PRAIRIE OR WOODLAND? RECONSTRUCTING PAST PLANT COMMUNITIES AT GOOD EARTH STATE PARK VIA SOIL CORE AND TREE RING ANALYSIS

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ABSTRACT

The hills and ravines of Good Earth State Park, located in southeastern South Dakota, currently support extensive woodlands interspersed with small upland prairies. Analysis of stable carbon isotopes from soil cores suggests that the prairies were much more extensive in the past and that the woodlands have expanded in recent years. Soil carbon isotope values ($\delta^{13}C$) from forested ravines and upland prairie sites show a strong C_4 native grass signature, around -16‰ at the deeper depths, suggesting widespread prairie dominance throughout the park in the past. At the forested sites, $\delta^{13}C$ values decreased significantly towards the soil surface reaching average values from -23 to -25‰. Such values are characteristic of C_3 woody plants, providing evidence that over time, woodlands have replaced the native prairies. By contrast, soil cores from the few remaining upland prairie sites showed consistent $\delta^{13}C$ values from top to bottom, around -16‰, suggesting these sites have remained dominated by prairies for many years.

Tree core samples taken from the larger bur oaks (*Quercus macrocarpa*) at Good Earth yielded maximum ages of approximately 125 years. The apparent absence of older trees in the park is consistent with the stable isotope analysis suggesting that the woodlands at Good Earth have appeared rather recently.

The expansive prairies of the past were reliant upon frequent wildfires which, coupled with tree harvest by Native Americans, likely prevented forest encroachment. Following abandonment of the Blood Run site around 1700, the settlement by European immigrants throughout the region and subsequent suppression of prairie fires, the woodlands have expanded considerably. If recent trends continue, the few remaining tracts of native prairie at Good Earth will disappear within a few decades. We applaud recent efforts by park management to begin restoring some of the lost prairie habitat.

Keywords

stable isotopes, soil cores, forest encroachment, prairie loss, Blood Run

INTRODUCTION

Established in 2013, Good Earth at Blood Run is South Dakota's newest state park. It is located 10 miles southeast of Sioux Falls, SD, at 48072 270th St. The park is situated in the vicinity of a historic Native American community within the Blood Run National Historic Landmark. The park contains several small native prairies that appear to be remnants of more extensive grassland habitat. Throughout the upper Midwest less than 1% of the once extensive tall-grass prairie remains (Samuels 1999), making it one of the most endangered biomes on Earth (Samson et al. 2004). Most of the prairie loss has resulted from agricultural development. The remaining prairie remnants face additional threats including forest encroachment and the spread of invasive species. The tall-grass prairie is dependent upon periodic fires. Before European settlement, frequent prairie fires kept forests from encroaching into the prairies, as first recorded in the journals of Lewis and Clark (Thwaites 1905). In the absence of prairie fires, shrubs and trees gradually replace prairie vegetation through the process of ecological succession (see reviews by Collins and Wallace 1990; Samson and Knopf 1994).

Many of the remaining native tall-grass prairie tracts in the upper mid-west are concentrated on hilly landscapes that were not easily plowed and converted to row-crop agriculture. In southeastern South Dakota, some of the best native prairie remnants are found in the dissected landscapes of Good Earth and Newton Hills State Parks. A number of studies have been conducted at Newton Hills documenting present and historical plant communities. For example, in 1863, land surveyors noted crossing extensive, grassy prairies on the ridges with scattered timber stands in the ravines (Rogers 1972). Recent studies have documented the dramatic loss of these ridge-top prairies at Newton Hills due to expansion of forests from the ravines (Tieszen and Pfau 1995; Steck and Spencer 2003; Spencer et al. 2009). Historically, fires swept off the broad flat prairies to the west and onto the ridges of Newton Hills, helping maintain the prairie vegetation (Spencer et al. 2009). These fires likely burned part-way down the flanks of the ridges, but did not appear to travel down to the bottoms of the ravines, due to wetter conditions and protection from wind. Consequently, the ravines and valley bottoms were historically forested at Newton Hills (Spencer et al. 2009) and other similar sites throughout the mid-West (Anderson, 1990). In the absence of wildfires over the last 150 years, forests have moved up from the ravines and eliminated much of the upland prairie habitat of Newton Hills (Spencer et al. 2009), and elsewhere (Anderson 1990).

Evidence for plant community change described above is based in part on analysis of stable carbon isotopes in soil cores (Dzurec et al. 1985; Tieszen 1991; Spencer et al. 2009). The dominant native grasses of the tall-grass prairie use a C_4 photosynthetic pathway which produces $\delta^{13}C$ values ranging from -12 to -14‰, while woody plants use a C_3 pathway which yields $\delta^{13}C$ values ranging from -26 to -28‰ (Cerling et al. 1989; Tieszen 1991). These characteristic isotope "signatures" are retained following incorporation of plant material into soil organic matter (Balesdent et al. 1988); consequently, changes in $\delta^{13}C$ with depth in soil cores have been used as evidence of plant community change. For example, a number of studies have reported C_3 forest expansion into C_4 dominated grasslands as evidenced by decreasing $\delta^{13}C$ values in more shallow soil layers at Newton Hills (Tieszen and Pfau 1995; Spencer et al. 2009) and elsewhere (Steuter et al. 1990; McPherson et al. 1993; Biggs et al. 2002).

The present study evaluates evidence of plant community change at Good Earth, using the same carbon isotope techniques employed at Newton Hills (Spencer et al. 2009). Located 25 kilometers south of Good Earth, Newton Hills contains very similar landscape and topography, with rolling hills and steep ravines, which support a mosaic of woodlands and prairies. We initially hypothesized that the history of plant community change at Good Earth would be similar to that of Newton Hills with past communities characterized by greatly expanded prairies in the upland areas and woodlands restricted to the ravines.

STUDY SITE

The western half of Good Earth State Park is characterized by upland farmland (Figure 1). Historical land surveys in 1863 described this area as "gently rolling prairie," with soils variously rated as "first rate" or "second rate" for farming (Mellin 1863). Following settlement by European immigrants, this area was largely converted to agricultural use including row crops and pastureland. These uses continued up until 2013 when the park opened. The eastern half of the park consists of steeper topography characterized by ridges and steep ravines. Mellin (1863) reported scattered trees on some of the "bluffs" in this area. The upland ridges and bluffs lead down to a riparian floodplain along the Big Sioux River, which forms the eastern boundary of the park (Figure 1). The broad floodplain in the northeastern part of the park previously supported row-crop agriculture and pastureland.

Our study focused on the dissected landscape of woodlands and prairie between the upland agricultural land and the floodplain. The ravines in this area currently support dense woodlands which extend up the flanks of the ravines all the way to the top in some places. The woodlands are classified as Northern Bur Oak Mesic forest (Ode 2010). They are dominated by bur oak (*Quercus macrocarpa*), along with scattered basswood (*Tilia americana*), American elm (*Ulmus americana*), and an understory including ironwood (*Ostrya virginiana*), and more recently invasive, non-native species including buckthorn (*Rhamnus cathartica*), garlic mustard (*Alliaria petiolata*) and Dame's rocket (*Hesperis matronalis*).

Native prairie remnants exist on a few isolated ridges which extend east from the flatter agricultural land, and form some scenic overlooks over the Big Sioux River (Figure 1). A few of the more isolated ridges support a good mix of native species dominated by big bluestem (*Andropogon gerardi*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), along with a few scattered native forbs such as purple

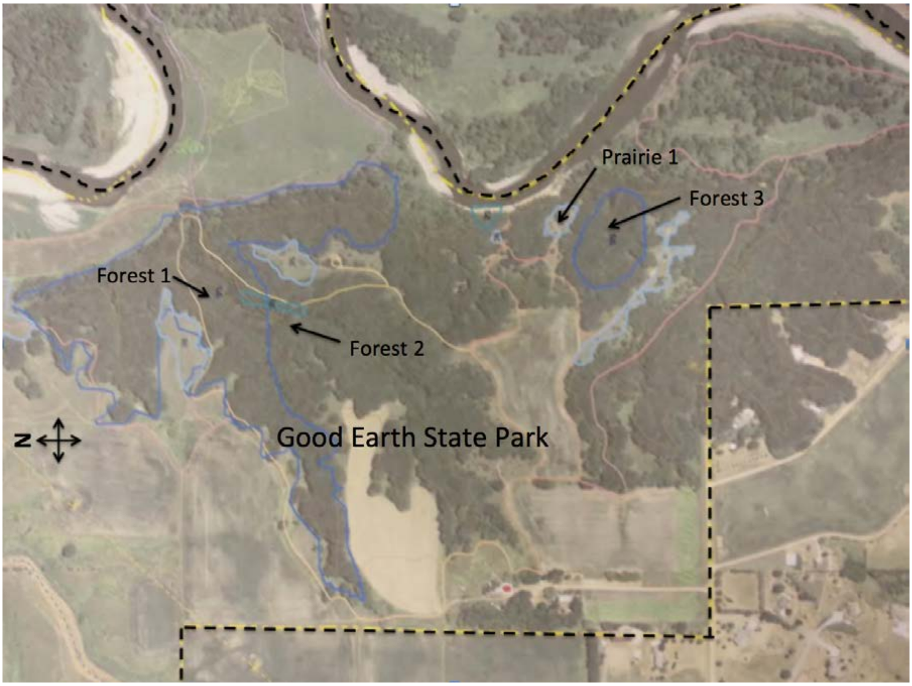

Figure 1. Map of Good Earth State Park showing soil core sampling sites, current vegetative cover in the Park, and Park boundaries.

coneflower (*Echinacea purpurea*), and prairie violet (*Viola pedatifida*). Adjacent pasturelands are dominated by non-native grasses such as smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*), and these grasses are expanding onto the prairie ridges. Pioneer tree and shrub species that are found along the margins of the prairies include eastern red cedar (*Juniperus virginiana*) and smooth sumac (*Rhus glabrus*), along with occasional large open-grown bur oak trees.

Blood Run—Although much of the Native American settlement of Blood Run was concentrated on the east side of the Big Sioux River in present day Iowa, a series of interrelated villages paralleled both sides of the Big Sioux River for nearly three and a half miles, extending through the present day borders of Good Earth State Park (Henning and Schnepf 2014). The community was likely established in the 1400's and flourished until the early 1700's. The community appeared to serve as a major regional trading center for pipestone and other goods. At its peak, the population of Blood Run was thought to exceed 6,000 people (Henning and Schnepf 2014).

METHODS

During the summer of 2014, three replicate soil cores were taken at each of four sites in the Park. Three of the sites were located in forested ravines and one site was located on a prairie ridge (Figure 1). The soil type at all sites was classified as Steinauer-Shindler clay loam (Driessen 1971). Soil cores were taken at each site using a slide hammer core sampler (AMS Inc., American Falls, ID) down to an overall depth of 50 cm. Each soil core was separated into four sections; 0-1 cm (the O horizon was scraped off before sampling), 1-6 cm, 10-15 cm, 15-25 cm, and 35-50 cm. The preparation of soil samples followed procedures outlined by Von Fischer and Tieszen (1995). Percent C was determined via automated Dumas combustion using an NA 1500 elemental analyzer (CE Elantech, Inc., Lakewood, NJ). Carbon content of the mineral soil (fine roots were removed by hand) was determined from 2.4 cm diameter soil cores. Samples were decarbonated with HCl prior to stable isotope analysis. Carbon isotope ratios were measured on a VG SIRA series II triple trap isotope ratio mass spectrometer (GV Instruments, Hudson, NH and Manchester, UK) and values were expressed per mil (‰) $\delta^{13}C$.

Comparisons of carbon isotope values and percentage of carbon between different depths and sites were analyzed using analysis of variance techniques and Kruskal-Wallis tests with a significance level of 0.05 (JMP®, Version 7, SAS Institute Inc., Cary, NC). Post-hoc multiple comparison analyses were determined using Tukey-Kramer HSD tests.

RESULTS AND DISCUSSION

Average $\delta^{13}C$ values from soil cores collected at the upland prairie site showed minor variation with depth, fluctuating between -15.1 and -16.6‰ from the surface to the bottom (Fig. 2). The site currently supports prairie vegetation, and is dominated by C_4 grasses which are relatively enriched in ^{13}C and typically yield $\delta^{13}C$ values in soil organic carbon ranging from -15 to -17‰ (Cerling et al. 1989; Tieszen 1991). Measurement of similar $\delta^{13}C$ values around -16‰ across all depths in our prairie site provides evidence that this area has supported prairie vegetation for many years. By contrast, the three forested ravine sites showed significant decreases in $\delta^{13}C$ in the more shallow depths, providing evidence of plant community change over time ($p<0.05$, Figure 2). Average $\delta^{13}C$ values in the deeper soil strata below 15cm ranged from -14.1 to -17.5‰, suggesting that these sites were once dominated by prairie vegetation (Figure 2). Above 10 cm, there was a decrease in $\delta^{13}C$ reaching minimums of -23.1 to -24.9‰ near the surface (Figure 2). These surface values are characteristic of soils derived from C_3 plants such as trees (Cerling et al. 1989; Tieszen 1991). The decrease in $\delta^{13}C$ towards the surface is consistent with steady replacement of the once-dominant C_4 grasses by encroaching C_3 woodland species. Although other processes may cause shifts in the $\delta^{13}C$ values in soil over time in the range of 1-3‰ (Friedli et al. 1987; Trolier et al. 1996; Ehleringer et al. 2000), our study showed much greater average shifts of 6-8‰ in the forested sites (Figure 2). This indicates that the predominant cause of the observed shift in $\delta^{13}C$ in our soil cores has been forest encroachment into former prairie habitat.

Other stable isotope studies from the Midwest report similar findings. In Iowa, Wang et al. (1993) reported similar $\delta^{13}C$ values of -16 to -19‰ below 20 cm soil depths and upper soil values between -22 to -27‰ and concluded that forests had expanded into areas previously dominated by tall-grass prairie. In nearby Newton Hills State Park, Tieszen and Pfau (1995) and Spencer et al. (2009) reported similar declines in $\delta^{13}C$ in soil cores from upland sites which were attributed to forest encroachment into prairie habitat. Numerous authors from these and other studies have suggested that the primary stimulus for forest encroachment into prairie habitat is suppression of wildfires following settlement by European immigrants (see reviews in Collins and Wallace 1990).

As hypothesized, our $\delta^{13}C$ data showed evidence of forest encroachment into the upland prairies at Good Earth which is consistent with similar evidence from nearby Newton Hills (Spencer et al. 2009). However, other results from Good Earth were not consistent with results from Newton Hills. In particular, cores from the forested ravines at Good Earth had average $\delta^{13}C$ values from -14 to -17‰ at the 35-50cm depths (Figure 2) compared to much lower values around -23‰ at similar sites and depths at Newton Hills (Spencer et al. 2009; Tieszen and Pfau 1995). Based on these depleted values and other evidence, including land survey records of 1863, previous studies concluded that the ravines at Newton Hills have been at least partially forested for many years (Spencer et al. 2009; Tieszen and Pfau 1995). By contrast, the more elevated $\delta^{13}C$ values in the deeper soil horizons at Good Earth provide evidence that the ravines there were historically dominated by prairies rather than woodlands and that forests have appeared fairly recently (Figure 2).

Other evidence for the more recent appearance of forests at Good Earth includes the species composition of the woodlands. At Newton Hills, the largest trees in the ravines are dominated by climax species, including basswood, American elm, and black walnut (*Juglans nigra*), which is consistent with a forest that has been there for hundreds of years (Spencer et al. 2009). By contrast, 80% of the larger trees in the ravines of Good Earth are bur oak, with only scattered, smaller American elm and basswood trees, and a relatively low diversity of understory species (Ode 2010). This species composition is indicative of a younger forest. As the forest ages, the mid-successional stage oaks at Good Earth will be replaced by climax species such as basswood, and American elm through the process of ecological succession.

We offer several potential explanations for the differences in present and past plant communities at Good Earth and Newton Hills. First, it is possible that prairie fires, which typically do not carry into steep ravines due to moist conditions and lack of wind, were somehow able to penetrate down into the ravines at Good Earth and prevent the woodlands from growing there. Although both areas are characterized by similar dissected landscapes, subtle differences in slope, aspect, moisture, wind, or other factors could have altered fire behavior at Good Earth.

A second explanation for the historical lack of forests in the ravines at Good Earth may have been timber harvest activities by Native Americans. Beginning

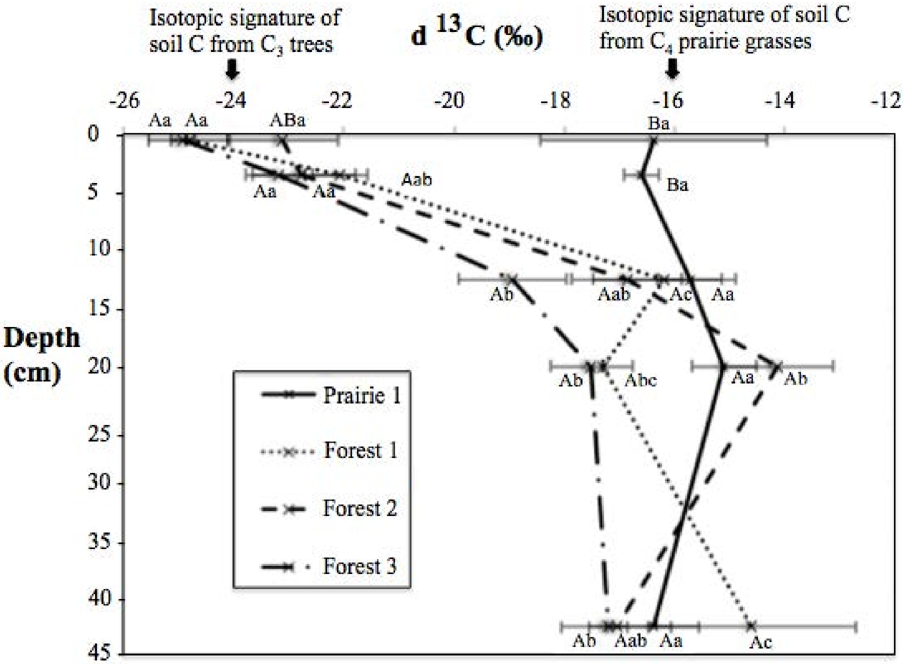

Figure 2. Relationship between δ^{13}C and soil depth for cores collected in Good Earth State Park from four sites shown in Figure 1. Three of the sites were located in forested ravines and one was on a prairie ridge. The uppercase letters indicate statistical differences (for a given depth) between the four sites and lowercase letter indicate statistical differences with soil depth within a site. Each point represents the mean (± SE).

in the 1400's, the Native American community of Blood Run existed in and around the present day boundaries of Good Earth State Park (Henning and Schnepf 2014). The site contained more than 65 lodges, a fortification, and over 200 mounds, making it one of the largest Native American communities in the area (Henning and Schnepf 2014). Previous studies of other Native American settlements along the Missouri River concluded that deforestation was significant around these communities (Abel 1939; Griffin 1977). Given the needs for fuel and building materials for the community at Blood Run, archeologists have suggested that nearby woodlands would likely have been deforested there as well (Adrien Hannus, personal communication). Prolonged harvest of trees over the 300 year history of Blood Run may have allowed prairies to dominate the ravines, replacing the woodlands that otherwise may have been found there. Unlike Good Earth, we are unaware of evidence for the existence of permanent Native American communities near Newton Hills. Thus, forests appeared to have historically dominated the ravines there due to the absence of fires and timber harvest. Following European settlement, selected timber harvest likely took place at Good Earth and Newton Hills until the parks were established.

Tree core samples taken from the larger bur oaks at Good Earth yielded a mean age of 125 years (n = 3). The apparent lack of older trees is consistent with our other evidence that the forests at Good Earth have appeared rather recently.

SUMMARY AND IMPLICATIONS

Stable carbon isotope data provide evidence that forests are encroaching into the remaining prairies of Good Earth State Park. Similar community changes have been documented at nearby Newton Hills and a number of other prairie sites throughout the Midwest (Collins and Wallace 1990; Briggs and Gibson 1992; Gehring and Bragg 1992; Spencer et al. 2009). If recent trends continue, the few remaining native prairies at Good Earth will disappear within the next several decades. Responding to this threat, park managers at Good Earth and Newton Hills have begun to take steps to reclaim lost prairie habitat by clearing encroaching trees and shrubs and utilizing prescribed burns in an attempt to limit forest expansion and slow the spread of non-native species. In other parts of Good Earth, the upland agricultural land is being replanted to native prairie, and the agricultural land in the riparian zone along the river is being replanted with native trees.

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