|----------|-------------|------|------|-----------------|-------------|------|-----------------|------|-------------|------|------|
| Vr*  | $p(\Delta)$ | n(B) |      | Vr<br>Vr | $n(\Delta)$ | n(B) | p(C) | ) portice<br>Vr | $n(\Delta)$ | n(B) | p(C)            | Vr   | $p(\Delta)$ | n(B) | p(C) |
| 0000   | p(r)        |      | p(0) | 1077     | $p(\pi)$    |      | p(0) | 4054            | p(r)        |      | $p(\mathbf{O})$ | 4005 | p(r)        |      | p(0) |
| 2003   | 0.0         | 0.0  | 0.0  | 19//     | 0.0         | 0.0  | 0.0  | 1951            | 0.0         | 0.0  | 0.0             | 1925 | 0.0         | 0.0  | 0.0  |
| 2002   | 0.0         | 0.0  | 0.0  | 1976     | 0.0         | 0.0  | 0.0  | 1950            | 0.0         | 0.0  | .60             | 1924 | 0.0         | 0.0  | 0.0  |
| 2001   | 0.0         | .10  | .43  | 1975     | 0.0         | .29  | .60  | 1949            | 0.0         | 0.0  | 0.0             | 1923 | 0.0         | 0.0  | 0.0  |
| 2000   | 0.0         | 0.0  | 0.0  | 1974     | 0.0         | 0.0  | 0.0  | 1948            | .13         | .75  | .80             | 1922 | 0.0         | 0.0  | 0.0  |
| 1999   | 0.0         | 0.0  | 0.0  | 1973     | 0.0         | 0.0  | 0.0  | 1947            | 0.0         | 0.0  | 0.0             | 1921 | 0.0         | 0.0  | 0.0  |
| 1998   | 0.0         | .40  | .50  | 1972     | 0.0         | 0.0  | 0.0  | 1946            | 0.0         | 0.0  | 0.0             | 1920 | 0.0         | 0.0  | 0.0  |
| 1997   | 0.0         | 0.0  | 0.0  | 1971     | 0.0         | 0.0  | 0.0  | 1945            | 0.0         | .50  | .40             | 1919 | 0.0         | 0.0  | 0.0  |
| 1996   | 0.0         | 0.0  | 0.0  | 1970     | 0.0         | .43  | .40  | 1944            | 0.0         | 0.0  | 0.0             | 1918 | .33         | .10  | 0.0  |
| 1995   | 0.0         | 0.0  | 0.0  | 1969     | 0.0         | 0.0  | 0.0  | 1943            | 0.0         | 0.0  | 0.0             | 1917 | 0.0         | 0.0  | 0.0  |
| 1994   | 0.0         | 0.0  | 0.0  | 1968     | 0.0         | .43  | 0.0  | 1942            | 0.0         | .66  | 0.0             | 1916 | 0.0         | 0.0  | 0.0  |
| 1993   | 0.0         | .10  | .29  | 1967     | 0.0         | 0.0  | 0.0  | 1941            | 0.0         | 0.0  | 0.0             | 1915 | 0.0         | 0.0  | 0.0  |
| 1992   | 0.0         | .20  | .29  | 1966     | 0.0         | 0.0  | 0.0  | 1940            | 0.0         | 0.0  | 0.0             | 1914 | 0.0         | 0.0  | 0.0  |
| 1991   | 0.0         | 0.0  | 0.0  | 1965     | 0.0         | .83  | .60  | 1939            | 0.0         | 0.0  | 0.0             | 1913 | 0.0         | 0.0  | 0.0  |
| 1990   | 0.0         | 0.0  | 0.0  | 1964     | 0.0         | 0.0  | 0.0  | 1938            | 0.0         | .50  | .10             | 1912 | 0.0         | 0.0  | 0.0  |
| 1989   | 0.0         | 0.0  | 0.0  | 1963     | 0.0         | 0.0  | .40  | 1937            | 0.0         | 0.0  | 0.0             | 1911 | 0.0         | 0.0  | 0.0  |
| 1988   | 0.0         | 0.0  | 0.0  | 1962     | .10         | .50  | .20  | 1936            | 0.0         | .50  | .30             | 1910 | 0.0         | 0.0  | 0.0  |
| 1987   | 0.0         | 0.0  | 0.0  | 1961     | 0.0         | 0.0  | 0.0  | 1935            | 0.0         | 0.0  | 0.0             | 1909 | .60         | 0.0  | 0.0  |
| 1986   | 0.0         | 0.0  | .29  | 1960     | 0.0         | 0.0  | 0.0  | 1934            | 0.0         | 0.0  | 0.0             | 1908 | 0.0         | 0.0  | 0.0  |
| 1985   | 0.0         | .22  | .29  | 1959     | 0.0         | 0.0  | 0.0  | 1933            | 0.0         | 0.0  | 0.0             | 1907 | 0.0         | 0.0  | 0.0  |
| 1984   | 0.0         | .10  | .13  | 1958     | 0.0         | .33  | 0.0  | 1932            | 0.0         | .10  | 0.0             | 1906 | 0.0         | 0.0  | 0.0  |
| 1983   | 0.0         | 0.0  | 0.0  | 1957     | 0.0         | 0.0  | 0.0  | 1931            | 0.0         | .10  | 0.0             | 1905 | 0.0         | 0.0  | 0.0  |
| 1982   | 0.0         | .33  | .50  | 1956     | .11         | .17  | .20  | 1930            | 0.0         | 0.0  | 0.0             | 1904 | 1.0         | .10  | 0.0  |
| 1981   | 0.0         | 0.0  | 0.0  | 1955     | 0.0         | 0.0  | 0.0  | 1929            | .57         | 0.0  | 0.0             | 1903 | 0.0         | 0.0  | 0.0  |
| 1980   | 0.0         | .43  | 0.0  | 1954     | 0.0         | 0.0  | 0.0  | 1928            | 0.0         | 0.0  | 0.0             | 1902 | 0.0         | 0.0  | 0.0  |
| 1979   | 0.0         | 0.0  | 0.0  | 1953     | 0.0         | 0.0  | 0.0  | 1927            | 0.0         | 0.0  | 0.0             | 1901 | 0.0         | 0.0  | .10  |
| 1978   | .36         | 0.0  | 0.0  | 1952     | .38         | .83  | .40  | 1926            | 0.0         | .10  | 0.0             | 1900 | 0.0         | 0.0  | 0.0  |
| *Yr = vear: $p(A)$ = proportion in area A: $p(B)$ = proportion area B: $p(C)$ = proportion area C.   |             |      |      |          |             |      |      |                 |             |      |                 |      |             |      |      |