Paleoecological Reconstruction of Big Spring Run, Lancaster, PA

Ali Neugebauer
Earth and Environment Department
Franklin and Marshall College

Advisor: Dorothy Merritts, Department of Earth and Environment
Franklin and Marshall College
ENV 490: Independent Study
Project Submission: May 6th, 2011
Graduation: May 14th, 2011

Honors Thesis Defense Committee:
Jeff Hartranft, PA Department of Environmental Protection
William Hilgartner, Engineering for Professionals, The Johns Hopkins University
Suzanna Richter, Earth and Environment Department, Franklin and Marshall College
Chris Williams, Earth and Environment Department, Franklin and Marshall College

Table of Contents

Abstract

Seeds from sediments buried beneath post-European settlement millpond sediment can be used to reconstruct pre-settlement paleoecological conditions. At a valley bottom location along Big Spring Run in southern Lancaster County, PA, pre-

and early post-settlement sediments were sampled for seed extraction and identification. In the upper 68 cm of this sediment column, samples were collected at 2-cm increments. Below this level, two samples were collected as 9-cm and 14-cm thick blocks, and then sub-sampled to 3- to 4-cm thick increments in the lab. Nuts that fell from trees on an adjacent hillslope into the sediments were collected throughout the sample column for radiocarbon dating and geochronological control. Early post-European contact sediment was identified by radiocarbon dating and presence of dandelion seeds (an old world plant). From each sediment sample, 40 ml of soil was examined microscopically for seed presence. Seed identification, particularly of *Carex sp.*, reveals that seeds in the pre-settlement sediment are characteristic of wet meadows and obligate wetland conditions. Radiocarbon dates of nuts indicate that a wet meadow formed as early as 3300 yrs ago and existed as recently as possibly ~1810 AD (140 Cal BP). The spring-fed Big Spring Run valley bottom supported an obligate wetland environment for about 3000 years, indicating a prolonged period of ecological stasis. European settlement resulted in rapid sedimentation and burial of the late Holocene wet meadow. No obligate wetland species characteristics of a wet meadow occur in the sedimentary record from post-settlement age sediments. *Eleocharis obtusa* (blunt spikerush) appears in the sedimentary record at the onset of burial of the wet meadow, and indicates that the post-settlement environment was characterized by conditions typical of a mudflat. We correlate this transformation with the onset of European settlement and an increase in sedimentation, perhaps as a result of upland land clearing. The *E. obtusa* seeds disappear coincident with occurrence of *Alisma plantago-aquatica (*water

plantain), which indicates shallow water conditions. We interpret this record to indicate that a period of both increased water depth and sedimentation resulted from land clearing and near-simultaneous downstream changes in grade control of the water level in the Big Spring valley. The existence of multiple historic dams within hundreds of meters downstream provides a causal mechanism for an increase in water depth.

Introduction

The primary purpose of this project is to reconstruct the history of ecological change for the headwater reach of the Big Spring Run (BSR) valley bottom, Lancaster County, PA, for the past ~3500 yrs (Figure 1). This record of paleo-ecologic change might provide information on past climate change, because ecosystems respond to changes in climatic conditions. A second objective is to test the hypothesis that land use change (e.g. with the arrival of Native Americans or colonial settlers) might be recorded in the sedimentary archive of wetland and valley bottom sediments and buried soils at BSR (Table 1). The types of artifacts collected by local farmers indicate that Native Americans occupied the area for at least the past 5000 to 6000 years, and possibly longer (pers. comm., Dr. Dorothy Merritts). The earliest European settlers in Lancaster County, the Swiss Mennonite Hans Herr family, settled at the uppermost headwaters of BSR, within 1 km of the study site.

At present, the majority of land within the BSR watershed is used for agriculture, with limited suburbanization and development occurring during the past 15 years. Most farming consists of growing corn or raising cattle, and all

farmers in the BSR watershed practice no-till. The watershed is included on the EPA 303d impaired water body list for high loads of suspended sediment and nutrients (Merritts et al., 2010).

Restoration Research at BSR

The headwaters of Big Spring Run have been the focus of numerous scientific studies related to restoration science during the past six years (2006-2011). Scientists from several agencies (PA Department of Environmental Protection, United States Geological Survey, and the United States Environmental Protection Agency) and multiple institutions (Franklin and Marshall College, Penn State University, University of Arkansas, University of Maryland, University of Rhode Island, and the University of Illinois) are investigating the hydrology, paleoecology, ecology, geomorphology, groundwater chemistry, and geochemistry of the area prior to restoration that will occur in 2011 (Merritts et al., 2010). The restoration is a pilot project by PA Department of Environmental Protection to test a floodplain-wetland approach that involves removal of historic sediment. The ongoing scientific investigations will continue for at least one year after restoration in order to quantify and assess the environmental benefits of the restoration approach.

The work presented here provides significant information to the restoration plan, because it documents the types of plants and ecologic conditions that existed in the BSR valley bottom prior to and after European settlement, spanning the period from ~3500 yrs BP to ~1750 AD. The paleoecological conditions that existed prior to European settlement, agriculture, mill damming, and other practices represent the ecological potential of the site in the pre-impacted state.

Wetlands and their Ecological Value

Wetlands are areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Such areas are: swamps, marshes, bogs, and meadows (Clean Water Act). They are important landscape features because of the ecosystem services that they provide. Examples of the ecosystem services they provide are: habitats for fish and wildlife, improve water quality, store floodwaters, maintain surface water flow, and the services they provide with nitrogen fixation. In Pennsylvania, we are considered to be a part of Region 1 (EPA). There are many different classifications for the types of plants found in wetlands. An obligate wetland species means it is found in a wetland 99% of the time. Facultative wetland species occur in wetlands 67-99% of the time, and lastly facultative plants are as equally likely to occur in wetlands as they are in non-wetlands (USDA Plant Database).

Historic descriptions of Lancaster County describe low ground and marshes with numerous fine springs and multiple rivulets in the 18th c. (Voli unpub. data, 2008). Early accounts document that settlers converted marshes to farmland for crops and grazing. Pehr Kalm (1716-1779), a Swedish-Finnish botanist who traveled in early Colonial America, described the conversion of swamps to cornfields and pastures in southeastern Pennsylvania (Voli, unpub data, 2008).

Wetlands provide substantial ecological functions. These services include, but are not limited to, flood abatement, enhanced water quality, and support for

biodiversity. In recent years, wetland preservation has gained much attention because of the ecological value of wetlands. Minimizing further wetland loss is a top concern of federal and local governments (USDA Plant Database).

Background

Site Description and Climate

Big Spring Run (BSR) is a 2nd-order stream located in Lancaster County, southeastern Pennsylvania, in the mid-Atlantic region (39°59°45. 37" longitude, 76°15°50. 54" latitude). This study focuses on a site in the headwaters of BSR. Big Spring Run flows into Mill Creek, which joins the Conestoga River, a tributary to the Susquehanna River. The Susquehanna River watershed contributes to the discharge to the Chesapeake Bay. The drainage area of the BSR watershed is 15 km^2 (Merritts et al., 2010).

The climate of Lancaster County is mesic and temperate, with an average precipitation of 104 cm (41 inches) dispersed relatively evenly throughout the year (Table 2). The late summer-early fall is hurricane season, and during some years hurricanes from the Atlantic Ocean bring greater amounts of rainfall that persists for days. The average annual temperature is 11°C (52°F) (Galeone et al., 2006). The year 2009 was unusually wet with a total rainfall of 167.1 cm (65.8 inches) followed by a dry year in 2010, which as of October had only 96.5 cm (38 inches) of precipitation. The winter of 2010 experienced higher than average snowfall, with 127.5 cm (50.2 inches) in February alone. The typical amount of snow each year is 63.5 cm (25 inches).

Climate during the Holocene Epoch, the past 10,000 yrs, had millennial-scale variations in temperature and precipitation. Willard et al (2005) present data indicating that several periods of cool, dry climate occurred about every 1400 years and lasted from 300-500 years (2005). These findings were derived from pollen data from Chesapeake Bay cores, and are consistent with terrestrial and marine records of cool, dry episodes during the Holocene (Willard et al. 2005). The most recent cool, dry episode coincided with the Little Ice Age, and Willard et al's pollen data and radiocarbon dating indicate that it occurred from 1400-1600 AD.

BSR lies within the Piedmont physiographic province and is characterized by broad rolling hills and valleys. Overall, relief is low to moderate (Galeone et al., 2006). Maximum and minimum elevations in the watershed are 152 and 81 m, respectively, and total relief is about 70 meters (Figure 2). Big Spring Run's minimum elevation, 81 m, occurs at the stream's confluence with Mill Creek.

BSR begins at numerous springs and receives additional spring water along its length. The stream flows northward over deeply weathered Paleozoic limestone (Galeone et al., 2006). The limestone is mapped on the Quarryville and Conestoga geologic quadrangles as Cambrian to Ordovician age Conestoga Formation (Blackmer, 2007). The Conestoga Formation consists of medium gray phyllitic limestone, with light to medium gray crystalline limestone and phyllitic partings (Blackmer, 2007). Quartz veins throughout the formation vary in size from several millimeters to as much as a meter. Along with the quartz, mica (muscovite and phlogopite) and accessory minerals (pyrite) occur in variable amounts (Blackmer, 2007).

Site History

The study location is currently an incised stream surrounded by farmland, but this has not always been the case. A preliminary study of seed species and genera preserved at the base of incised stream bank sediments and age dating of buried paleosols at BSR and two nearby sites determined that late Holocene paleoecological conditions were much different than today (Voli et al., 2009). During the late Holocene Epoch, BSR and nearby sites supported many herbaceous wet meadows, which persisted from at least 3,200 to 300 yrs BP.

The BSR watershed was one of the first areas settled in Lancaster County. A well-used trail connecting the Delaware and Susquehanna Rivers passes through the headwaters of BSR within several hundred meters of the study site. Trading posts existed along this trail during the period of the early Native American fur trade. In 1709, European immigrants settled within the county, and the first settlement (Hans Herr family) was near the drainage divide at the BSR headwaters (Merritts et al., 2010). Settlers in the area began to build dams for waterpower (e.g., for grist mills) from the early 1700s to the early 1900s, trapping sediment upstream of the impoundments (Walter and Merritts, 2008). These impounded sediments buried the pre-existing valley bottom landscape and vegetation, and because deposition occurred in relatively quiet-water conditions, the pre-existing flora and sedimentary features were undisturbed and well preserved (Walter and Merritts, 2008). Rapid, quiet-water burial of the landscape is similar to deposition of a volcanic ash that blankets the landscape, i.e., a “Pompeii effect”.

A milldam at the mouth of BSR can be seen on the 1864 Atlas of Lancaster County (ref). This dam was used to operate a machine shop near the mouth of Big Spring Run. Evidence of a breached dam and incised channel at this location can be seen in the first aerial photos of the area taken in the late 1930s (Merritts et al., 2010). Bridges, road crossings, and small dams for ice ponds and other purposes created additional changes along the BSR valley bottom that decreased stream flow velocity and rates of sediment transport. Local landowners changed the landscape in other ways once early dams breached and an incised stream channel formed. Mr. Harlan Keener, owner of the farm 1-km downstream of the study site, reported that his grandfather shifted the course of the incised BSR stream channel in the early 1900s. Mr. Keener described how his grandfather straightened the main stem of BSR and move it westward with a team of horses in 1916 (Shilling, 2010). The reason given for this practice was that the stream was eroding too closely to a springhouse located near the farmhouse. Furthermore, channel relocation enabled the farmer to have a larger area of valley bottom for pasturage.

The incised banks of modern streams expose historic ("legacy") sediment that accumulated in backwater areas upstream of the various grade control structures (i.e., dams, roads, bridges) that existed along the BSR valley bottom. The historic sediment is thicker near the breached dams. Buried beneath the fine-grained historic sediment is the pre-settlement landscape, which varies from toe-of-slope colluvium on valley margins to hydric (wetland) organic-rich soil along the original valley bottom center.

Previous Paleoecology and Paleoclimate Studies in the Region

Wetlands are determined by three characteristics: vegetation, soil, and hydrology (US Army Corps of Engineers). It is difficult to determine pre-historic hydrology, but the prehistoric wetland soils can be identified through the use of radiocarbon dating, magnetic susceptibility (MS), and seed identification (Merritts et al., 2006). This study focuses on the identification of prehistoric wetland vegetation. Previous ecological conditions can be reconstructed by the collection and identification of macrofossils (c.f., Hilgartner and Brush, 2006).

An example of a paleo-wetland that dates to the early Holocene was studied by Paul S. Martin in 1958. This study focused on the use of pollen from core samples to reconstruct pre-existing Holocene vegetation in the Marsh Creek Valley in Chester, County, PA (Martin, 1958). Today, Marsh Creek is a spring-fed wet meadow dominated by tussock sedges. The dominant species identified by Martin from pollen in the sedimentary record were *Polygonum* species, sedges, and grasses. Martin concluded from radiocarbon dates at the base of the sediments at Marsh Creek that a wetland existed at this site since about 13,000 yrs BP. Martin noted that no similar wet meadows occur in the Piedmont region of PA today, and concluded that the Marsh Creek wet meadow might be an example of a Pleistocene refugium.

Analyses of seeds also have been used to reconstruct paleo-environments along the shores of the Chesapeake Bay. In a 2006 study, fossil seeds and pollen were combined with historical records to reconstruct an 1800-year ecological history for the mouth of Otter Point Creek (Hilgartner and Brush, 2006). From this

analysis, it was found that a period of rapid change from wetland to riparian forest occurred from 1840-1880 AD, synchronous with a period of high sedimentation rates and progradation of the mouth of Otter Point Creek into the Chesapeake Bay.

Li et al (2006) determined that Holocene lake levels at a site 160 km northeast of Big Spring Run, in northern New Jersey,, varied at a millennial scale, with low levels occurring at 1.3, 3.0, 4.4, and 6.1 ka (1 ka = 1000 cal yr BP). These low stands are characterized by layers of oxidized marl in the lacustrine sedimentary record, and are inferred to represent dry periods (Li et al., 2007). The timing of the low stands corresponds with cold episodes, known as Bond events, recorded in North Atlantic Ocean sediments (Bond et al., 1997, 2001). Cool intervals at 3.1, 4.4, and 5.9 ka also were inferred to occur in eastern North America from decreases in *Pinus* pollen abundance (Willard et al., 2005). Severe drought at 4.4 ka has been detected in the northeast US, mid-continental North America, Mesopotamia, and elsewhere (c.f., Booth et al., 2004, 2005).

Previous Work at Big Spring Run

In a previous, preliminary study at BSR, M. Voli concluded that a wet meadow herbaceous wetland existed for at least 3,200 years until buried beneath historic sediment (Voli, 2009). It was determined that a downstream dam had buried the wetland. This buried wetland was exhumed after the dam breached, which led to channel incision and exposure of the buried features. This previous work was based on analysis of only a few samples of buried soil at three locations with the BSR valley, and no analysis of changes with depth was completed. For the study

presented here, the goal was to evaluate changes in paleo-ecological conditions with time at a single location within the BSR valley.

Methods

Sampling

The paleo-seed sampling site used in this study is located along BSR at the base of an incised stream bank about 60 m north of State Route 741. The sampling site is referred to as Site 8, and the height of the incised stream bank is ~1.4 m (Figures 3 & 4).

Sampling was begun 72 cm below the top of the incised stream bank, about 70 cm above the buried pre-settlement landscape surface (Figure 5). The sample column height was 89 cm. Above the sample column, the uppermost 72 cm of the stream bank consists of historic sediment that contains objects such as bricks and European ceramics. This historic sediment has been mapped throughout the BSR valley bottom by other F&M researchers, and is documented to consist of laminated silt, fine sand, and clay that were deposited in quiet water conditions.

The exact boundary between pre- and post-settlement sediment was not known at the time of sampling; however, a black (10 YR 2.510) buried soil begins at a depth of ~120 cm below the top of bank. Between the historic sediment and buried dark soil is a lighter colored stratum (dark brown, 10 YR 3/2) that occurs along some parts of the incised BSR stream banks where the channel is located close to valley margins. About 22 cm of our sample column consisted of this light colored unit. The uppermost 26 cm of the sample column was brown (10 YR 4/2).

Sediment samples were collected at 2-cm increments from a depth of 72 cm to water level, at a depth of 138 cm. Below the water level, blocks of sediment were removed from 138-147 cm and 147 to 161 cm in depth, and then separated into 3-to 5 cm increments in the lab. Samples were cut from the incised stream banks with large, flat mortar blades. The rectangular sample blocks were ~10 cm wide and ~10 cm deep. Before storage, the samples were split into two parts. Half was stored in labeled, plastic bags in a refrigerator, while the other half was packaged and sent to Chris Bernhardt (USGS office, Reston, VA) for pollen analysis.

Seed Extraction

For seed extraction, 40 ml of each sample was analyzed. Sample volume was measured by simple liquid displacement. For this method, sediment is placed in distilled water and displacement is recorded to determine sample volume. Samples were wet sieved through a 28-mesh (0.6 mm) screen. The larger fraction trapped on the sieve screen was examined for seeds under a binocular microscope (2 to 5 x magnification). Seeds were removed with tweezers or a water dropper, placed in distilled water with formalin in a labeled plastic vial for preservation, and stored at 4°C in a refrigerator.

Photographing and Identifying Seeds

Seeds were photographed at high magnification (up to 10 x) with a Nikon camera-mounted microscope. For each seed, two to five pictures were taken to get a view of the seed from all angles. All seeds and digital photos were archived. The number of seeds per sample was recorded in order to determine frequency and

abundance. All data could be normalized to 100 ml of sample to account for differences in the amount of sediment processed. For example, if 20 seeds were extracted from 40 ml and 40 seeds were extracted from 50 ml, the resultant normalized values would be 50 and 80 seeds per 100 ml, respectively. To date, the same volume of 40 ml was used for each sample, but if future work is done to extract more seeds from individual layers, the final values of seed abundance can be converted to 100 ml so as to standardize all comparisons. The values given throughout this paper are in reference to 40 ml.

Multiple digital images and the original seeds were used in the identification process. Seed identification was done based on standard reference works that illustrate seed size, shape, and other diagnostic features (Appendix 1) and the United State Department of Agriculture Plants Database[1]. To help with identification, ecologists Dr. William Hilgartner (The Johns Hopkins University) and Jeff Hartranft (PA DEP) assisted with basic identification protocols and expert advice. Hannah Jantzi, F&M research assistant, also assisted in seed extraction, photography, and identification.

In seed bank studies, the similarity among species is one of the most important properties to determine (Hopfensperger, 2007). In this study, the Sorenson similarity index (SSI) was calculated for each layer. The SSI is a measure of similarity between two samples. Using the following equation completed this:

$$SSI = 2C/(A+B)$$

[1] http://plants.usda.gov/java/

with A and B equal to the number of species in each sample and C equal to the number of species shared by the two samples. A number close to 1 indicates similarity and a value close to 0 indicates no similarity among the samples.

Radiocarbon Dates

The best material for radiocarbon dating is nuts or seeds, as these represent single years in terms of age. In contrast, a piece of wood might span decades or even a hundred years or more in age. We searched for nuts that had fallen into the sediment and extracted them from their in situ stratigraphic position (Figure 5). Two types of nuts, black walnut and black cherry, were dated. The nuts were dried in a Precision Economy Oven at low temperature, 100°C, for two to three days. Dried samples were placed in labeled plastic bags and stored at room temperature. Samples selected for dating were weighed, repackaged in foil, and sent to Beta Analytical., Inc., in Miami, FL, for radiocarbon dating.

Results

Radiocarbon ages from the sampled sediment column ranged from ~3000 to ~90 yrs BP (see Table 3). With one exception (Sample #6), all dates older than ~230-270 BP are in correct order with respect to stratigraphic position, with deeper samples yielding greater ages**.** At the depth interval 157-161 cm, two dates of 2690±40 and 3000±40 BP were obtained. Four samples from depths of 121.5 to 126.5 cm yielded dates close to the approximate limit of radiocarbon dating—approximately 200 BP—and had multiple calibration intercepts. For example, two nuts at 126.5 and one nut at 125.5 cm yielded ages of 230±40, 230±40, and

270±40BP, respectively, but calibration intercepts result in a range of possible ages from 140 to 440 Cal BP (Table 3).

European settlement in Lancaster County began less than a km from the study site, in the Big Spring Run headwaters, with the arrival of the Hans Herr family in 1709. If the timing of settlement were assigned a conventional radiocarbon age, it would be 241 BP. All samples below a depth of 126.5 cm had pre-settlement ages that were greater than this age. Given that a sample from a depth of 128.5 yielded an age of 850±40 BP, we conclude from the radiocarbon dates that the pre-settlement to post-settlement boundary occurs between depths of 119.5 and 126.5 cm. We further constrain this estimate below based on changes in plant species based on seed extracted from the sediments.

Based on the five dates obtained at multiple depths at or below 128.5 cm, we determined a long-term average sedimentation rate of 0.014 cm/yr (increasing to present time) for the period spanning ~3000 to 850 BP (Figure 6). We did not calculate the sedimentation rate for any layer above 128.5 cm because these sample depths are close to post-settlement in age or younger and yielded multiple calibration intercept dates. From the oldest date at a sample depth of 158.5 cm to the youngest date that predates European settlement at a sample depth of 128.5 cm, the sedimentation rate was 0.014 cm/yr. We inferred the ages for each undated layer below 128.5 cm based on the assumption of a constant sedimentation rate between the dated sample depths.

From the 89 cm of sediment sampled, 2,485 seeds were extracted (Figure 7). Thirty-eight different plant species were identified, with 1,403 (58% of total) of the

seeds identified as one of the following eight species: *Carex prasina type* (drooping sedge), *Carex stipata* (awlfruit sedge), *Carex hystericina (*bottlebrush sedge), *Carex sp.* (sedge*), Eleocharis obtusa* (blunt spikerush), *Liriodendron tulipifera* (tulip tree), *Glyceria striata* (fowl mannagrass), and *Alisma plantago* (water plantain). The most common plant species were sedges. Overall, 1,547 seeds were identified, leaving 938 seeds unidentified *(*Figures 8 & 9).

The sample depth with greatest number of seeds was 118-120 cm, with 260 seeds per 40 ml of sample. Layers 72-92 cm contained fewer than 20 seeds per 40 ml of sediment from each 2-cm sample interval. Samples from 144-161 cm also had fewer than 20 seeds per 40 ml of sample.

Seeds of both introduced and now extinct species were identified. At depth 106-108 cm, two *Taraxacum officinale* (common dandelion) seeds were isolated. Dandelion is an old world plant introduced by European settlers.

The Sorenson similarity index (SSI) showed consistently substantial ecological similarity below a sample depth of 114 cm. Below a depth of 132 cm all SSI values were >0.7, but from 114-132 cm the SSI averaged 0.86. Above 114 cm, SSI values ranged from 0 to 0.81 (Figure 10). In previous studies, 0.4 has been considered the value at which there is a significant difference between two samples (Hilgartner et al., 2009). This test was used to identify trends over various depths and possible changes in environmental patterns (Hopfensperger, 2007).

Discussion

Geochronology

With one exception, each dated stratum yielded radiocarbon ages that were younger than those of underlying strata. The radiocarbon age for a nut from 151.5 cm was inconsistent in terms of stratigraphic position with respect to dated samples above and below it. Possible explanations for this out-of-sequence date are bioturbation, possibly from animal burrowing or other disturbance (e.g., an herbivore grazing and walking in the sediment). It also is possible that annual freeze-thaw during the winter might have led to some vertical mixing of sediment from different depths.

Reconstructing the Late-Holocene Paleo-environment

No organic soil occurs below a depth of 161 cm, and colluvial gravel from the adjacent hillslope underlies the stratigraphic section. The oldest date, 3000 ±40 BP, from a nut in black organic rich sediment is interpreted to represent the onset of a wetland and accumulation of organic matter. We hypothesize that one or both of the droughts that occurred in the region about 3.0 and 4.1 ka years ago might account for the lack of evidence of wetland soil older than ~3000 BP at this site (Li et al., 2007). Drought might have led to a drop in the water table and a shrinking of the original extent of the wetland. It is plausible that wetland recovery began after the drought, but that some period of time was required for plant growth to become established and for seed abundance to increase.

Within the depth interval of 138-161 cm, which spans a depositional time period of ~3000 to 1400 BP as determined from radiocarbon dates and inferred from a long-term sedimentation rate, few seeds are present. Average seed abundance is 21 seeds per 40 ml per 2-cm layer, and the range in abundance is as few as 7 to as many as 38 seeds per 40 ml per sample depth interval. The most common seed in these layers is *Carex prasina type,* an obligate wetland species. The seeds are labeled as *Carex prasina type* because they are very similar to *Carex prasina,* but slight variations in size, color, and shape exist among the seeds examined. The typical environment that corresponds with *Carex prasina* is a wet meadow. This species has a low tolerance to drought (United State Department of Agriculture Plants Database). It is possible that *Carex prasina* existed in this area before circa 3000 BP, but perhaps its habitat coverage was diminished in aerial extent during the one or both of the droughts that occurred circa 3000 and 4100 BP (Li iet al., 2007). After the drought(s) ended, *Carex prasina* might have expanded in extent as the valley bottom became wetter and conditions were favorable to a wet meadow.

Several possible reasons could explain the gradual upward increase in seed abundance from 138-161 to 110-136 cm. The first is that circa 3000 years ago, wetland plant establishment might have been incipient if the site was recovering from drought conditions. Second, mineral matter increases with depth, so the proportion of seeds per unit sample volume decreases downward. In the bottom layers from 138-161 cm, the soil contains more gravel. The proportion of seeds would be expected to be lower when mineral matter content is greater with respect

to organic matter. Third, perhaps the more gravelly substrate at the base of the section was less conducive to wetland plant growth than higher stratigraphic levels that were more organic rich. Lastly, preservation error is likely to exist throughout the record. This could be due to the fact that not as many seeds were preserved at different times or that certain species that might have been common produce fewer seeds.

The sample depth interval of 110 to 136 cm differs markedly from lower strata (138-161 cm) because, on average, these upper levels yield 124 seeds per 40 ml sample and a range in seed abundance of 70-189 seeds per 40 ml. A possible cause of this increase in seed abundance relative to samples below 136 cm is a greater likelihood of seed preservation in established wetland conditions or perhaps an actual greater abundance in particular species because of increased maturity of the wetland.

From the SSI, the level of species similarity between 112-114 cm and 114-116 cm is only 53%, suggesting that disturbance occurred between the times of deposition of sediment at these depths. Strata at the depth range of 114-136 cm are dominated by three species: *Carex prasina type, Carex stipata, and Carex hystericina.* Radiocarbon dates and ages inferred from the long-term sedimentation rate range from 422 to 1417 BP for the depth interval from 122-136 cm. Above 122 cm, the sediment is too young to accurately date with the radiocarbon method.

These three *Carex* species are associated with shallow water obligate wetlands and, more specifically, with wet meadows. A wet meadow is dominated by water-loving grasses and sedges and resembles a fallow field (Tiner, 1998). This

type of habitat contains nearly 100% vegetation cover and has little open water. Such wetlands commonly are dominated by 2-3 species. Wet meadows often form a transition zone between aquatic communities and uplands with soils that are frequently saturated and mucky (Tiner, 1998). We conclude that sedge-dominated wet meadows were common at the BSR study site from 3300-3000 yrs BP until ~1700 AD, when a marked change in seed types and abundance indicates that some type of marked environmental change occurred.

Within the depth range of 96-98 cm to 108-112 cm, the abundances of *Carex prasina type* and *Carex hystericina* decrease substantially. At the stratigraphic level of 96-98 cm (clearly post-settlement because dandelion occurs at 106-108 cm), *Eleocharis obtusa* appears and the abundance of *Glyceria striata* increases. *Eleocharis obtusa* commonly grows in a mudflat or at the edge of a muddy pond. These environmental conditions are consistent with the previously presented hypothesis of a change in environment occurring circa 1710 AD. The seed evidence supports an interpretation that the area became the edge of a shallow muddy pond. Development of a shallow muddy pond at the site of a wet meadow that existed previously for nearly 3000 years is consistent with an interpretation that water deepened and the supply of sediments from adjacent hill slopes increased. Water deepening might have been the result of downstream damming. Multiple historic dams have been identified along the length of BSR, and any one of these could have led to an increase in water depth (personal communication, Merritts, 2011).

Above the depth interval of 88-90 cm, seeds of *Alisma plantago-aquatica* (water plantain) appear in the sedimentary record. This seed is abundant from 72

to 90 cm. *A. plantago-aquatica* is an obligate wetland plant, but is an aquatic species indicative of a shallow pond with water depths up to 15 cm deep (USDA Plant Database). The appearance of a plant type that requires greater water depth than those of lower strata supports the hypothesis stated above that water depth might have been increasing along BSR, first leading to a mud flat along the shores of the pond, and then submerging the mud flat as water depth increased further.

The remainder of the sample section above 76 cm contains progressively fewer seeds. It is possible that water depth or sedimentation rate, or both, increased and led to a decline in relative seed abundance. Samples were not collected from sediment above 72 cm, as higher strata are oxidized and contain evidence of colluvial gravel input from the adjacent hillslope. They also contain material such as fire-baked stone that is anthropogenic in origin. We interpret these upper sediments, albeit with little direct investigation here, as either historic pond sediments or hillslope-derived colluvium from agriculture and road building activities or some combination of these two types of processes. This interpretation is supported by numerous studies of historic sediment throughout the BSR valley bottom by other F&M researchers (ongoing research).

Post-European Settlement Decrease in Tree Abundance

An interesting pattern occurs in the abundance of seeds of *Liriodendron tulipifera* (tulip tree). There is evidence of this seed in the record from the base of the sampled sedimentary section to a depth of 114-116 cm. We interpret the first arrival of European settlers, and likely land clearing, to be associated with a depth of 121.5 to 125 cm. A plausible explanation for the sudden decrease in seed

abundance is that all of the tulip poplar trees in the nearby area were cut down or removed. The tulip poplar was the tallest tree in the region prior to European settlement, with heights up to ~30-40 m, and its branches would have extended far into the margins of the wet meadow at Big Spring. In addition, it is considered to be a prolific species in terms of seed abundance. Indeed, numerous *L. tulipfera* seeds occur at depths below 116 cm, but none between 72 and 116 cm.

Distinct and relatively abrupt drops in seed abundance for three other species are illustrated in Figure 8. These species are *Carex prasina, Carex hystericina, and Eleocharis obtusa.* For all three of these species, seed abundances drop markedly over a depth interval of 2 to 4 cm. Rapid drops in seed abundance are consistent with sudden ecosystem change as a result of disturbance, such as an increase in water depth and/or sedimentation rate.

Given that about 120 cm of sediment is estimated to have been deposited since about 1710 AD, we estimate that the post-settlement sedimentation rate was 0.5 cm/yr. If deposition ceased by 1900 AD, the time of channel incision estimated by other researchers at BSR, then sedimentation rates from 1710 to 1900 might have been as high as 0.6 cm/yr.

Future Work

From this project, many additional studies could ensue. Further tests could be done with the remaining samples. For example, work could be done on pollen, diatoms, charcoal content, and grain size. This information would allow for a more accurate reconstruction of the paleo-environmental changes that occurred during the past ~3000 yrs.

An additional study that could take place would be another column from a different area along the modern incised stream to determine whether similar paleo-environments existed throughout the BSR valley bottom. It would be helpful to identify the nature of the paleo-wetlands that existed at a given time at different locations along the valley bottom.

Furthermore it is important to note that 144 seeds that have been identified are not among the eight most common species, and 938 seeds remain unidentified. The other 116 identified seeds also are of obligate wetland plants (Appendix 2). Further study could include investigation of these species and continued effort to identify those seeds not yet identified.

Conclusion

In conclusion, a wet meadow wetland persisted from approximately 3000 to approximately 300 years ago at the headwaters at BSR during a period of habitat stasis. During this time period, the most abundant and therefore dominant species of this pristine habitat were *Carex hystericina, Carex prasina,* and *Carex stipata*. Circa 1700-1750 AD, a major environmental change occurred, causing the disappearance of sedge species and the appearance of initially mud flat and then pond species in the stratigraphic record. This finding is consistent with known land use changes associated with European settlement. These changes included deforestation, land clearing, increased rates of upland soil erosion, dam construction and valley bottom sedimentation. The results show that ecological stability occurred from about 3000 to 300 years ago. Long-term ecosystem stability was sustained, even with the probable occurrence of drought, hurricanes, beaver damming, and

other natural climatic phenomena. The abrupt end of this stability indicates that European anthropogenic impact caused the major change in environment. Without these impacts, it is possible that the site would still be a wet meadow today.

Acknowledgments

I would like to thank Dr. Dorothy Merritts for all of her insight and help throughout this entire process. There were so many times where I wanted to give up, but she continued to push me through. I would also like to thank Dr. William Hilgartner and Jeff Hartranft for helping me to identify seeds and to interpret results throughout the entire process. Additionally, I am grateful to Dr. Robert Walter '75 for all of his help in and out of the field. I would like to especially thank Hannah Jantzi for all of her help with extracting, photographing, and identifying seeds, and for her enjoyable company as we worked together. Among my peers, I want to thank Erik Olsen '11, Aakash Ahamed '12, Katie Datin '11, and Laura Kratz '11 for their entertainment over the summer. Lastly, I would like to thank my parents for basically dealing with all of my craziness this past year.

References

Blackmer, Gale C. *Bedrock Geologic Map of the Quarryville and Conestoga Quadrangles, Lancaster County, Pennsylvania*. Open File Report. 4th Series. Harrisburg, PA: Pennsylvania Geological Survey, 2007. http://www.dcnr.state.pa.us/topogeo/openfile/conquarry.pdf.

Bond, G.C., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal., P., Priore, P., Cullen, H., Hajdas, I. and Bonani, G. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. *Science* 278, 1257-66: 1997.

Bond, G.C., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I. and Bonani G. Persistent solar influence on North Atlantic climate during the Holocene. *Science* 294, 2130-36: 2001.

Booth, R.K., Jackson, S.T. and Gray, C.E.D. Paleoecology and high-resolution paleohydrology of a kettle peatland in Upper Michigan. *Quaternary Research* 61, 1-13: 2004.

Booth, R.K., Jackson, S.T., Forman, S.L., Kutzbach, J.E., Bettis, E.A., III, Kreig, J. and Wright, D.K. A severe centennial scalevdrought in mid-continental North America 4200 years ago and apparent global linkages. *The Holocene* 15, 321-28: 2005.

Brush, Grace S., and William B. Hilgartner. "Paleoecology of Submerged Macrophytes in the Upper Chesapeake Bay." *Ecological Monographs* 70, no. 4 (November 2000): 645-667.

Galeone, Daniel G., Dennis J. Low, and Robin A. Brightbill. *Effects of streambank fencing of near-stream pasture land on a small watershed in Lancaster County, Pennsylvania*. Fact Sheet 2006-3112. Reston, VA: U.S. Geological Survey, 2006. http://pubs.er.usgs.gov/usgspubs/fs/fs20063112.

Hilgartner, William B., and Grace S. Brush. "Prehistoric habitat stability and post-settlement habitat change in a Chesapeake Bay freshwater tidal wetland, USA." *The Holocene* 16, no. 4 (May 1, 2006): 479-494.

Hilgartner, William B., Mark Nejako, and Ryan Casey. "A 200-year paleoecological record of *Pinus virginiana*, trace metals, sedimentation, and mining disturbance in a Maryland serpentine barren." *Journal of the Torrey Botanical Society* 136, no. 2 (2009): 257-271.

Hopfensperger, K.N. "A review of similarity between seed bank and standing vegetation across ecosystems." *Oikos,* 116 (October, 2007): 1438-1448.

Martin, Paul Schultz. "Taiga-tundra and the full-glacial period in Chester County, Pennsylvania." *American Journal of Science* 256, no. 7 (September 1, 1958): 470-502.

Merritts, Dorothy. (Pers. Com., email dated April 4th, 2011).

Merritts, Dorothy, Robert Walter, Michael Rahnis, Jeff Hartranft, Scott Cox, Allen Gellis, Noel Potter, et al. "Anthropocene streams and base-level controls from historic dams in the unglaciated mid-Atlantic region, USA." *Philosophical Transactions of the Royal Society A: Mathematical., Physical and Engineering Sciences* 369, no. 1938 (March 13, 2011): 976 -1009.

Merritts, Dorothy, Walter, Robert, and Oberholtzer, Ward. "Buried Holocene Streams and Legacy Sediment: Late Pleistocene to Historical Changes in Stream Form and Process and Implications for Stream Restoration, Mid-Atlantic Piedmont Region." Field Trip Guidebook, Geological Society of America Annual Meeting. Philadelphia, PA, October 21, 2006.

Shilling, Andrea. "Rates and processes of stream bank erosion to suspend sediment load, Big Spring Run, PA." Undergraduate Honors Thesis. Franklin and Marshall College, May 2010.

Voli, Mark. "Reconstructing pre-European settlement paleo-environments in Piedmont valley bottoms." Senior Thesis. Unpublished. April 2009.

Voli, Mark, Dorothy Merritts, Robert Walter, Erik Ohlson, Katherine Datin, Michael Rahnis, Laura Kratz, Wanlin Deng, William Hilgartner, and Jeffrey Hartranft. "Preliminary Reconstruction of a Pre-European Settlement Valley Bottom Wetland, Southeastern Pennsylvania." *Water Resources Impact* 11, no. 5 (September 2009): 11-12.

Walter, Robert C., and Dorothy J. Merritts. "Natural Streams and the Legacy of Water-Powered Mills." *Science* 319, no. 5861 (January 18, 2008): 299-304.

Willard, Debra A., Christopher E. Bernhardt, David A. Korejwo, and Stephen R. Meyers. "Impact of millennial-scale Holocene climate variability on eastern North American terrestrial ecosystems: pollen-based climatic reconstruction." *Global and Planetary Change* 47, no. 1 (May 2005): 17-35.

Figures and Tables

Term	Definition
Deposit	Either consolidated or unconsolidated material of any type that has accumulated by natural processes or by human activity
Landform	Any physical, recognizable form or feature on the earth's surface having a characteristic shape and internal composition, that is produced by natural cause(s)
Soil	The collection of natural bodies occupying parts of the Earth's surface that is capable of supporting plant growth and that has properties resulting from the integrated effects of climate

Table 1. Definitions table.

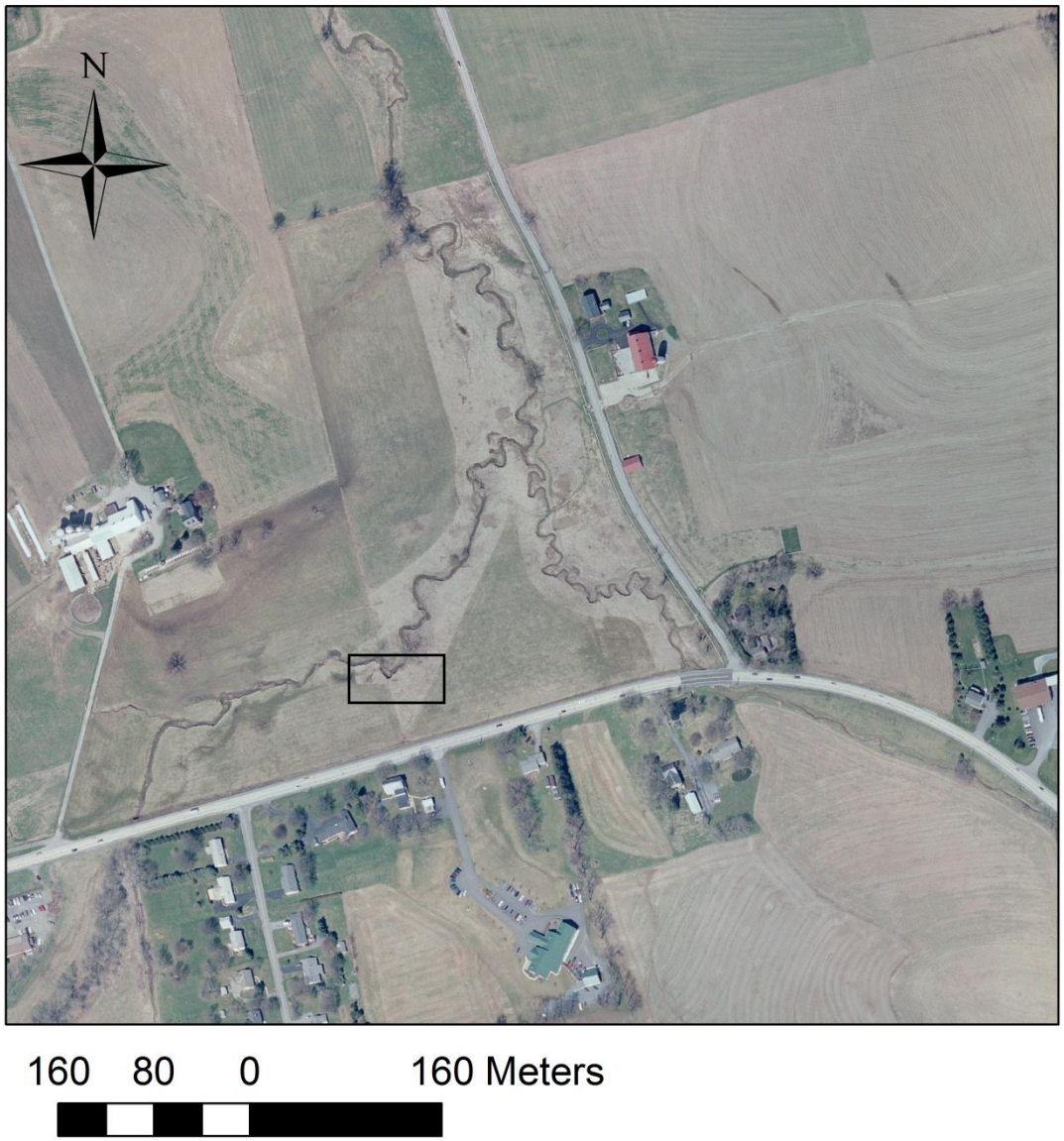

Figure 1. Two headwater tributaries, bottom left and right, join to form Big Spring Run and flow northward (toward top of figure) to Mill Creek, which is out of view to the north. PAMAP digital orthoimage acquired in 2005. Black box indicates the area shown in Figure 3.

Month	Average Temp °F	Total Precipitation (Inches)	Snow (inches)
		2009	
January	26.8	1.77	7.7
February	35.8	0.33	2.1
March	41.8	1.64	6.5
April	53.7	4.31	0
May	63	4.83	
June	70.4	5.25	
July	72.5	22.28	
August	75.3	8.23	
September	65	5.56	
October	53.8	5.78	
November	48.2	2.04	0
December	33.7	5.55	20.2
Total		67.57	36.5

Month	Average Temp °F	Total Precipitation (Inches)	Snow (inches)
		2010	
January	31	1.66	1.5
February	30.7	3.4	50.3
March	47.5	3.13	0
April	56.4	1.84	0
May	65.5	5.39	
June	75	3	
July	78.5	7.4	
August	75.7	1.31	
September	70	7.36	
October	55.8	3.44	
Novermber	53.8	0.22	
December	45	2.35	2.3
Total		40.5	54.1

Month	Average Temp °F	Total Precipitation (Inches)	Snow (inches)
		2011	
January	33.5	2.36	22.3
February	44.6	2.48	4.9
March	49.7	4.61	0.1

Table 2. Average monthly temperature, precipitation, and snowfall in Lancaster, PA, for the past two years.
(Data from http://www.atmos.millersville.edu/~cws/climo/monthly-data.html)

Figure 2. Lidar-derived digital elevation model of Big Spring Run headwaters. Two headwater tributaries join to form Big Spring Run and flow northward to Mill Creek, out of the view to the north. Elevation data from NCALM lidar.

Figure 3. Site 8 location. Yellow dot represents the incised stream bank from which samples were collected.

Figure 4. Photograph of sample column. Note boundary marked by line of red, pink, and orange flags from lower left to right, indicating a distinct color change in the sediment, from black below to dark brown above. Orange flag at upper right indicates top of sample section. Lowest samples were collected below water. Gravel at base of sample column was placed to hold back water.

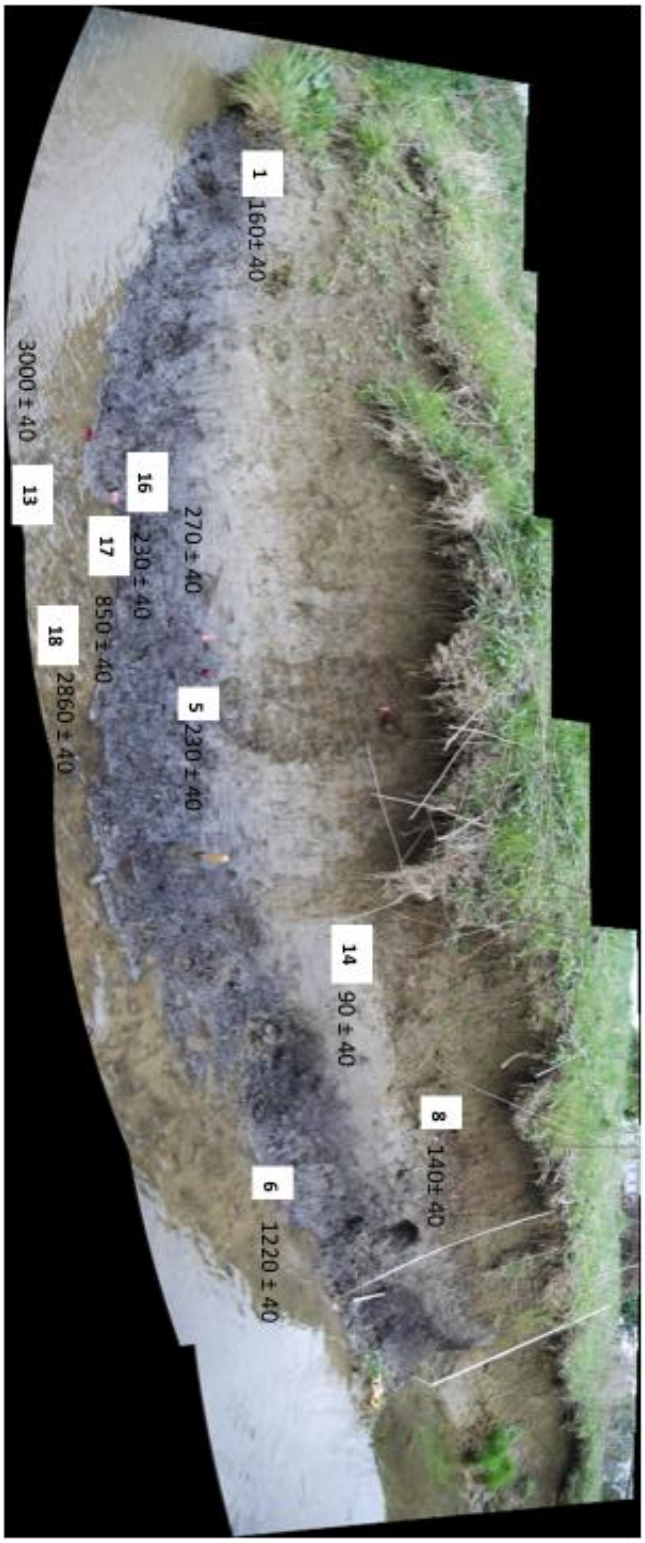

Figure 5. Panorama of photographs with locations of nuts collected for radiocarbon dating. Conventional radiocarbon age (yrs) with one standard deviation listed next to each sample number. Samples 5, 13, and 16-18 are at site of sample column for seed analyses, and other samples are at stratigraphic boundaries correlated along the face of the incised stream bank.

Sample No.	Depth, cm	Conventional Age (BP)	2 Sigma Calibration Age (Cal BP)
8	72.5	140 ± 40	Cal BP 290 to 0
	106-108		DANDELION SEEDS (post-European settlement)
1	119.5	160 ± 40	Cal BP 290 to 0
14	121.5	90 ±40	Cal BP 270 to 180/Cal BP 150 to 10
4	125.5	270±40	Cal BP 440 to 350/
			Cal BP 340 to 280/Cal BP 170 to 150
5	126.5	230 ±40	Cal BP 420 to 400/
			Cal BP 320 to 270/Cal BP 210 to 140
16	126.5	230 ±40	Cal BP 420 to 400/
			Cal BP 320 to 270/Cal BP 210 to 140
17	128.5	850±40	Cal BP 900 to 860/
			Cal BP 820 to 810/Cal BP 810 to 690
3	146.5	1940±40	Cal BP 1980 to 1820
6	151.5	1220±40	Cal BP 1270 to 1060
18	157-161	2690 ±40	Cal BP 2860 to 2750
13	158.5	3000 ±40	Cal BP 3330 to 3070

Table 3. Radiocarbon dates of black cherry and black walnuts nuts determined by Beta Analytic, Inc., Miami, FL.

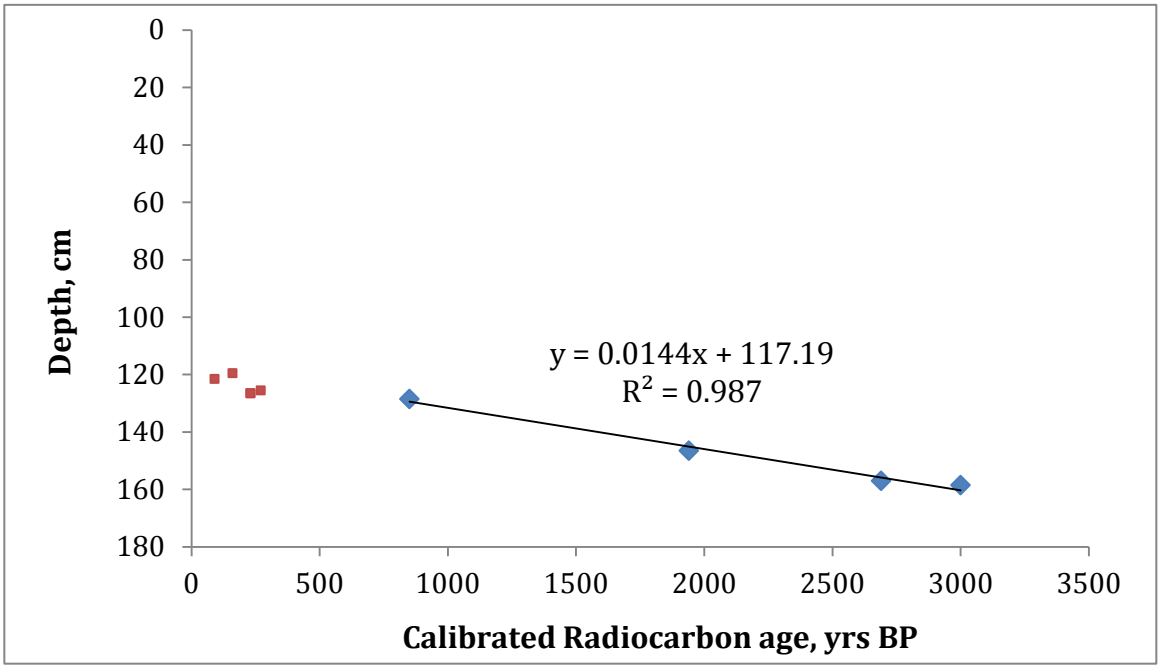

Figure 6. Sedimentation rates determined from radiocarbon ages and sample depths. Above 125 cm the sedimentation rate accelerates. Only dates from samples older than ~500 years (n=4) were used to obtain a long-term pre-settlement sedimentation rate, which is the slope of a best-fit line from a linear regression. Sedimentation rate is 0.01 cm/yr. Red squares are samples from depths of 119.5-126.5 (n = 6; sample numbers 14, 1, 4, 5, and 16), all of which yielded young radiocarbon ages. These samples are at depths consistent with the long-term trend of slowly increasing sedimentation rates, confirming our interpretation that accelerated sedimentation associated with European settlement occurs at a depth of about 119 cm.

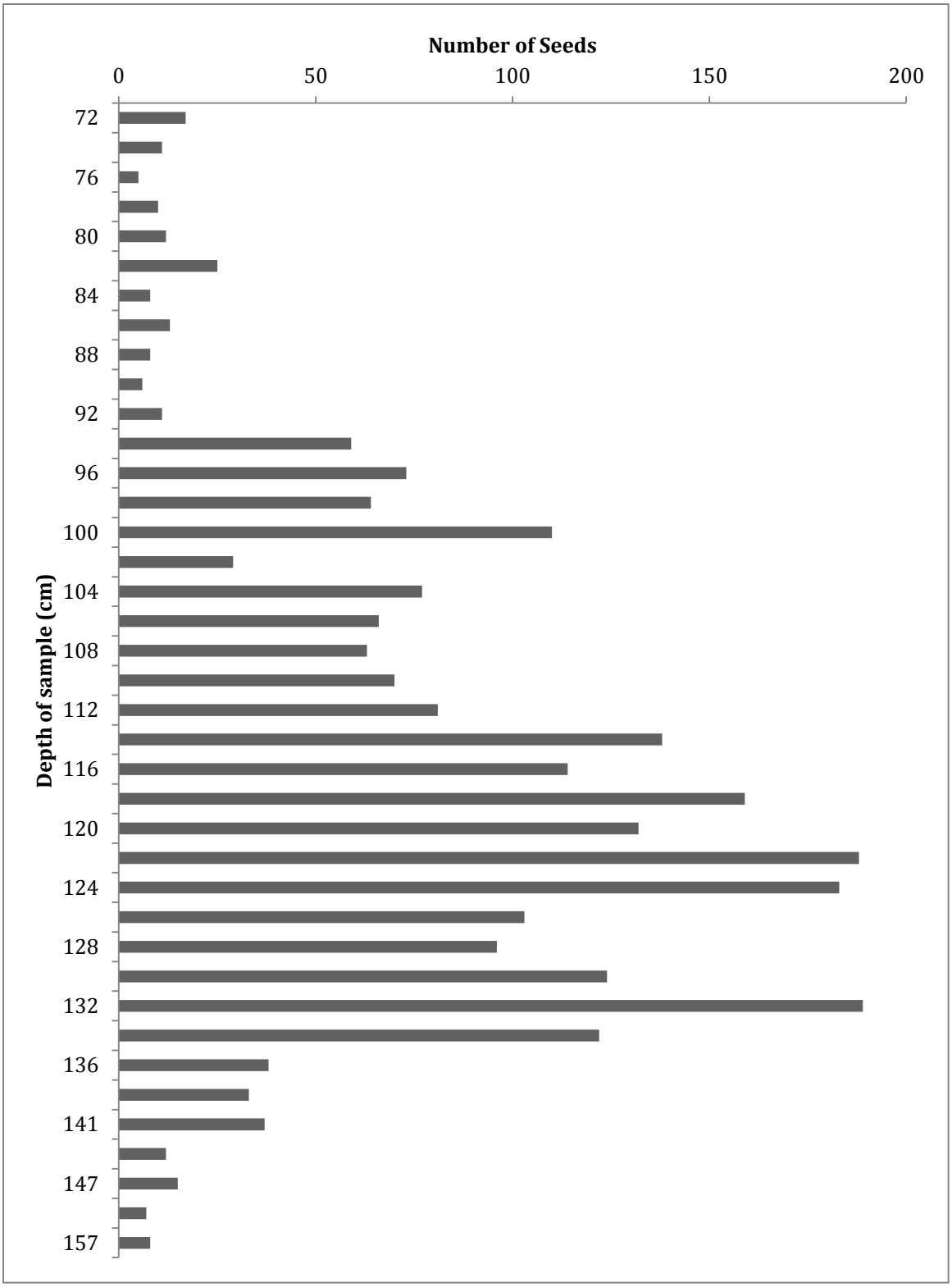

Figure 7. Seed abundance with depth throughout the sample column.

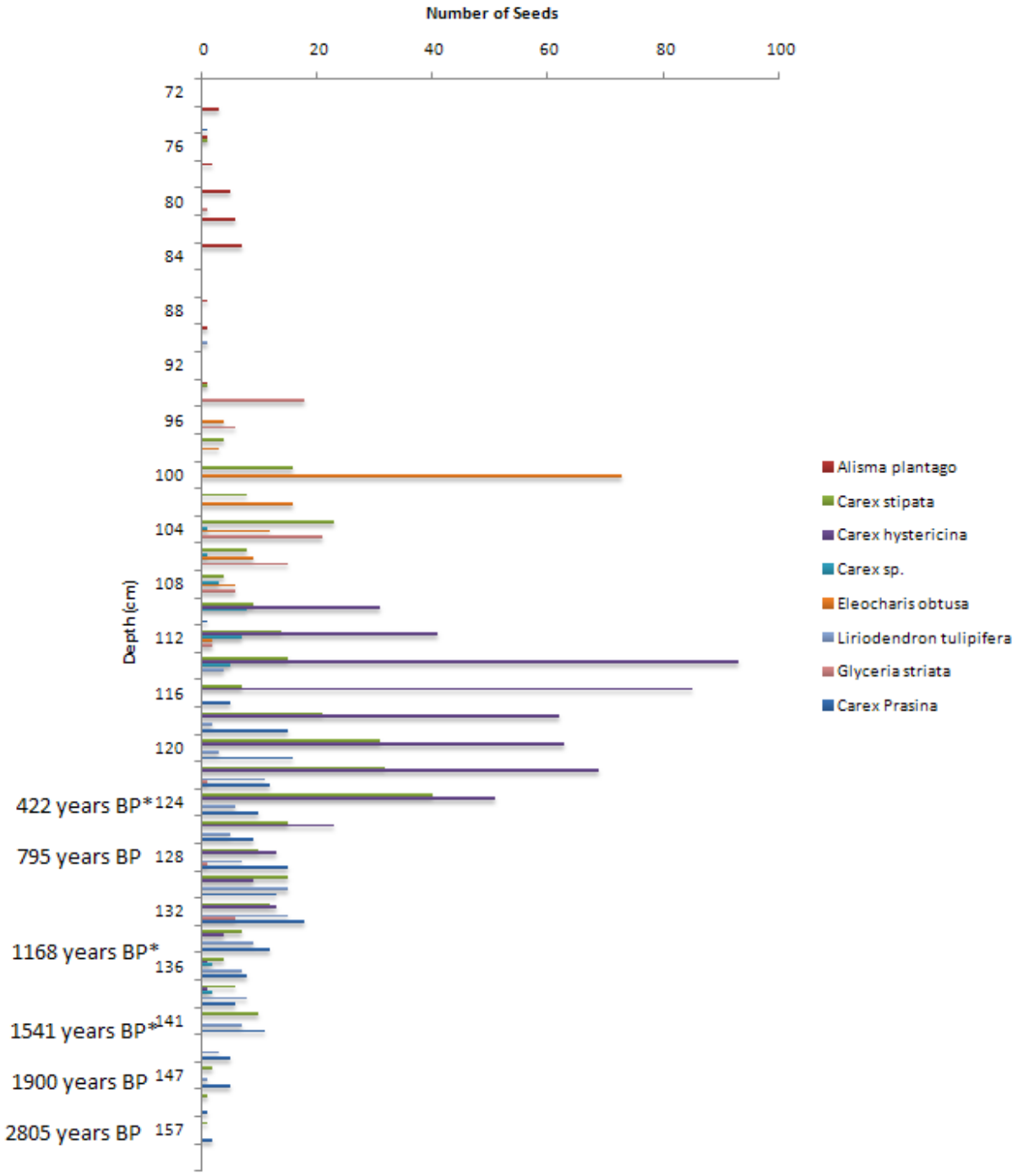

Figure 8. Most common seed species throughout the sample column. Ages listed to left of vertical axis. Ages with an asterisk were inferred from the long-term pre-settlement sedimentation rate of 0.01 cm/yr. Other ages are based on radiocarbon dates.

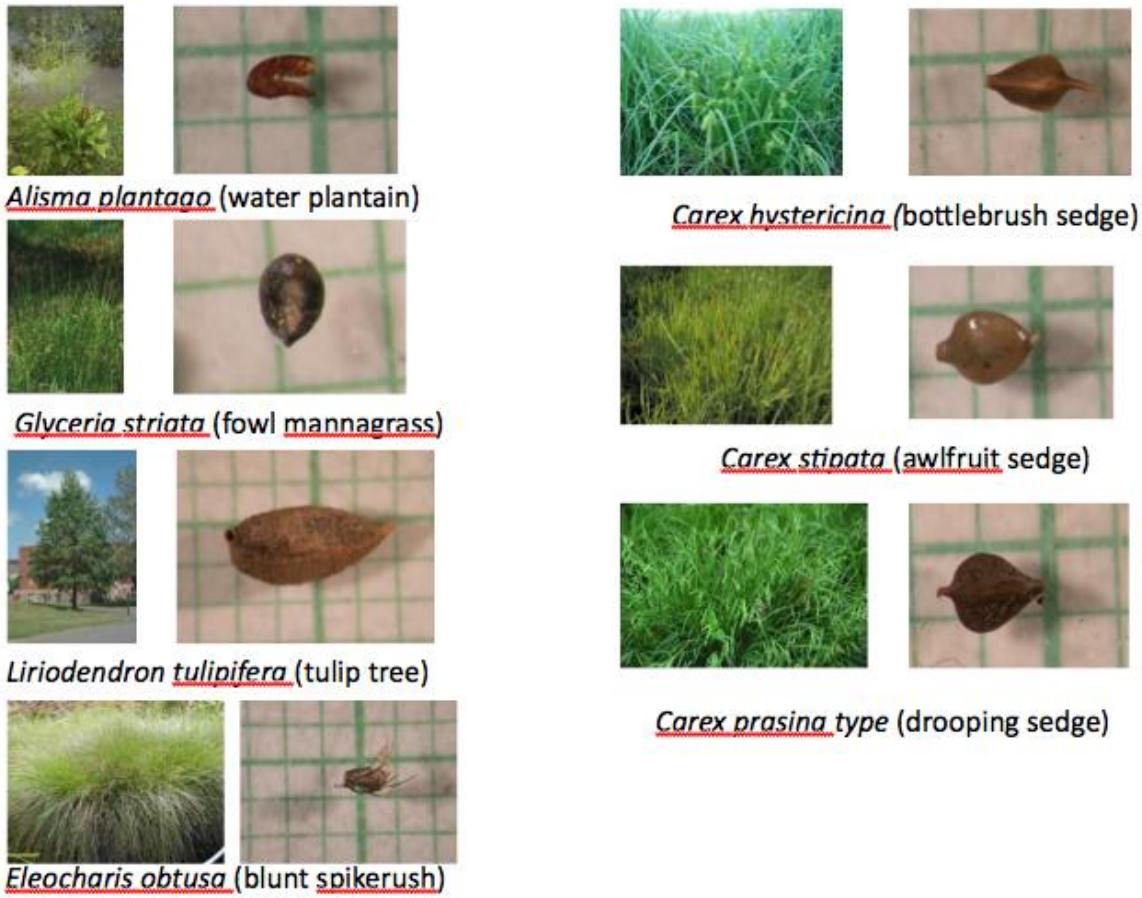

Figure 9. Photographs of common seeds extracted from samples analyzed in this study. Each photograph was taken with a camera-mounted microscope, and green markings are mm-scale lines. Photograph of each plant is provided to left (source of plant photos is USDA Plant Database). Each blue box is 1 mm x 1 mm

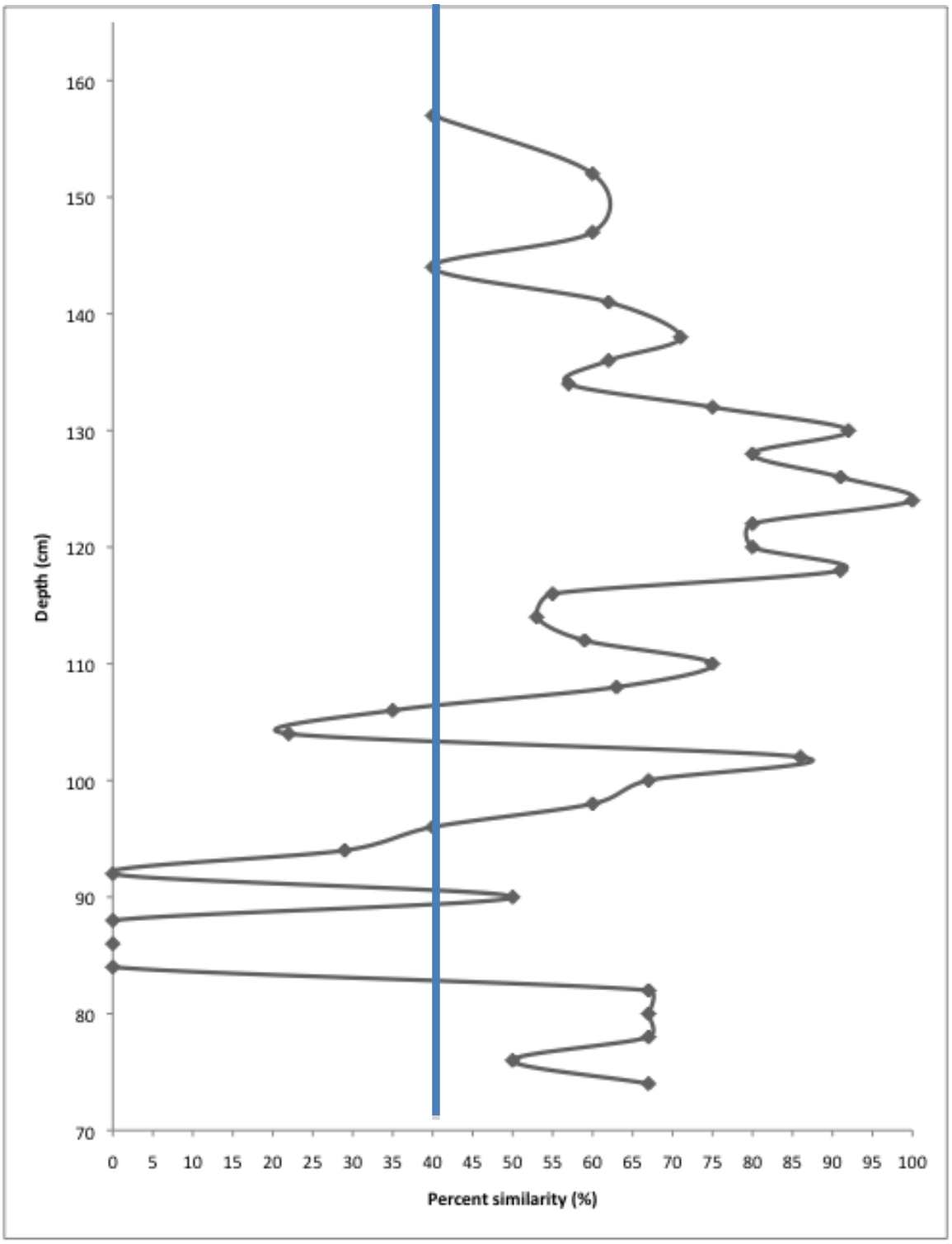

Figure 10. Sorenson Index and percent similarity. Note distinct change from high to low similarity at ~120 cm. This study concludes that sample depths above ~120 cm are post-European settlement in age, and the marked change in similarity might indicate disturbance at the time of settlement. Blue line indicates 0.4, or the point where there is significant difference between the samples.

Appendices

Appendix 1- List of seed identification resources

Crow, G.E. and C.B Hellquist. Aquatic and Wetland Plants of Northeastern North America: Volume 1. The University of Wisconsin Press. 2000.

Crow, G.E. and C.B Hellquist. Aquatic and Wetland Plants of Northeastern North America: Volume 2. The University of Wisconsin Press. 2000.

Holmgren, N.H. Gleaseon and Cronquist Manual. The New York Botanical Garden. 1998.

Holmgren, N.H. Illustrated Companion to Gleaseon and Cronquist Manual. The New York Botanical Garden. 1998.

Martin, A.C and W.D. Barkley. Seed Identification Manual. University of California Press. 1973.

Montgomery, F.H. Seed and fruits of plants of eastern Canada and northeastern United States. University of Toronto Press. 1977.

Rhoad, A.F. & T. Block. The Plants of Pennsylvania. Philadelphia: University of Pennsylvanis Press. 2000.

Appendix 2- List of all identified seeds

Plant Species	Number of Seeds
Alisma plantago-aquatica	27
Awned Grass sp. A	1
Bidens cernua	10
Carex barrattii	1
Carex cf. comosa	2
Carex cf. vulpinoidea	7
Carex comosa	1
Carex hystericina	559
Carex lurida	1
Carex prasina	165
Carex sp.	29
Carex stipata	315
Carex stricta	1
Cruciferae sp A	25
Cyperus strigosus	32
Eleocharis ambigens/fallax	2
Eleocharis obtusa	125
Euphorbia maculata type	3
Glyceria striata	77
grass sp.	6
Liriodendron tulipifera	104
Mollugo type	1
Panicum sp.	1
Poa type (grass)	1
Polygonum punctatum type	1
Polygonum sp.	16
Ranunculus pennsylvanicus type	3
Rosaceae sp.	1
Rhynchospora capilacea type	10
Rubus sp.	3
Scirpus sp	3
Scleria reticularis	1
Stellaria cf. alsine	5
Taraxacum officinale	2
Viola sp.	6
Total	**1547**