# Natural Resources Preservation Program Annual Report

TITLE: Paper birch decline in the Niobrara Valley: Interactions of weather, microclimate, and genetics

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# Paper birch decline in the Niobrara Valley: Interactions of weather, microclimate, and genetics

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## Introduction

The Niobrara Valley is widely known as the biological crossroads of the Great Plains. Three distinct prairie (sandhills, mixed-grass, tallgrass) and three distinct forest (western coniferous, eastern deciduous, northern boreal) ecosystem types, some of them at or beyond their normal geographic limit, meet and mix in this region. The boreal forest is primarily represented by scattered stands of paper birch (*Betula papyrifera* Marsh); over thirty stands of paper birch are known to occur within the Niobrara Valley, far from the edge of the species' primary range. These stands are considered to be relictual populations that have persisted since the end of the Wisconsin glaciation, approximately 10,000 years ago, when regional flora was much more boreal in nature (Wright 1970, Kaul and others, 1988). Resource managers with the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), and The Nature Conservancy (TNC) believe that the stands of paper birch are at risk for population decline, due to apparent dieback of canopy-sized trees. Although a few boreal ferns, shrubs, forbs and club mosses also occur in the Niobrara Valley, loss of paper birch trees would eliminate the principal component of one of the six major ecosystem types that comprise the "biological crossroads" of the region.

Paper birch is a cold climate species and rarely occurs naturally where average July temperatures exceed 21°C (U.S. Dept of Agriculture 1965). The annual warmest month average for the Niobrara region is 23°C as recorded at nearby weather stations at Valentine Regional Airport and at Springview, Nebraska. It is probable that spring branch canyons and north-facing slopes along the Niobrara River support a microclimate that differs significantly from the local climate as measured at nearby weather stations. Relict populations of prehistoric flora can persist for thousands of years in sites far from a species' contemporary range in sites with favorable microclimates (Stebbins and Major 1965, Billings and Anderson 1966).

No previous work has been done on understanding the reasons for current paper birch dieback in the Niobrara Valley, and the date of onset is unclear. Notes from a 1982 inventory of birch stands in the Niobrara Valley do not mention dieback of birch trees and list only erosion and grazing as threats to stand viability (Churchill and Freeman, 1982). It is possible that the current dieback event started around or after the early 1980's. Reasons for the current dieback event may include changes in microclimate, pest or pathogen infestations, or loss of genetic diversity and therefore population resilience.

Widespread dieback of birch trees was observed in Nova Scotia, Canada and Maine, USA from 1935 through the mid 1940's, killing 67% of paper birch and yellow birch (*Betula alleghaniensis* Britt) in Maine and leaving 15% of remaining birch in a dying condition (Nash and Duda 1951). Although no clear reason for the dieback was discerned, likely causes were attributed to low winter temperatures, late spring freezes, and unfavorable combinations of precipitation and temperature (Nash and Duda 1951, Braathe 2005). Although a root fungus (*Armillaria mellea* (Vahl: Fr.) Kummer) and the bronze birch borer (*Agrilus anxius* Gory) were associated with both healthy and dying birch, neither was attributed as the primary cause of the widespread dieback (Nash and Duda 1951). Birch dieback has also been associated with infection by the silver-leaf fungus *Chondrostereum purpureum* (Setliff 2002), with cold winter temperatures with minimal snow cover (Pomerleau 1991, Braathe 2005) and with early spring thaws followed by hard frosts (Cox and Malcolm 1997, Braathe 2005).

Steuter and Steinauer (1993) concluded that stands of paper birch in the middle Niobrara Valley are reproducing primarily by sprouting and suggested that the species may be at risk for reduced genetic diversity. Genetic variation in paper birch has been found to be strongly correlated with a number of traits related to germination, fall and winter frost hardiness, and several physiological traits (Benowicz and others, 2001). If most recruitment in a given stand is by sprouts rather than cross-pollinated seed, within-stand genetic diversity can be even lower and among-stand genetic differentiation even higher than predicted by population size alone. Differential levels of genetic diversity among stands may help explain any differential dieback among stands.

This project has four objectives:

1. Characterize microclimate parameters within large and small birch stands
2. Construct a regional and local climatic history of the Middle Niobrara Valley and develop a model of relict site microclimate conditions based on local weather conditions
3. Estimate percent canopy dieback in paper birch stands and test for correlation of canopy dieback and recruitment with genetic diversity, genetic similarity, and environmental parameters
4. Estimate genetic diversity and similarity of paper birch canopy and understory trees along Niobrara National Scenic River using ISSR molecular markers and diagram genetic relationships of stands for both canopy and understory trees.

In 2005, we selected ten birch stands as microclimate monitoring sites, installed temperature and humidity data loggers, and collected and reported on initial microclimate data from June 2005 through October 2005. We installed a Campbell automatic weather station at The Nature Conservancy's Niobrara Valley Preserve headquarters in April 2005. The station data are automatically updated every five minutes and are available for public viewing at: http://agebb.missouri.edu/weather/realtime/niobrara.asp. We screened ten and selected four intersimple sequence repeat (ISSR) primers for use with birch DNA analysis. This report describes our project activities and progress during Fiscal Year 2006.

# Methods

## *Objective 1: Microclimate*

Using site location data from the 1982 Churchill and Freeman birch survey, we selected ten birch stands for microclimate monitoring. Sites were selected to represent a variety of locations: upper river sites (Figure 1), lower river sites (Figure 2), and the much less common north bank sites (Figure 1). Sites were also selected to represent the two types of birch stands: spring branch canyons and north-facing slopes along the river mainstem. Two of each site type were selected on both the upper and lower river. No previous microclimate data for the birch stands exist. Microclimate data from these sites will be used to examine current microclimate similarities and differences among birch stands and between birch stands and the nearby automated weather station. We will also use microclimate data to develop a model of birch site microclimate conditions in relation to local climate (weather station) conditions.

Two Hobo® Pro RH/Temp Data Loggers **(**Onset Computer Corporation) were positioned in each microclimate monitoring site. In linear river-front sites, one monitor was positioned near the uppermost (western) birch tree in the stand and the other was positioned near the lowermost (eastern) birch tree in the stand. In canyon sites, one monitor was positioned on the west facing canyon slope and one on the east facing canyon slope. Each data logger was mounted inside a translucent white plastic box to protect from rainfall; the boxes are open at the bottom for ventilation. In order to not affect birch trees, plastic boxes were tied with nylon cord to the boles of nearby small trees, usually *Ostrya virginiana* (Figure 3). At each data logger location, percent slope was measured using a clinometer, and aspect was estimated to the nearest degree using a compass. Data loggers were programmed to take temperature and humidity measurements on the hour and half-hour beginning in mid June 2005. Data were downloaded in October 2005, May or June 2006, and October 2006. Daily mean values for temperature and relative humidity were calculated from all half-hour values on a given date; daily temperature range was calculated as the difference between the maximum and minimum recorded values on a given date.

The automated weather station installed at the TNC Niobrara Valley preserve headquarters compound is closer to the river than the local weather station at Valentine Miller Field. Therefore, the TNC weather station is used as a reference site for river valley conditions in locations where birch are absent. A metric of environmental distance between each birch microclimate monitoring site and the TNC weather station was calculated for each of the following microclimate parameters: daily minimum temperature, daily maximum temperature, and daily temperature range. Environmental distance (ED) has been used by others to compare microclimatic conditions between study and reference sites (Sanders and McGraw 2005) and is calculated as:

$$ED_j = \sum_{i=9/30/06}^{10/01/05} \sqrt{(\mathrm{E}_{\mathrm{i,j}} - \mathrm{E}_{\mathrm{i,TNC}})^2}$$

where $ED_j$ = the environmental distance of birch site $j$ from the TNC weather station for the period October 1, 2005 through September 30, 2006; $E_{i,j}$ = is the mean value for a given environmental parameter on day $i$ at birch site $j$.

Growing degree days (GDD) provide information on favorable growth conditions for agricultural and native species. In order to estimate spring thaw conditions, GDD was calculated using March 2006 data for each birch microclimate monitoring site and for the TNC automated weather station as follows:

$$GDD = \sum [(T\ max - T\ min)/2] - 4$$

where T max = maximum temperature and T min = minimum temperature (in degrees Celsius) on a given day. This calculation method is similar to the 1971 National Oceanic and Atmospheric Administration formula which uses 10 $^{o}$C as a baseline for corn growth (Nielson 2001). We used 4 $^{o}$C as a baseline temperature because it represents the daily temperature above which biological activity occurs in yellow birch (Borque and others 2005) and this temperature has been used as the threshold for biological activity when measuring injury to paper birch roots during periods of freezing temperatures followed by thaws (Braathe 1995, Cox and Malcolm 1997). The lowest minimum daily temperature recorded during May 2006 was selected from each birch site and from the TNC weather station to describe late spring temperature minima.

Figure 1. Location of upper river birch microclimate monitoring sites (purple circles) and other birch study sites (pink circles).

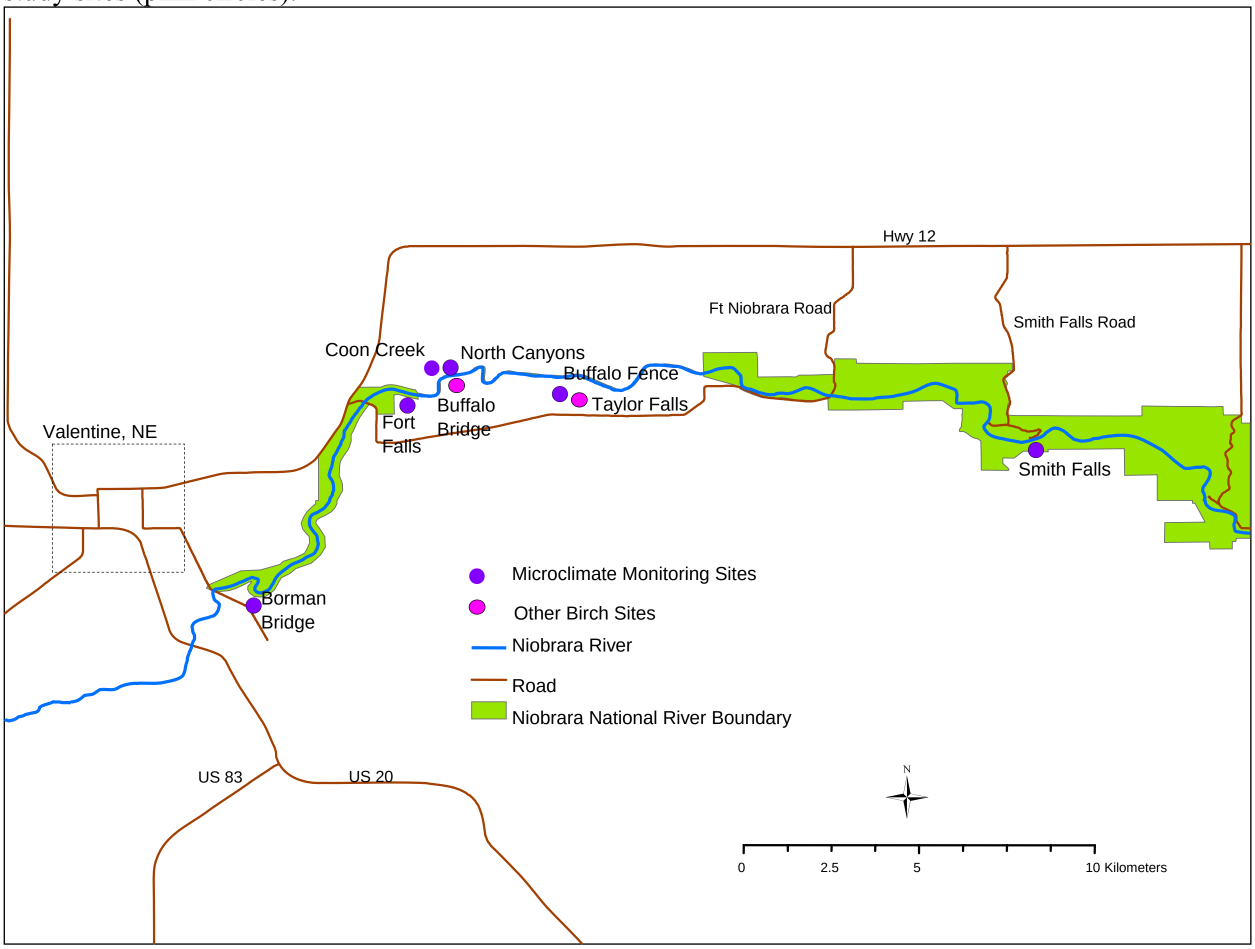


Figure 2. Location of lower river birch microclimate monitoring sites (purple circles), other birch study sites (pink circles), and automated weather station at TNC headquarters.

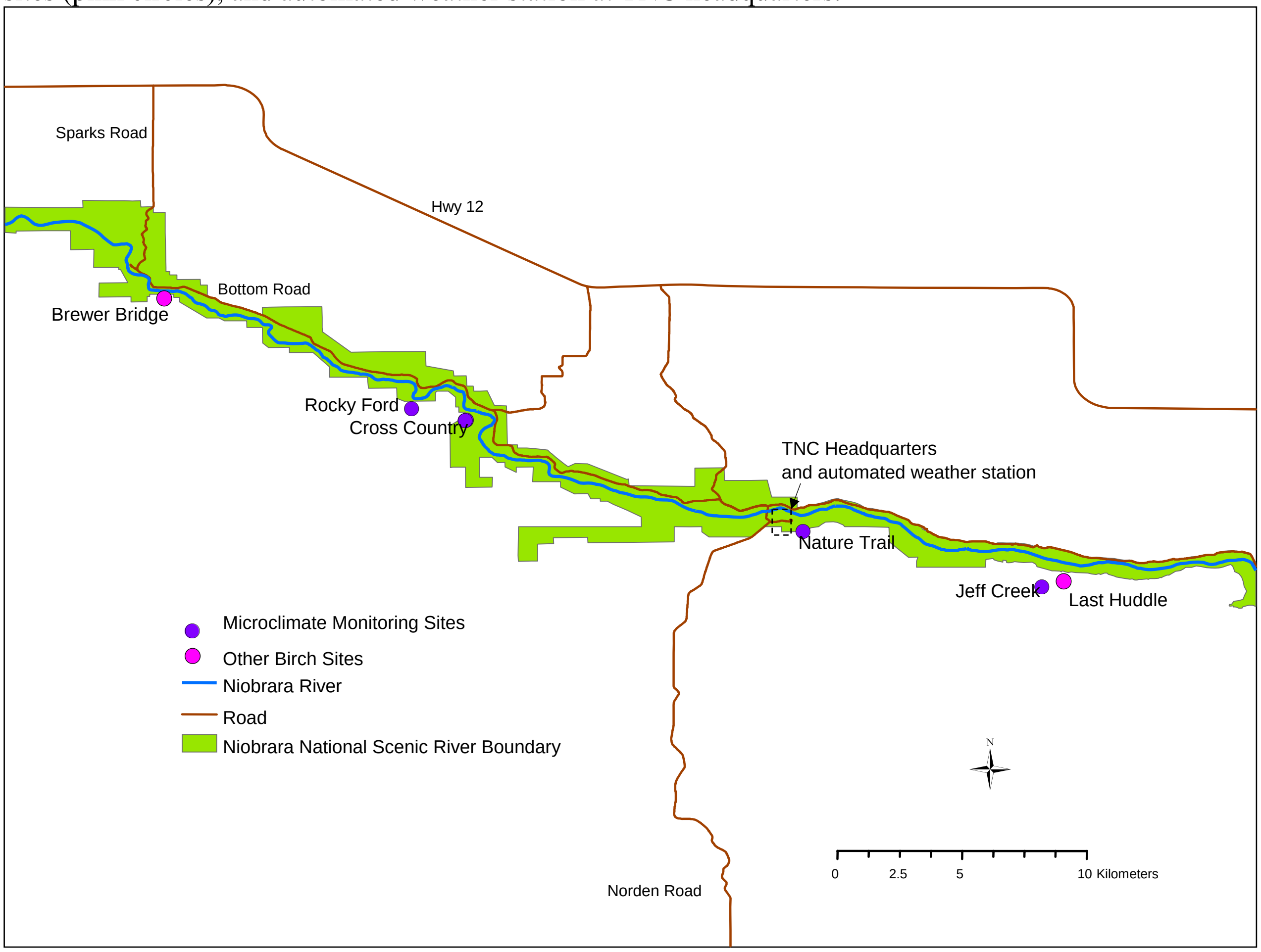
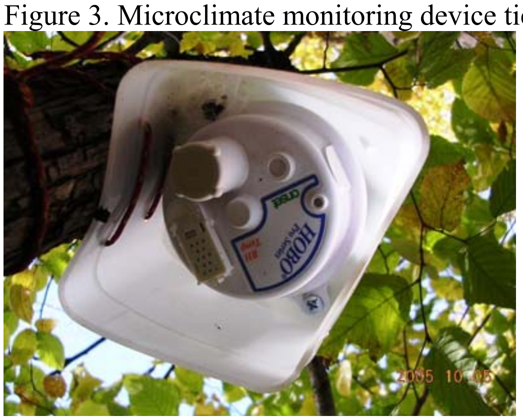



Figure 3. Microclimate monitoring device tied to a small *Ostrya virginiana* in a birch stand.



### *Objective 2: Regional Climate*

We obtained historic weather data from the Valentine Miller Field cooperative weather station in Valentine Nebraska for the period of record (1948 through 2006). Growing degree days for each March from 1949 – 2006 were calculated using the formula above. The lowest minimum daily temperature recorded for each May 1949-2006 was selected to indicate late spring temperature minima.

We used data from the Campbell automated weather station we installed at TNC Niobrara Valley Preserve in April 2005 and historic data from two National Weather Service stations to reconstruct local climate at TNC back to 1948. Daily weather data from 1948-2005 were obtained from weather stations at Valentine Miller Field (VMF) approximately 44 km west-northwest and Ainsworth (AIN) approximately 32 km southeast from the TNC station. Covariances and means among stations were estimated using data from all three weather stations for the period 4/12/05 – 12/31/05, and these climatic relationships were assumed to remain constant for the entire period of interest (1948 – 12/31/05). Any differences in instrumentation among sites should not matter as long as this assumption hold true, which should be revealed as we test and refine our model.

Using daily averages for maximum and minimum temperature at VMF and AIN weather stations from 1971- 2000, we centered (standardized) values of the VMF and AIN data from 1/1/48 to 12/31/05. The centered values were used in Kalman filter and Kalman smoother models to estimate maximum and minimum temperature averages for each day of the year at TNC. The Kalman filter and Kalman smoother are recursive models best used for sequential updating with linear model operators and Gaussian error distributions (Kalman 1960, Cohn and others, 1994). The Kalman filter algorithm uses data from a known starting point until time *t* to reconstruct the climatic history for not only observed data but also missing data. The Kalman smoother considers all the data. For instance, estimates at time *t* are based on information before and after that time point; thus, a backwards recursion formula gives smoother distributions (Cohn and others, 1994).

### *Objective 3: Birch Stand Conditions*

We visited fourteen sites for health assessment of birch stands in May and June 2005. We visited each of the ten stands in which microclimate is being monitored, plus one additional canyon site and one additional riverfront site on both the upper and lower river sections (Figures 1 and 2). Sites on the north side of the river were each assessed as two sites, since the birch stands in these sites are close to each other but not contiguous, as is the case with all south bank sites.

At each health assessment site, we estimated stand area by walking the perimeter and logging a polygon a Thales Mobile Mapper. We searched for and tallied any birch seedlings or saplings (≤ 2.5 cm stem diameter) and tallied all live and all dead birch trees within the stand boundaries using click-type counters. Every live birch tree encountered was marked as a waypoint. If the number of live birch trees within a site was less than or equal to ten, we assessed them all.

Otherwise, we randomly selected eight waypoints using a random number table. These eight live birch trees and two others were used for stand health assessment. In riverfront sites, the easternmost and westernmost living birch trees were selected, and in canyon sites, the living birches closest to the canyon top and canyon mouth were selected for assessment. We purposely selected these "stand edge" birches in addition to the randomly chosen ones in order to cover the range of environmental gradients with each stand. For each tree assessed, we:

- recorded its GPS location,
- affixed a numbered aluminum tag with copper wire,
- recorded aspect (degrees) and percent slope,
- measured the diameter at breast height (dbh) for each living and each dead bole using a diameter tape,
- recorded distance to nearest canopy opening to the nearest meter,
- estimated percent bare ground within the tree dripline to the nearest 5 percent,
- recorded crown class of the tree (suppressed, co-dominant or dominant),
- noted presence of male and female catkins, if any
- took one or more digital photographs

We assigned each tree a number according to its dieback classification category (from Nash and Duda 1951):

1. Normal, apparently healthy tree
2. Trees with abnormally small, thin, curled, chlorotic foliage (any one or combination)
3. Trees with bare or dead twigs, but with no dead branches
4. Trees with dead branches constituting less than one-half the crown
5. Trees with over one-half the crown dead
6. Foliage only on one to several trunk sprouts (< 2.5 cm max. diameter)
7. Tree entirely dead

We also checked for evidence of any of the following common birch pests and pathogens, and commented on extent if evidence was found:

1. *Armillaria* root disease
2. bronze birch borer
3. leaf miners
4. birch anthracnose
5. *Chondrostereum purpureum*
6. ambrosia beetles
7. frost cracks
8. sooty mold
9. sapsucker damage
10. Storm damage

At each birch tree assessed, we estimated local basal area per hectare of all tree species using an English basal area factor (BAF) 10 on a Jim-Gem® cruz-all. Each stem counted in an English BAF 10 plot is equivalent to basal area of 2.296 $m^2$ per hectare for that species. If a dead birch tree was included in the cruz-all plot, we performed a health assessment on it, until we had assessed two dead birch trees per site.

## *Objective 4: Genetics of Birch Stands*

During birch stand assessment, we collected three to five leaves from each live birch tree assessed (n = 122) and placed them in a labeled plastic zip bag containing silica gel. We also collected leaf tissue from other relict birch populations in six locations in South Dakota; three locations in the northern Black Hills along Spearfish Canyon (N = 21), and three locations in the southern Black Hills in Custer State Park (N = 21). In addition, we collected leaf tissue from three birch populations in Minnesota (N = 64). The Minnesota populations are located in the core of the present-day range of paper birch and were haphazardly selected to in order to compare genetic diversity of disjunct populations to that of central populations. We extracted DNA from silica-dried leaf tissue using the standard procedure outlined in Doyle and Doyle (1987) as modified by the Soltis Laboratory (2002).

# FY 2006 Results

## *Objective 1: Microclimate*

Mean values for minimum and maximum temperature, daily temperature range, and mean relative humidity for each birch microclimate monitoring site and the TNC automated weather station are given in Table 1. Values for environmental distances from the TNC weather station for maximum temperature, minimum temperature, daily temperature range, and overall mean ED are given in Table 2. March growing degree days and minimum May temperatures in the birch microclimate monitoring sites and at the TNC weather station are given in Table 3.

Table 1. Mean values for minimum and maximum temperature (T min and T max), daily temperature range (T range), and mean relative humidity (RH) for each birch microclimate monitoring site and the TNC automated weather station in the Niobrara River Valley, Nebraska from October 1, 2005 through September 30, 2006.

| Site | T min $^oC$ | T max $^oC$ | T range $^oC$ | RH % |
|---|---|---|---|---|
| Nature Trail | 3.04 | 16.85 | 13.81 | 72.83 |
| Jeff Creek | 2.78 | 18.13 | 15.35 | 74.11 |
| Rocky Ford | 2.90 | 16.84 | 13.94 | 72.50 |
| Cross Country | 2.33 | 16.60 | 14.28 | 72.81 |
| Coon Creek | 1.38 | 18.08 | 16.70 | 71.39 |
| North Canyons | 1.86 | 19.50 | 17.64 | 71.93 |
| Borman Bridge | 2.84 | 16.54 | 13.70 | 73.72 |
| Smith Falls | 2.86 | 16.90 | 14.04 | 72.26 |
| Fort Falls | 2.12 | 16.34 | 14.23 | 72.61 |
| Buffalo Fence | 2.42 | 16.35 | 13.93 | 74.75 |
| TNC | 1.93 | 19.28 | 17.35 | 66.80 |

Table 2. Environmental distance (ED) values calculated for differences in daily minimum temperature (T min), maximum temperature (T max), temperature range (T range) and the overall mean ED between ten birch stands and a reference weather station at TNC headquarters along the Niobrara River, Nebraska from October 1, 2005 through September 30, 2006. Units are degrees Celsius.

| Site | Location | Type | T min ED | T max ED | T range ED | Mean ED |
|---|---|---|---|---|---|---|
| Nature Trail | Lower | Canyon | 29.34 | 60.93 | 83.50 | 57.92 |
| Jeff Creek | Lower | Canyon | 32.79 | 51.81 | 68.42 | 51.01 |
| Rocky Ford | Lower | River | 26.72 | 61.41 | 80.24 | 56.12 |
| Cross Country | Lower | River | 19.96 | 68.50 | 78.19 | 55.55 |
| Coon Creek | North | North | 27.31 | 45.75 | 49.45 | 40.84 |
| North Canyons | North | North | 25.11 | 54.05 | 59.19 | 46.12 |
| Borman Bridge | Upper | Canyon | 34.44 | 65.34 | 87.87 | 62.55 |
| Smith Falls | Upper | Canyon | 31.58 | 57.13 | 78.12 | 55.61 |
| Fort Falls | Upper | River | 25.82 | 68.90 | 77.13 | 57.29 |
| Buffalo Fence | Upper | River | 27.88 | 65.21 | 78.09 | 57.06 |

Table 3. March growing degree days (GDD) and lowest May minimum temperature in ten birch stands along the Niobrara River, at The Nature Conservancy Niobrara Valley Preserve Headquarters (TNC) and at Valentine Miller Field (VMF) for 2006.

| Location | March GDD | May T min |
|---|---|---|
| Nature Trail | 59.54 | -1.71 |
| Jeff Creek | 74.44 | -2.12 |
| Rocky Ford | 58.60 | -0.97 |
| Cross Country | 47.50 | -2.50 |
| Coon Creek | 66.97 | -4.15 |
| North Canyons | 91.60 | -3.50 |
| Borman Bridge | 48.50 | -0.75 |
| Smith Falls | 46.90 | -1.71 |
| Fort Falls | 41.86 | -2.93 |
| Buffalo Fence | 33.60 | -1.54 |
| TNC | 78.30 | -2.60 |

## *Objective 2: Regional Climate*

The recursive model is currently being validated using data from 2006, as scheduled in our project work plan.

March degree days and May minimum temperatures recorded at Valentine Miller Field cooperative weather station from 1949 through 2006 are given in Table 4.

## *Objective 3: Birch Stand Conditions*

Birch stand size was bimodal, with about half of the sites (N = 9) measuring 0.2 Ha or less, and the remainder (N = 7) measuring 0.37 – 0.70 Ha; these stands were designated small and large, respectively (Table 5). Most of the large stands were on the lower section of the river. The number of birch trees per site ranged from 7 at the Coon Creek West site on the upper river to 81 at the Brewer Bridge site on the lower river; proportion live birch ranged from 0.20 at the Box

Canyon site to 0.88 at the Buffalo Bridge site; and mean health code (1 = healthy, 7 = tree completely dead) ranged from 3.17 at the Buffalo Fence site to 6.50 at the Coon Creek West site (Table 5).

Birch trees are prolific sprouters, and individuals often consist of multiple stems. Mean number of boles per tree ranged from 1.5 at the Brewer Bridge site to 5.0 at the Coon Creek East site (Table 1). Total birch basal area per hectare is lowest at the Jeff Creek site (0.58 $m^2$/Ha) and highest at the Coon Creek West site (19.34 $m^2$/Ha, Table 1). This may be an artifact of stand size; the very smallest "stands" on the north side of the river tended to be isolated clumps of trees closely spaced, while larger "stands" were composed of scattered trees in an easily definable area. The ratio of live basal area to dead basal area was greatest at the Taylor Falls site (5.59) and lowest at the Side Canyon site (0.01).

No birch seedlings were observed in any site; saplings were found at only two sites: one at Taylor Falls and six at the Rocky Ford site (Table 1). The Taylor Falls sapling was found in the bottom of the canyon at the edge of the flowing creek; the Rocky Ford saplings were closely grouped at the edge of the riverbank. A group of nine saplings was found at Smith Falls State Park in a location outside the boundaries of the Smith Falls study site within 10 meters of two mature birch trees that produced seed in 2005 and 2006.

Birch trees produce separate male and female flowers in the form of catkins; very few trees with catkins were found. On the lower river, one tree at the Last Huddle site and one at the Rocky Ford site produced catkins; on the upper river, two trees at the Taylor Falls site and two at the Buffalo Fence site produced catkins; and on the North side of the river, catkins were found on two trees at the Coon Creek East site. One tree near the Borman Bridge study site outside of stand boundaries was observed bearing catkins.

### *Objective 4: Genetics of Birch Stands*

We extracted DNA from all birch leaf samples collected in summer 2006 (N = 228). Beginning in January, 2007 as scheduled, we will perform Polymerase Chain Reactions (PCR) with these samples using DNA primers we screened in 2005. DNA analysis will follow in February through April, 2007, also as scheduled.

## Discussion

Data analysis is still underway for microclimate, genetics, regional climate, and birch stand conditions. Additional field data and microclimate data will be collected and analyzed in FY 2007.

## Management Implications

This is the second year of a three-year project, and management implications are not clear at this time.

Table 4. March Growing Degree Days (GDD) and lowest May minimum temperature at Valentine Miller Field from 1949 to 2005 using 4$^o$ C as baseline temperature. Years in which March GDD exceeded 100$^o$ C are highlighted in yellow; years in which May minimum temperatures fell below -4$^o$ C are highlighted in blue.

| Year | March GDD | May Min | Year | March GDD | May Min |
|---|---|---|---|---|---|
| 1949 | 33.56 | 1.11 | 1978 | 57.89 | 1.11 |
| 1950 | -8.67 | -4.44 | 1979 | 37.67 | -4.44 |
| 1951 | -18.67 | -1.67 | 1980 | 36.33 | -6.11 |
| 1952 | -28.39 | -0.56 | 1981 | 135.50 | -5.56 |
| 1953 | 82.61 | -3.33 | 1982 | 74.33 | -2.22 |
| 1954 | -6.17 | -6.67 | 1983 | 44.67 | -1.67 |
| 1955 | 35.22 | 0.00 | 1984 | 30.50 | -5.56 |
| 1956 | 57.72 | -2.78 | 1985 | 113.83 | -2.22 |
| 1957 | 34.94 | 0.00 | 1986 | 137.61 | -1.11 |
| 1958 | -32.00 | -0.56 | 1987 | 44.11 | 4.44 |
| 1959 | 82.72 | -3.33 | 1988 | 84.11 | 1.11 |
| 1960 | -21.22 | -1.67 | 1989 | 66.33 | -6.11 |
| 1961 | 71.83 | -2.22 | 1990 | 92.17 | -5.00 |
| 1962 | -13.11 | -3.33 | 1991 | 110.17 | -5.00 |
| 1963 | 129.78 | -3.33 | 1992 | 122.61 | -2.22 |
| 1964 | 25.22 | -0.56 | 1993 | 82.33 | -4.44 |
| 1965 | -50.33 | -1.11 | 1994 | 131.00 | -1.67 |
| 1966 | 96.06 | -3.89 | 1995 | 88.78 | 0.56 |
| 1967 | 103.78 | -7.22 | 1996 | 1.33 | 0.56 |
| 1968 | 136.00 | -2.22 | 1997 | 129.89 | -3.89 |
| 1969 | -29.22 | -2.78 | 1998 | -9.67 | -1.11 |
| 1970 | 0.78 | -1.11 | 1999 | 109.00 | -1.11 |
| 1971 | 43.00 | -1.11 | 2000 | 141.83 | -2.22 |
| 1972 | 118.28 | -3.89 | 2001 | 93.00 | 0.56 |
| 1973 | 93.28 | -3.33 | 2002 | -25.33 | -3.89 |
| 1974 | 99.11 | 0.00 | 2003 | 109.28 | -4.44 |
| 1975 | 7.72 | -0.56 | 2004 | 137.06 | -3.33 |
| 1976 | 69.06 | -6.11 | 2005 | 99.94 | -7.78 |
| 1977 | 36.83 | 3.33 | 2006 | 66.83 | -2.78 |

Table 5. Summary of paper birch stand conditions along the Niobrara River, Nebraska. (Health Code: 1 = Normal, apparently healthy, 2 = Trees with abnormally small, thin, curled, chlorotic foliage, 3 = Trees with bare or dead twigs, 4 = Trees with dead branches, comprising less than one-half the crown, 5 = Trees with over one-half the crown dead, 6 = Foliage only on one to several trunk sprouts (< 2.5 cm max. diameter), 7 = Tree entirely dead). BA = basal area ($m^2$).

| Site Name | Owner | Site Type | River Location | Area (Ha) | Size | # Live Birch | # Dead Birch | # Sap-lings | Prop. Live Birch | Mean Health Code ( 1 – 7) | Mean # Boles/ Tree | Total Birch BA/Ha | Ratio Live to Dead BA/Ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nature Trail | TNC | Canyon | Lower | 0.36 | large | 20 | 33 | 0 | 0.38 | 5.77 | 2.80 | 3.06 | 2.00 |
| Jeff Creek | TNC | Canyon | Lower | 0.70 | large | 50 | 30 | 0 | 0.63 | 4.63 | 3.42 | 0.58 | 1.06 |
| Last Huddle | TNC | Canyon | Lower | 0.37 | large | 11 | 23 | 0 | 0.32 | 5.27 | 4.07 | 4.08 | 1.60 |
| Rocky Ford | TNC | River | Lower | 0.42 | large | 22 | 35 | 6 | 0.39 | 3.93 | 3.07 | 3.79 | 0.38 |
| Cross country | TNC | River | Lower | 0.61 | large | 12 | 32 | 0 | 0.27 | 5.33 | 3.00 | 2.10 | 1.17 |
| Brewer Bridge | TNC | River | Lower | 0.56 | large | 29 | 52 | 0 | 0.36 | 5.33 | 1.50 | 1.93 | 0.59 |
| Borman Bridge | State | Canyon | Upper | 0.19 | small | 19 | 18 | 0 | 0.51 | 5.00 | 2.08 | 5.23 | 0.81 |
| Smith Falls | State | Canyon | Upper | 0.12 | small | 22 | 19 | 0 | 0.54 | 4.42 | 2.75 | 7.76 | 2.21 |
| Taylor Falls | FWS | Canyon | Upper | 0.20 | small | 17 | 17 | 1 | 0.50 | 3.58 | 3.30 | 3.42 | 5.59 |
| Fort Falls | FWS | River | Upper | 0.60 | large | 31 | 17 | 0 | 0.65 | 5.00 | 4.82 | 2.88 | 1.40 |
| Buffalo Fence | FWS | River | Upper | 0.13 | small | 44 | 14 | 0 | 0.76 | 3.17 | 3.33 | 6.68 | 3.42 |
| Buffalo Bridge | FWS | River | Upper | 0.06 | small | 21 | 3 | 0 | 0.88 | 5.00 | 1.54 | 9.06 | 0.73 |
| Coon Creek E | FWS | N. Canyon | North Side | 0.07 | small | 3 | 7 | 0 | 0.30 | 5.80 | 5.00 | 10.83 | 0.08 |
| Coon Creek W | FWS | N. Canyon | North Side | 0.02 | small | 2 | 5 | 0 | 0.29 | 6.50 | 3.75 | 19.34 | 0.18 |
| Box Canyon | FWS | N. Canyon | North Side | 0.03 | small | 2 | 8 | 0 | 0.20 | 4.00 | 4.00 | 3.09 | 0.30 |
| Side Canyon | FWS | N. Canyon | North Side | 0.04 | small | 2 | 6 | 0 | 0.25 | 6.40 | 4.20 | 11.55 | 0.01 |

## Literature Cited

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