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## Effects of drought on the growth of young and mature temperate forests in West Virginia

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**Effects of Drought on the Growth of Young and  
Mature Temperate Forests in West Virginia**

**Nicholas R. Doner**

**Thesis Submitted to the College of Arts and Sciences  
at West Virginia University  
in Partial Fulfillment of the Requirements for  
the Degree of**

**Master of Arts in Geography**

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**Morgantown, West Virginia  
2004**

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Aboveground Net Primary Productivity, Drought**

## **ABSTRACT**

### **Effects of Drought on the Growth of Young and Mature Temperate Forests in West Virginia**

**Nicholas R. Doner**

Recent research suggests that the temperate deciduous forests of the eastern United States may have played a significant role in the sequestration of atmospheric carbon dioxide over the last 100 years. However, little is known about the role of forest management and climatic variability on the productivity of these forests. The purpose of this study was to determine the variation in aboveground production between two different aged forest stands and to evaluate the effect of drought on inter-annual variation in productivity. Aboveground net primary production (ANPP) was compared with precipitation and the Palmer Drought Severity Index to determine the effects of drought on aboveground productivity. I found that: 1) there was a significant difference in rates of ANPP between the two watersheds due to age; 2) drought conditions reduce the rate of aboveground productivity; and 3) the reduction of aboveground productivity was significantly related to species-specific factors; thus the productivity of some temperate species may be affected more by drought than others.

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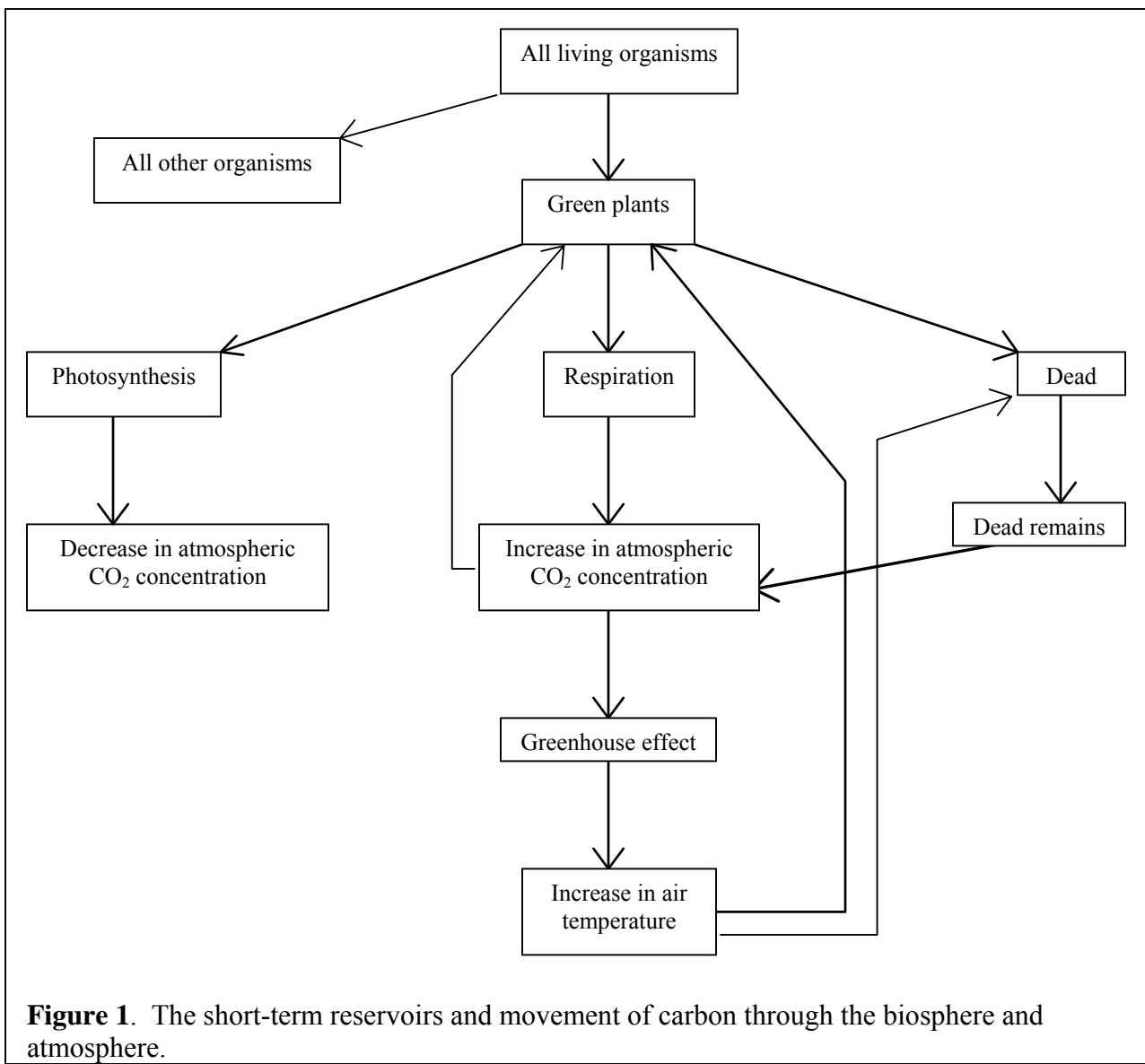
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## INTRODUCTION

Atmospheric carbon dioxide concentrations have increased approximately 30% over the last 200 years due to the combustion of fossil fuels (Ciais *et al.*, 2000; IPCC, 2001). However, atmospheric carbon dioxide is just one component of a complex carbon cycle, which includes living organisms, as well as dead organisms, carbonates, and fossil fuels (Schlesinger, 1997) (Figure 1).



**Figure 1.** The short-term reservoirs and movement of carbon through the biosphere and atmosphere.

An important aspect of the carbon cycle is the fact that living organisms are partly composed of carbon. Through photosynthesis, trees and other plants remove carbon dioxide from the atmosphere, and as a result, have the potential to decrease the concentration of atmospheric carbon dioxide. Therefore, vegetation and especially forest biomes play an integral role in the sequestration of carbon, via carbon dioxide (DeLucia *et al.*, 1999; Harmon, 2001). However, while plants can remove carbon dioxide from the atmosphere, they also release carbon dioxide back into the atmosphere through respiration, as well as decomposition via microbes. This in turn can enhance the greenhouse effect, potentially increasing air temperature and altering other climatic variables.

Terrestrial vegetation accounts for the third largest carbon pool ( $5.6 \times 10^{17}$  g C; 1.4% of total) of the total active global carbon cycle/budget ( $\approx 4.0 \times 10^{19}$  g C), with the atmospheric pool ( $7.5 \times 10^{17}$  g C; 1.9%) and the oceanic pool ( $3.8 \times 10^{19}$  g C; 95%) being larger (Schlesinger, 1997). Forests cover roughly 28% of Earth's terrestrial surface and have higher net primary production than other terrestrial vegetation types (Carey *et al.*, 2001). However, forests have the potential to store more carbon than they already do through increasing the size of forested area and carefully selecting the management system(s) used (Harmon, 2001). Enhanced forest growth is important because it helps sequester carbon dioxide, thereby offsetting some of the emissions due to human activity (Moffat, 1998). Exploiting this potential is one of several proposed strategies to temporarily slow the increase of atmospheric carbon dioxide concentrations (Harmon, 2001).

The temperate deciduous forests of the eastern United States are the largest assemblage of deciduous tree species found anywhere in the world, and may be a significant carbon sink. Modeling of atmospheric carbon dioxide suggests that forests of the United States may play a

disproportionate role in removing carbon from the atmosphere (Schimel *et al.*, 2000; Goodale *et al.*, 2002). Ciais *et al.* (2000) found that the largest biospheric sink ( $2.1 \times 10^{15}$  g C/yr) is in the middle to high latitudes in the northern hemisphere. In addition, Ciais *et al.* (2000) indirectly determined the net carbon sink(s) over North America were  $5-6 \times 10^{14}$  g C/yr. One explanation for this large sink lies in the temperate deciduous forests of the eastern U.S. that were clear-cut more than once in the last 300 years. Since the last major timbering period, eastern deciduous forests may have sequestered more atmospheric carbon dioxide due to re-growth (Goulden *et al.*, 1996). In addition to long term increases in sequestration due to forest re-growth, inter-annual climatic variations on seasonal time scales may modify annual carbon dioxide exchange and capture (Goulden *et al.*, 1996)

Many climatic factors may affect tree growth, and by extension carbon sequestration, in eastern deciduous forests. Persistent above average tree growth in old growth oak forests in the Blue Ridge Mountains appears to be associated with wetter than average conditions (Abrams *et al.* 1997). Similarly, increment growth was reduced by 23% due to drought in deciduous forests in Kentucky, with canopy trees more strongly affected than understory trees (Liu and Muller 1993). In southern Quebec, major growth declines in *Acer saccharum* are triggered by drought, but exacerbated by insects and disease (Payette *et al.* 1996). *Prunus serotina*, *Quercus rubra*, *Fraxinus americana*, and *Liriodendron tulipifera*, in the Fernow Experimental Forest, West Virginia, show positive growth responses to rainfall of prior summer, autumn, and current summer (Pan *et al.* 1997). In summary, both heavy precipitation and drought during and prior to the growing season may have major effects on radial growth. However, these studies focused on radial growth, and did not consider how radial growth translates into productivity or carbon storage.

In addition to precipitation, tree age may influence rates of carbon sequestration in forests. Previous research concluded that old growth forests were carbon sources because: 1) tree growth declines with age and 2) respiration in older trees uses more photosynthate, therefore, trees cannot accumulate carbon as biomass (Odum, 1969; Odum, 1971; Carey *et al.*, 2001). As a result, many believe that young forests are optimal for sequestering carbon because they are growing faster than older forests (Harmon, 2001). In addition, older forests have more dead trees and higher rates of decomposition; so, they should release more carbon than younger forests. While older forests do have more dead and decaying material, production tends to offset losses (Harmon 2001). Replacing old forests by young, fast-growing trees following clear-cutting could in fact, result in a net release of carbon into the atmosphere due to a carbon “legacy” - coarse woody debris that continues to decay while young forests grow. Most of the work that has supported these conclusions is based on research in the Pacific Northwest, dominated by evergreen needleleaf forests with moist maritime climatic conditions (Cohen and Harmon, 1996; Law *et al.*, 2001). Additional research is required to determine whether these conclusions apply to the moist deciduous broadleaf forests of the eastern United States. Additional research is also needed that addresses temporal, spatial, and climatic aspects of forest growth to develop a better understanding of NPP in the world’s forests; ecosystems that play a major role in the global carbon budget (Clark *et al.*, 2001).

## OBJECTIVES

The purpose of this study is to determine the differences in productivity by young and mature forests, the differences in productivity between major temperate deciduous tree species, and the effects of drought in the productivity of different aged temperate forests. I hypothesize the following:

### Hypothesis I:

- **H<sub>0</sub>:** Young forests will have higher rates of aboveground productivity than mature forests.  
**H<sub>1</sub>:** Mature forests will have higher rates of aboveground productivity than young forests.

### Hypothesis II:

- **H<sub>0</sub>:** Drought event(s) will not affect the aboveground net primary production in different aged watersheds differentially.  
**H<sub>1</sub>:** Drought event(s) will reduce the aboveground net primary production in different aged watersheds differentially.

### Hypothesis III:

- **H<sub>0</sub>:** Drought will not affect the productivity of temperate tree species differently.  
**H<sub>1</sub>:** Drought will affect the productivity of temperate tree species differently, such that, species that prefer moist habitats will be affected more.

## BACKGROUND

### Measuring Growth (Aboveground Net Primary Production/Carbon Sequestration) in Forests

Net primary production (NPP) is gross primary production minus plant respiration or the formation of plant tissues and reserve substances during a given period (Newbould, 1967). Thus,

$$P_n = P_g - R$$

where  $P_n$  is the net primary production,  $P_g$  is the gross primary production, and  $R$  is plant respiration (Hall *et al.*, 1993). Because of the difficulty in measuring biomass in forested vegetation, forest NPP cannot be directly measured. Instead several indirect measuring techniques have been developed in order to estimate the NPP of forested ecosystems. The sum of aboveground biomass increment and fine litterfall are considered equivalent to aboveground net primary productivity (ANPP). Quite often though, forest ANPP is underestimated because branchfall and leaf litter, or litterfall, is not taken into account in allometric equations (Clark *et al.*, 2001).

Two widely accepted methods of sampling, increment cores and trunk discs, are used to obtain aboveground biomass increment measurements for individual trees. Increment cores, taken at breast height (1.37 m) yield annual rings that are measured and then converted to biomass increments via allometric equations (Phipps, 1985; Clark *et al.*, 2001; Fritts, 2001). Alternatively, an entire disc or partial disc of the tree's trunk can be collected to measure annual increment growth (Newbould, 1967). If the tree is alive and the complete destruction of the tree is not wanted, or needed, a tree stump or a solid log from the remains of a nearby tree can be used to obtain a viable disc for measurement (Newbould, 1967; Stokes and Smiley, 1996). As

with increment cores, the annual rings are measured and then converted to biomass increments via allometric equations (Clark *et al.*, 2001; Fritts, 2001).

### Dendrochronology

In order to calculate yearly biomass and ANPP, it is crucial to correctly measure the size and characteristics of each tree ring. Dendrochronology is the science that deals with the dating and study of annual growth rings in wood (Schweingruber, 1993; Fritts, 2001). While many have restricted the term to dating events, the application of dendrochronology to biological, environmental, and climatic phenomena, such as tree growth, productivity, and drought, has become increasingly useful (Fritts, 2001). In general, tree ring widths respond to varying environmental conditions, including climate (Schweingruber, 1993; Fritts, 2001). Tree rings can be matched with the corresponding annual and seasonal climatic information, such as precipitation and temperature, in order to determine the effects of different climatic phenomena on tree growth (Fritts, 2001). Appalachian forests appear to be especially responsive to drought conditions. For example, *Pinus strobus* in the southern Appalachian Mountains responded to a severe drought period with a substantial decrease in annual radial increment (Clinton *et al.*, 1997). Following drought episodes, trees in northern Virginia exhibited growth reductions lasting two to three years, with some species showing reductions lasting up to six years (Orwig and Abrams, 1997). Overall, *Quercus alba* was the only species that experienced statistically significant growth reductions associated with drought years. Other species studied (*Liriodendron tulipifera*, *Carya glabra*, *Nyssa sylvatica*, *Pinus virginiana*, and *Quercus velutina*) experienced growth reductions associated with drought years, but these variations in growth were not significant to the same degree. These results indicate that tree species in West Virginia may be

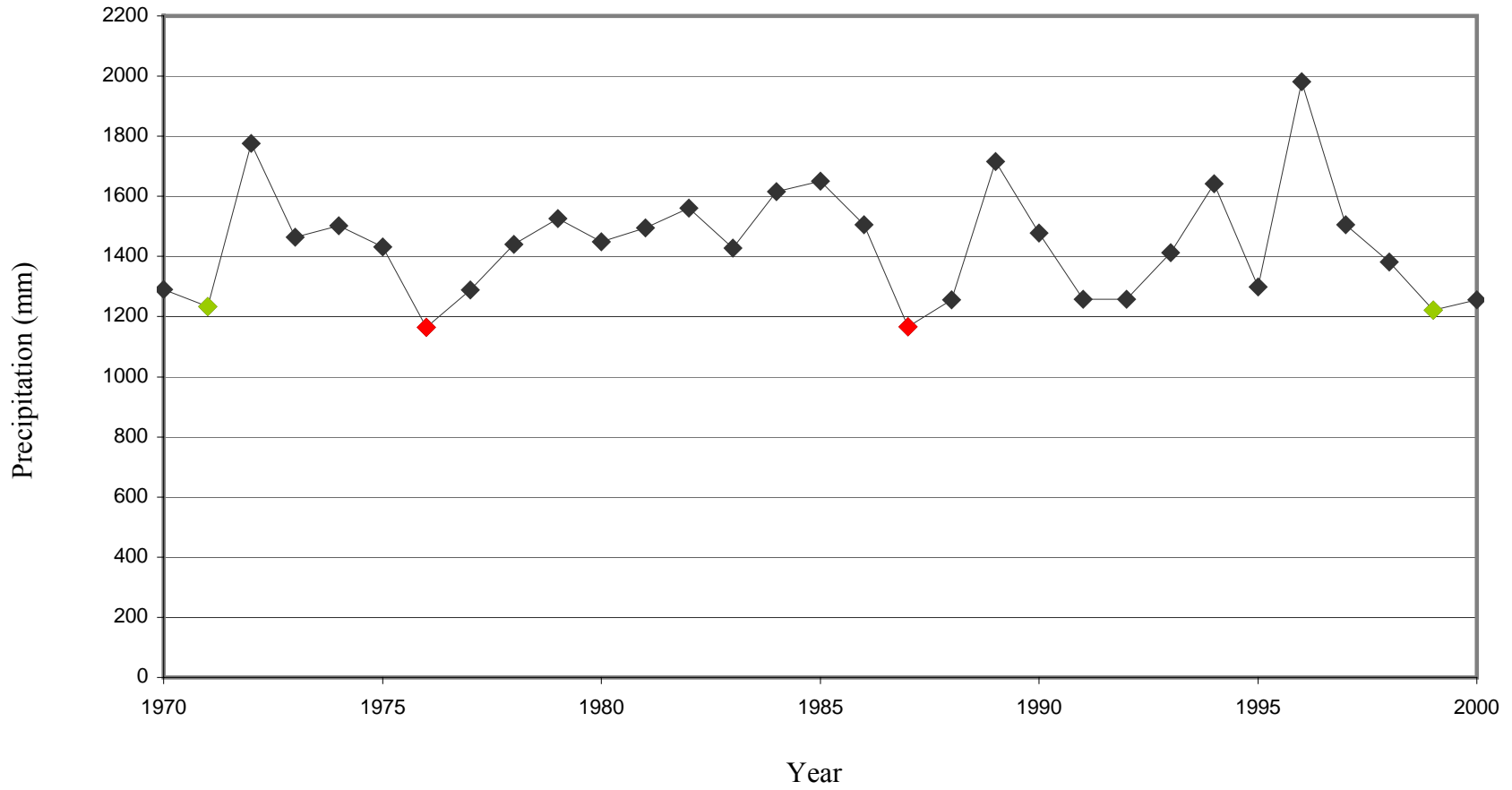


responsive to drought and that the ANPP of West Virginia forests may also be similarly related to climatic variability.

### Drought and PDSI

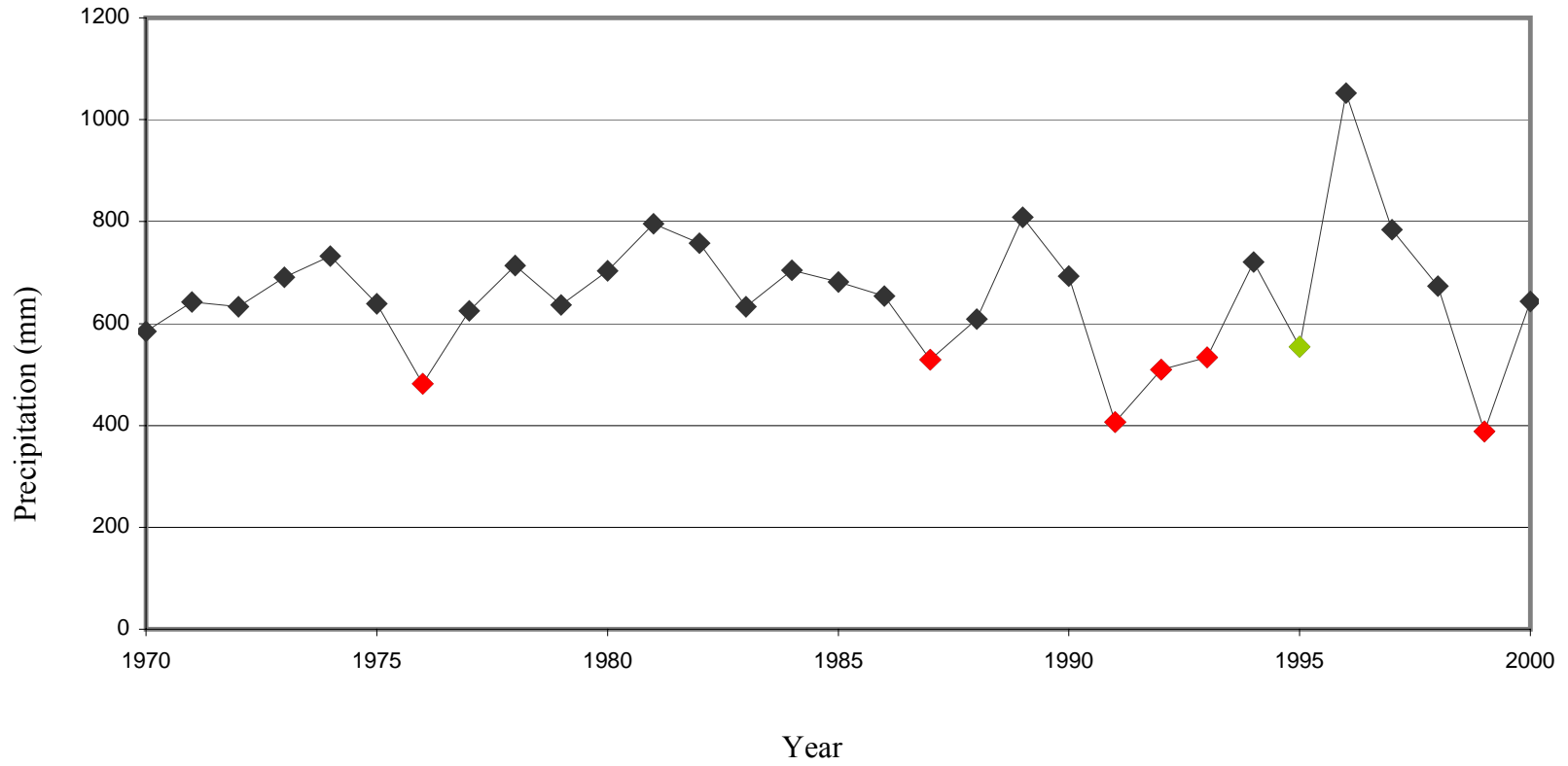
A key factor affecting tree growth at a regional scale in the eastern United States is drought (Liu and Muller, 1993). Palmer defined a drought period as “an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given time rather consistently falls short of the climatically expected or climatically appropriate moisture supply” (Palmer, 1965; Alley, 1984). It is important to remember that droughts are, by nature, regional phenomena (Alley, 1984). For the eastern region of the United States a deficit of 15% or greater over a six to twelve month period is considered a drought (Weather Forecast Office Pittsburgh, 2002). Several droughts of this magnitude have occurred in the last 30 years (Figures 2 and 3).

Fernow Experimental Forest Precipitation Data (1970-2000) WS7



**Figure 2.** Fernow Experimental Forest total annual precipitation (1970-2000) with full-drought (red diamonds), partial-drought (green diamonds), and non-drought (gray diamonds) years plotted.

Fernow Experimental Forest Growing Season Precipitation Data (1970-2000) WS7



**Figure 3.** Fernow Experimental Forest growing season (May-September) precipitation (1970-2000) with full-drought (red diamonds), partial-drought (green diamonds), and non-drought (gray diamonds) years plotted.

The Palmer Drought Severity Index (PDSI) is a widely used index that addresses two of the most elusive properties of droughts, their intensity and their duration (Alley, 1984) (Table 1). Palmer developed the PDSI as a means of measuring the severity of drought using a water-balance model, enabling him to develop his index at the regional level. In doing so, the PDSI has several advantages: 1) it can be applied throughout the U.S. (with some modifications for snow and/or frozen ground) and 2) it considers both precipitation and temperature and their combined influences on evapotranspiration, soil moisture and runoff. On the other hand, the PDSI has several disadvantages: 1) simulation of runoff by a water balance model is quite unreliable and difficult to determine; 2) measurement of variables that go into the PDSI index are problematic, due to the difficulty and indirectness of measurement; and 3) not enough information is known about the relationships between the simulated variables and the actual physical conditions.

**Table 1.** Palmer classes for wet and dry periods (Palmer, 1965).

| <b>Palmer Drought Severity Index Value</b> | <b>Class</b>        |
|--|---------------------|
| ≥ 4.00                                     | Extremely wet       |
| 3.00 to 3.99                               | Very wet            |
| 2.00 to 2.99                               | Moderately wet      |
| 1.00 to 1.99                               | Slightly wet        |
| 0.50 to 0.99                               | Incipient wet spell |
| 0.49 to -0.49                              | Near normal         |
| -0.50 to -0.99                             | Incipient drought   |
| -1.00 to -1.99                             | Mild drought        |
| -2.00 to -2.99                             | Moderate drought    |
| -3.00 to -3.99                             | Severe drought      |
| ≤ -4.00                                    | Extreme drought     |

1970-1995 PDSI Values (Cook *et al.*, 1999) Cell 135

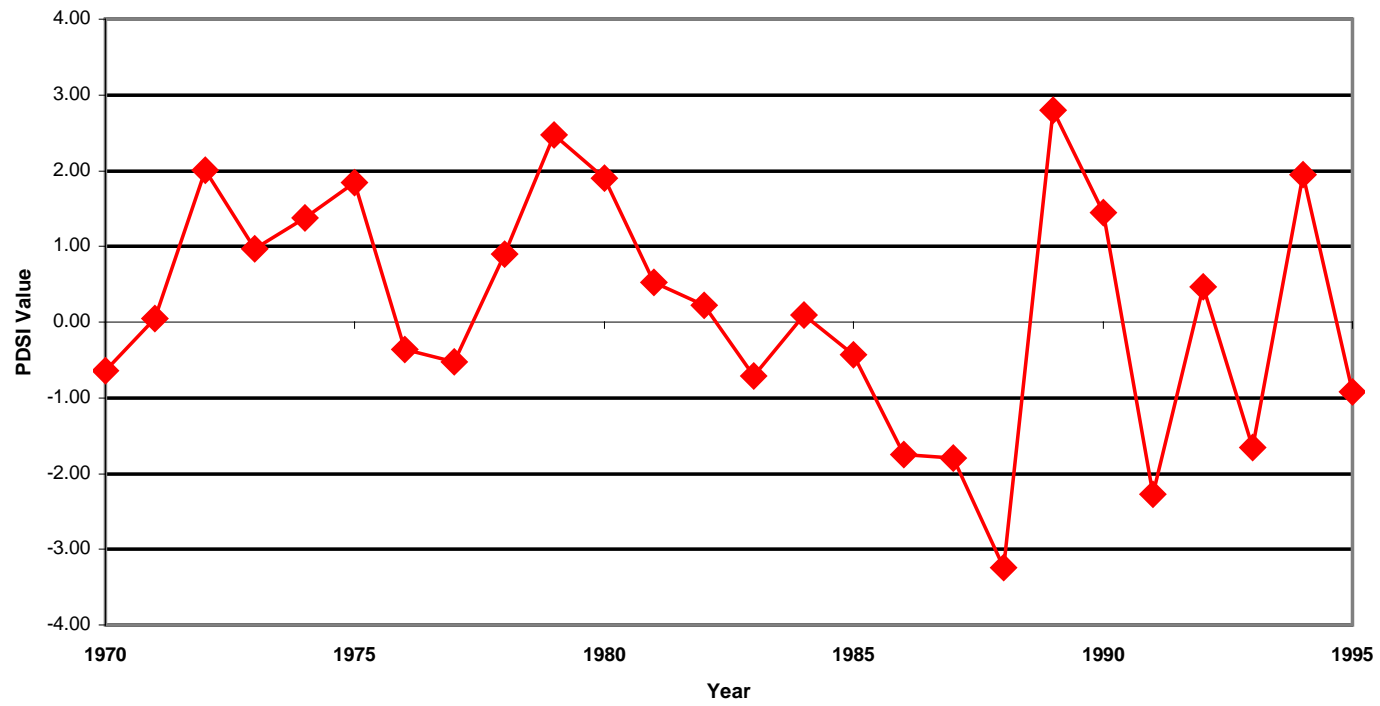


Figure 4. 1970-1995 PDSI values (grid point135) (Cook *et al.*, 1999).

## METHODS

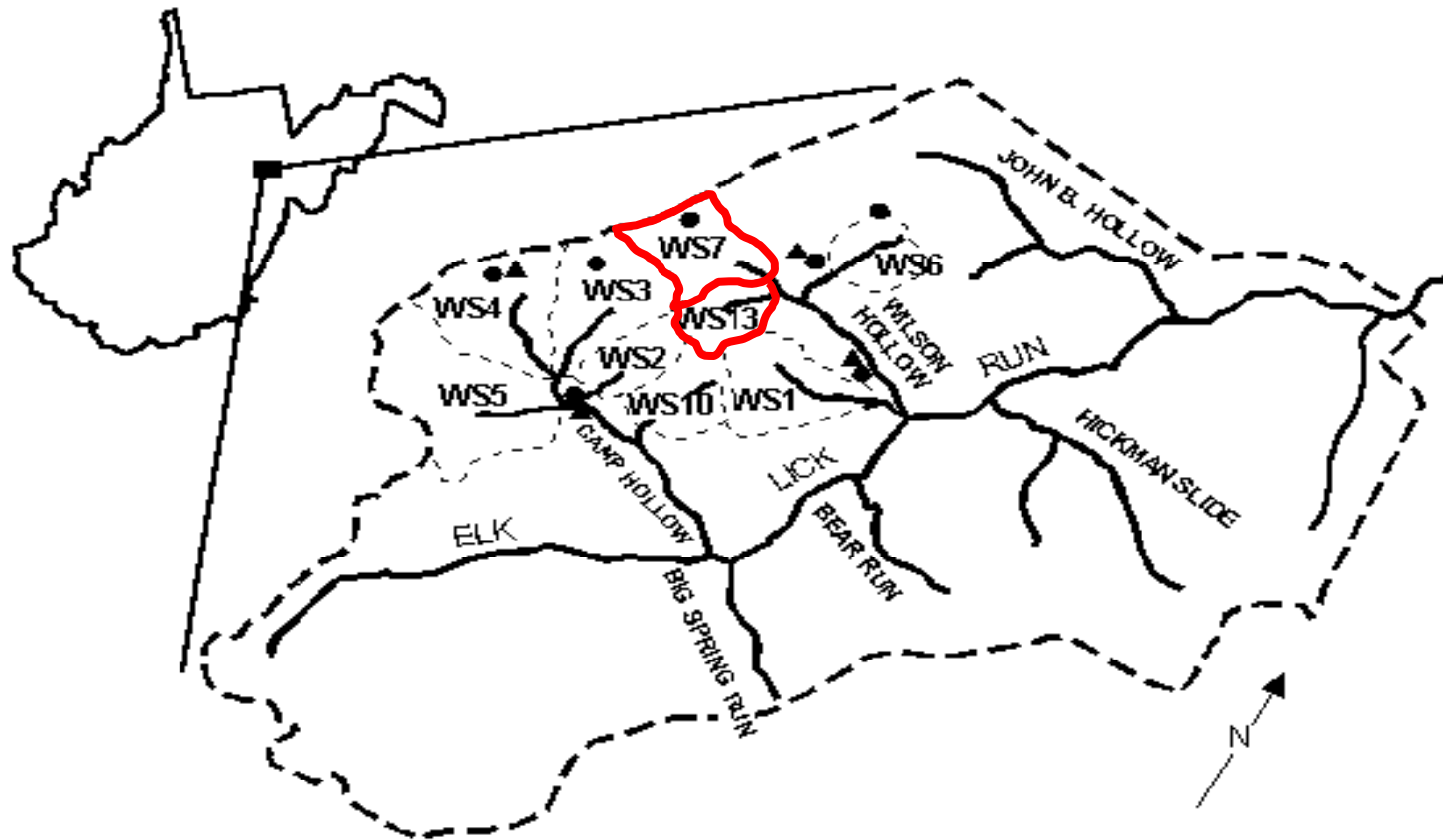
### Study Sites

The study was conducted in two watersheds (watershed 7 and watershed 13) in the Fernow Experimental Forest, near Parsons, West Virginia (Table 2 and Figure 5). The Fernow Experimental Forest is part of the Monongahela National Forest, and is located at 39° 05' N, 79° 41' W (Adams *et al.*, 1994).

**Table 2.** Physical and ecological characteristics of watershed 7 and watershed 13 (Adams *et al.*, 1994).

| <b>Attribute</b>          | <b>Watershed 7</b>   | <b>Watershed 13</b>  |
|---------------------------|--|--|
| <b>Size</b>               | 24.23 ha   | 14.23 ha   |
| <b>Elevation</b>          | 729-857 m  | 715-808 m  |
| <b>Aspect</b>             | Eastern  | North-northeastern   |
| <b>Management History</b> | Clear-cut in two phases (1963-1964 and 1966-1967), left barren with herbicides until 1969, then released | No clear-cut or treatment since the early part of the 20 <sup>th</sup> century |
| <b>Dominant trees</b>     | BELE, LITU, PRSE*  | ACSA, FAGR, QURU   |
| <b>Age of trees</b>       | ≤ 30 years old; even aged stand  | ≤ 90 years old, uneven aged stand  |
| <b>Simpson index</b>      | 0.166  | 0.292  |
| <b>Shannon index</b>      | 2.087  | 1.610  |

\*Tree species and abbreviations are located in Appendix A.



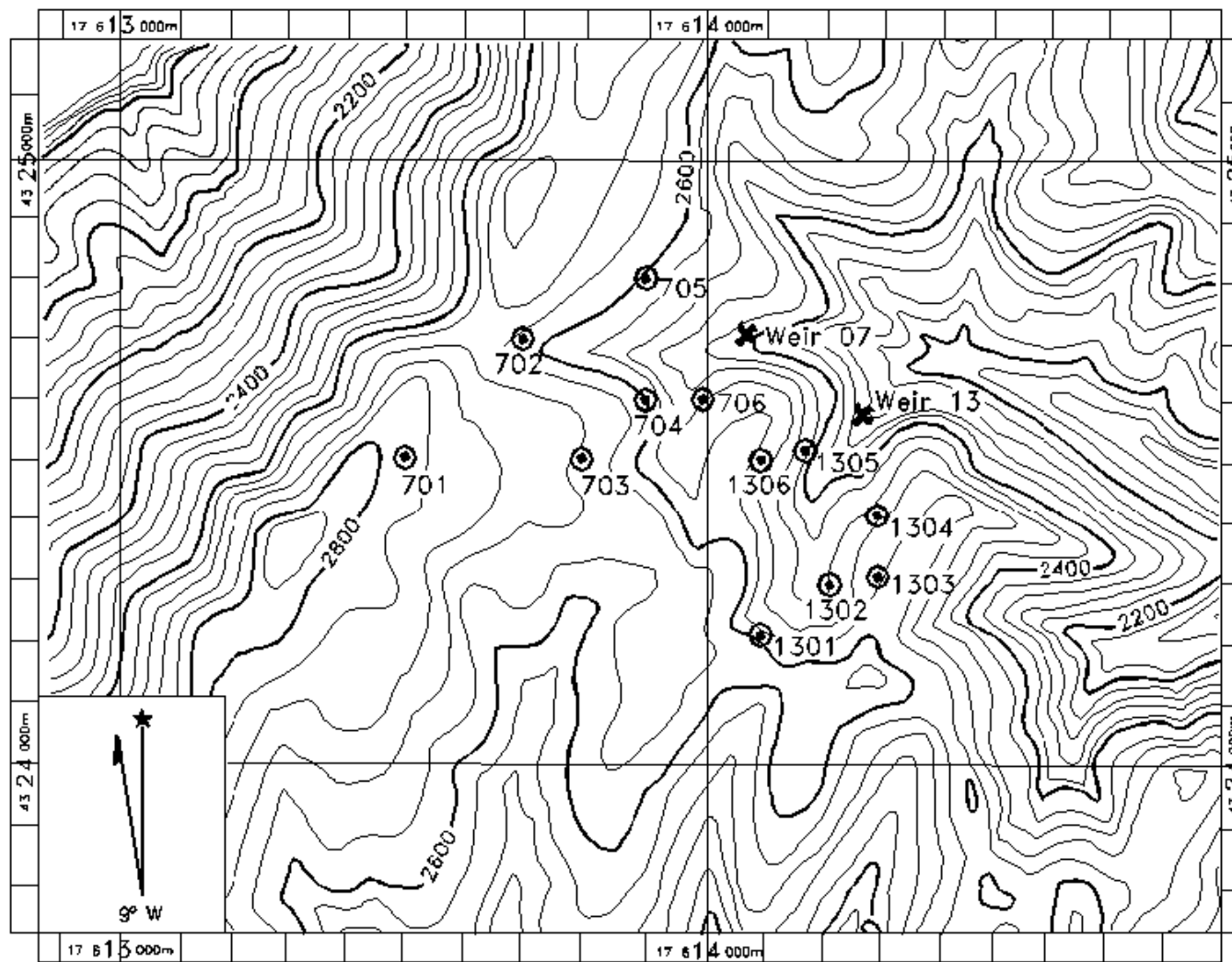
**Figure 5.** Locations of watershed 7 (WS 7) and watershed 13 (WS 13) in relation to one another and other watersheds at the Fernow Experimental Forest, Parsons, West Virginia (Adams *et al.*, 1994).

The climate of the two watersheds is moderate, with a mean annual precipitation of 1421 mm from 1957-2000 (Adams *et al.*, 1994). In general, precipitation is distributed relatively evenly throughout the year, however, March through August have the greatest amount of precipitation. The average January temperature range is -1°C to 5°C, while the average July temperature is 25°C. The soils in both watersheds are relatively thin (<1 m in depth), acidic, sandy-loam Inceptisols of the Berks and Calvin series (Gilliam *et al.*, 1995). The soil texture is on average roughly 67% sand, 11% clay, and 22% silt. Species richness and evenness were calculated using Simpson and Shannon indices to examine the possibly different species diversities and relative abundances of different species between the two watersheds (Schuler and Gillespie, 2000). These indices confirmed that the younger watershed is less species rich and even than the mature watershed (Table 2).

#### Field Methods

Six plots were established in each watershed, for a total of 12 study plots (Figure 6) (Table 3). Each plot was randomly chosen based on a 100 m x 100 m grid system, and located in the field using a GPS unit. A 10 m radius circle was then established at each selected grid intersection. All trees with a dbh (diameter at 1.37 m) greater than 5 cm were included in a tree inventory. Tree species, dbh, tree height, crown height, and status (live or dead) for each tree were recorded (Appendix F). Two increment cores were taken from each tree at breast height (1.37 m). Each core was given an identification number and transported back to the laboratory for analysis. The increment boring was performed using standard tree-ring methods that do not harm the living tree (Stokes and Smiley, 1996).





**Figure 6.** Location of the 12 study plots (circles) in watershed 7 and watershed 13 (distances expressed in UTM).

**Table 3.** Aspect, slope, and elevation position for the 12 plots in watershed 7 and watershed 13.

| <b>Plot</b> | <b>Aspect (°)</b> | <b>Slope (%)</b> | <b>Topographic Position</b> |
|-------------|-------------------|------------------|-----------------------------|
| <b>1301</b> | 29                | 50               | ridge-top                   |
| <b>1302</b> | 286               | 33               | mid-slope                   |
| <b>1303</b> | 350               | 18               | valley                      |
| <b>1304</b> | 327               | 18               | mid-slope                   |
| <b>1305</b> | 118               | 35               | mid-slope                   |
| <b>1306</b> | 319               | 20               | ridge-top                   |
| <b>701</b>  | 75                | 8                | ridge-top                   |
| <b>702</b>  | 51                | 10               | valley                      |
| <b>703</b>  | 99                | 13               | mid-slope                   |
| <b>704</b>  | 94                | 16               | mid-slope                   |
| <b>705</b>  | 166               | 18               | mid-slope                   |
| <b>706</b>  | 319               | 25               | valley                      |

#### Laboratory Preparation

Each increment core was prepared for measurement by mounting and then sanding, beginning with coarse-grit sandpaper (100-grit) and then using finer-grit sandpaper until 400-grit sandpaper was used to finish the smoothing process. Crossdating using skeleton plotting and marker years was attempted on the mature watershed's cores. With a maximum of 30 years of increment growth, the young watershed's cores were too short to be crossdated with confidence. Following measurement and subsequent crosschecking with COFECHA, a method of quality control on measured ring-widths, crossdating of the mature watershed's cores did not appear to be better than ring counting due to a lack of marker years. Approximately 10% of the increment cores were recounted to determine whether errors had been made in ring counting. It was concluded that the measurements and ring counts were correct, therefore, only "ring counting," is used to describe the corresponding year for each tree ring in both watersheds.

### Biomass/Net Primary Productivity Calculations

Tree species classification, dbh, bark coefficients, and ring measurements were used in combination with allometric equations (Brenneman *et al.* 1978), to calculate yearly biomass estimates for 1970-2002. Yearly diameters were calculated using:

$$D_{t-1} = \frac{[D_t - (1 - B_s) * D_t - 2 * R_t]}{B_s}$$

where D is the dbh at a given time (t or t-1),  $B_s$  is the bark coefficient for a given species, and  $R_t$  is the ring width at time t. Yearly biomass values were calculated using species-specific equations (when applicable) or a general hardwood equation (Appendices B, E, F, and G).

From the individual aboveground tree biomass estimates, approximations of ANPP were calculated using:

$$B_t - B_{t-1} = A$$

where  $B_t$  is the biomass for year t,  $B_{t-1}$  is the biomass for the previous year, and A is the ANPP excluding litterfall. If a tree had more than one increment core, the annual ANPP of all cores was averaged after the calculations. Basal areas for each plot were calculated, using the following equation, to examine possible relationships to variability of plot ANPP:

$$TBA = \pi r^2$$

where TBA is the total basal area of a living tree and r is the radius of the tree at breast height (dbh/2).

### Litterfall

Litterfall data was collected to examine the possible yearly patterns associated with drought years, as well as to determine if Brenneman *et al.* (1978) was correct in using an across-the-board 5% deduction for litterfall, using trees with ages ranging from 37 to 80 years, in his allometric equations used here. Two litterfall collection containers (each 0.23 m<sup>2</sup>) were placed at

each study plot to determine the amount of biomass released through litterfall by the standing trees throughout the year. Litterfall was collected every two weeks from September 6, 2002, to November 16, 2002, to ensure that little to no decomposition occurred (Clark *et al.*, 2001). Collection containers that had been turned over were repositioned in order to collect litterfall. Plot 703 litterfall collection containers were stolen midway through litterfall collection. Subsequently, the litterfall collection containers were replaced, and the time period (three weeks) of data was lost. After collection, litterfall was dried and then separated by species. Litterfall that could not be identified to species, as well as twigs and bare stems, were placed into an unknown/misc. category. After drying and separation, the litterfall was weighed (Table 5b). The plot total was then calculated by summing the species totals from both baskets and then extrapolating to the total plot area (Appendix D).

Litterfall weights were also obtained for 1991-2002 by the Fernow staff (Table 5a) (Fernow Experimental Forest, 2003) from five existing 1m<sup>2</sup> litterfall traps located near my newly established plots. This close proximity allowed comparisons between their measurements and my measurements (Adams *et al.*, 1995). Fernow litterfall data was collected, dried, and weighed multiple times throughout the fall season. Only the total weight for each collection basket was recorded, thus there was no separation by species.

#### Precipitation Data

Total annual and growing-season precipitation from the Fernow Experimental Forest was summarized from daily precipitation data for 1970-2000 (Adams *et al.*, 1994; Fernow Experimental Forest, 2003). Years or growing-seasons with a 15% or more decrease in precipitation from the 30-year growing-season average were considered drought years (Figures 2

and 3). Additional drought information included annual instrumental Palmer Drought Severity Index data for grid point 135, located at 39°00'N, 80°30'W (Figure 4) (Cook *et al.*, 1999).

### Statistical Analysis

The ANPP estimates were compared with annual and growing-season (May - September) precipitation data using a variety of statistical techniques. To determine whether there is a significant difference in ANPP of young versus mature watersheds, I used an ANOVA (Hypothesis I). An analysis of covariance (ANCOVA) was used to determine whether there is a difference in drought's effect on the aboveground productivity of young versus mature watersheds (Hypothesis II). An analysis of covariance (ANCOVA) was used to identify whether there are species-specific effects of drought on productivity (Hypothesis III). For both hypotheses II and III, two sets of ANCOVAs were performed to determine if there is a possible lag time between amount of precipitation and ANPP (*sensu* Orwig and Abrams 1997).

## RESULTS

### Tree Survey

Of the 404 trees surveyed, 110 living trees were sampled in the mature watershed and 206 living trees were sampled in the young watershed, for a total of 316 living trees. There were 21 different species present, however most of the living trees (83.5%) consisted of only six species (Table 4 and Appendix C). Summary of the ring width data between the two watersheds demonstrates that trees in the young watershed have larger average ring widths than trees in the mature watershed (Table 5).

**Table 4.** Frequency of tree species sampled in watershed 7 and watershed 13.

| Species      | Total # | WS 7 # (%) | WS 13 # (%) | Total % |
|--------------|---------|------------|-------------|---------|
| <b>ACSA</b>  | 73      | 23 (11.2)  | 50 (45.5)   | 23.1    |
| <b>BELE</b>  | 61      | 61 (29.6)  | 0 (0.0)     | 19.3    |
| <b>FAGR</b>  | 39      | 11 (5.3)   | 28 (25.5)   | 12.3    |
| <b>LITU</b>  | 39      | 38 (18.4)  | 1 (0.9)     | 12.3    |
| <b>PRSE</b>  | 30      | 30 (14.6)  | 0 (0.0)     | 9.5     |
| <b>QURU</b>  | 22      | 8 (3.9)    | 14 (12.7)   | 7.0     |
| <b>Other</b> | 52      | 35 (17.0)  | 17 (15.5)   | 16.5    |
| <b>Total</b> | 316     | 206        | 110         | 100.0   |

**Table 5.** Summary of ring width measurements for watershed 7 and watershed 13 expressed in cm.

| Species                | WS 7<br>(Average) | WS 7<br>(Standard<br>deviation) | WS 13<br>(Average) | WS 13<br>(Standard<br>deviation) |
|------------------------|-------------------|---------------------------------|--------------------|----------------------------------|
| <b>ACSA</b>            | 0.149             | 0.069                           | 0.110              | 0.061                            |
| <b>BELE</b>            | 0.230             | 0.076                           | -----              | -----                            |
| <b>FAGR</b>            | 0.224             | 0.150                           | 0.088              | 0.050                            |
| <b>LITU</b>            | 0.394             | 0.149                           | 0.246              | -----                            |
| <b>Whole watershed</b> | 0.263             | 0.132                           | 0.130              | 0.085                            |

## Litterfall

Average weight of the litterfall collected in the two watersheds reflects little difference with regards to the maturity of the trees in watershed 13 and the high tree density found in watershed 7. If the assumption was made that plot 703, which experienced a loss of data, litterfall was similar to the overall numbers found throughout the remaining plots, then the total watershed weights among the two watersheds would be relatively similar. Thus, leaf production and subsequent litterfall appear to be similar with little to no substantial difference due to stand age. Furthermore, litterfall weights taken for 2002 are greater than the 12-year Fernow average, however, similar weights can be observed several times throughout the 12-year collection history provided by the Fernow staff (Table 6 and Appendix D). Litterfall production appears to decrease substantially, by up to 25%, during drought episodes, such as 1997. On the other hand, a substantial increase in precipitation does not necessarily mean that more litterfall will be produced; such is the case in 1994 and 1996. Litterfall weights were compared to the 2002 biomass calculations for each watershed. This work demonstrated that Brenneman *et al.* (1978) was incorrect in using an across-the-board 5% deduction for litterfall in his allometric equations. A more reliable value for litterfall relative to total biomass would be 2-5% for mature forests and 12-15% for young forests. However, my results do not fully go against Brenneman *et al.*'s (1978) work. The ages of the trees examined ranged from 37 to 80 years, with the overall average of 63 years (Brenneman *et al.*, 1978). Thus, Brenneman *et al.* (1978) only examined mature trees, where a 5% deduction was a reliable value to use.

**Table 6.** Summary of litterfall weight for the Fernow from 1991-2002 for selected collection baskets in watershed 7, expressed in kg/ha/year (a), and for 2002 in newly established collection baskets in watershed 7 and watershed 13, expressed in kg/ha/year (b).

(a)

| Collection # | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 12-Year Average |
|--------------|------|------|------|------|------|------|------|------|------|------|------|------|-----------------|
| 56           | 2935 | 3180 | 2828 | 2778 | 2763 | 2511 | 1878 | 2326 | 2337 | 3163 | 3092 | 2785 | 2715            |
| 60           | 3081 | 2789 | 2956 | 3300 | 3202 | 2750 | 1949 | 2554 | 2968 | 3452 | 3414 | 3022 | 2953            |
| 69           | 2358 | 2685 | 1817 | 1927 | 2095 | 2081 | 1755 | 1792 | 1838 | 1754 | 2697 | 2178 | 2081            |
| 72           | 2321 | 2204 | 2192 | 2014 | 2268 | 2488 | 1762 | 1775 | 2209 | 1612 | 3369 | 2079 | 2191            |
| 74           | 2323 | 2251 | 2500 | 2149 | 2361 | 2064 | 1548 | 1904 | 1728 | 1649 | 2281 | 2068 | 2069            |

(b)

| Plot  | 2002   |
|-------|--------|
| 701   | 3288   |
| 702   | 3688   |
| 703   | 1298*  |
| 704   | 3284   |
| 705   | 1384   |
| 706   | 2964   |
| 1301  | 3760   |
| 1302  | 1644   |
| 1303  | 3520   |
| 1304  | 3398   |
| 1305  | 3936   |
| 1306  | 3130   |
| WS 7  | 2922** |
| WS 13 | 3231   |

\*Three weeks of litterfall data during the fall was lost due to stolen collection baskets.

\*\*Average was calculated excluding plot 703.

### Productivity

There were a total of 738 increment cores taken from live and dead trees in both watersheds. 41 increment cores were rotten or unreadable, thus 697 increment cores were

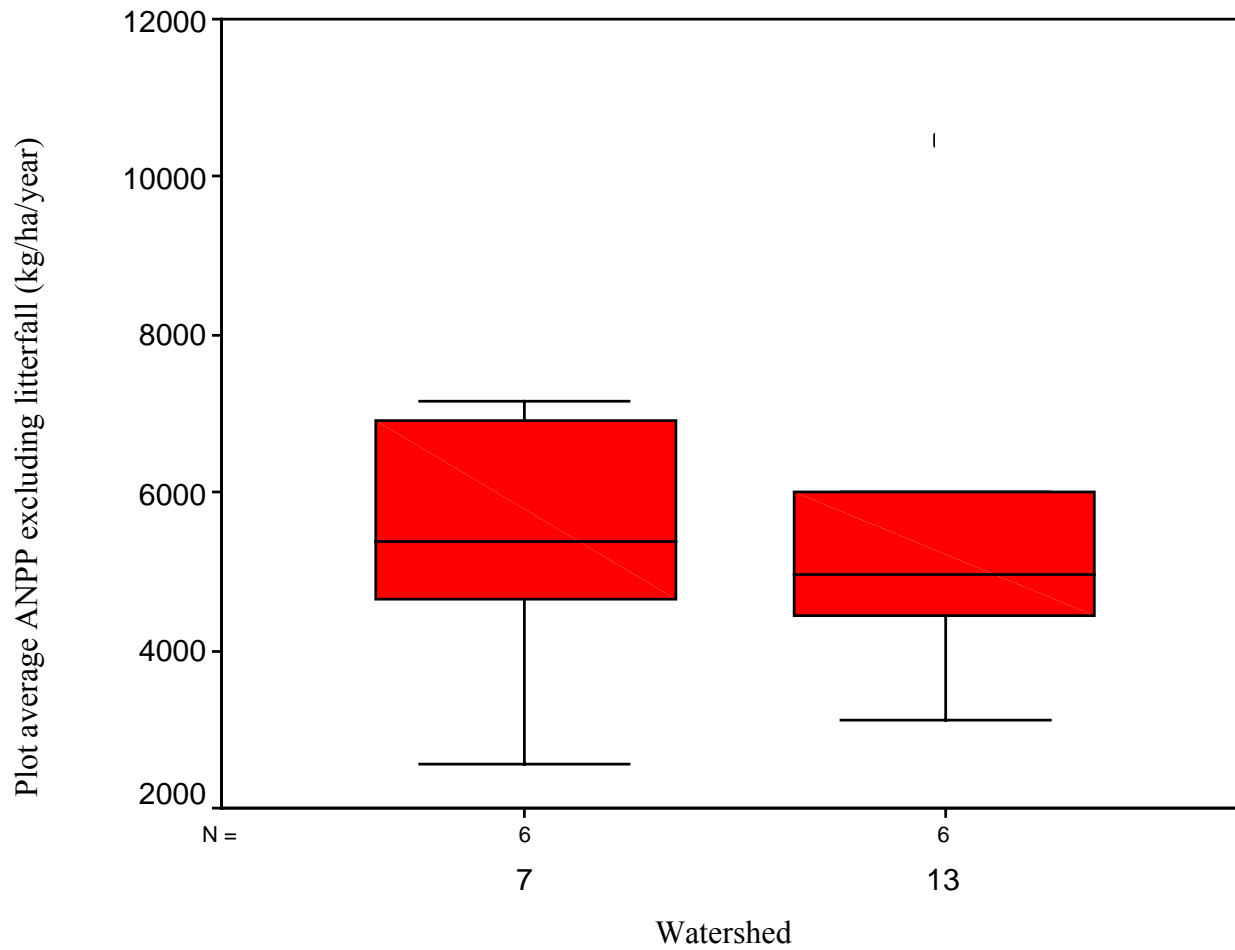


measured. However all dead tree increment cores were removed from ANPP calculations due to crossdating problems.

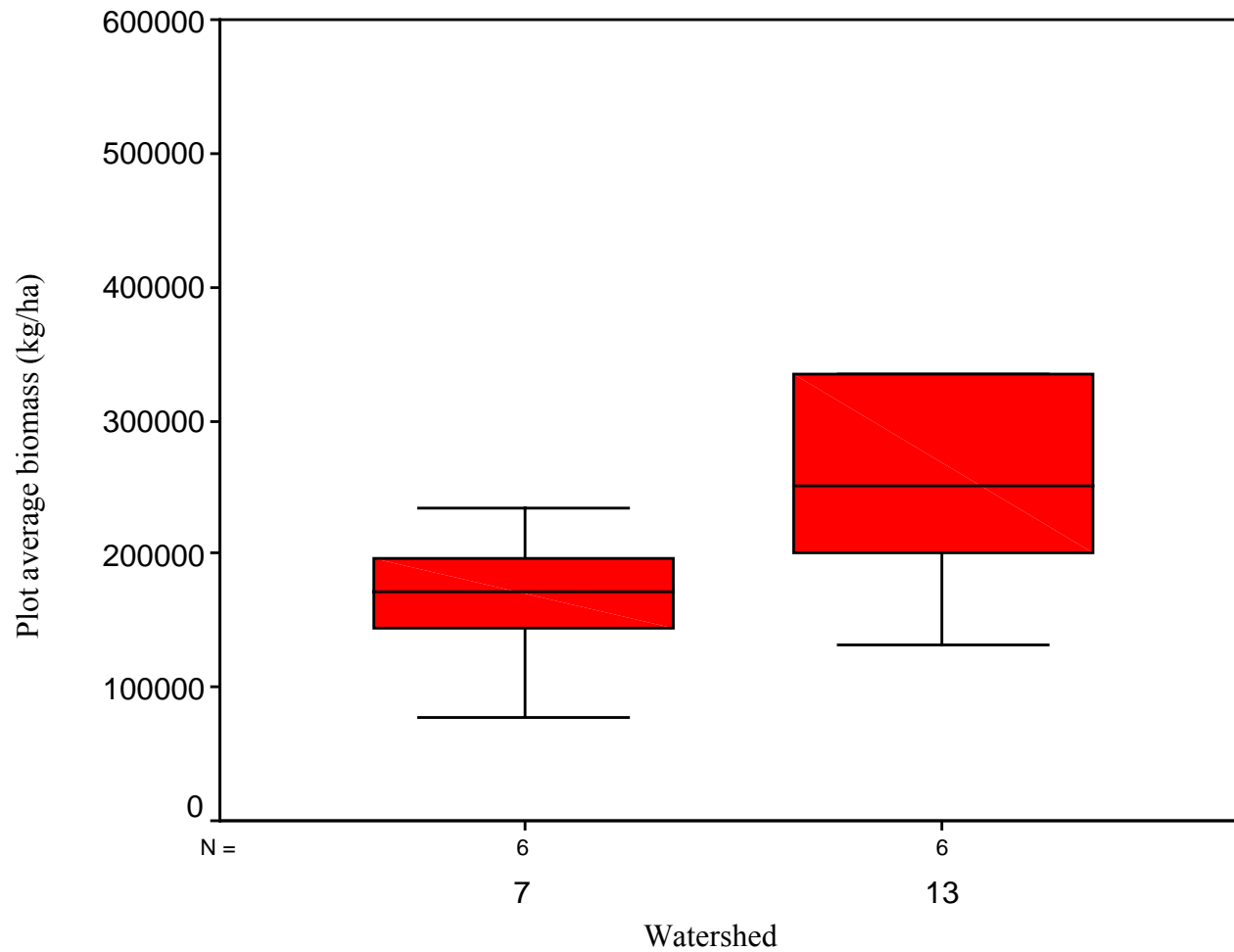
During the 1971-2001 time period, the mature watershed's plots had greater mean ANPP than the young watershed's plots due to the larger size (height and diameter) of the trees in the mature watershed and lower ANPP values of the young watershed during the beginning years of its re-vegetation (Table 7). However, towards the later part of the 30-year period examined, the ANPP values of the young watershed were greater than observed values in the mature watershed, thus the mean ANPP, appears to be similar in value. The mature watershed's plots also have higher mean biomass compared to the young watershed's plots. However, great variability was also found among plots in the same watershed, especially the young watershed, which had more ANPP outliers (Figures 7 and 8).

**Table 7.** Mean ANPP excluding litterfall (1971-2001) expressed in kg/ha/year, and biomass (2002) for plots in watershed 7 and watershed 13 expressed in kg/ha.

|              | <b>Mean ANPP (kg/ha/yr)</b> | <b>Standard deviation ANPP (kg/ha/yr)</b> | <b>Mean biomass (kg/ha)</b> | <b>Standard deviation biomass (kg/ha)</b> |
|--------------|-----------------------------|---|-----------------------------|---|
| <b>WS 7</b>  | 5344.7                      | 1681.6                                    | 166163.2                    | 53194.3                                   |
| <b>WS 13</b> | 5655.1                      | 2546.9                                    | 287454.6                    | 149202.3                                  |



**Figure 7.** Box plots of plot average ANPP excluding litterfall (kg/ha/year) for watershed 7 and watershed 13 for 1971-2001, with the middle line showing the median.

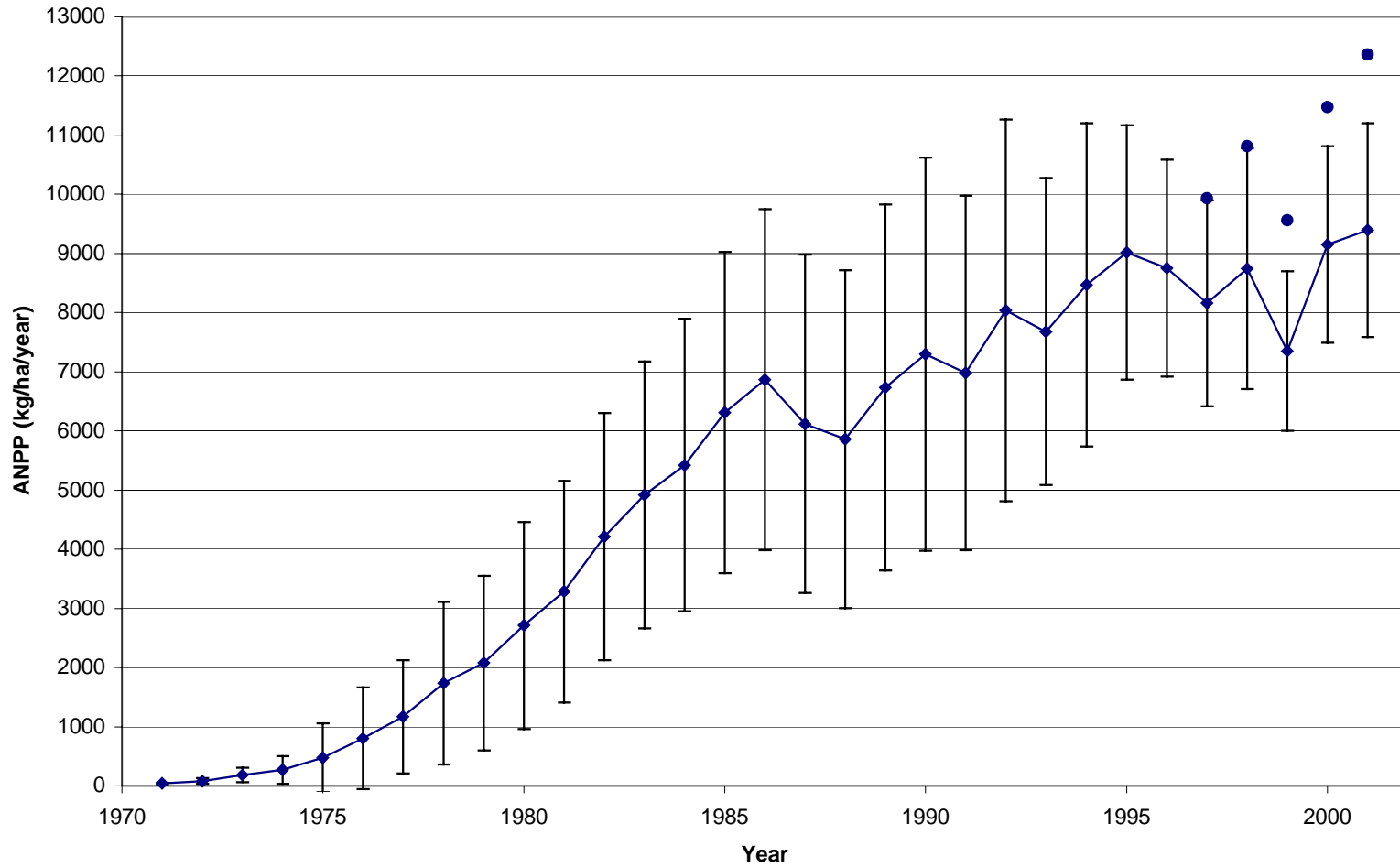


**Figure 8.** Box plots of plot average biomass (kg/ha) for watershed 7 and watershed 13 for 2002, with the middle line showing the median.

Substantial differences in the pattern of aboveground ANPP (kg/plot) for 1971-2001 in the two watersheds were found. The young watershed demonstrated increasing ANPP of a re-vegetating area as the number of trees and size of existing trees increased over time (Figure 9). In contrast, the mature watershed demonstrated a “leveled off” pattern of aboveground ANPP typical of a forested area that has reached a later stage of succession (Figure 10).

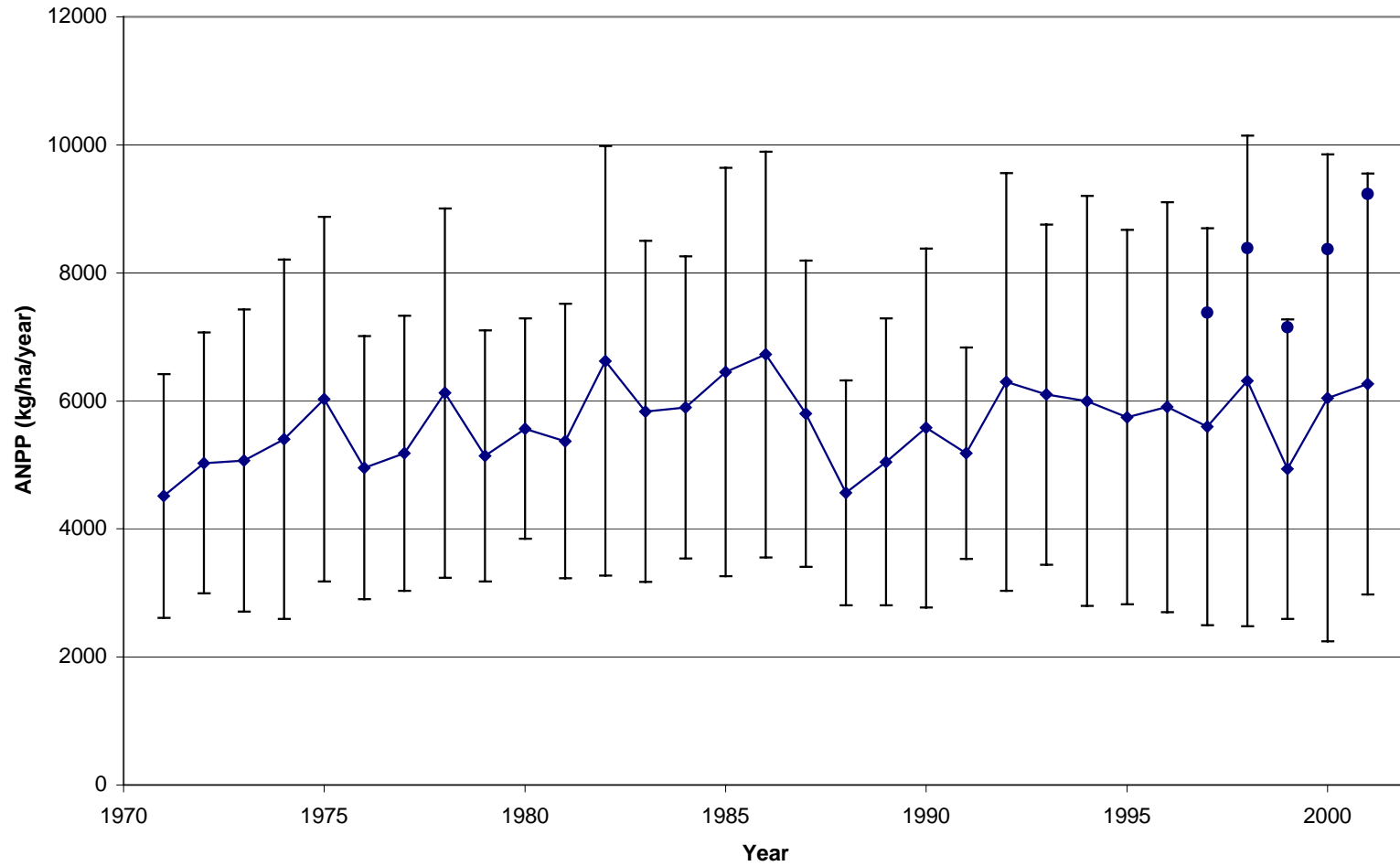
There was a substantial drop of ANPP in 1987, 1999 (both watersheds), and 1976 (watershed 13). These drops in ANPP coincided with corresponding drops in total annual precipitation and growing season precipitation (Figures 9 and 10). However, changes in ANPP only occurred with considerable decreases in precipitation, otherwise, precipitation (total annual precipitation, growing season precipitation, and PDSI) did not correlate well with ANPP. For the 1970-1995 time period, plots 701, 703 and 706 were only weakly negatively correlated with PDSI data ( $R = -0.381$ ,  $P = 0.066$ ;  $R = -0.45$ ,  $P = 0.099$ ; and  $R = -0.370$ ,  $P = 0.069$ , respectively). Furthermore, no plots were significantly correlated with total annual precipitation and only plot 1305 was significantly, but negatively, correlated with growing season precipitation ( $R = -0.373$ ,  $P = 0.043$ ) (Table 8a). While the general pattern of correlation was weak, the correlation between ANPP and precipitation did become stronger when examining the longer time period (1957-2000) available with data from the mature watershed. For the mature watershed, correlations were most significant when examining the relationship between ANPP and growing season precipitation. Plots 1302, 1304, and 1306 were all found to be correlated with growing season precipitation ( $R = 0.288$ ,  $P = 0.058$ ;  $R = 0.309$ ,  $P = 0.041$ ; and  $R = 0.308$ ,  $P = 0.042$  respectively), while plot 1306 was also found to be weakly correlated with annual total precipitation ( $R = 0.253$ ,  $P = 0.098$ ) (Table 8b).

WS7



**Figure 9.** ANPP excluding litterfall (kg/ha/year) for watershed 7 (1971-2001) with diamonds showing estimated values, standard deviations bars; circles showing the estimated values including litterfall collected by the Fernow staff (WS 7).

### WS13



**Figure 10.** ANPP excluding litterfall (kg/ha/year) for watershed 13 (1971-2001) with diamonds showing estimated values, standard deviations bars; circles showing the estimated values including litterfall collected by the Fernow staff (WS 7).

**Table 8.** Pearson correlation coefficients (r) for the mean annual ANPP for each plot and total annual precipitation, growing season precipitation, and PDSI values for the 1971-1995 time period (a), and for the 1957-2000 time period (b).

(a)

| Plot | Correlation to Annual Precipitation | Correlation to Growing Season Precipitation | Correlation to PDSI values |
|------|-------------------------------------|---|----------------------------|
| 701  | -0.050                              | 0.040                                       | -0.381**                   |
| 702  | -0.012                              | 0.029                                       | -0.239                     |
| 703  | 0.061                               | 0.049                                       | -0.345**                   |
| 704  | 0.063                               | 0.023                                       | -0.327                     |
| 705  | 0.079                               | -0.016                                      | -0.357                     |
| 706  | 0.041                               | -0.045                                      | -0.370**                   |
| 1301 | 0.166                               | 0.155                                       | -0.217                     |
| 1302 | 0.159                               | 0.109                                       | 0.047                      |
| 1303 | 0.021                               | -0.041                                      | -0.181                     |
| 1304 | 0.271                               | 0.294                                       | 0.090                      |
| 1305 | -0.155                              | -0.373*                                     | -0.199                     |
| 1306 | 0.206                               | 0.249                                       | 0.041                      |

(b)

| Plot | Correlation to Annual Precipitation | Correlation to Growing Season Precipitation |
|------|-------------------------------------|---|
| 1301 | 0.137                               | 0.195                                       |
| 1302 | 0.231                               | 0.288**                                     |
| 1303 | 0.122                               | 0.157                                       |
| 1304 | 0.240                               | 0.309*                                      |
| 1305 | 0.009                               | 0.027                                       |
| 1306 | 0.253**                             | 0.308*                                      |

\* Significant at the  $\alpha = 0.05$ .

\*\* Significant at the  $\alpha = 0.10$ .

Closer examination of each watershed, on the individual plot level, demonstrated that the declines of ANPP during drought events are also found to occur over the time period of the study. Each plot, with the exception of plot 1305, showed noteworthy decreases during the drought year of 1999, however, this appearance of a relation is not consistent with the correlation results. This is also apparent, but not as noteworthy, in the drought year of 1987.

In watershed 7, each plot, with the exception of plot 702, has similar growth curves. In the case of plot 702, located in a topographic depression, growth was slow until 1990 after which trees grew at a greater rate (Figure 11). Two anomalies can be found in watershed 13. Plot 1305 acts counter to the norm throughout the entire study period when drought years occur (Figure 12). The most probable reason for this anomaly is the aspect of 1305, which is 118°, or roughly ESE, which would effect the microclimate of the plot. Plot 1306, on the other hand, follows the norm, however at a much higher level of ANPP. After calculation of basal area, it is most likely that the existence of several extremely large individual trees gives plot 1306 a higher basal area, as well as a higher rate of ANPP (Figures 11 and 12) (Table 9).



WS7

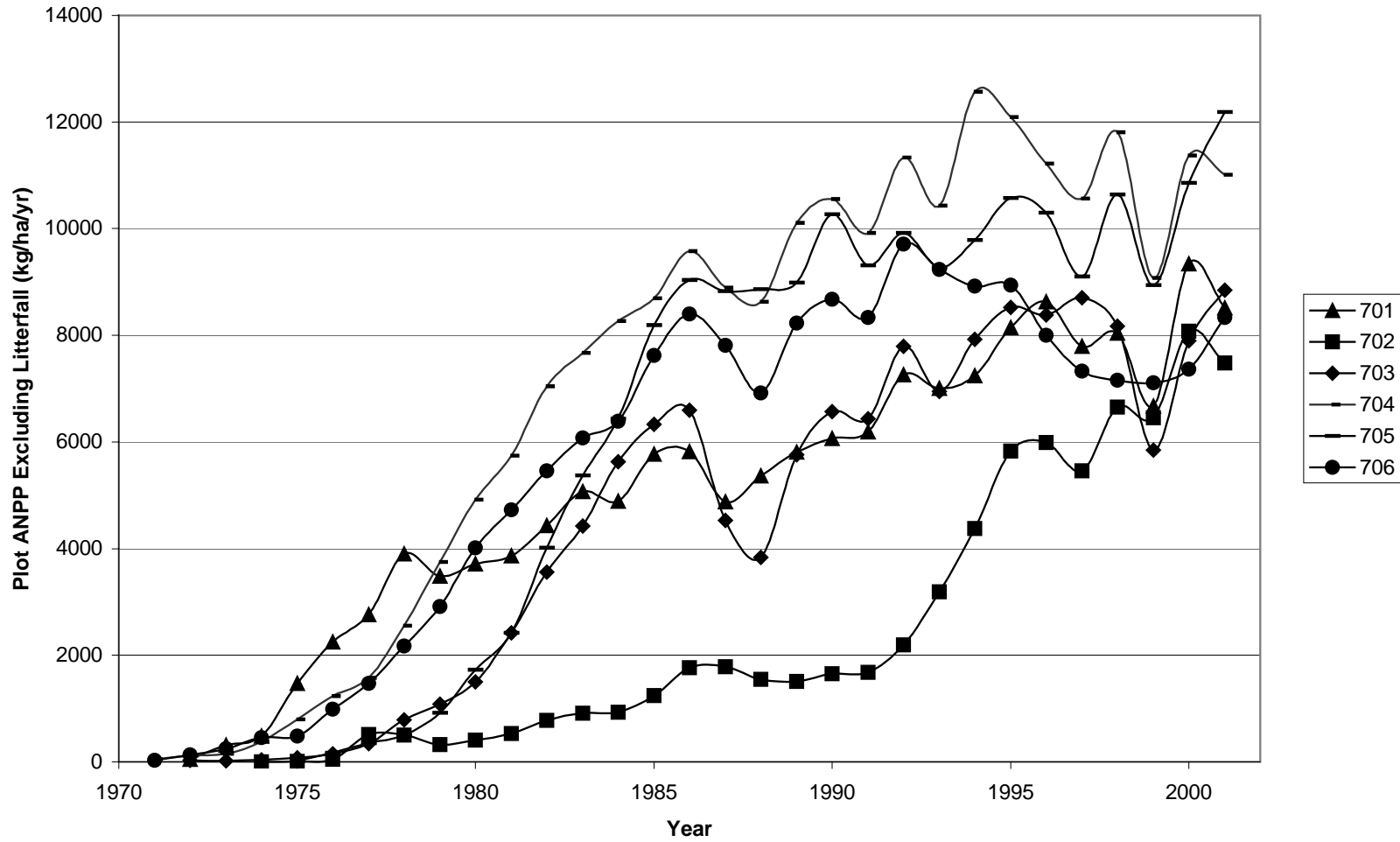


Figure 11. ANPP excluding litterfall (kg/ha/year) for watershed 7 plots for 1971-2001.

WS13

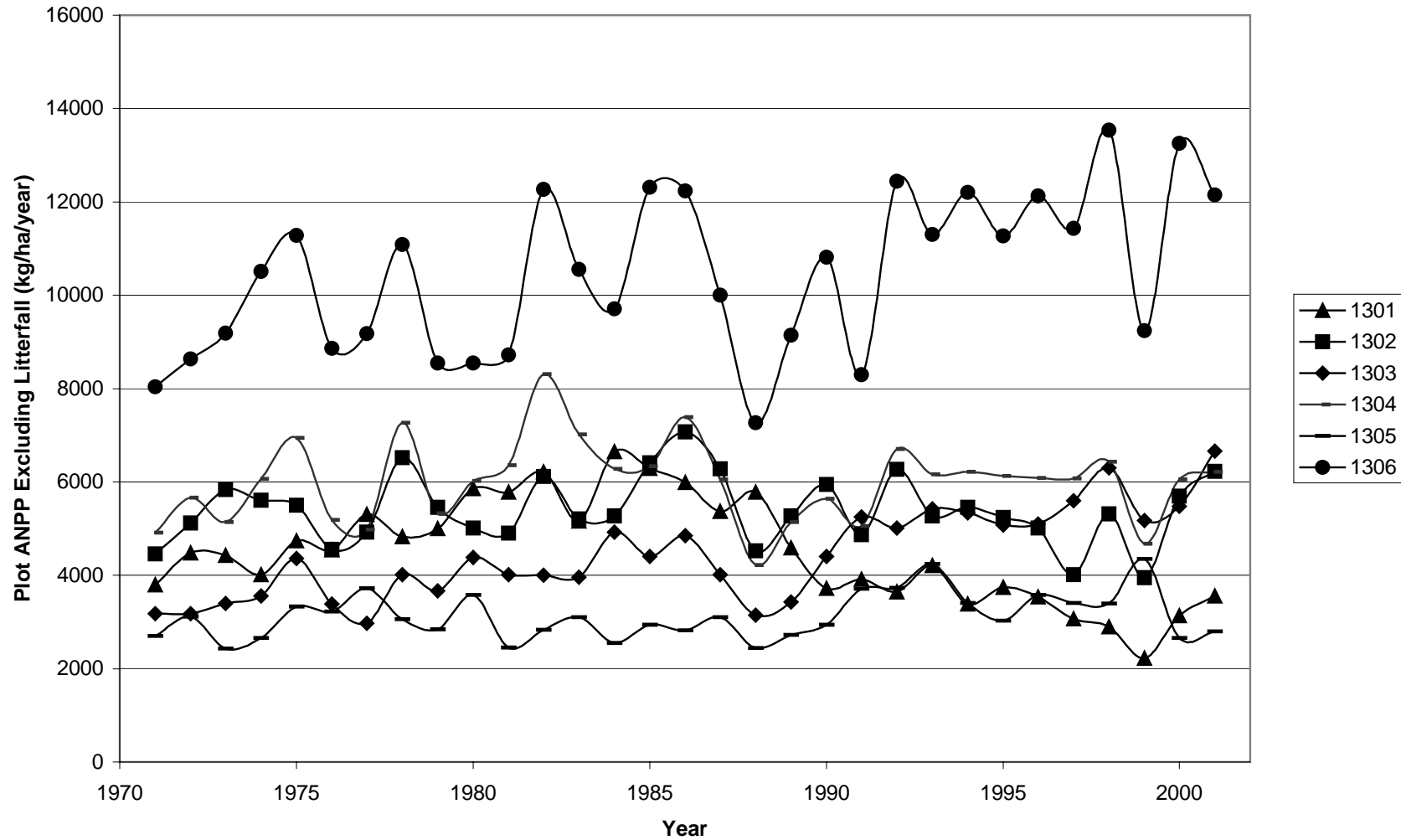


Figure 12. ANPP excluding litterfall (kg/ha/year) for watershed 13 plots for 1971-2001.

### Basal Area

The basal area calculations do account for the higher plot ANPP found at 1306 as opposed to 1301, which lie at similar elevations (Table 9). The average basal area also explains the higher plot ANPP found in the mature watershed, as opposed to the young watershed, which is further evidence that in these watersheds tree size plays a greater role in productivity than tree density.

**Table 9.** Basal area for each plot and watershed average (cm<sup>2</sup>/ha).

| <b>Plot #</b>            | <b>WS 7</b> | <b>WS 13</b> |
|--------------------------|-------------|--------------|
| <b>1</b>                 | 280,983     | 213,686      |
| <b>2</b>                 | 125,661     | 345,688      |
| <b>3</b>                 | 257,009     | 281,930      |
| <b>4</b>                 | 364,021     | 399,112      |
| <b>5</b>                 | 347,228     | 174,399      |
| <b>6</b>                 | 315,334     | 584,379      |
| <b>Watershed Average</b> | 281,706     | 333,199      |

### Hypothesis I (ANPP and WS age)

An ANOVA was run on the mean annual ANPP for each plot per year to determine if young and mature watersheds have a significantly different rate of ANPP. Over the first 15 years of the study, the average annual ANPP rate of the mature watershed was higher than the young watershed, while in the second 15 years of the study, the young watershed had a higher rate of growth than the mature watershed. Thus, while there is a substantial difference in rate over the entire period in the younger watershed, the overall average was relatively similar to the older watershed ( $F = 0.02$ ,  $P = 0.889$ ) (Table 10).

### Hypothesis II (ANPP, WS age, and drought)

An ANCOVA was performed on the mean annual ANPP with regards to drought classifications (annual totals and growing season totals) to determine if drought events affect the

ANPP in different aged watersheds differently; thus watershed was the covariate in the model in order to address the significant difference between the two watersheds found in hypothesis I. Two ANCOVAs were run. One examined annual ANPP relative to same year classification, while the second ANCOVA examined annual ANPP relative to the previous year classification.

#### Same Year Classification

Over all years (1971-2001), the effect of same year drought classification is associated with a lower value of ANPP ( $F = 2.72$ ,  $P = 0.100$ ). However, the same year growing season drought classification does not appear to be associated with the rate of ANPP ( $F = 1.75$ ,  $P = 0.186$ ) (Table 10).

#### Previous Year Classification

Over all years (1971-2001), the previous year's (1970-2000) annual drought classification does not appear to play a significant role in the following year's ANPP ( $F = 0.30$ ,  $P = 0.585$ ). However, the previous year's growing season classification appears to be associated with a much greater role than the same year growing season classification ( $F = 7.36$ ,  $P = 0.007$ ) (Table 10).

#### Hypothesis III (ANPP, tree species, and drought)

An ANCOVA was used to identify whether there are species-specific effects of drought with regards to the four most common species (ACSA, BELE, FAGR, and LITU (tree species and abbreviations are located in Appendix A)). This statistical test determined if drought events would affect the ANPP of different temperate tree species differently. Two ANCOVAs were run. One examined annual ANPP relative to same year drought classification, while the second ANCOVA examined annual ANPP relative to the previous year drought classification.

Same Year Classification

Over all years (1971-2001), species does not affect the relationship between same year drought classification and ANPP ( $F = 0.93$ ,  $P = 0.334$ ). Furthermore, species does not affect whether the same year growing season drought classification has an effect on the rate of ANPP ( $F = 0.02$ ,  $P = 0.895$ ) (Table 10).

Previous Year Classification

Over all years (1971-2001), the effects of species may play a more notable role with regards to the previous year's (1970-2000) annual drought classification ( $F = 2.70$ ,  $P = 0.101$ ), however this role is not significant at the  $\alpha = 0.05$  level. On the other hand, the previous year's growing season classification does not necessarily determine a lower value of ANPP ( $F = 0.97$ ,  $P = 0.325$ ). However, the previous year's growing season classification appears to have a stronger relation to ANPP than the same year growing season drought classification (Table 10).

**Table 10.** ANOVA and ANCOVA results for each of the three hypotheses examined.

| Hypothesis  |                                 |                   | ANCOVA<br>(F-values) | ANOVA<br>(F-values) |
|---|---------------------------------|-------------------|----------------------|---------------------|
| Hypothesis I (response=ANPP; variate=WS age)  |                                 |                   |                      | 0.02                |
| Hypothesis II<br>(response=ANPP;<br>variate=drought;<br>covariate=WS age)           | Same year<br>classification     | Annual<br>precip. | 2.72**               |                     |
|   |                                 | G.S. precip.      | 1.75                 |                     |
|   | Previous year<br>classification | Annual<br>precip. | 0.30                 |                     |
|   |                                 | G.S. precip.      | 7.36*                |                     |
| Hypothesis III<br>(response=ANPP;<br>variate=drought;<br>covariate=tree<br>species) | Same year<br>classification     | Annual<br>precip. | 0.93                 |                     |
|   |                                 | G.S. precip.      | 0.02                 |                     |
|   | Previous year<br>classification | Annual<br>precip. | 2.70**               |                     |
|   |                                 | G.S. precip.      | 0.97                 |                     |

\* Significant at the  $\alpha = 0.05$ .

\*\* Significant at the  $\alpha = 0.10$ .

## DISCUSSION

The mean ANPP for each plot indicated that over the whole time period examined (1971-2002), both watersheds had relatively equal rates of growth. However, upon closer examination of growth rate pattern(s) of each plot over the entire time period, year-by-year, the mature watershed demonstrated a leveled-off growth pattern that is expected of mature forested areas. On the other hand, the younger watershed demonstrated an increasing rate of growth throughout the entire time period examined, typical of recently disturbed forests. Therefore, the first 15 years of the younger watershed's re-vegetation produced growth rates lower than the mature watershed. The second 15 years produced growth rates that were greater than the mature watershed. The cause of this shift is due to the greater density of trees in the younger watershed trumping the rate of growth of the mature watershed. Prior to the shift, when the mature watershed had a higher rate of growth, the much greater height and girth of the mature trees compensated for the lower radial growth of measured. In other words, it is important to look at the forest in all three dimensions, length, width, and height, because a small radial growth measurement does not necessarily correspond to a low rate of growth in large trees. Therefore, while the overall mean and analysis of variance used to test this first hypothesis may have demonstrated a relatively equal ANPP, a closer examination of the temporal aspect of growth is just as important and needs to be taken into account.

The analysis of covariance of average annual ANPP with regards to age, annual drought classifications indicate that the same year drought classification does determine a lower value of ANPP, while growing season drought classifications did not significantly indicate a lower value of ANPP. However, the opposite occurs when examining the previous year drought classifications. In this case, annual drought classifications indicate that the previous year

drought classification does not determine a lower value of ANPP, while growing season drought classifications indicated that the previous year drought classification does determine a lower value of ANPP, and thus is a much better indicator of future values of aboveground ANPP. This type of time-lag forecasting in tree growth has been found to exist up to six years (Orwig and Abrams, 1997), thus a significant drought year may also continue to dampen the ANPP of an individual tree or forested area for a number of years following the event.

Similar work has shown that July PHDI (Palmer Hydrological Drought Index) correlated better with tree growth than annual precipitation (Cleaveland and Duvick, 1992). This study demonstrated the opposite for ANPP. I found that the annual drought classification was a better indicator of future productivity than growing season drought classification. The most likely reason for the results in this study to be different than other studies is inverse-distance weighting of PDSI measurements for cell 135, located 71 km from the Fernow Experimental Forest (Cook *et al.*, 1999). Therefore, areas included in cell 135 PDSI measurements were low-land areas near the Ohio river and on the western, wetter, side of the mountains, which have a distinctly different climate than the mountainous region where the Fernow Experimental Forest is located.

The analysis of covariance of mean annual ANPP with regards to species, annual drought classification, and growing season drought classifications indicated that the previous year drought classification is a better indicator of future values of ANPP, as opposed to the same year drought classification. Thus, a time-lag response mechanism also appears to exist among the four most common species in the two watersheds. More importantly, it is most likely that previous studies that found that birch species are more affected by drought than maple species are supported by this study (Brenneman *et al.*, 1978). Therefore species' preference with regards to moist habitats or dry habitats does play a significant role.

Pearson correlations demonstrated variable relationships between precipitation and ANPP. While certain plots did show a significant negative relationship between the amount of precipitation received and ANPP, overall, the correlations did not demonstrate a viable relationship between precipitation and ANPP, thus the correlations suggest a need to examine other possible factors that play a role in the annual ANPP of forested areas. These other factors may include the size of the individual trees, the number of individual trees, sunlight availability, species composition, and nutrient availability, which are discussed in more detail with regards to basal area (Gilliam *et al.*, 1995; MacDonald, 2003). However, previous studies have shown few differences in nutrient availability among both watersheds (Gilliam *et al.*, 1994). For example, one explanation for the unusual negative correlations of the young watershed's plots with PDSI is the high number of birch (BELE) found in the young watershed and absence of birch trees in the mature watershed. Birch prefer drier habitat, therefore a lack of precipitation or lower PDSI value may lead to increased growth of birch. Any one, or a combination, of these factors is a possible explanation for the unusual negative correlations of the young watershed's plots with regards to PDSI and precipitation.

The basal area calculations were able to answer many of the questions concerning the variations of ANPP among the individual plots. The three main factors appear to be: 1) the size of the trees, 2) the surrounding environment, and 3) the number of individuals, or density. Upon examining individual plots in watershed 13, plot 1306 demonstrated a higher rate in overall ANPP each year, for the entire time period examined. This substantial difference was more compelling due to the fact that plot 1306 and plot 1301 are found at similar elevations in the watershed (both along the ridge-top). However, when examining the basal area of the plots in watershed 13, and specifically 1301 and 1306, tree size is shown to play an important role in the



annual ANPP. Thus, the ANPP of individual plots can be greatly affected by the size of the individual trees found at each plot. The second main factor, the surrounding environment, is better demonstrated in watershed 7. The surrounding environments were classified into 1) valley, 2) ridge-top, and 3) mid-slope (Table 3). The valley environment exhibited the lowest annual ANPP among all plots, demonstrated by plot 702 (Figure 6). The ridge-top environment, oddly, exhibited a median annual ANPP among all plots, demonstrated by plot 701. The mid-slope environment exhibited the highest annual ANPP among all plots, demonstrated by plots 704, 705, and 706. The final main factor, the number of individuals, is also better demonstrated in watershed 7. Plots 701 and 703 have equivalent numbers of individuals as well as relatively equivalent basal areas, however, plots 704 and 706 also have equivalent, but larger, numbers of individuals as well as relatively equivalent, but larger, basal areas.

One of the most surprising findings is the relatively quick rebound, of forested areas that have been clear-cut and then allowed to re-grow. This was demonstrated by the younger watershed, which shows that a clear-cut forest appears to re-vegetate relatively quickly, on the order of 15 years, and thus, approach values, approximately 10,000 kg/ha/year, seen in the mature watershed and at Oak Ridge and Hubbard Brook (Cole and Rapp, 1981). However, while the younger watershed did return to mature levels of annual ANPP found in the mature watershed, it quickly surpassed those values, and continued to grow at an accelerated rate. Therefore, the younger watershed has yet to reach the tipping point of growth and level off at mature watershed's rates. Furthermore, the younger watershed should not be called or even considered a mature watershed, due to the younger watershed having twice the density of the mature watershed in order to reach the corresponding level of annual ANPP and then surpass that level. Thus, the younger watershed is still several decades from becoming as mature a forest in

terms of forest structure. Future expectations of the younger watershed would include thinning of weaker trees and the continual growth of the stronger trees creating a lower rate of growth, and ANPP, that will correspond to the levels seen in the mature watershed.

Overall litterfall calculations of this study revealed values that did not closely relate to values seen in temperate deciduous forests studied by Cole and Rapp (1981). Fernow Experimental Forest litterfall values corresponded more closely to boreal deciduous forest litterfall values. One possible explanation of this difference is the higher elevation of the Fernow Experimental forest, thus producing a cooler climate. A further aspect of this study was the examination of the allometric equations produced by Brenneman *et al.* (1978). In order to produce their equations, Brenneman (1978) used an across-the-board 5% of the green bole aboveground biomass for all litterfall weights. My own biomass calculations and litterfall weight, suggest that 5% is not an acceptable amount to use for litterfall weights with regards to total biomass. A more reliable amount for litterfall weight use with regards to total biomass would be 2-5% for mature forests and 12-15% for young forests. This difference in litterfall weights between mature watersheds and young watersheds, as well as Brenneman's examination of only mature trees (37-80 years in age with a mean age of 63 years) produced relatively correct total biomass (and ANPP) values for the mature watershed, but substantially overestimated the values for the total biomass (and ANPP) of the young watershed when Brenneman's equations were used.

A small number of difficulties in field work and laboratory preparation/work, such as sample preparation and litterfall collection, may have led to errors that influenced my results. The greatest difficulty was the possible dating errors that were a result of the lack of crossdating of the increment cores. This lack of crossdating may have let a year shift occur among some of

the increment cores where a possible false ring or missing ring was located. A related problem associated with the lack of crossdating cores was the subsequent removal of all dead trees. Each of these dead trees did contribute to ANPP but this contribution was removed from my estimates due to the inability to date the core. Thus, due to the absence of dead trees, the ANPP was likely underestimated to a minor degree; however, the overall pattern over time is accurate. However, this problem would not have affected biomass estimates and the comparison to Brenneman *et al.*'s (1978) work, previously discussed. Another weakness of this work is the exclusion of all belowground factors with regards to NPP. While large carbon pools and sequestration was shown to exist aboveground, there may be several belowground factors, such as belowground growth, respiration, and root death that offset the aboveground benefits of large carbon pools and sequestration. However, comparable carbon net uptake amounts found at the Harvard Forest, demonstrated that 70% of the mean ecosystem net uptake occurred aboveground, which is typical for eastern deciduous forests (Barford *et al.*, 2001). Finally, one variable that has been used in the past that was not directly included in this study was temperature. Pan *et al.* (1997) concluded that air temperature is as important as precipitation in its influence on growth of most species in the Fernow Experimental Forest. The exclusion of this factor may very well have been associated with the anomalies, such as the unusual patterns at plot 1305 and 702, found at some of the plots. However, temperature was indirectly included through the use of PDSI data.

Furthermore, all of the previous results create a problem when looked at together. The correlations tend to show that precipitation is not a significant variable with regards to ANPP. On the other hand, ANOVA and ANCOVA results demonstrate that there is some significance with regards to the present year and future year ANPP. Previous work has shown that both

methods of analyzing data, correlations and ANOVA/ANCOVA, are valid, therefore, creating a fundamental difficulty in interpreting the results of this study.

It appears that productivity in these forests is only weakly sensitive to climatic variation. While both watersheds show a weak relationship with precipitation, this relationship does not appear in the younger watershed until after 15 years. Thus, a younger watershed's growth curve is more important to the total annual aboveground productivity than interannual climatic variability. Also, based on this study's aspect and topographic position, it is likely that the surrounding environment and related factors play a more important role in determining aboveground productivity than climatic variation.

This is an important step forward from previous studies, such as Orwig and Abrams (1997), which examined several similar tree species in Virginia, and found a strong association between precipitation, temperature, PDSI, and ring widths. Similar results were obtained with regards to a time-lag mechanism between precipitation and future radial growth (ANPP in this study). A similar time-lag mechanism was also found by Pan *et al.* (1997) in the Fernow Experimental Forest, which demonstrated that variations in precipitation in the previous year is more important to tree growth than variation in precipitation in the current year. In both of these studies, only one relatively even-aged mature stand was used; therefore, one step forward in this study was the inclusion of two stand ages, young and mature. This allowed for the study of age effects in ANPP, drought response, and species, which was found to be significant.

In conclusion, while climatic variability plays a part in ANPP only when drought events are substantial, future productivity of temperate deciduous forests will most likely rely more heavily on activities such as land use and management that directly affect the age and structure of these forests. My research demonstrates that a lower rate of productivity among young

watersheds is the norm in the first 15 years of re-vegetation. The difficult decision that must be made is to determine the optimal cutting interval that allows the maximum amount of growth coupled with the economic benefits of the timber industry. With regards to ecological benefits, this study suggests that a minimum of 30+ years is required for a young watershed to approach the productivity rate of a mature watershed, however, while the productivity may be relatively equivalent, the younger trees are still too immature and have yet to reach a leveled-off growth rate. Therefore, the next step in this line of research is the study of tree stands/watersheds that are closer in age, such as 60 years and 90 years, to determine if at that time, the younger watershed has reached a leveled-off growth rate and can be considered suitable for timber harvest without excessive carbon losses.

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**APPENDIX A**  
Tree Species and Abbreviations

| <b>Common name</b>       | <b>Scientific name</b>         | <b>Abbreviation</b> |
|--------------------------|--------------------------------|---------------------|
| <b>Basswood</b>          | <i>Tilia americana</i>         | TIAM                |
| <b>Beech</b>             | <i>Fagus grandifolia</i>       | FAGR                |
| <b>Birch</b>             | <i>Betula lenta</i>            | BELE                |
| <b>Black cherry</b>      | <i>Prunus serotina</i>         | PRSE                |
| <b>Black gum</b>         | <i>Nyssa sylvatica</i>         | NYSY                |
| <b>Black locust</b>      | <i>Robinia pseudoacacia</i>    | ROPS                |
| <b>Chestnut oak</b>      | <i>Quercus prinus</i>          | QUPR                |
| <b>Cucumber magnolia</b> | <i>Magnolia acuminata</i>      | MAAC                |
| <b>Dotted thorn</b>      | <i>Crataegus punctata</i>      | CRPU                |
| <b>Frazer magnolia</b>   | <i>Magnolia fraseri</i>        | MAFR                |
| <b>Hickory</b>           | <i>Carya cordiformis</i>       | CACO                |
| <b>Red maple</b>         | <i>Acer rubrum</i>             | ACRU                |
| <b>Red oak</b>           | <i>Quercus rubra</i>           | QURU                |
| <b>Sassafras</b>         | <i>Sassafras albidum</i>       | SAAL                |
| <b>Scarlet oak</b>       | <i>Quercus coccinea</i>        | QUCO                |
| <b>Spicebush</b>         | <i>Lindera benzoin</i>         | LIBE                |
| <b>Striped maple</b>     | <i>Acer pensylvanicum</i>      | ACPE                |
| <b>Sugar maple</b>       | <i>Acer saccharum</i>          | ACSA                |
| <b>Tulip poplar</b>      | <i>Liriodendron tulipifera</i> | LITU                |
| <b>Umbrella</b>          | <i>Magnolia tripetala</i>      | MATR                |
| <b>Unk./misc.</b>        | ---                            | ---                 |
| <b>White ash</b>         | <i>Fraxinus americana</i>      | FRAM                |
| <b>White oak</b>         | <i>Quercus alba</i>            | QUAL                |
| <b>Witchhazel</b>        | <i>Hamamelis virginiana</i>    | HAVI                |

**APPENDIX B**  
Tree Biomass Allometric Equations

| <b>Species</b>  | <b>Allometric equation</b>                        | <b>Diameter Range</b> |
|-----------------|---|-----------------------|
| <b>ACSA</b>     | $Wt = 2.4439 \text{ dbh}^{2.5735}$                | 5-50 cm               |
| <b>BELE</b>     | $Wt = 1.6542 \text{ dbh}^{2.6606}$                | 5-50 cm               |
| <b>LITU</b>     | $Wt = 1.0259 \text{ dbh}^{2.7324}$                | 5-50 cm               |
| <b>FAGR</b>     | $Wt = 2.0394 \text{ dbh}^{2.5715}$                | 5-50 cm               |
| <b>PRSE</b>     | $Wt = 1.8082 \text{ dbh}^{2.6174}$                | 5-50 cm               |
| <b>QUPR</b>     | $Wt = 1.5509 \text{ dbh}^{2.7276}$                | 5-50 cm               |
| <b>CACO</b>     | $Wt = 2.0340 \text{ dbh}^{2.6349}$                | 5-50 cm               |
| <b>ACRU</b>     | $Wt = 2.0772 \text{ dbh}^{2.5080}$                | 5-50 cm               |
| <b>QURU</b>     | $Wt = 2.4601 \text{ dbh}^{2.4572}$                | 5-50 cm               |
| <b>QUCO</b>     | $Wt = 2.65743 \text{ dbh}^{2.43948}$              | 5-40 cm               |
| <b>FRAM</b>     | $Wt = 2.3626 \text{ dbh}^{2.4798}$                | 5-50 cm               |
| <b>QUAL</b>     | $Wt = 1.5647 \text{ dbh}^{2.6887}$                | 5-50 cm               |
| <b>Hardwood</b> | $\text{LN } Wt = 0.95595 + 2.42640 \text{ LNdbh}$ | 2.5-25 cm             |

\*(Brenneman *et al.*, 1978).

\*\*“Wt” is equal to the dry weights (in pounds) of aboveground forests biomass.

**APPENDIX C**  
Tree Species Frequency by Plot

|              | 701 | 702 | 703 | 704 | 705 | 706 | 1301 | 1302 | 1303 | 1304 | 1305 | 1306 |
|--------------|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|
| <b>TIAM</b>  | 0   | 1   | 0   | 0   | 0   | 0   | 0    | 0    | 5    | 0    | 0    | 0    |
| <b>FAGR</b>  | 0   | 2   | 1   | 1   | 3   | 4   | 1    | 18   | 4    | 2    | 2    | 1    |
| <b>BELE</b>  | 20  | 3   | 3   | 10  | 10  | 15  | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>PRSE</b>  | 3   | 1   | 0   | 18  | 1   | 7   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>NYSY</b>  | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0    | 1    | 0    | 0    |
| <b>ROPS</b>  | 9   | 1   | 0   | 0   | 0   | 2   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>QUPR</b>  | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 1    | 0    | 0    | 0    | 0    |
| <b>MAAC</b>  | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 1    | 0    | 1    | 0    |
| <b>CRPU</b>  | 0   | 4   | 0   | 0   | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>MAFR</b>  | 0   | 0   | 1   | 0   | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>CACO</b>  | 0   | 0   | 0   | 0   | 0   | 2   | 0    | 0    | 2    | 0    | 0    | 0    |
| <b>ACRU</b>  | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 1    | 0    | 0    | 0    |
| <b>QURU</b>  | 0   | 0   | 4   | 2   | 0   | 2   | 0    | 2    | 0    | 4    | 1    | 7    |
| <b>SAAL</b>  | 0   | 0   | 0   | 0   | 0   | 8   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>QUCO</b>  | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0    | 1    | 0    | 0    |
| <b>ACPE</b>  | 0   | 1   | 0   | 0   | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>ACSA</b>  | 0   | 5   | 8   | 5   | 2   | 3   | 12   | 1    | 4    | 14   | 12   | 7    |
| <b>LITU</b>  | 6   | 3   | 14  | 1   | 14  | 0   | 0    | 0    | 1    | 0    | 0    | 0    |
| <b>MATR</b>  | 0   | 0   | 0   | 1   | 0   | 0   | 0    | 0    | 0    | 3    | 0    | 0    |
| <b>FRAM</b>  | 0   | 0   | 0   | 0   | 0   | 5   | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>QUAL</b>  | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 1    |
| <b>Total</b> | 38  | 21  | 31  | 38  | 30  | 48  | 13   | 22   | 18   | 25   | 16   | 16   |

**APPENDIX D**  
Litterfall Weights (g) per Species per Plot

|                   | <b>701</b> | <b>702</b> | <b>703</b> | <b>704</b> | <b>705</b> | <b>706</b> | <b>1301</b> | <b>1302</b> | <b>1303</b> | <b>1304</b> | <b>1305</b> | <b>1306</b> |
|-------------------|------------|------------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>TIAM</b>       | 0          | 1.2        | 0          | 0          | 0          | 0          | 0           | 0           | 41.6        | 0           | 0           | 0           |
| <b>FAGR</b>       | 0          | 1.0        | 0.5        | 0          | 0          | 8.7        | 6.0         | 14.5        | 16.8        | 12.0        | 1.9         | 1.6         |
| <b>BELE</b>       | 36.6       | 10.1       | 2.4        | 17.7       | 12.3       | 35.1       | 8.1         | 1.0         | 12.0        | 1.5         | 17.1        | 2.3         |
| <b>PRSE</b>       | 40.1       | 46.3       | 0.9        | 74.9       | 11.4       | 29.8       | 4.1         | 0           | 0           | 0           | 0.9         | 0.6         |
| <b>NYSY</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 9.9         | 0           | 0           |
| <b>ROPS</b>       | 25.3       | 6.2        | 0          | 0          | 0          | 1.7        | 0           | 0           | 0           | 0           | 0           | 0           |
| <b>QUPR</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 13.8        | 7.0         | 0           | 0           | 4.0         | 0           |
| <b>MAAC</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 6.2         | 0           | 10.7        | 0           |
| <b>CRPU</b>       | 0          | 0.7        | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0           | 0           | 0           |
| <b>MAFR</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 12.3        | 0           | 0           |
| <b>CACO</b>       | 0          | 0          | 0          | 0          | 0          | 3.2        | 0           | 0           | 5.6         | 0           | 0           | 0           |
| <b>ACRU</b>       | 0          | 0          | 0          | 2.3        | 0          | 0          | 0           | 0           | 0           | 0           | 0.6         | 7.7         |
| <b>QURU</b>       | 0          | 0          | 3.6        | 2.7        | 1.0        | 3.0        | 7.1         | 35.8        | 26.4        | 44.7        | 73.5        | 40.1        |
| <b>SAAL</b>       | 0          | 0          | 0          | 0          | 0          | 9.5        | 0           | 0           | 0           | 0           | 0           | 0           |
| <b>QUCO</b>       | 1.7        | 0          | 0          | 0          | 0          | 0          | 12.8        | 0           | 1.5         | 29.8        | 0           | 0           |
| <b>LIBE</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0           | 0           | 0           |
| <b>ACPE</b>       | 0          | 3.4        | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0           | 8.0         | 0           |
| <b>ACSA</b>       | 7.7        | 44.3       | 2.2        | 5.9        | 3.2        | 12.0       | 84.2        | 0.5         | 20.4        | 31.4        | 29.8        | 21.7        |
| <b>LITU</b>       | 15.1       | 17.4       | 33.7       | 9.6        | 17.7       | 5.5        | 0           | 1.1         | 14.6        | 0           | 3.9         | 1.1         |
| <b>MATR</b>       | 0          | 0          | 0          | 1.8        | 0          | 0          | 0           | 0           | 0           | 0.5         | 0           | 0           |
| <b>FRAM</b>       | 0          | 0          | 0          | 0          | 0          | 0.7        | 0           | 0           | 0           | 0           | 0           | 0           |
| <b>QUAL</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 0           | 0           | 13.6        |
| <b>HAVI</b>       | 0          | 0          | 0          | 0          | 0          | 0          | 0           | 0           | 0           | 1.2         | 0           | 0           |
| <b>Unk./misc.</b> | 37.9       | 53.8       | 21.6       | 49.3       | 23.5       | 39.0       | 51.9        | 22.3        | 30.9        | 26.6        | 46.4        | 67.8        |
| <b>Total**</b>    | 3288       | 3688       | 1298*      | 3284       | 1382       | 2964       | 3760        | 1644        | 3520        | 3398        | 3936        | 3130        |

\* Three weeks of litterfall data during the fall was lost due to stolen collection baskets.

\*\* Totals are calculated estimates of litterfall expressed in kg/ha/year.

**APPENDIX E**  
Bark Coefficients\*

| <b>Tree Species</b> | <b>Bark Coefficients (DBH<sub>ib</sub>/DBH<sub>ob</sub>)**</b> |
|---------------------|--|
| <b>TIAM</b>         | 0.907  |
| <b>FAGR</b>         | 0.968  |
| <b>BELE</b>         | 0.939  |
| <b>PRSE</b>         | 0.923  |
| <b>ROPS</b>         | 0.861  |
| <b>QUPR</b>         | 0.887  |
| <b>MAAC</b>         | 0.912  |
| <b>CACO</b>         | 0.915  |
| <b>ACRU</b>         | 0.942  |
| <b>QURU</b>         | 0.921  |
| <b>QUCO</b>         | 0.926  |
| <b>ACSA</b>         | 0.942  |
| <b>LITU</b>         | 0.896  |
| <b>FRAM</b>         | 0.913  |
| <b>QUAL</b>         | 0.929  |
| <b>All species</b>  | 0.918  |

\*(Martin, 1981).

\*\*“ib” is inside of bark and “ob” is outside of bark.

**APPENDIX F**  
Tree Survey and Measurements

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 701    | 1      | LITU    | L      | 26.0     | 18.72           |
| 701    | 2      | ROPS    | L      | 22.8     | 20.16           |
| 701    | 3      | LITU    | L      | 29.0     | 22.10           |
| 701    | 4      | LITU    | L      | 21.4     | 20.32           |
| 701    | 5      | BELE    | L      | 8.3      | 10.00           |
| 701    | 6      | PRSE    | L      | 31.3     | 24.00           |
| 701    | 7      | BELE    | L      | 9.4      | 10.00           |
| 701    | 8      | BELE    | L      | 10.8     | 13.44           |
| 701    | 9      | BELE    | L      | 9.5      | 13.44           |
| 701    | 10     | BELE    | L      | 18.0     | 19.84           |
| 701    | 11     | PRSE    | L      | 38.4     | 22.50           |
| 701    | 12     | BELE    | L      | 7.6      | 13.65           |
| 701    | 13     | ROPS    | L      | 21.4     | 16.80           |
| 701    | 14     | ROPS    | D      | 8.5      | 8.00            |
| 701    | 15     | BELE    | L      | 10.1     | 14.10           |
| 701    | 16     | ROPS    | L      | 26.0     | 23.00           |
| 701    | 17     | ROPS    | D      | 12.1     | 10.00           |
| 701    | 18     | PRSE    | L      | 15.1     | 16.05           |
| 701    | 19     | BELE    | L      | 8.2      | 11.88           |
| 701    | 20     | BELE    | L      | 9.5      | 12.60           |
| 701    | 21     | ROPS    | L      | 21.9     | 18.70           |
| 701    | 22     | BELE    | L      | 12.8     | 14.00           |
| 701    | 23     | BELE    | L      | 13.3     | 16.28           |
| 701    | 24     | LITU    | L      | 18.8     | 17.67           |
| 701    | 25     | ROPS    | L      | 17.9     | 23.10           |
| 701    | 26     | BELE    | D      | 11.5     | 2.50            |
| 701    | 27     | BELE    | L      | 11.0     | 13.13           |
| 701    | 28     | BELE    | L      | 12.4     | 12.60           |
| 701    | 29     | ROPS    | L      | 21.1     | 23.37           |
| 701    | 30     | BELE    | L      | 7.2      | 11.04           |
| 701    | 31     | BELE    | L      | 11.7     | 13.50           |
| 701    | 32     | ROPS    | L      | 21.2     | 20.30           |
| 701    | 33     | BELE    | D      | 5.6      | 1.50            |
| 701    | 34     | BELE    | L      | 8.9      | 10.73           |
| 701    | 35     | LITU    | L      | 26.6     | 16.75           |
| 701    | 36     | ROPS    | L      | 22.7     | 21.13           |
| 701    | 37     | BELE    | D      | 31.0     | 5.50            |
| 701    | 38     | ROPS    | L      | 16.7     | 15.08           |
| 701    | 39     | ROPS    | D      | 7.7      | 7.50            |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 701    | 40     | BELE    | L      | 9.3      | 15.50           |
| 701    | 41     | LITU    | D      | 8.3      | 12.00           |
| 701    | 42     | LITU    | L      | 7.9      | 13.44           |
| 701    | 43     | BELE    | L      | 7.0      | 10.88           |
| 701    | 44     | BELE    | L      | 10.4     | 14.00           |
| 701    | 45     | BELE    | L      | 6.7      | 10.50           |
| 702    | 1      | ACSA    | L      | 8.9      | 10.03           |
| 702    | 2      | ACSA    | L      | 18.4     | 10.92           |
| 702    | 3      | TIAM    | L      | 8.9      | 11.00           |
| 702    | 4      | FAGR    | L      | 7.3      | 13.50           |
| 702    | 5      | LITU    | L      | 7.6      | 7.50            |
| 702    | 6      | ROPS    | L      | 6.7      | 10.00           |
| 702    | 7      | CRPU    | L      | 7.2      | 7.15            |
| 702    | 8      | CRPU    | L      | 9.0      | 5.98            |
| 702    | 9      | CRPU    | L      | 9.6      | 9.36            |
| 702    | 10     | ACPE    | D      | 14.0     | 8.97            |
| 702    | 11     | ACPE    | L      | 34.1     | 18.85           |
| 702    | 12     | FAGR    | D      | 20.3     | 6.50            |
| 702    | 13     | FAGR    | L      | 13.5     | 11.40           |
| 702    | 14     | FAGR    | D      | 19.7     | 8.50            |
| 702    | 15     | CRPU    | L      | 6.2      | 8.00            |
| 702    | 16     | ACSA    | L      | 6.8      | 7.50            |
| 702    | 17     | ACSA    | L      | 6.9      | 10.50           |
| 702    | 18     | ACSA    | L      | 9.3      | 10.50           |
| 702    | 19     | BELE    | L      | 11.3     | 16.33           |
| 702    | 20     | LITU    | L      | 31.6     | 21.87           |
| 702    | 21     | BELE    | L      | 6.8      | 6.00            |
| 702    | 22     | PRSE    | L      | 13.5     | 18.75           |
| 702    | 23     | BELE    | L      | 19.8     | 20.16           |
| 702    | 24     | LITU    | L      | 39.3     | 28.35           |
| 703    | 1      | BELE    | L      | 5.7      | 9.50            |
| 703    | 2      | LITU    | L      | 18.1     | 19.20           |
| 703    | 3      | ACSA    | L      | 5.4      | 9.50            |
| 703    | 4      | ACSA    | L      | 6.0      | 12.00           |
| 703    | 5      | unk     | D      | 11.5     | 10.70           |
| 703    | 6      | QURU    | L      | 6.5      | 10.68           |
| 703    | 7      | QURU    | L      | 5.8      | 11.50           |
| 703    | 8      | unk     | D      | 6.8      | 2.50            |
| 703    | 9      | unk     | D      | 5.5      | 7.50            |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 703    | 10     | LITU    | L      | 5.5      | 10.50           |
| 703    | 11     | BELE    | L      | 6.4      | 11.50           |
| 703    | 12     | ACSA    | L      | 6.1      | 12.00           |
| 703    | 13     | unk     | D      | 8.2      | 10.50           |
| 703    | 14     | ACSA    | L      | 5.7      | 9.72            |
| 703    | 15     | ACSA    | L      | 6.4      | 9.41            |
| 703    | 16     | unk     | D      | 9.3      | 7.94            |
| 703    | 17     | unk     | D      | 11.9     | 11.27           |
| 703    | 18     | unk     | D      | 10.4     | 11.27           |
| 703    | 19     | QURU    | L      | 7.5      | 12.00           |
| 703    | 20     | LITU    | L      | 43.2     | 26.25           |
| 703    | 21     | unk     | D      | 5.9      | 2.50            |
| 703    | 22     | LITU    | L      | 16.5     | 23.59           |
| 703    | 23     | ACSA    | L      | 23.6     | 25.43           |
| 703    | 24     | LITU    | L      | 26.6     | 23.60           |
| 703    | 25     | BELE    | L      | 17.8     | 19.53           |
| 703    | 26     | LITU    | L      | 27.6     | 22.62           |
| 703    | 27     | LITU    | L      | 23.4     | 21.86           |
| 703    | 28     | LITU    | L      | 19.5     | 22.36           |
| 703    | 29     | LITU    | L      | 23.5     | 18.36           |
| 703    | 30     | unk     | D      | 10.7     | 8.64            |
| 703    | 31     | unk     | D      | 15.4     | 13.12           |
| 703    | 32     | LITU    | L      | 16.7     | 23.20           |
| 703    | 33     | FAGR    | L      | 24.7     | 23.97           |
| 703    | 34     | QURU    | L      | 6.6      | 9.64            |
| 703    | 35     | LITU    | L      | 39.6     | 26.09           |
| 703    | 36     | unk     | D      | 8.6      | 12.50           |
| 703    | 37     | LITU    | L      | 8.3      | 14.00           |
| 703    | 38     | LITU    | L      | 20.0     | 23.29           |
| 703    | 39     | ACSA    | L      | 11.3     | 14.24           |
| 703    | 40     | LITU    | L      | 17.2     | 18.63           |
| 703    | 41     | ACSA    | L      | 9.5      | 12.76           |
| 703    | 42     | MAFR    | L      | 9.8      | 13.13           |
| 704    | 1      | PRSE    | L      | 22.4     | 11.16           |
| 704    | 2      | PRSE    | L      | 18.0     | 20.80           |
| 704    | 3      | unk     | D      | 12.2     | 5.85            |
| 704    | 4      | PRSE    | L      | 13.1     | 22.36           |
| 704    | 5      | unk     | D      | 10.5     | 2.50            |
| 704    | 6      | PRSE    | L      | 28.5     | 29.70           |
| 704    | 7      | unk     | D      | 6.9      | 7.00            |
| 704    | 8      | unk     | D      | 13.2     | 6.50            |
| 704    | 9      | unk     | D      | 9.1      | 6.30            |
| 704    | 10     | unk     | D      | 10.8     | 7.00            |
| 704    | 11     | ACSA    | L      | 9.1      | 12.45           |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 704    | 12     | PRSE    | L      | 12.1     | 13.80           |
| 704    | 13     | PRSE    | L      | 33.2     | 29.85           |
| 704    | 14     | unk     | D      | 8.4      | 3.00            |
| 704    | 15     | PRSE    | L      | 27.5     | 29.04           |
| 704    | 16     | unk     | D      | 7.5      | 7.00            |
| 704    | 17     | unk     | D      | 16.0     | 14.41           |
| 704    | 18     | unk     | D      | 13.0     | 11.16           |
| 704    | 19     | LITU    | L      | 28.9     | 29.05           |
| 704    | 20     | BELE    | L      | 10.7     | 13.72           |
| 704    | 21     | PRSE    | L      | 31.5     | 33.22           |
| 704    | 22     | BELE    | L      | 15.5     | 20.39           |
| 704    | 23     | unk     | D      | 6.0      | 2.50            |
| 704    | 24     | PRSE    | L      | 25.3     | 27.80           |
| 704    | 25     | PRSE    | L      | 13.0     | 15.60           |
| 704    | 26     | PRSE    | L      | 9.7      | 13.59           |
| 704    | 27     | unk     | D      | 8.9      | 10.00           |
| 704    | 28     | FAGR    | L      | 6.3      | 10.00           |
| 704    | 29     | unk     | D      | 9.6      | 8.25            |
| 704    | 30     | unk     | D      | 7.9      | 7.25            |
| 704    | 31     | ACSA    | L      | 5.7      | 9.02            |
| 704    | 32     | MATR    | L      | 13.4     | 16.01           |
| 704    | 33     | QURU    | L      | 9.3      | 11.70           |
| 704    | 34     | LITU    | D      | 11.1     | 16.34           |
| 704    | 35     | BELE    | L      | 17.3     | 25.48           |
| 704    | 36     | QURU    | L      | 10.8     | 14.40           |
| 704    | 37     | BELE    | L      | 16.4     | 18.69           |
| 704    | 38     | unk     | D      | 10.1     | 14.84           |
| 704    | 39     | PRSE    | L      | 29.1     | 23.87           |
| 704    | 40     | BELE    | L      | 16.4     | 20.91           |
| 704    | 41     | unk     | D      | 8.1      | 7.00            |
| 704    | 42     | unk     | D      | 9.8      | 6.00            |
| 704    | 43     | unk     | D      | 5.8      | 3.50            |
| 704    | 44     | unk     | D      | 6.2      | 3.00            |
| 704    | 46     | ACSA    | L      | 6.4      | 7.50            |
| 704    | 47     | BELE    | L      | 12.1     | 31.08           |
| 704    | 48     | BELE    | L      | 23.0     | 25.52           |
| 704    | 49     | BELE    | L      | 11.4     | 18.73           |
| 704    | 50     | BELE    | L      | 19.8     | 24.15           |
| 704    | 51     | ACSA    | L      | 7.5      | 7.50            |
| 704    | 52     | PRSE    | L      | 20.2     | 26.08           |
| 704    | 53     | BELE    | D      | 8.0      | 6.50            |
| 704    | 54     | BELE    | L      | 22.8     | 24.70           |
| 704    | 55     | PRSE    | L      | 26.0     | 21.60           |
| 704    | 56     | PRSE    | L      | 19.4     | 24.96           |



| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 704    | 57     | PRSE    | L      | 9.6      | 10.26           |
| 704    | 58     | ACSA    | L      | 8.9      | 7.92            |
| 704    | 59     | unk     | D      | 7.2      | 8.00            |
| 704    | 60     | PRSE    | L      | 32.6     | 27.72           |
| 704    | 62     | PRSE    | L      | 30.5     | 23.98           |
| 705    | 1      | ACSA    | L      | 5.9      | 8.55            |
| 705    | 2      | unk     | D      | 10.0     | 4.00            |
| 705    | 3      | unk     | D      | 7.9      | 5.50            |
| 705    | 4      | unk     | D      | 7.1      | 6.50            |
| 705    | 5      | LITU    | L      | 24.6     | 26.52           |
| 705    | 6      | LITU    | L      | 12.5     | 15.98           |
| 705    | 7      | BELE    | L      | 24.9     | 23.69           |
| 705    | 8      | LITU    | L      | 31.4     | 29.03           |
| 705    | 9      | LITU    | L      | 27.1     | 24.19           |
| 705    | 10     | BELE    | L      | 12.6     | 14.45           |
| 705    | 11     | LITU    | L      | 38.7     | 25.67           |
| 705    | 12     | BELE    | L      | 12.3     | 13.92           |
| 705    | 13     | LITU    | L      | 15.9     | 16.17           |
| 705    | 14     | unk     | D      | 5.2      | 5.61            |
| 705    | 15     | unk     | D      | 12.5     | 14.28           |
| 705    | 16     | LITU    | L      | 24.7     | 26.43           |
| 705    | 17     | LITU    | L      | 29.8     | 25.30           |
| 705    | 18     | BELE    | L      | 14.3     | 16.08           |
| 705    | 19     | BELE    | L      | 11.8     | 16.99           |
| 705    | 20     | BELE    | L      | 19.0     | 16.80           |
| 705    | 21     | unk     | D      | 10.6     | 4.00            |
| 705    | 22     | unk     | D      | 13.7     | 14.69           |
| 705    | 23     | unk     | D      | 7.1      | 3.50            |
| 705    | 24     | unk     | D      | 7.0      | 6.50            |
| 705    | 25     | unk     | D      | 8.4      | 5.50            |
| 705    | 26     | BELE    | L      | 18.8     | 18.04           |
| 705    | 27     | LITU    | L      | 21.0     | 23.65           |
| 705    | 28     | PRSE    | L      | 21.4     | 21.94           |
| 705    | 29     | unk     | D      | 8.8      | 6.00            |
| 705    | 30     | ACSA    | L      | 13.7     | 11.90           |
| 705    | 31     | BELE    | L      | 18.3     | 22.68           |
| 705    | 32     | BELE    | L      | 13.1     | 19.32           |
| 705    | 33     | BELE    | L      | 16.4     | 19.74           |
| 705    | 34     | FAGR    | L      | 8.0      | 10.64           |
| 705    | 35     | LITU    | L      | 37.0     | 28.67           |
| 705    | 36     | LITU    | L      | 13.9     | 19.75           |
| 705    | 37     | LITU    | L      | 23.1     | 27.23           |
| 705    | 38     | LITU    | L      | 16.2     | 20.01           |
| 705    | 39     | FAGR    | L      | 5.9      | 6.08            |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 705    | 40     | LITU    | L      | 25.7     | 25.30           |
| 705    | 41     | FAGR    | L      | 34.0     | 28.50           |
| 706    | 1      | unk     | D      | 8.6      | 11.50           |
| 706    | 2      | PRSE    | L      | 8.0      | 7.00            |
| 706    | 3      | PRSE    | L      | 26.9     | 20.86           |
| 706    | 4      | BELE    | L      | 12.5     | 18.76           |
| 706    | 5      | PRSE    | L      | 28.5     | 26.60           |
| 706    | 6      | QURU    | L      | 15.0     | 17.52           |
| 706    | 7      | CACO    | L      | 14.0     | 19.00           |
| 706    | 8      | ACSA    | L      | 5.5      | 9.00            |
| 706    | 9      | PRSE    | L      | 31.2     | 28.68           |
| 706    | 10     | unk     | D      | 22.0     | 26.04           |
| 706    | 11     | CACO    | L      | 11.3     | 15.00           |
| 706    | 12     | PRSE    | L      | 14.7     | 19.63           |
| 706    | 13     | PRSE    | L      | 18.0     | 22.08           |
| 706    | 14     | FRAM    | L      | 13.5     | 23.12           |
| 706    | 15     | unk     | D      | 8.4      | 12.29           |
| 706    | 16     | ROPS    | L      | 17.2     | 15.58           |
| 706    | 17     | BELE    | L      | 7.1      | 12.42           |
| 706    | 18     | FAGR    | L      | 24.2     | 22.20           |
| 706    | 19     | BELE    | L      | 8.1      | 10.24           |
| 706    | 20     | BELE    | L      | 23.3     | 21.25           |
| 706    | 21     | QURU    | L      | 9.5      | 11.34           |
| 706    | 22     | BELE    | L      | 18.6     | 20.01           |
| 706    | 23     | BELE    | L      | 9.5      | 17.11           |
| 706    | 24     | unk     | D      | 12.7     | 14.25           |
| 706    | 25     | FAGR    | L      | 9.2      | 8.23            |
| 706    | 26     | BELE    | L      | 16.3     | 17.34           |
| 706    | 27     | BELE    | L      | 15.2     | 15.64           |
| 706    | 28     | ROPS    | L      | 16.6     | 19.38           |
| 706    | 29     | unk     | D      | 6.6      | 5.50            |
| 706    | 30     | ACSA    | L      | 5.6      | 10.50           |
| 706    | 31     | SAAL    | L      | 14.2     | 14.55           |
| 706    | 32     | unk     | D      | 6.7      | 5.00            |
| 706    | 33     | unk     | D      | 9.6      | 7.70            |
| 706    | 34     | SAAL    | L      | 14.8     | 17.22           |
| 706    | 35     | SAAL    | D      | 9.1      | 6.50            |
| 706    | 36     | FRAM    | D      | 6.5      | 11.38           |
| 706    | 37     | FRAM    | L      | 11.9     | 20.52           |
| 706    | 38     | SAAL    | L      | 17.8     | 21.72           |
| 706    | 39     | unk     | D      | 10.5     | 12.36           |
| 706    | 40     | BELE    | L      | 6.7      | 12.00           |
| 706    | 41     | FRAM    | L      | 16.6     | 20.17           |
| 706    | 42     | SAAL    | L      | 12.8     | 16.8            |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 706    | 43     | SAAL    | L      | 13.0     | 20.21           |
| 706    | 44     | SAAL    | L      | 15.4     | 20.58           |
| 706    | 45     | SAAL    | L      | 18.1     | 18.92           |
| 706    | 46     | SAAL    | L      | 15.8     | 21.20           |
| 706    | 47     | SAAL    | D      | 10.5     | 13.32           |
| 706    | 48     | unk     | D      | 7.6      | 10.50           |
| 706    | 49     | unk     | D      | 10.5     | 2.50            |
| 706    | 50     | SAAL    | D      | 9.7      | 15.00           |
| 706    | 51     | BELE    | L      | 6.7      | 10.45           |
| 706    | 52     | unk     | D      | 7.2      | 6.00            |
| 706    | 53     | FRAM    | L      | 12.4     | 16.25           |
| 706    | 54     | FAGR    | L      | 10.3     | 12.65           |
| 706    | 55     | FRAM    | L      | 13.6     | 18.84           |
| 706    | 56     | unk     | D      | 7.4      | 9.36            |
| 706    | 57     | BELE    | L      | 14.2     | 20.23           |
| 706    | 58     | BELE    | L      | 17.8     | 16.80           |
| 706    | 59     | BELE    | L      | 16.6     | 20.23           |
| 706    | 60     | PRSE    | L      | 28.3     | 19.84           |
| 706    | 61     | BELE    | L      | 23.6     | 25.28           |
| 706    | 62     | ACSA    | L      | 8.6      | 16.35           |
| 706    | 63     | FAGR    | L      | 6.0      | 8.00            |
| 706    | 64     | BELE    | L      | 23.0     | 20.06           |
| 1301   | 1      | ACSA    | L      | 16.3     | 20.16           |
| 1301   | 2      | ACSA    | L      | 51.5     | 33.93           |
| 1301   | 3      | ACSA    | L      | 17.5     | 20.79           |
| 1301   | 4      | ACSA    | L      | 17.7     | 23.04           |
| 1301   | 5      | ACSA    | L      | 21.3     | 27.45           |
| 1301   | 6      | ACSA    | L      | 12.2     | 23.45           |
| 1301   | 7      | unk     | D      | 19.0     | 7.00            |
| 1301   | 8      | ACSA    | L      | 20.1     | 21.88           |
| 1301   | 9      | ACSA    | L      | 9.3      | 12.20           |
| 1301   | 10     | ACSA    | L      | 23.8     | 21.83           |
| 1301   | 11     | ACSA    | L      | 26.3     | 9.36            |
| 1301   | 12     | ACSA    | L      | 6.7      | 26.98           |
| 1301   | 13     | ACSA    | L      | 35.8     | 27.15           |
| 1301   | 14     | FAGR    | L      | 36.5     | 31.27           |
| 1302   | 1      | FAGR    | L      | 25.5     | 19.13           |
| 1302   | 2      | FAGR    | L      | 12.8     | 11.25           |
| 1302   | 3      | FAGR    | L      | 11.8     | 10.13           |
| 1302   | 4      | unk     | D      | 14.5     | 6.36            |
| 1302   | 5      | unk     | D      | 28.2     | 12.09           |
| 1302   | 6      | FAGR    | L      | 6.1      | 6.24            |
| 1302   | 7      | FAGR    | L      | 14.1     | 11.59           |
| 1302   | 8      | unk     | D      | 17.5     | 10.00           |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 1302   | 9      | QUPR    | L      | 34.0     | 24.78           |
| 1302   | 10     | FAGR    | L      | 9.5      | 10.11           |
| 1302   | 11     | unk     | D      | 22.9     | 20.70           |
| 1302   | 12     | unk     | D      | 15.6     | 2.50            |
| 1302   | 13     | unk     | D      | 8.5      | 13.50           |
| 1302   | 14     | FAGR    | L      | 5.7      | 7.02            |
| 1302   | 15     | unk     | D      | 16.5     | 4.00            |
| 1302   | 16     | ACSA    | L      | 31.0     | 26.25           |
| 1302   | 17     | FAGR    | L      | 8.4      | 14.04           |
| 1302   | 18     | FAGR    | L      | 6.7      | 9.90            |
| 1302   | 19     | FAGR    | L      | 11.9     | 16.56           |
| 1302   | 20     | unk     | D      | 26.0     | 26.45           |
| 1302   | 21     | unk     | D      | 22.0     | 11.50           |
| 1302   | 22     | FAGR    | L      | 8.7      | 12.74           |
| 1302   | 23     | FAGR    | L      | 7.7      | 7.65            |
| 1302   | 24     | FAGR    | L      | 17.4     | 18.29           |
| 1302   | 25     | FAGR    | L      | 25.3     | 26.07           |
| 1302   | 26     | FAGR    | L      | 27.1     | 16.80           |
| 1302   | 27     | FAGR    | L      | 11.6     | 12.87           |
| 1302   | 28     | unk     | D      | 15.5     | 5.52            |
| 1302   | 29     | QURU    | L      | 77.0     | 35.71           |
| 1302   | 30     | QURU    | L      | 40.5     | 29.05           |
| 1302   | 31     | FAGR    | L      | 24.3     | 22.56           |
| 1302   | 32     | FAGR    | L      | 5.9      | 7.00            |
| 1303   | 1      | TIAM    | L      | 9.3      | 12.42           |
| 1303   | 2      | TIAM    | L      | 19.4     | 21.87           |
| 1303   | 3      | TIAM    | L      | 38.7     | 25.92           |
| 1303   | 4      | TIAM    | L      | 29.1     | 25.38           |
| 1303   | 5      | FAGR    | L      | 7.8      | 10.15           |
| 1303   | 6      | FAGR    | L      | 15.3     | 15.96           |
| 1303   | 7      | FAGR    | L      | 11.5     | 13.20           |
| 1303   | 8      | MAAC    | L      | 24.4     | 24.64           |
| 1303   | 9      | ACSA    | L      | 7.4      | 9.72            |
| 1303   | 10     | CACO    | L      | 28.5     | 32.34           |
| 1303   | 11     | LITU    | L      | 25.6     | 32.00           |
| 1303   | 12     | CACO    | L      | 18.3     | 25.65           |
| 1303   | 13     | CACO    | D      | 14.0     | 15.75           |
| 1303   | 14     | ACSA    | L      | 19.6     | 25.00           |
| 1303   | 15     | FAGR    | L      | 25.2     | 30.80           |
| 1303   | 16     | ACSA    | L      | 7.5      | 9.60            |
| 1303   | 17     | ACSA    | L      | 9.8      | 13.20           |
| 1303   | 18     | ACRU    | L      | 17.6     | 14.70           |
| 1303   | 19     | TIAM    | L      | 64.1     | 37.50           |
| 1304   | 1      | ACSA    | L      | 20.9     | 17.08           |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 1304   | 2      | ACSA    | L      | 6.0      | 8.68            |
| 1304   | 3      | FAGR    | L      | 7.0      | 6.50            |
| 1304   | 4      | ACSA    | L      | 17.4     | 20.30           |
| 1304   | 5      | MATR    | L      | 8.1      | 10.40           |
| 1304   | 6      | ACSA    | L      | 7.3      | 9.00            |
| 1304   | 7      | unk     | D      | 15.8     | 14.22           |
| 1304   | 8      | ACSA    | L      | 6.2      | 8.19            |
| 1304   | 9      | ACSA    | L      | 8.4      | 9.36            |
| 1304   | 10     | QUCO    | L      | 71.9     | 33.54           |
| 1304   | 11     | FAGR    | L      | 5.2      | 5.39            |
| 1304   | 12     | ACSA    | L      | 13.2     | 18.43           |
| 1304   | 13     | unk     | D      | 17.8     | 14.90           |
| 1304   | 14     | ACSA    | L      | 12.7     | 12.58           |
| 1304   | 15     | QURU    | L      | 46.0     | 26.28           |
| 1304   | 16     | QURU    | L      | 33.7     | 27.75           |
| 1304   | 17     | ACSA    | L      | 8.4      | 6.50            |
| 1304   | 18     | ACSA    | L      | 19.7     | 20.77           |
| 1304   | 19     | QURU    | L      | 31.2     | 25.38           |
| 1304   | 20     | NYSY    | L      | 35.4     | 21.33           |
| 1304   | 21     | MATR    | L      | 24.8     | 16.44           |
| 1304   | 22     | QURU    | L      | 48.7     | 30.71           |
| 1304   | 23     | MATR    | L      | 39.5     | 26.03           |
| 1304   | 24     | ACSA    | L      | 7.5      | 10.88           |
| 1304   | 25     | ACSA    | L      | 12.1     | 13.58           |
| 1304   | 26     | ACSA    | L      | 15.1     | 18.96           |
| 1304   | 27     | ACSA    | L      | 20.1     | 19.80           |
| 1305   | 1      | ACSA    | L      | 21.3     | 18.13           |
| 1305   | 2      | MAAC    | L      | 47.1     | 26.00           |
| 1305   | 3      | ACSA    | L      | 5.5      | 6.50            |
| 1305   | 4      | ACSA    | L      | 7.3      | 10.50           |
| 1305   | 5      | ACSA    | L      | 11.5     | 13.75           |
| 1305   | 6      | QURU    | L      | 26.7     | 26.35           |
| 1305   | 7      | FAGR    | L      | 21.0     | 14.95           |

| plot # | tree # | species | status | dbh (cm) | tree height (m) |
|--------|--------|---------|--------|----------|-----------------|
| 1305   | 8      | FAGR    | L      | 38.5     | 27.30           |
| 1305   | 9      | ACSA    | L      | 7.4      | 11.00           |
| 1305   | 10     | ACSA    | D      | 5.7      | 6.00            |
| 1305   | 11     | ACSA    | L      | 25.1     | 24.30           |
| 1305   | 12     | ACSA    | L      | 11.0     | 12.15           |
| 1305   | 13     | ACSA    | L      | 5.3      | 5.50            |
| 1305   | 14     | unk     | D      | 27.1     | 3.00            |
| 1305   | 15     | ACSA    | L      | 7.2      | 6.00            |
| 1305   | 16     | ACSA    | L      | 7.3      | 8.00            |
| 1305   | 17     | ACSA    | L      | 5.5      | 5.00            |
| 1305   | 18     | ACSA    | L      | 22.6     | 11.90           |
| 1306   | 1      | unk     | D      | 19.6     | 5.40            |
| 1306   | 2      | QUAL    | L      | 38.0     | 28.38           |
| 1306   | 3      | ACSA    | L      | 5.8      | 7.50            |
| 1306   | 4      | unk     | D      | 19.5     | 12.00           |
| 1306   | 5      | ACSA    | L      | 30.2     | 21.25           |
| 1306   | 6      | ACSA    | L      | 30.5     | 20.25           |
| 1306   | 7      | ACSA    | L      | 11.0     | 12.00           |
| 1306   | 8      | unk     | D      | 25.0     | 21.00           |
| 1306   | 9      | unk     | D      | 28.8     | 23.24           |
| 1306   | 10     | QURU    | L      | 56.2     | 25.58           |
| 1306   | 11     | QURU    | L      | 88.5     | 25.58           |
| 1306   | 12     | ACSA    | L      | 34.2     | 23.20           |
| 1306   | 13     | ACSA    | L      | 7.4      | 10.00           |
| 1306   | 14     | QURU    | L      | 47.5     | 26.25           |
| 1306   | 15     | FAGR    | L      | 29.6     | 28.14           |
| 1306   | 16     | QURU    | L      | 54.0     | 33.06           |
| 1306   | 17     | QURU    | L      | 14.2     | 11.55           |
| 1306   | 18     | ACSA    | L      | 5.5      | 14.00           |
| 1306   | 19     | QURU    | L      | 37.1     | 29.12           |
| 1306   | 20     | QURU    | D      | 23.1     | 20.00           |
| 1306   | 21     | QURU    | L      | 7.9      | 6.00            |





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130621B 2000 28 42 32-9999

\*Increment core identification code consists of watershed (07 or 13), plot (01 to 06), tree number, then core number (A or B).

Measurements are listed in a decadal series and expressed in 0.01 mm.

## VITAE

Nicholas R. Doner

## EDUCATION

**M. A. in Geography**, West Virginia University, 2004. Thesis: Effects of drought on the growth of young and mature temperate forests in West Virginia.

**B. S. in Biology** (Geography minor, History minor), West Virginia University, 2001.  
Independent undergraduate research: Spatial patterns of nitrate availability in three forested watershed in the Fernow Experimental Forest.

## TEACHING EXPERIENCE

**Laboratory Instructor/Teaching Assistant**. West Virginia University. Six sections, two semesters, 2002-2003.

### Courses Taught:

Physical Geography Laboratory

## AWARDS AND GRANTS

2003 Travel support money (award) to the 99<sup>th</sup> Annual Meeting of the Association of American Geographers (\$200). West Virginia University, Eberly College of Arts and Sciences.

## PUBLICATIONS

Kernan, J. T., N. Doner, H. Freeman, S. Kazar, A. E. Hessel. (in review). Can mangroves serve as indicators of global sea level change? Submitted to *Southeastern Geographer*, 2003.

## PAPER PRESENTATIONS

N. R. Doner and A. E. Hessel. 2003. Effects of drought on the growth of young and mature temperate forests in West Virginia. Special Session at Association of American Geographers, sponsored by Biogeography Specialty Group, Annual meeting, New Orleans, LA. March 2003.

## **OTHER ACADEMIC EMPLOYMENT**

Department physical geography laboratory manual proofreader. Department of Geology and Geography, Eberly College of Arts and Sciences, West Virginia University. May 2003 – June 2003.

Research assistant (Dr. Amy E. Hessler). Department of Geology and Geography, Eberly College of Arts and Sciences, West Virginia University. May 2002 – May 2003.

Laboratory employee (Hollowfill project). Natural Resource Analysis Center, Davis College of Agriculture, Forestry, and Consumer Sciences, West Virginia University. May 2001 – May 2002.

Laboratory employee (Dr. Jonathan Cumming). Department of Biology, Eberly College of Arts and Sciences, West Virginia University. January 2001 – May 2001.

Laboratory employee (Dr. William Peterjohn and Dr. Martin Christ). Department of Biology, Eberly College of Arts and Sciences, West Virginia University. September 1999 – December 2000.

## **MEMBERSHIPS IN PROFESSIONAL SOCIETIES**

|   |                 |
|---|-----------------|
| Association of American Geographers (AAG) | 2002 to present |
| SouthEastern Division of the AAG          | 2002 to present |