LITTLE BIGHORN BATTLEFIELD NATIONAL MONUMENT RIPARIAN FOREST DEMOGRAPHY:

HYDROCLIMATIC TREE-ESTABLISHMENT CONDITIONS AND A SEARCH FOR "WITNESS" TREES

Final Report to the National Park Service
Submitted 1 September 2012
Revised 23 October 2012

Permit No: LIBI-2011-SCI-0002
NPS Study No: LIBI-00016
NPS Agreement No: P11AG00089
Rocky Mountains CESU Agreement No: H1200-09-0004

By: [1]Gregory T. Pederson*, [2]Stephen T. Gray, [3]Mark Lesser, and [1]Leslie Allen

[1]U.S. Geological Survey, Northern Rocky Mountain Science Center, 2327 University Way (Suite 2), Bozeman, MT, 59715
[2]U.S. Geological Survey, Alaska Climate Science Center, 4210 University Drive, Anchorage, AK 99508
[3]University of Wyoming, Department of Botany, Laramie, WY 82079

* To whom correspondence should be addressed: gpederson@usgs.gov (406) 994-7390

ABSTRACT

A dendroecological analysis of riparian area cottonwoods (*Populus deltoides*) along the Little Bighorn River at the Little Bighorn Battlefield National Monument (LIBI) in southeastern Montana was conducted to (1) describe the age structure of the gallery forests, targeting in particular trees that may have been alive during the battle in 1876; (2) identify potential hydroclimatic factors (e.g. floods, drought) that may have influenced establishment and development of the stands; and (3) indentify cottonwoods and other trees with potentially dateable fire scars. Of particular interest for this study was the sampling of a lone cottonwood at Medicine Tail Coulee since it may be the same tree documented on the 1876 Kill Eagle map demarcating the point where the Cheyenne drove Custer back. Although there were no riparian area trees definitively dated back to the year of the battle, uncertainty related to tree age at coring height suggests a good number of trees were probably seedlings or saplings. The lone cottonwood "witness" tree, was at least 25-years old at the time of the battle in 1876, and is likely the tree documented in the Kill Eagle map – assuming a death date of 1970. No fire scars were found within the riparian area forests, suggesting fires on surrounding grasslands didn't burn through the riparian area; haven't burned through the riparian area since before the 1880s, or; burn at such a low intensity they fail to scar the trees. The current stands can be grouped into two cohorts, with a major establishment pulse c. 1880-1900, with minimal recruitment occurring c. 1900-1925. With the exception of a single tree establishing in 1961, we found no evidence of cottonwood establishment since the 1930s even though floods of sufficient magnitude to expose new sediment have occurred. The temporal and spatial pattern of cottonwood demography is consistent with the flood-driven model of cottonwood establishment in the western U.S. The lack of substantial cottonwood establishment in the riparian area since the 1930s is similar to results reported in other studies and may arise from either natural demographic fluctuations or land-use changes.

PURPOSE OF SCIENTIFIC STUDY

Little Bighorn Battlefield National Monument (LIBI) commemorates one of the last armed actions between the U.S. Army and the Northern Plains Indians as the tribes fought boldly to preserve their way of life. In 1876 Lt. Col. George A. Custer and 262 soldiers and attached personnel of the Seventh Cavalry met defeat and death by an overwhelming force of more than 1,500 Lakota Sioux, Cheyenne, and Arapaho warriors. The primary purpose of Little Bighorn is to preserve and protect the historic and natural resources pertaining to the Battle of the Little Bighorn and to provide visitors with a greater understanding of those events which led up to the battle, the encounter itself, and the various effects the encounter had on the two cultures involved. The riparian cottonwood forest at Little Bighorn was, and remains, a critical element of the cultural landscape, providing shelter, timber, firewood, forage, and wildlife habitat. In addition, individual cottonwood trees along Little Bighorn River, both living and dead, have cultural and spiritual significance because of their association with the Indian encampments and the battle itself.

The riparian ecosystem at the National Monument appears to have changed significantly over the 137 years since the battle. Historical photographs show far fewer trees along the river than are now present (Figure 1). Management of this riparian ecosystem requires better understanding of the sites vegetative and environmental history, current conditions, changes that have occurred over time, and possible causes of those changes. For example, historical changes in human land and fire use, climate, and/or a significant reduction in mammalian (i.e. beaver, bison, horse) tree-harvest/damage activity since the nineteenth century may all play a role in the documented riparian landcover change. A goal of this project is to provide baseline cottonwood forest demography datasets that allow for preliminary and long-term investigation into the potential factors underlying the photographically documented ecosystem change.

In light of documented riparian area vegetation change, information needs of National Park Service (NPS) managers, and because of the historical and cultural importance of the area, we conducted a study on the demographic structure of the cottonwood forests along the Little Bighorn River at LIBI in southeastern Montana. The main research objectives of this project were to: (1) describe the age structure of the gallery cottonwood forests, targeting in particular trees that may have been alive during the battle in 1876; (2) identify potential hydroclimatic factors (e.g. floods, drought) that may have influenced establishment and development of the

Figure 1. (Top) An 1886 image showing historic vegetation structure along the west side of Reno Crossing on the Little Bighorn River, MT, coupled with (Bottom) a 1999 repeat photograph of the same location (Repeat photo courtesy of James Brust, 1999). Historic photo courtesy of the National Park Service archive.

stands; and (3) indentify cottonwoods and other trees with potentially dateable fire scars. Of particular interest for this study was the sampling of a lone cottonwood at Medicine Tail Coulee near the Battlefield Tour Road. The tree is potentially significant, as it could be a "witness" to the Battle of Little Bighorn in 1876. It may be the same tree documented on the 1876 Kill Eagle map (Little Bighorn Battlefield National Monument collection), which demarcated the point where the Cheyenne drove Custer back and was published in Drawing Battle Lines (i.e. The Map Testimony of Custer's Last Fight by Michael N. Donahue). This study will also explore how hydroclimatic regimes of the past have influenced riparian area development, and in this way provide useful information pertaining to how future climatic conditions might influence these stands. The scientific data will supplement 3 park projects (Historic Base Map Update, Environmental History, and Vegetation Map) by supporting historical depictions of the river course, adding to the knowledge of the areas forest demography, and potentially the fire history of cottonwoods. The provision of demographic data on stand age will also assist the park in managing the trees as a culturally important resource and implementing fuel reduction strategies, including returning fire to the landscape if deemed appropriate.

STUDY AREA DESCRIPTION

The project area is the 1.75 km reach of the Little Bighorn River, which forms the southwest boundary of the Custer Battlefield (Figure 2). This river corridor also serves as the geopolitical boundary between LIBI and the Crow Indian Reservation, within which LIBI is situated. The riparian areas are defined by the meandering oxbows of the Little Bighorn River, and support a high diversity of vegetation with an overstory today comprised mostly of plains cottonwood (*Populus deltoides*) and box elder (*Acer negundo*) (Bock and Bock 2006). Around 1876, however, cottonwood trees were reportedly rare with a more common shrubby overstory composed of two species of willow (*Salix amygdaloides and S. exigua;* Figure 1*)* – though they are scarcer today (Bock and Bock 2006). Upland areas are largely composed of mixed grass prairie, with dominant perennial grasses from the genera *Agropyron, Poa, Stipa,* and *Bouteloua* (Risser et al. 1981).

The climate of LIBI is continental, with a seasonal climatology defined by cold, dry winters followed by cool wet springs, and a commonly hot and dry summer. Diurnal temperature swings can be extreme. The annual average precipitation of LIBI is 214 cm with

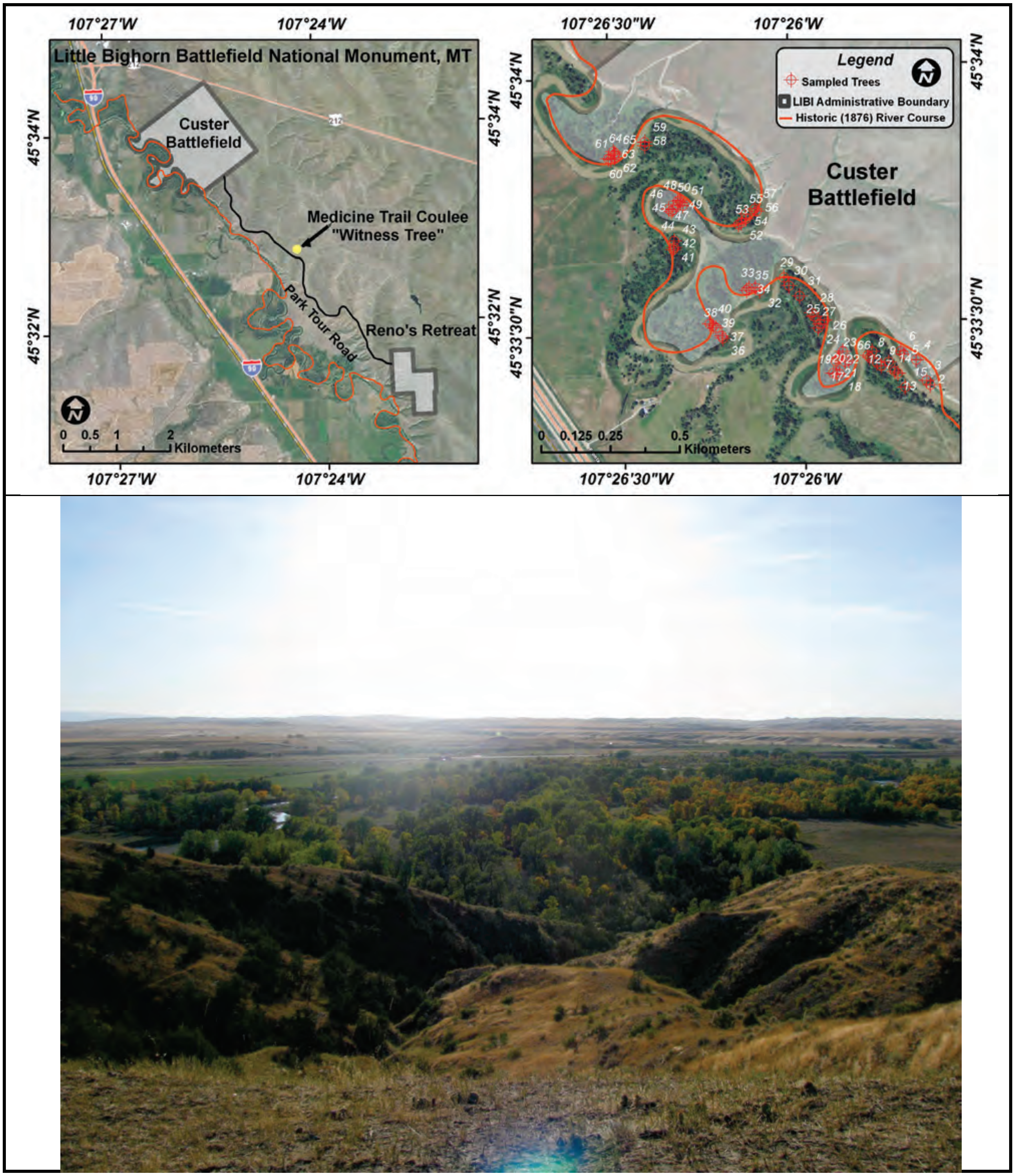

Figure 2. The 1.75 km reach of the LIBI cottonwood demography study area (top), and a photographic overview of the cottonwood gallery forests (bottom). All samples collected in the course of the study are mapped and labeled here by sample number. Historic 1876 river course and park administrative boundary provided by National Park Service (2011).

peak precipitation occurring in June (avg. = 50 cm) and a precipitation minima commonly occurring in February (avg. = 5.7 cm). Summers (Jul-Sep) are typically hot (avg. max. temps ~ 30°C) and experience little precipitation. Average annual temperatures are cool at 7.8°C, with the lowest average monthly temperatures occurring in January (avg. =-7.7°C) and the highest average temperature peak in July and August (avg. = 22.2°C). The majority of the peak and total annual streamflow of the Little Bighorn River derives from mountain snowpack of the Bighorn Mountains. Spring precipitation and late summer drought conditions, however, can exert a substantial influence on total water year flows.

GENERAL TIMELINE OF WORK COMPLETED

The park completed compliance with the National Environmental Policy Act and Section 106 of the National Historic Preservation Act on April 28, 2011. The project initiated with a survey of field conditions conducted by Greg Pederson and Leslie Allen in early July of 2011. Wilford Bird In Ground, Bureau of Indian Affairs (BIA), assisted with land access. At the time of the survey there was substantial spring flooding due to high spring snowpack and precipitation, which created potentially dangerous working conditions along the banks of the Little Bighorn, so sampling plans were postponed until the fall of 2011. All project fieldwork and sample collections were completed over the course of five days in September 2011 by Greg Pederson, Leslie Allen, and Mark Lesser. A total of 68 samples were collected from 65 trees, three of which were extracted from the documented lone cottonwood "witness" tree snag (Figure 3; died ~1970). From October 2011 through March 2012, Mark Lesser

Figure 3. The sampled lone cottonwood "witness" tree located outside of the riparian area at Medicine Tail Coulee near the Battlefield Tour Road. This tree could be a "witness" to the Battle of Little Bighorn in 1876, and may be the same tree documented on the 1876 Kill Eagle map. The lone cottonwood tree is now dead, but was documented as living into the early 1970s (Melana Stichman, personal communication, January 10, 2012). Photo by Greg Pederson (U.S. Geological Survey).

mounted and sanded the tree cores before attempting to crossdate each sample such that an accurate calendar date could be obtained for each growth ring. The completed age-class dataset was then sent to Greg Pederson for mapping, cataloging with the NPS, and demographic and hydroclimatic analyses. Samples were cataloged and entered into the NPS specimen catalog by Pederson in May 2012, with the assistance of NPS curator Sharon Small, before being sent to Pearce Paul Creasman at the University of Arizona's Laboratory of Tree-Ring Research for long-term archiving (Samples sent on the 24^{th} of July, 2012). On September 1, 2012, we submitted a draft report to Melana Stichman of the NPS for review. Upon acceptance of the revised report, copies of the report, databases, maps, photos, and/or other materials will be provided to Sharon Small - curator of Little Bighorn Battlefield NM.

METHODS

Project fieldwork and sample collections were completed using standard dendroecological sampling methods (Speer 2010). Since a major goal of this project was to attempt to identify old trees alive in 1876, we began the project with an extensive field survey of trees growing along the documented 1876 river channel in addition to looking for potential fire scars (Figure 2). Trees found to exhibit characteristic signs of advanced age (e.g. large basal diameter, deeply furrowed bark, etc.), and were free of extensive bole rot, had 1-2 core samples taken (using an increment borer) from the root collar, or at a distance above the root buttress such that a pith sample was close or obtained (Figure 4). The increment borer produced core

Figure 4. Mark Lesser shown sampling a cottonwood tree for age (left), and extracting a core from the base of the tree (right). Photo by Leslie Allen (U.S. Geological Survey).

samples 4 mm or 0.4 cm (approximately the diameter of a pencil) and was used with a lubricant that kills funguses and other potentially harmful organisms. For all sampled trees we recorded (a) measured diameter at breast height (DBH; ~1.3m from ground); (b) coring height; (c) location with a GPS unit; and (d) presence or absence of obvious fire scars. If a tree had multiple stems from a single base, we sampled the largest stem.

After completing the initial "old tree" survey, we next quantified the population demography of the gallery forest along river (Figure 2). Since the gallery forest is essentially a linear feature enclosing the stream channel, we used a random sampling procedure similar to methods employed by Lucas and Woodhouse (2006), designed to capture diversity in age-class structure. Working from boats, we randomly selected landing points, or "points of origin", on both shorelines from a randomly gridded network of points generated within a GIS framework and loaded onto field GPS units (Figure 5). From these points of origin, if trees were found to be present, we selected and sampled approximately five to ten trees that were relatively evenly spaced through the full width of the gallery forest. Trees were sampled and data was collected using the same methodology employed in the "old tree" survey described above (Figure 4).

Tree cores were mounted and sanded to >400 grit, at which point individual cell structure was apparent and annual rings were clearly defined. Rings were then visually counted under a dissecting microscope. Due to the low sensitivity (insufficient year-to-year ring-width variation) of each tree to hydroclimatic variability, cores could not be accurately crossdated. Furthermore, because we were often able to obtain a single sample from each tree, even though multiple samples were attempted, we could not account for coring height in our age estimates. Hence, all obtained ages should be interpreted as minimum ages. Depending on grazing pressure, climate, fire, and

Figure 5. Working from boats, Greg Pederson and Leslie Allen are organizing to sample from a "point of origin". Photos by Mark Lesser (University of Wyoming).

other land-uses, trees may take between 2 and 15 years to reach sampling height. Thus, for each of the estimated minimum tree ages, there is an assumed error of between 2-15 additional years that corresponds to the actual germination date of the trees. For cores where the pith was not obtained, but inner rings showed curvature, we estimated the pith date using overlaid concentric circles (Applequist 1958, Brown and Cook 2006). To constrain uncertainty arising from this method, only trees with pith age estimates of ≤ 5 years were retained in the final analyses. Figure 6 shows the final quality controlled dataset of accurately aged trees used in the final analyses (or stated another way, all the trees with ≥5 years of age uncertainty have been removed). To assess potential tree-diameter and age relationships, final quality controlled tree ages were regressed against diameter using a simple general linear model (GLM) in the statistical software platform R.

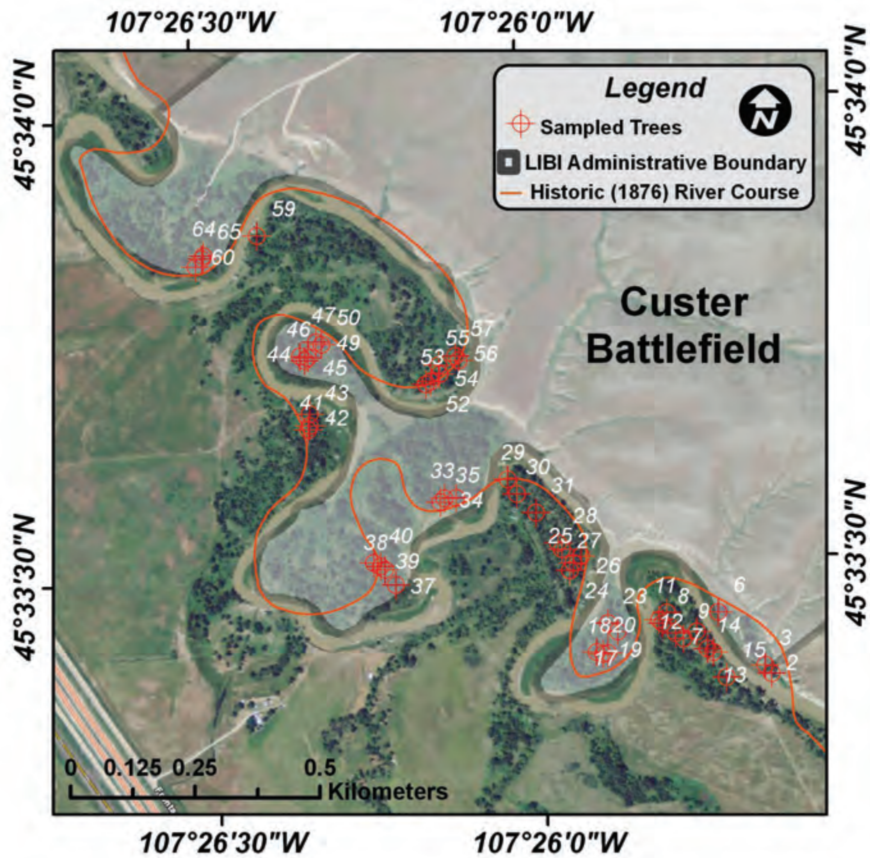

Figure 6. The final quality controlled demographic dataset of samples used in all project analyses with sample number indicated next to location. Samples mapped here either captured the pith in the core sample or have ≤ 5 years to the estimated pith date (n = 52). Historic 1876 river course and park administrative boundary provided by National Park Service (2011).

The final suite of analyses included an assessment of hydroclimatic conditions associated with the germination and establishment of cottonwood trees. Hydroclimatic data used to provide a detailed regional climatic history and compare against the cottonwood demographic data extends from the following USGS instrumental stream gages and tree-ring based paleoclimatic reconstructions:

- A >800-year summer drought (Jun-Aug) reconstruction of the Palmer Drought Severity Index (PDSI) from Cook et al. (2004). This is a spatially distributed climate dataset (encompassing most of North America), so data from grid point 100 was used in this study since it centers over the Little Bighorn Battlefield National Monument.
- A 600-year reconstruction of 1 April Snow Water Equivalent for the Bighorn Basin from Pederson et al. (2011).
- A 650-year total water year (Oct-Sep) streamflow reconstruction of the Little Bighorn River (Swindell 2011). The reconstruction was calibrated on the U.S. Geological Survey's gage located in Wyola, MT (USGS ID: 6289000).
- A 39-year record of peak discharge from U.S. Geological Survey gauge located near Crow Agency, MT (USGS ID: 06293500).

RESULTS AND DISCUSSION

(The MS Excel file LIBI_TreeData_082712.xlsx, LIBI-GPS_TreeData_082712.xlsx, and LIBI_TreeAge_Field Notes_082712, contains all of the field notes, GPS receiver files, and preliminary and final data from the sampled trees)

Diameter and Age Relationships

Due to the common problem of extensive bole-rot in riparian tree species, we were only able to retrieve viable samples from a total of 65 trees, 52 of which we obtained accurate cambial ages (≤ 5 years from pith) at coring height (mean coring height = 41.9 cm) (Appendix Table 1). The trees within the forest gallery were generally quite large, with an average DBH of 76.8 cm, but ranged from 35-131 cm. The majority of trees established between 1890 and 1910, with the oldest establishing in 1878 (135 years old) and youngest in 1961 (51 years old) (Figure 7). It is likely, however, trees older than 135 years of age do exist since a small number of large individual trees (DBH > 150 cm) are present, but have extensive rot prohibiting sampling. Unfortunately, results from the age-size model indicate no significant (*p-value* = 0.75) relationship exists, hindering efforts to extrapolate tree age from DBH (Figure 8).

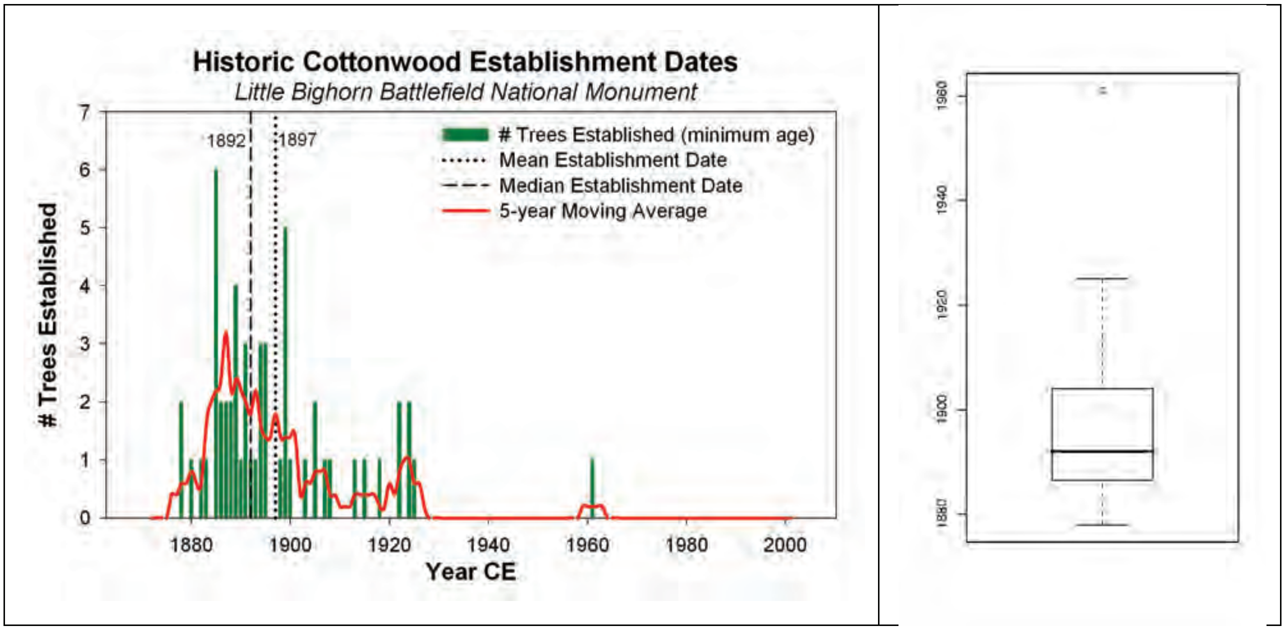

Figure 7. Cottonwood establishment dates for the gallery forests of Little Bighorn Battlefield National Monument, Montana. A histogram of tree establishment is shown (left) along with a 5-year running average to highlight multi-year establishment pulses, and a boxplot (right) details the median, distribution, and outliers. All plotted dates are minimum ages only, and the actual germination date may have occurred 2-15 years earlier.

Geographic and Temporal Distribution of Age Classes

Note, that within this discussion we are only referring to successful tree establishment events, not germination events or pulses since they are two distinctly different demographic measures. Seedling germination is a measure of the potential to recruit into a population, but without long-term monitoring cannot be tracked through time, whereas the successful establishers are represented by the forest stand structure of today. The cottonwood demographic data does show two establishment pulses, with a major interval of recruitment occurring between 1880 and 1910, and a much smaller recruitment event in

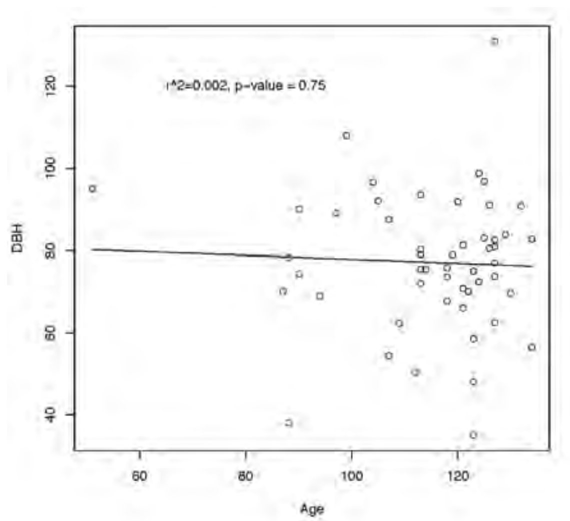

Figure 8. Non-significant ($p \leq 0.05$) age-size model results for LIBI cottonwood trees.

the early 1920s (Figure 7). The few trees that established during the 1920s tend to be positioned closer to the stream channel of today, whereas the major late-nineteenth century establishment pulse aligns well with the historic river course of 1876 (Figure 9). Note, the mapped 1876 GIS river course is close to accurate in these figures, but due to the resolution of our maps there are often misalignments of the actual 1876 river course as compared to the mapped version and actual stream position in the field. Other than these two events, both figure 7 and figure 9 indicate a relatively even age-class across this section of the riparian cottonwood forest. With the exception of one tree establishing in the 1960s, we found no evidence of *widespread* cottonwood establishment within the study area since the 1930s. There is second-hand evidence, however, from Mike Britten (NPS) and Melana Stichman (NPS) that a small stand of trees (~15) exist along an oxbow with DBH values between 12.7 cm and 25.4 cm, and may represent a small establishment pulse occurring sometime after the 1960s. The potential relationship between establishment pulses, climate, and the Battle of Little Bighorn of 1876 will be discussed in sections below.

Fire Scar Assessment

No fire scars were found within tree core samples, or in the field survey. This likely indicates fires on surrounding grasslands didn't burn through the riparian area; haven't burned through the riparian area since before the 1880s, or; burn at such a low intensity they fail to scar the trees, or simply kill the trees when a fire does burn through. Fire commonly kills cottonwood trees (Adams et al. 1982, Gom and Rood 1999), and it's also uncommon for cottonwood trees to produce fire scars when burned (Maisenhelder 1951), or for fire evidence to be left in stumps of woody debris due to the rapid rate at which woody material decays in these environments. This survey was performed out of due diligence, and at the request of the National Park Service. Evidence for substantial tree girdling activity exists (possibly of beaver origin), and dates back to a similar point in time. Though we did not sample these scars, it's likely the girdling occurred between 20-50 years ago, due to the amount of cambial overgrowth of the scar since the girdling event. Additional sampling is needed to establish the year or years in which the tree girdling was occurring.

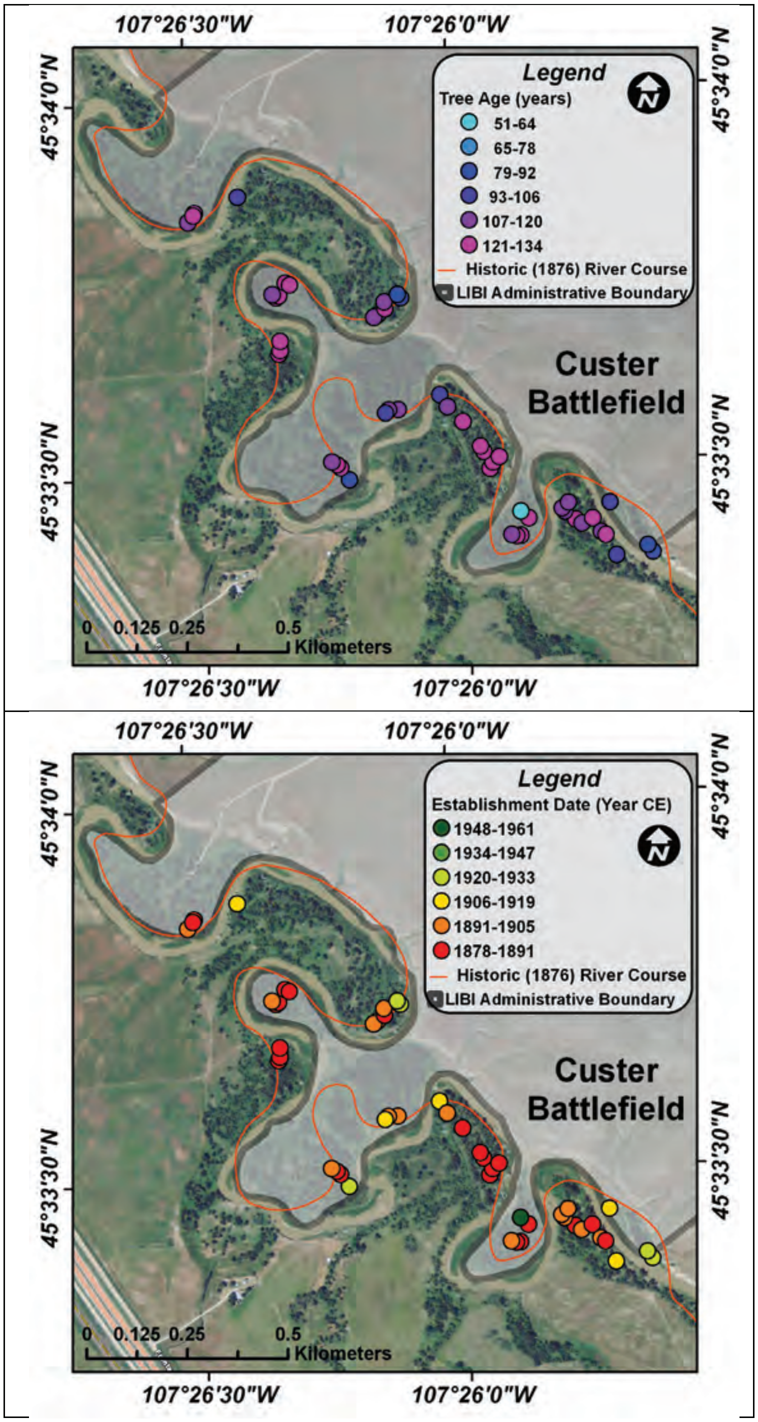

Figure 9. Maps of estimated tree age (top) and establishment dates (bottom) of cottonwood trees growing along the historic river course of 1876, 1891, and at present. All mapped ages and dates extend from samples that either captured the pith in the core sample or have ≤ 5 years to the estimated pith date (n = 52). Estimated tree ages should be viewed as minimum ages since accurate crossdating was not possible, and 2-15 years may exist between the date obtained at sampling height and the true germination date of the tree. Historic 1876 river course and park administrative boundary provided by National Park Service (2011).

Evidence of Potential "Witness" trees

Among the samples from the cottonwood gallery forest, we found no evidence that any of the trees we sampled were alive at the time of the battle in 1876 (Figure 7). There is, however, substantial support in our data that a small number of trees on the landscape today were present during the battle of Little Bighorn. First, there are a small number of trees located along historic river channels with a DBH > 130 cm, and exhibit signs of advanced age (i.e. deeply furrowed bark, large branches, substantial portions of dead canopy, etc.). Establishing ages for these trees was problematic, however, since in every case the basal area was hollow or rotten beyond salvage. In all likelihood these trees represent what remains of the age-class predating the establishment pulse of the 1880s and 1890s. Second, within the subset of riparian area trees sampled for this purpose, dating errors exist due to the height at which we cored these trees (average of 41.9 cm), and in some cases from not capturing the pith with the sample taken. Figure 10 shows a map of potential "witness' trees from the cottonwood gallery forests, assuming an establishment date uncertainty of up to 15 years. These potential "witness" trees, however, would have been less than ~41 cm in height at the time of the battle since their age uncertainty extends from the time required to reach coring height. Finally, the dead tree (Figure 2 and 3), documented on the 1876 Kill Eagle map as demarcating the point where the Cheyenne drove Custer back (M. Stichman, personal communication, January 10, 2012), yields age estimates consistent with being present during the battle (Appendix Table 1, sample LBB1a,b,d). This now dead "witness" tree was documented to have been alive into the early 1970s (M. Stichman, personal communication, December 1, 2011). Using a single successful core from the base of the tree (LBB1d, Appendix Table 1), and assuming a death date of 1970, yields an establishment date estimate of 1851. This would imply the lone cottonwood tree was at least 25 years old at the time of the battle in 1876, and is likely the tree documented in the 1876 Kill Eagle map.

Climate Variability and Establishment

Climatic conditions indicated in previous studies as most important for the germination and establishment of cottonwood trees can be reduced to a single type of hydroclimatic event, and that is flooding (Baker 1990, Cordes et al. 1997, Friedman et al. 1996, Friedman and Lee 2002, Johnson 1992, Scott et al. 1996, Scott et al. 1997, Lucas and Woodhouse 2006). Each of

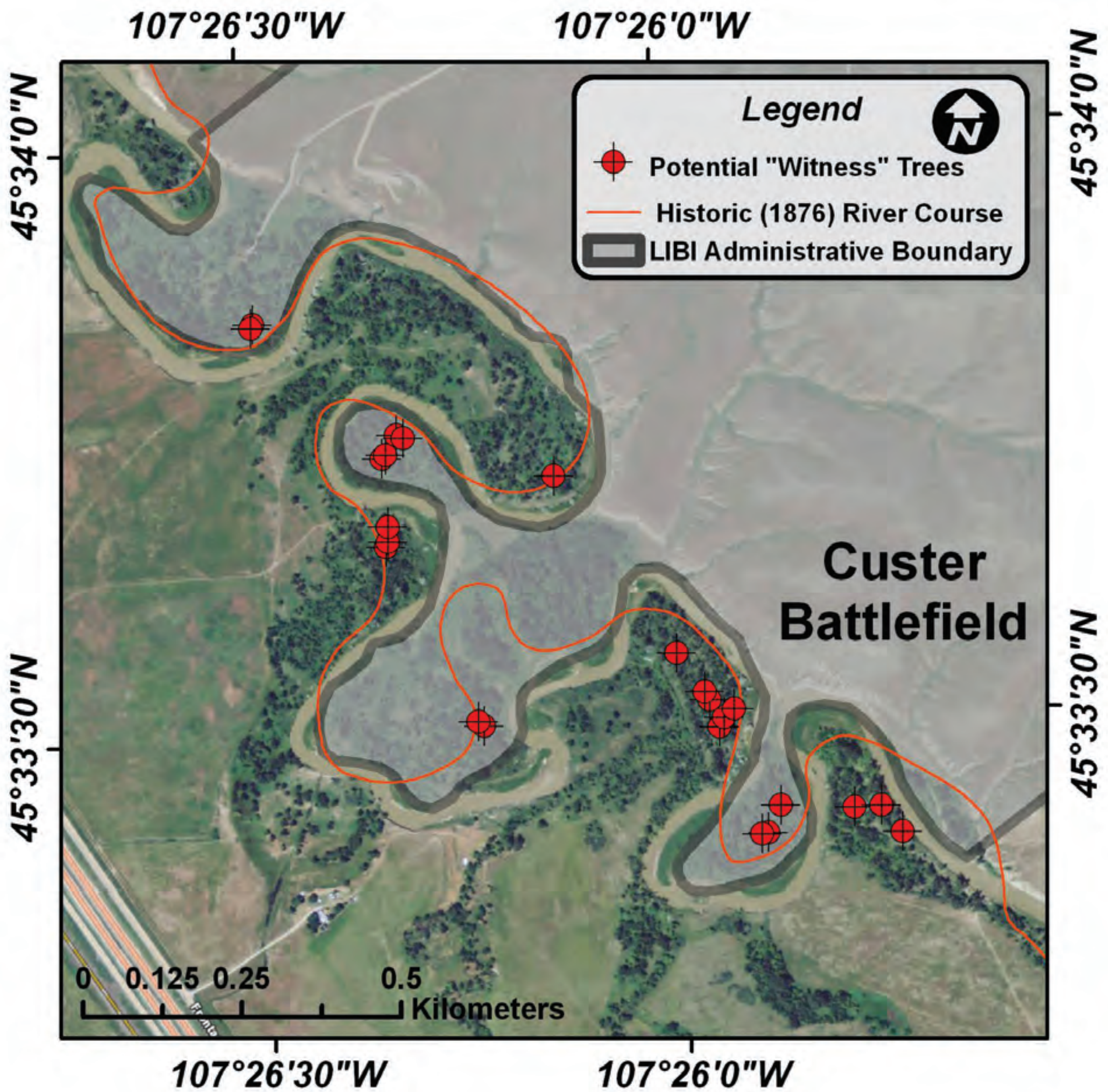

Figure 10. Map of potential "witness" trees when accounting for additional error in age estimates due to the average coring height of 41.9 cm. This analysis assumes the actual germination date may have occurred up to15 years earlier, depending on growth conditions, and that the trees plotted here would have been recent establishers and less than 40 cm in height at the time of the battle. Historic 1876 river course and park administrative boundary provided by National Park Service (2011).

the aforementioned studies indicate flood events precondition the site for widespread cottonwood germination and subsequent establishment through the clearing of competing vegetation, deposition of fresh sediment, and raising the elevation of the water table. These studies also note that many seedlings will germinate during the year of the flood, but that germination and establishment often continues over successive years and may be unrelated to summer drought conditions (Lucas and Woodhouse 2006). With flood episodes of this magnitude occurring on average every decade for streams of this size (Friedman and Lee 2002), it is expected the resulting cohorts will be spaced in time and will tend to occur along bands parallel with the stream channel position at that time.

The documented major cohort of the 1880s followed by a minor pulse in the 1920s and the lone establisher of the 1960s (Figure 7) fits this general flood-driven model of establishment with recorded (or likely) flood events, and since age cohorts tend to cluster along current or abandoned stream channels (Figure 9). Evidence for significant flooding dating to the major 1880s cohort is another matter, however, since stream gages didn't exist along the Little Bighorn River at this time. Paleoclimatic reconstructions (from tree-rings) of summer drought, snowpack, and streamflow do allow for inferences to be made regarding the likelihood of flooding and favorable summer germination conditions over the last decades of the nineteenth century (Cook et al. 2004, Swindell 2011, Pederson et al. 2011). Whereas records of flood events from a USGS gauging station located on the Little Bighorn River near Crow Agency, MT (Gage # 06293500, http://mt.water.usgs.gov/freq?page_type=site&site_no=06293500) begin in 1912 and run to 1960, allowing direct comparison of the documented 20th-century cottonwood establishment events to flooding (Appendix Table 2).

The major cottonwood cohort of the 1880s was indeed preceded by several years of anomalously high total annual flows along the Little Bighorn River coupled with cool, wet summers as implied by the PDSI reconstruction for the area (Figure 11). Additionally, reconstructions of snowpack for the Bighorn Basin by Pederson et al. (2011) also show extremely high mountain snowpack conditions at this time, making it very likely there were multiple major spring flood events during the early 1880s. Thus, each of the paleoclimatic reconstructions indicates conditions were favorable for flood-induced disturbance and sedimentation with a brief period of favorable germination and growth conditions over the summer months. The pulse of cohorts, however, continues through the dry and relatively lowflow decades that followed the favorable conditions of the 1880s, which is somewhat perplexing.

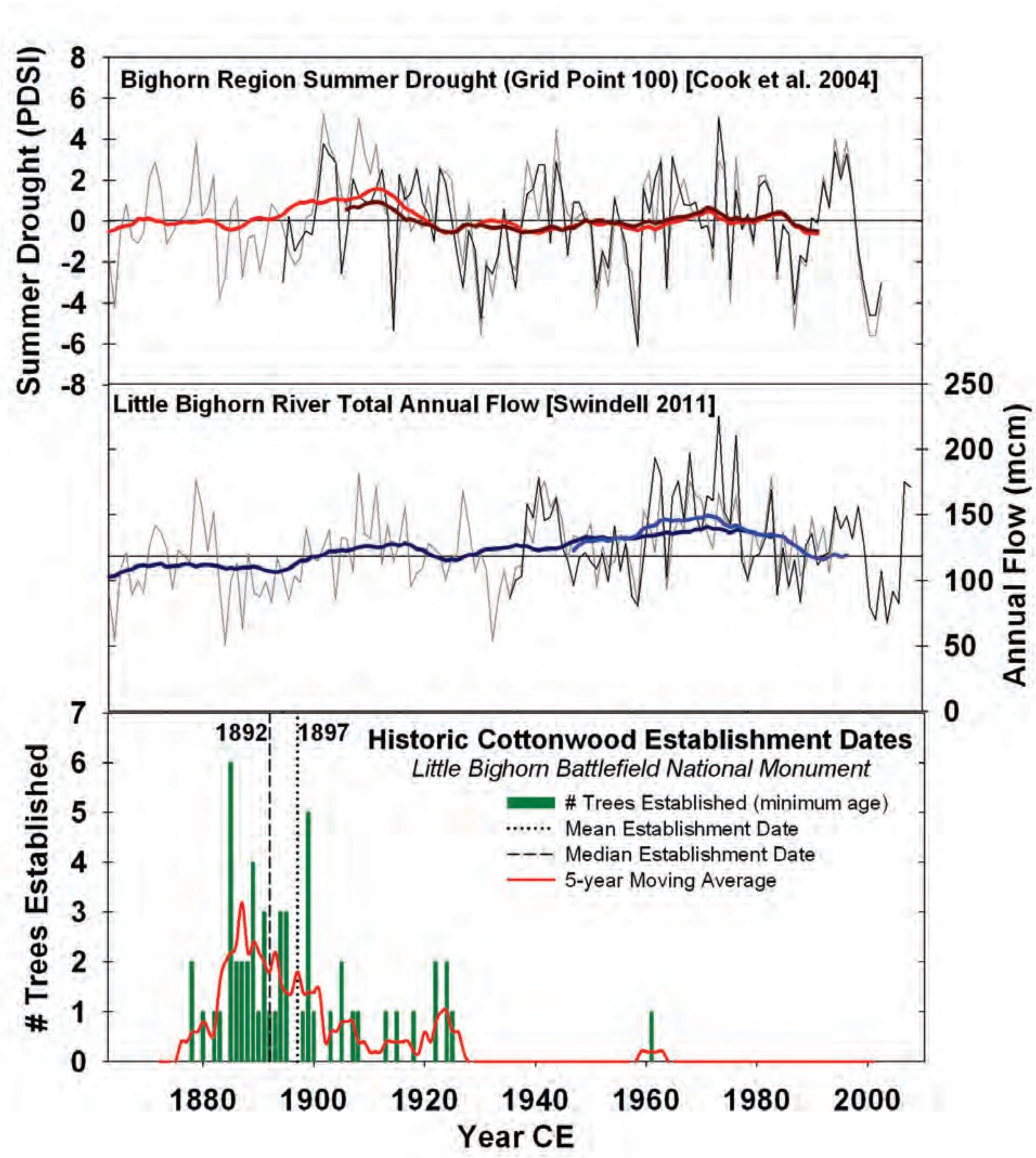

Figure 11. Historic cottonwood establishment in relation to hydroclimatic events. The climate time series shown here include the Cook et al. (2004) summer PDSI reconstructions, and reconstructions of streamflow on the Little Bighorn River for the USGS gage located in Wyola, MT from Swindell (2011). Instrumental time series are shown in black, with tree-ring based reconstructions shown in light gray. The heavy colored lines are a 20-year moving average to highlight low-frequency changes in hydroclimate.

Lucas and Woodhouse (2006) puzzled over a similar phenomenon documented with cottonwood establishment pulses at the Sand Creek Massacre National Historic Site. Results from both studies may suggest that substantial disturbance from flooding is the most important prerequisite to cottonwood establishment, with summer drought conditions (or lack thereof) only exerting a minor influence on the probability of successful establishment.

Cottonwood establishment during the early-20th century into the mid 1920s coincides with reconstructed high total annual flows and generally cool wet summers until the start of the 1930s dustbowl drought when establishment abruptly stops (Figure 11). The gage record for the Little Bighorn River near Crow Agency, MT, indicates a succession of major flood events in 1917, 1920, and 1924 – all exceeding gage heights of 10 ft with discharge estimated to be greater than 3,900 ft^3/sec (Appendix Table 2). Though this succession of flood events likely preconditioned the site for cottonwood establishment, it's unknown why floods of the same magnitude during the early 1930s and 1940s failed to produce additional cottonwood cohorts. In fact, it's not until after the major March 19th flood of 1960 (Appendix Table 2) do we capture any additional tree establishment (with the exception of the potential small, unsampled stand of ~15 trees discussed above), and there has been none since even though flood events of sufficient magnitude continue to occur on the Little Bighorn. This lack of observed cottonwood establishment since the 1960s may reflect the influence of changes in land management (horse, cattle, deer, beaver, and rabbits grazing/trampling, fire activity, upstream diversions, etc.) since flood frequency and magnitude should have been sufficient to continue exposing new sediment required for seedling establishment. The major spring flooding of 2011 within LIBI will certainly serve as a test of this hypothesis if cottonwood germination and establishment is monitored following this event.

ACKNOWLEDGEMENTS

We thank Melana Stichman and Sharon Small (NPS) and Wilford Bird In Ground (BIA) for assistance with permits, land access, sample curation, and their enthusiasm for this project. Mark Lesser and Leslie Allen were invaluable due to their assistance in the field and in the lab. Comments from two USGS reviewers and Melana, Mike Britten (NPS), and Billy Schweiger (NPS) aided in improving the report. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

REFERENCES

Adams, D.E., R.C. Anderson, S.L. Collins, 1982. Differential response of woody and herbaceous species to summer and winter burning in an Oklahoma grassland. *The Southwestern Naturalist*. 27: 55-61.

Applequist, M.B., 1958. A simple pith locator for use with off-center increment cores. *Journal of Forestry,* 56:141.

Baker, W.L., 1990. Climatic and hydrologic effects on the regeneration of Populus angustifolia James along the Animas River, Colorado. *Journal of Biogeography,* 17:59-73.

Bock, J.H., and C.E. Bock, 2006. A survey of the vascular plants and birds of Little Bighorn National Battlefield. *Final Report to the National Park Service*. pp. 44.

Brust, J.S., B.C. Pohanka, and S. Barnard, 2007. Where Custer Fell: Photographs of the Little Bighorn Battlefield Then and Now. University of Oklahoma Press, Ok. 196 pp.

Brown, P.M. and B. Cook, 2006. Early settlement forest structure in Black Hills ponderosa pine forests. *Forest Ecology and Management*, 223: 284-290.

Cook, E.R., C.A. Woodhouse, C.M. Eakin, D.M. Meko and D.W. Stahle, 2004. Long-Term Aridity Changes in the Western United States. *Science*, 306(5698): 1015-1018.

Cordes, L.D., F.M. Hughes, and M. Getty, 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river – the Red Deer River, Alberta, Canada. *Journal of Biogeography*, 24(5): 675-695.

Friedman, J. M., W.R. Osterkamp, and W.M. Lewis, 1996. Channel narrowing and vegetation development following a Great Plains flood. *Ecology,* 77(7): 2167-2181.

Friedman, J. M., and V. J. Lee, 2002. Extreme floods, channel change, and riparian forests along ephemeral streams. *Ecological Monographs,* 72(3): 409-425.

Gom, L.A., and S.B. Rood, 1999. Fire induces clonal sprouting of riparian cottonwoods. *Canadian Journal of Botany*. 77(11): 1604-1616.

Lukas, J. and C.A. Woodhouse, 2006. Riparian Forest Age Structure and Past Hydroclimatic Variability, Sand Creek Massacre National Historic Site. *Final Report to the National Park Service*. pp. 20.

Johnson, W.C., 1992. Dams and riparian forests: case study from the upper Missouri River. *Rivers* 3(4):229-242.

Maisenhelder, L.C., 1951. Planting and growing cottonwood on bottomlands. *Bulletin 485*. Mississippi State, MS: Mississippi State College, Agriculture Experiment Station. pp. 23.

National Park Service, 2011. Little Bighorn River in 1876 geodata for Little Bighorn National Monument, Montana. *National Park Service Intermountain Region Geographic Resources Program*.

Pederson, G.T., S.T. Gray, C.A. Woodhouse, J.L. Betancourt, D.B. Fagre, J.S. Littell, E.Watson, B.H. Luckman, and L.J. Graumlich, 2011. The Unusual Nature of Recent Snowpack Declines in the North American Cordillera. *Science*, 333, 332-335.

Risser, P.G., E.C. Birney, H.D. Blocker, S.W. May, W.J. Parton, and J.A. Wiens, 1981. *The true prairie ecosystem.* Hutchinson-Ross Publishing Company, Stroudsburg, Pennsylvania.

Scott, M. L., J. M. Friedman, and G. T. Auble, 1996. Fluvial process and the establishment of bottomland trees. *Geomorphology*, 14: 327-339

Scott, M. L., G. T. Auble, and J. M. Friedman, 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. *Ecological Applications*, 7(2): 677-690.

Speer, J.H., 2010. *Fundamentals of Tree-Ring Research*. The University of Arizona Press, Tucson, AZ. pp. 333.

Stichman, M. Personal communication, 10 January 2012.

Swindell, B.C., 2011. Tree-ring reconstructed streamflow and drought history for the Bighorn River Basin, Wyoming. M.S. Thesis in Earth Sciences, *Montana State University*, Bozeman, MT. pp. 104.

APPENDIX TABLES

Table 1. Demographic data for LIBI riparian area cottonwood forests. Gray shading indicates pith estimates were not possible due to a lack of curvature in the rings. All dates are minimum age estimates only.

Sample ID	DBH (cm)	Core Height (cm)	# of rings	Offset to pith	Total # rings	Year of core	Year of establishment	missed battle by
LBB1a			114		114	1970	1857	-19
LBB1b			83		83	1970	1888	12
LBB1d			120	0	120	1970	1851	-25
LBB2	70.0	42.0	84	3	87	2011	1925	49
LBB3	38.0	40.0	88	0	88	2011	1924	48
LBB4	69.6	47.5	80		80	2011	1932	56
LBB5	111.5	48.0	84		84	2011	1928	52
LBB6	108.0	39.0	96	3	99	2011	1913	37
LBB7	81.3	40.0	117	4	121	2011	1891	15
LBB8	79.0	48.5	107	6	113	2011	1899	23
LBB9	50.4	41.0	106	6	112	2011	1900	24
LBB10	93.5	45.5	110	3	113	2011	1899	23
LBB11	87.5	28.0	105	2	107	2011	1905	29
LBB12	83.0	62.0	123	2	125	2011	1887	11
LBB13	72.0	44.0	104	9	113	2011	1899	23
LBB14	80.5	36.5	126	0	126	2011	1886	10
LBB15	92.0	35.0	101	4	105	2011	1907	31
LBB16	61.2	40.0	119		119	2011	1893	17
LBB17	96.8	33.5	112	13	125	2011	1887	11
LBB17b	97.0	32.0	103		103	2011	1909	33
LBB18	80.9	38.0	122	5	127	2011	1885	9
LBB19	35.0	39.0	123	0	123	2011	1889	13
LBB20	79.0	40.0	117	2	119	2011	1893	17
LBB21	50.9	38.0	114		114	2011	1898	22
LBB22	66.8	38.0	102	8	110	2011	1902	26
LBB23	95.0	40.0	51	0	51	2011	1961	85
LBB24	77.0	43.0	126	1	127	2011	1885	9
LBB25	48.0	35.0	122	1	123	2011	1889	13
LBB26	131.0	50.0	122	5	127	2011	1885	9
LBB27	75.0	35.5	123	0	123	2011	1889	13
LBB28	91.0	40.0	126	0	126	2011	1886	10
LBB29	89.1	47.0	95	2	97	2011	1915	39
LBB30a	67.7	42.0	109	9	118	2011	1894	18
LBB30b	67.7	32.5	114		114	2011	1898	22
LBB31	69.7	45.0	128	2	130	2011	1882	6
LBB32	70.8	38.0	97		97	2011	1915	39
LBB33	62.3	34.0	106	3	109	2011	1903	27

Table 1. Demographic data continued….

Sample ID	DBH (cm)	Core Height (cm)	# of rings	Offset to pith	Total # rings	Year of core	Year of establishment	missed battle by
LBB34	75.8	32.0	114	4	118	2011	1894	18
LBB35	96.6	54.0	103	1	104	2011	1908	32
LBB36	68.1	36.5	90		90	2011	1922	46
LBB37	90.0	57.0	82	8	90	2011	1922	46
LBB38	70.1	39.1	122	0	122	2011	1890	14
LBB39	72.4	41.0	117	7	124	2011	1888	12
LBB40	75.4	36.0	109	5	114	2011	1898	22
LBB41	83.8	33.5	124	5	129	2011	1883	7
LBB42	82.7	46.3	132	2	134	2011	1878	2
LBB43	98.8	57.0	124	0	124	2011	1888	12
LBB44	90.8	39.0	126	6	132	2011	1880	4
LBB45	73.7	31.5	120	7	127	2011	1885	9
LBB46	54.4	34.5	107	0	107	2011	1905	29
LBB47	62.5	59.0	125	2	127	2011	1885	9
LBB48	69.5	46.5	124		124	2011	1888	12
LBB49	70.8	49.5	121	0	121	2011	1891	15
LBB50	58.5	37.0	123	0	123	2011	1889	13
LBB51	105.2	51.0	120		120	2011	1892	16
LBB52	73.6	52.5	110	8	118	2011	1894	18
LBB53	80.2	37.0	110	3	113	2011	1899	23
LBB54	66.0	37.0	120	1	121	2011	1891	15
LBB55	75.4	42.0	111	2	113	2011	1899	23
LBB56	78.2	30.0	84	4	88	2011	1924	48
LBB57	74.4	41.5	74	16	90	2011	1922	46
LBB58	90.1	58.8			0	2011	2012	136
LBB59	68.9	44.2	94	0	94	2011	1918	42
LBB60	91.8	47.0	117	3	120	2011	1892	16
LBB62	62.1	39.1	115		115	2011	1897	21
LBB63	80.6	45.0	120		120	2011	1892	16
LBB64	82.5	50.0	124	3	127	2011	1885	9
LBB65	56.4	43.0	134	0	134	2011	1878	2

Table 2. Recorded annual peak discharge for the Little Bighorn River near Crow Agency, MT (Gage ID# 06293500). Data provided by the U.S. Geological Survey flood-frequency and basin-characteristic data (http://mt.water.usgs.gov/freq?page_type=site&site_no=06293500).

Water Year	Date	Gage height (ft)	Flag	Discharge (ft^3/s)	Flag	Date of Max. Maximum gage height	Maximum gage height (ft)	Flag
1912	July 4, 1912	8.6		3380	_/7	--	--	
1914	July 25, 1914	6.9		2500		--	--	
1915	June 14, 1915	11		4020		--	--	
1916	June 20, 1916	6.65		1360		--	--	
1917	Apr. 6, 1917	10.8		3930		--	--	
1918	June 19, 1918	8.6		2500		--	--	
1919	May 21, 1919	5.46		467		--	--	
1920	May 11, 1920	11.69		4480		--	--	
1921	May 9, 1921	7.1		1460		--	--	
1922	July 31, 1922	7.85		1900		--	--	
1923	July 23, 1923	14		6200		--	--	
1924	Apr. 8, 1924	11.22		4150		--	--	
1929	Mar. 11, 1929	9.19		3080		--	--	
1930	Mar. 12, 1930	6.11		930		--	--	
1931	June 7, 1931	5.74		713		--	--	
1932	May 23, 1932	--	_/2	1880	_/1	Feb. 27, 1932	11.21	_/1
1938	May 21, 1938	6.85		1370		--	--	
1939	Mar. 21, 1939	10.52	_/1	3310		--	--	
1940	June 15, 1940	5.7		687	_/1	--	--	
1941	May 15, 1941	6.32		970	_/1	--	--	
1942	June 6, 1942	9.76		2740	_/1	--	--	
1943	Mar. 26, 1943	13.01	_/1	4970	_/1	--	--	
1944	June 6, 1944	11.84		4400	_/1	--	--	
1945	June 9, 1945	--	_/2	1780	_/1	Mar. 14, 1945	8.54	_/1
1946	June 13, 1946	--		1600	_/1	--	--	
1947	Mar. 16, 1947	--		4000	_/1	--	--	
1948	Apr. 20, 1948	7.78	_/2	1730	_/1	Feb. 28, 1948	8.52	_/1
1949	Mar. 28, 1949	--	_/2	600	_/1	Mar. 1, 1949	6.18	_/1
1950	June 19, 1950	5.7	_/2	630		Feb. 27, 1950	8.01	_/1
1951	Mar. 26, 1951	--	_/2	650		Feb. 10, 1951	8.63	_/1
1952	Mar. 20, 1952	7.67	_/2	1550		Mar. 28, 1952	7.73	_/1
1953	June 16, 1953	7.32		1470		--	--	
1954	May 23, 1954	6		765		--	--	
1955	Apr. 15, 1955	6.98		1360		--	--	
1956	Mar. 22, 1956	8.33		1960		--	--	
1957	June 19, 1957	9.84	_/2	2750		Feb. 27, 1957	10.69	_/1
1958	June 14, 1958	6.43		952		--	--	
1959	Mar. 18, 1959	--	_/2	1300		Mar. 2, 1959	8.17	_/1
1960	Mar. 21, 1960	9.56	_/2	2850		Mar. 19, 1960	11.02	_/1

_/ Explanation of the footnotes used for Gage height data:

1 Gage height affected by backwater.

2 Gage height not the maximum for the year.

_/ Explanation of the footnotes used for Discharge data:
  1 Discharge is maximum daily average.
  7 Discharge is an historic peak.

_/ Explanation of the footnotes used for Maximum gage height data:
  1 Gage height due to backwater.