Analyzing Water Isotopes in Mesic Bur Oak Forest, Homestead National Monument, Nebraska.

Report prepared for the Homestead National Monument

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Abstract

In Homestead National Monument, the bur oaks grow within the historical floodplain of Cub Creek. However, it is likely that streambank downcutting has occurred along Cub Creek. Because of the extent of the downcutting, questions have been raised regarding water availability for the lowland bur oak forest and how the forest may be impacted by management plans. Therefore, the objectives of our study were to determine: (1) the relative importance of groundwater vs. river water used by bur oaks, and (2) whether the proportion of groundwater/river water varied based on location relative to Cub Creek. Plant and soil samples for isotopic analysis were collected from three sites during 2008 and 2009. Water table depth, soil temperature and moisture were measured continuously and river stage and precipitation were monitored daily by Homestead NM staff. We analyzed river, ground, twig xylem, and soil water for natural isotopic abundance.

In summary, we found that bur oaks in Homestead NM are using deep water sources, and are unlikely to be affected hydrologically by current regional downcutting of the river. Downcutting and alteration of the floodplain can have major affects on other ecological parameters such as floodplain vegetation communities and tree regeneration, but that is outside the scope of this study. Given that bur oaks do not appear to be water stressed and are known to be fire tolerant, we feel that allowing fire into the bur oak stands will probably not be detrimental to the adult bur oaks. However, we suggest that fire be reintroduced experimentally into the southern forested section first, not directly into the less disturbed, mature bur oak forest.

1. Introduction

There are ~16 hectares (40 acres) of forested land along Cub Creek in Homestead National Monument of America in Nebraska. Historically, this riparian forest was likely dominated by bur oaks (*Quercus macrocarpa* Michaux) (Rolfmeier 2007). Currently, only a portion of the northern half of Homestead maintains a relatively undisturbed riparian forest with some canopy dominance by bur oaks (Rolfmeier 2007). This area is considered an "exemplary lowland bur oak forest" in the community classification of the Nebraska Natural Heritage Program (Steinauer and Rolfmeier 2003). Conversely, the southern half and prairie margins of this forested riparian area have been ecologically altered by human settlement (e.g., agriculture, cattle grazing, timber harvest, fire exclusion), subsequently, bur oaks are no longer a dominant species (NatureServe 2006, Rolfmeier 2007).

Bur oaks range from Alberta to New Brunswick in the north, down to New Mexico to Alabama in the south. Reflecting a tolerance of both wet and dry conditions, bur oaks are found growing on bottomlands and riparian slopes and in prairies. The ability of bur oaks to compete with prairie vegetation is attributed to rapid and deep root development starting at the seedling stage and high water use efficiency (Johnson 1990). By the end of the first growing season, bur oak roots can extend to over 1 meter (>4 ft) in depth (Johnson 1990). As a mature tree in the prairie, roots can extend down 3 to 6 m (10 to 20 ft) (Johnson 1990).

In Homestead National Monument, the bur oaks grow within the historical floodplain of Cub Creek. However, it is likely that streambank downcutting has occurred along Cub Creek. Because of the extent of the downcutting, questions have been raised regarding water availability for the lowland bur oak forest and how the forest may be impacted by management plans. Current management plans for the Monument, including the Prairie Management Action Plan, Resource Management Plan and Cultural Landscape Report, call on the Monument managers to allow prescribed fires to creep into the forest to help create a transition zone between the riparian forest and the prairie. If the primary source of water, whether from Cub Creek or groundwater is not significantly altered, then fire as a normal agent in the landscape could probably be allowed to move from prairie into the forest. If, however, the primary water source of the forest is degraded or degrading, then alternate fire and vegetation management strategies must be put in place to maintain this key cultural and natural resource. Therefore, the objectives of our study were to determine: (1) the relative importance of groundwater vs. river water used by bur oaks, and (2) whether the proportion of groundwater/river water varied based on location relative to Cub Creek.

2. Methods

2.1 Site sites

Plant and soil samples for isotopic analysis were collected from three sites during 2008 and 2009. At Site 1 (Mature forest) in the less-disturbed northern portion, we sampled 3-5 large diameter bur oaks (some of the trees did not have enough twigs near enough to the ground to reach for sampling). At Site 2 (Forest edge) in the disturbed southern portion on eastern side near prairie trail, we sampled 3-4 small diameter bur oaks. At Site 3 (Riverside) in the disturbed southern portion closer to western side near Cub Creek, we sampled 3 medium to small bur oaks.

2.2 Environmental parameters

Average pH of the river was 7.86, with a specific conductivity of 540 uS. The groundwater had lower pH levels of 6.5, but higher conductivity levels (1191 uS). We installed one groundwater monitoring well in the Mature forest site. The monitoring well was constructed from 3.8 cm diameter slotted PVC pipes and installed by hand auguring with a standard bucket auger of the same diameter as the well casing. The top of the well casings was inserted into the augured hole to a depth of 8.0 m and the top was sealed with native clay to prevent surface water from running into the casing. Water table depth was measured continuously with a Solinist (Canada) pressure transducer. River stage of cub creek and precipitation was monitored daily by Homestead National Monument staff.

Soil moisture and soil temperature data were measured in the Mature forest and Forest edge sites using two Campbell 10X dataloggers. We measured soil moisture content using Campbell CS616 (Logan, Utah) soil moisture probes. Probes were placed at a depth of 0-30 cm and 50-80 cm depth. Soil temperature data were measured with a Campbell thermocouple placed at 0-10 cm depth. Soil temperature data were measured only in 2008, because in 2009 the dataloggers were colonized by ants.

2.2 Isotopic sampling

We used stable isotopes of oxygen to track the water sources of the bur oaks. Stable isotope analysis has been widely utilized over the past 15 years to provide insight into the seasonal pattern of plant water sources (White et al., 1985; Ehleringer et al., 1991; Dawson and Ehleringer 1991). We measured the isotope ratios of groundwater, river water in Cub Creek, precipitation, and xylem water in twigs of bur oaks to quantify which sources of water bur oaks were using. During 2008 samples were collected from each study site approximately every four weeks from March through September, covering the entire growing season. During 2009, we collected samples only three times June to through August.

Groundwater samples were collected from baling the groundwater monitoring well after first emptying the casing and letting it refill with water. Rain was sampled from a small rain gauge immediately after rain events. Stream water was collected from Cub Creek periodically. Soil samples were collected using a hand auger from 0.2 - 0.3 m, which represents the near surface rooting zone.

Twig samples from bur oaks were collected by cutting fully suberized stem sections from the branches of the trees. We collected twigs from five trees in the Mature forest, three trees from the Riverside site, and three trees from the Forest edge site. All water, plant, and soil samples were packaged immediately in airtight bottles (bags for soil), wrapped with parafilm, and frozen immediately until analyzed.

Oxygen isotope ratios were analyzed at the Michigan Tech isotope lab using a GasBench II connected to a ThermoFinnigan Delta^{plus} Continuous Flow-Stable Isotope Ratio Mass

Spectrometer. Cryogenic distillation was used to collect water from soil and plant samples (West et al. 2006). We calculated the oxygen isotope ratio relative to that of a standard, $\delta^{18}O$, as: $\delta^{18}O$ (‰) = $\{[(^{18}O/^{16}O)$ sample $/(^{18}O/^{16}O)$standard$]-1\}$ x 1000, using Standard Mean Ocean Water (SMOW) as our standard.

Leaf samples were collected at the same time as twig samples for ^{13}C analysis. ^{13}C analysis gives an indication of water stress in plants because of differential stomatal conduction, resulting from stomatal closure during times of water stress. We collected 5 leaves from each tree analyzed for oxygen isotopes. Leaves were collected, immediately placed in a plastic bag, and frozen. In the lab, leaves were air dried, ground with a wiley mill, and analyzed for ^{13}C on a ThermoFinnigan Element 2 High Resolution ICP Mass Spectrometer.

3. Results

3.1 Environmental

Total precipitation varied between the two water years (Oct-Sept) of 2007-08 and 2008-09. Total precipitation was greater during 07-08 (79 cm), with 41 cm coming in the winter and spring (Oct. – April). Total precipitation was lower in 08-09 (54 cm), with much less coming in the winter and spring months (22 cm) (Figure 1). Summer precipitation (May-Sept) was similar between years with a total of 38 cm occurring in 2008 and 33 cm occurring in 2009.

The stage of Cub Creek fluctuated rapidly during the study period and was controlled by medium to large precipitation events (Figure 1). The maximum river stage was ~4 m and occurred several times during a period of heavy rains in May and June 2008, and again in October 2008 (Figure 1). Maximum river stage was ~3 m during the summer of 2009 and only occurred once during a period of rain in June (Figure 1). High peak flows lasted only a few days and dropped back down to prestorm levels. Minimum base flows of ~1 m occurred during any time of the year when rain did not fall for a week or two.

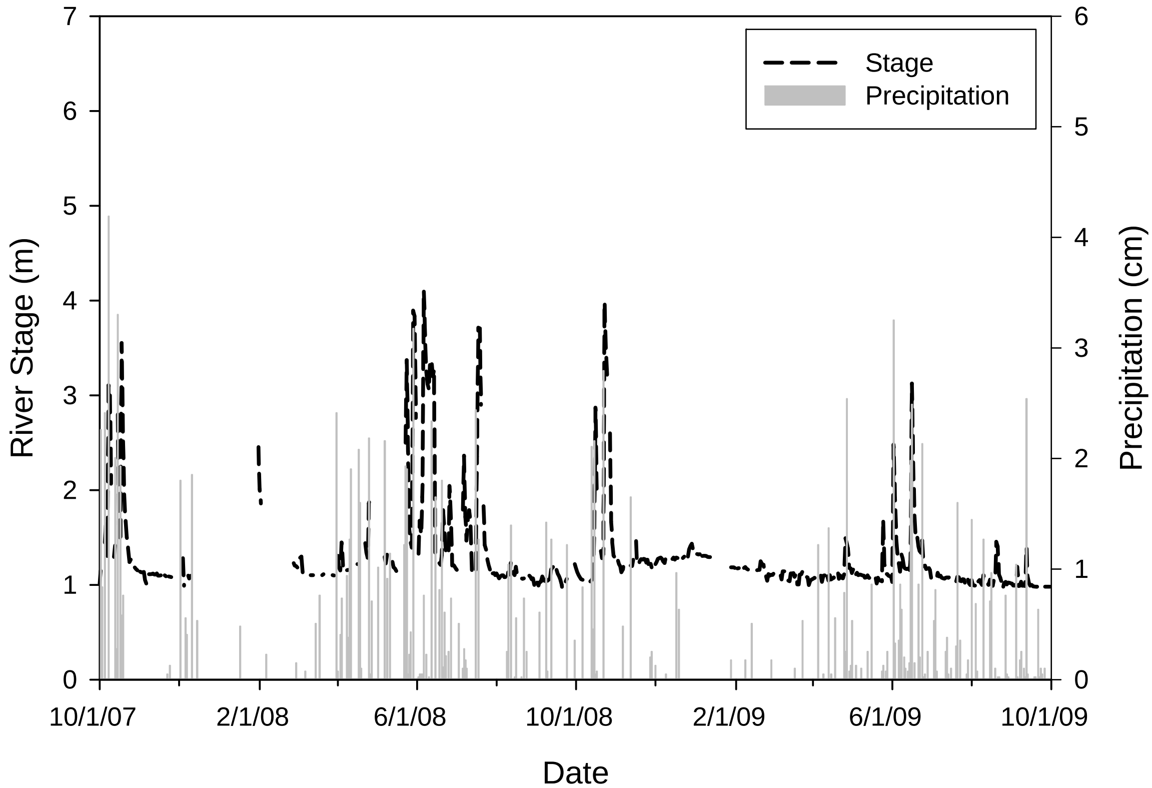

Figure 1. River stage of Cub Creek and daily precipitation.

The level of the groundwater averaged ~7 m below the soil surface (Figure 2). The groundwater was highest in the summers and lowest in the winters. The groundwater was higher during the summer of 2008 (~6.5 m below the soil surface) than during the summer of 2009 (~ 7 m). The lowest water table level (~7.5 m) occurred in the late fall/winter of 2008 and 2009. Groundwater temperature was similar between years. Maximum groundwater temperature occurred in the winters and minimum temperatures occurred in the summers (Figure 1).

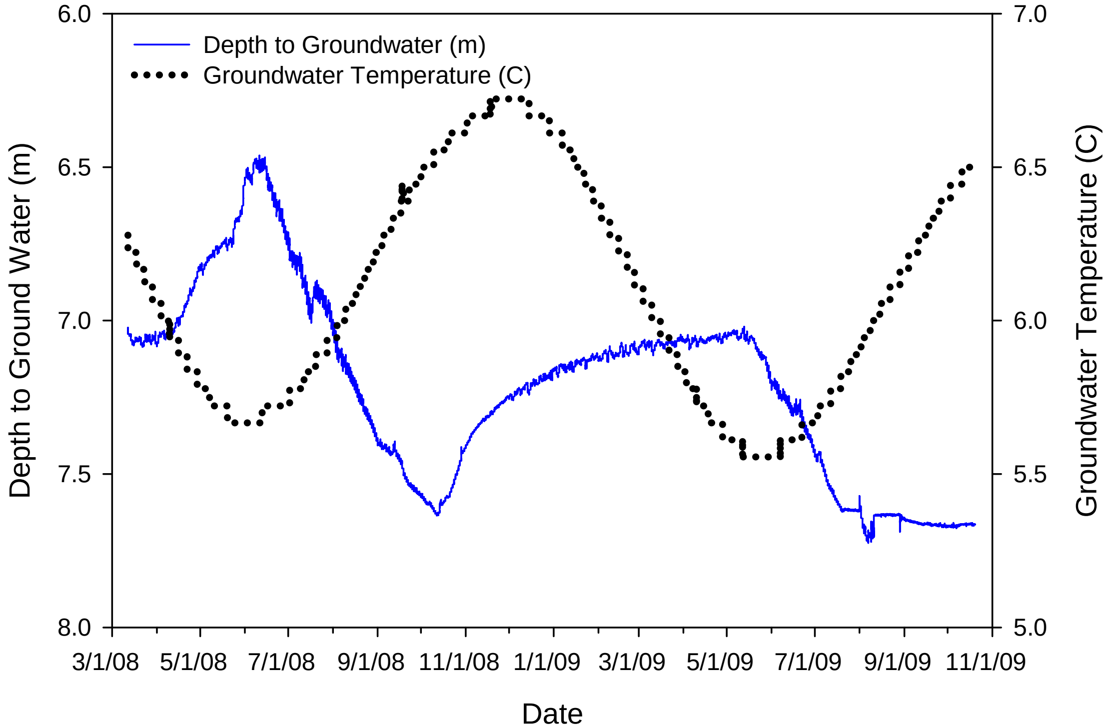

Figure 2. Depth to groundwater and groundwater temperature.

Soil moisture in 2008 was highest in the spring and early summer, and dropped consistently throughout the summer (Figure 3). Surface soils (0-30 cm) had lower soil moisture than the deeper soils (50-80 cm). Site 1 had lower soil moisture in the late summer at both soil depths compared to site 2. Soil temperature (5 cm) was similar between sites 1 and 2 (Figure 4). Soil temperature reached a maximum of ~28 °C in late July and early August.

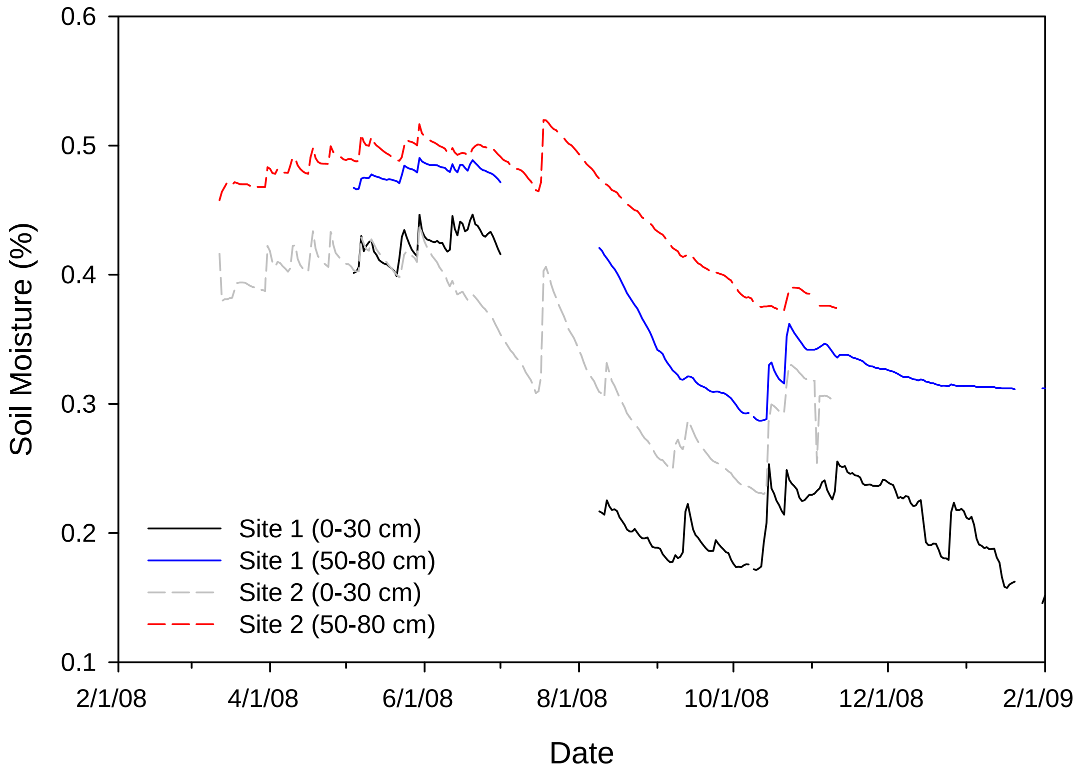

Figure 3. Soil moisture for surface and deep soils at sites 1 (Mature forest) and 2 (Forest edge).

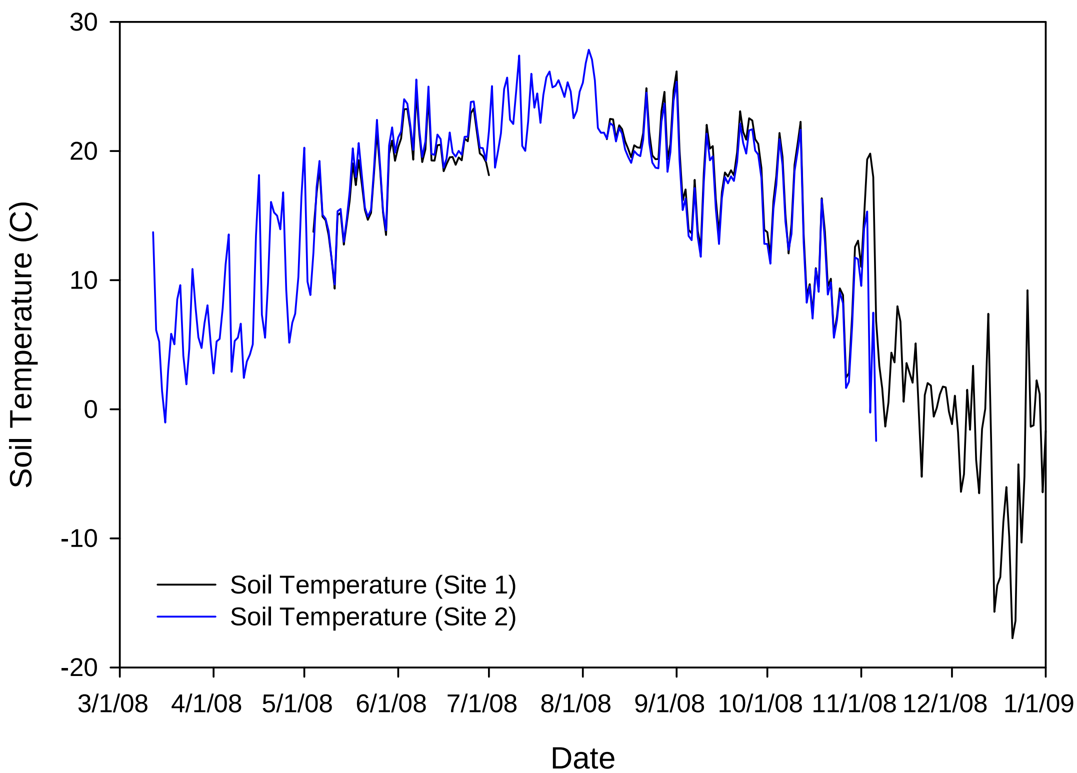

Figure 4. Soil temperature at 5 cm depth.

3.2. Isotopes

Stable isotope ratios for rain showed a high variability (Table 1). In general, the most depleted precipitation (most negative) occurred in the springs and the most enriched precipitation (least negative) occurred in the warmer months. At the other extreme, the oxygen isotopes of groundwater were very consistent and averaged -8.0 ‰ (Table 1). The oxygen isotope ratio of the river was also more consistent then precipitation, but not as consistent as groundwater (Table 1). The river oxygen isotope ratio averaged -5.3 ‰.

Table 1. Oxygen isotope ratios ($\delta^{18}O$ (‰)) for rain, river and groundwater (GW) arranged by date.

Date	Rain	Date	River	Date	GW
3/15/2008	-13.8	6/7/2008	-5.1	3/12/2008	-8.1
3/18/2008	-9.2	7/29/2008	-4.1	5/30/2008	-8.0
4/3/2008	-5.1	10/29/2008	-6.5	6/7/2008	-7.9
4/17/2008	-8.4	6/13/2009	-4.7	9/19/2008	-7.7
5/30/2008	-4.3	8/1/2009	-5.9	6/13/2009	-8.2
10/22/2008	-6.0	8/29/2009	-5.2	6/13/2009	-8.2
8/10/2009	-0.8				
8/20/2009	-5.3				
8/26/2009	-4.6				
Average	**-6.4**		**-5.3**		**-8.0**

Oxygen isotopic ratios of the soils showed no differences between sites ($P > 0.05$), so were therefore pooled (Figure 5). Oxygen isotopic ratios of the soils were the most depleted during the initial sampling date of March 2008 (Figure 5), corresponding to very depleted precipitation (Table 1). Soils were more enriched in the summer of 2008, averaging between -5 ‰ and -6 ‰. Soils became more depleted again in the fall of 2008 and $\delta^{18}O$ values dropped to – 7 ‰. Soil oxygen isotope ratios were more enriched during the summer of 2009 compared with that of 2008, averaging between -4 ‰ and -5 ‰ (Figure 5).

Xylem water in the twigs of bur oaks did not show as much variability as the soils. With the exception of the first sampling date in early March 2008, which occurred when the bur oaks were still not leafed out, the bur oaks had an average $\delta^{18}O$ value of -7.6 ‰ (Figure 5). There were no significant differences between the 3 sites for most of the sampling dates. However, on 7/29/08 the Riverside site (site 3) was more enriched than the other sites. Except for the first sampling date, the bur oaks were always more depleted then the soil water.

In additional to sampling bur oaks, we also sampled 1 cotton wood tree near site 2. The cottonwood tree had an average $\delta^{18}O$ value of -6.7 ‰ over the 2 years (data not shown).

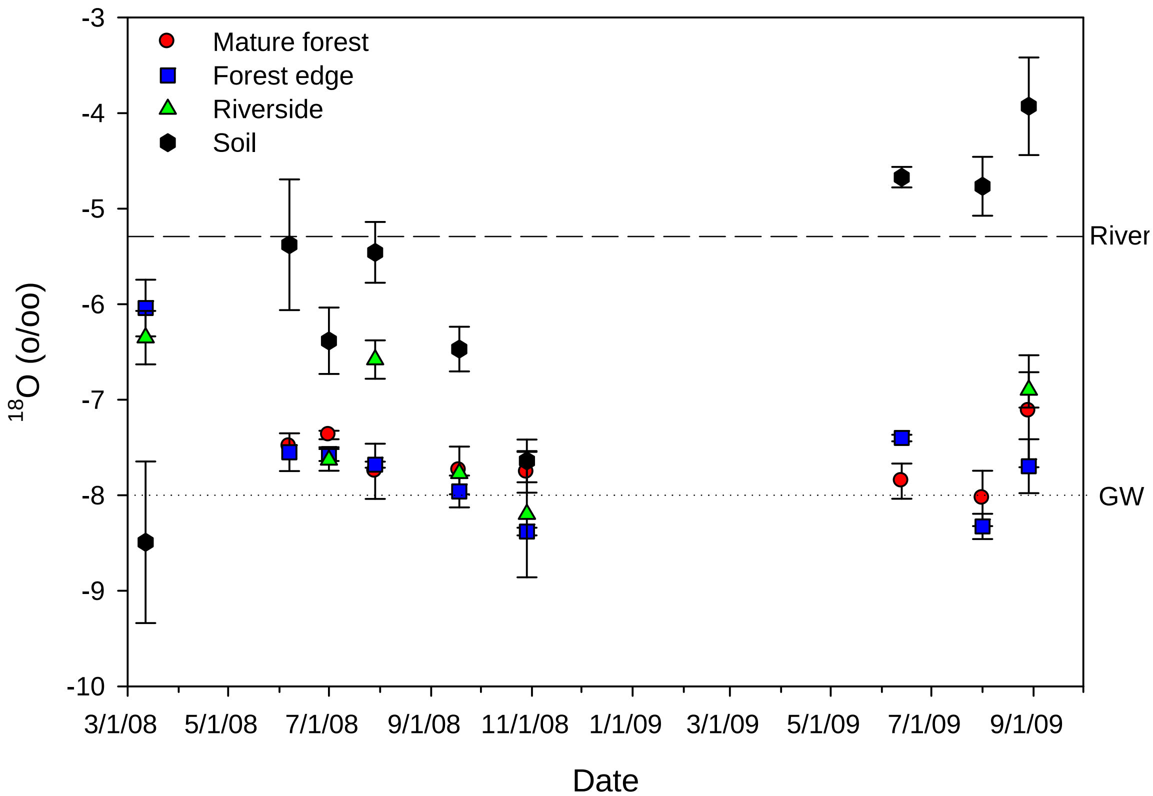

Figure 5. Oxygen isotope ratios ($\delta^{18}O$ (‰)) data of soil and bur oak twig samples. Dashed line is the average $\delta^{18}O$ value for the river and dotted line is the average $\delta^{18}O$ for groundwater (GW).

In 2008, we measured the carbon isotopic ratios of bur oak leaves (Table 2). The Mature forest had the most enriched ^{13}C leaf values and the Riverside and Forest edge trees had slightly more depleted values. All sites became more depleted as the summer progressed. This indicates that the trees were not water-stressed during the sampling year.

Table 2. Mean foliage (standard deviation) data by sample date and location.

Sampling Date	Location	Number of trees sampled*	**δ ^{13}C (‰)**	**%C**	**%N**
6/7/2008	Mature forest	5	-28.7 (0.5)	47.2 (0.8)	2.9 (0.5)
	Forest edge	5	-29.7 (0.3)	47.7 (0.6)	3.0 (0.2)
	Riverside	not sampled			
	Cottonwood	2	-29.6 (0.2)	44.7 (0.0)	1.9 (0.1)
7/1/2008	Mature forest	4	-29.4 (0.6)	47.2 (0.4)	2.6 (0.2)
	Forest edge	4	-30.5 (0.4)	46.4 (0.4)	2.4 (0.1)
	Riverside	3	-30.3 (0.9)	47.6 (0.7)	2.7 (0.2)
7/29/2008	Mature forest	3	-29.6 (0.4)	47.1 (0.4)	2.4 (0.1)
	Forest edge	3	-30.8 (0.5)	47.0 (0.1)	2.4 (0.1)
	Riverside	3	-30.9 (0.6)	46.8 (0.2)	2.5 (0.1)

* All samples are bur oak unless otherwise noted.

4. Summary

Our isotopic analysis indicates that bur oaks are using deep water sources, regardless of bur oak location in the Monument. Many trees have been found to use deep water, because it provides a more constant source of water compared to surface soil water (Ehleringer and Dawson 1992, Dawson 1993). The source of the deep water is groundwater, deep soil water, or likely a combination of the two. We collected some deep soil samples during the summer of 2009 and found that the deep soil (50-80 cm) had a more depleted ^{18}O value of -7.1‰ compared to surface soils, which would make it difficult to distinguish deep soil water from ground water isotopically. Asbjorson et al. (2008) also found that soils below 40 cm had similar ^{18}O values as groundwater in bur oak woodland and savanna. It is also difficult to distinguish deep soil water from groundwater because groundwater moves up into deep soils from capillary action (Chimner and Cooper 2004). For example, Thorburn et al. (1993) found that capillary rise could recharge soils to within 0.5 m of the soil surface from a water table at least 3 m deep at an Australian study site.

Additional evidence that bur oaks are using deep water is that the leaves showed no indication of water stress. We would expect bur oaks to show signs of water stress during summers if they only used shallow water. But we found no indication of water stress from any of the trees sampled. Interestingly, we also found little difference between the different sites. However, the lack of water stress could solely be due to the fact that the summer of 2008 was a cool and wet summer which masked any differences.

Given that 2008 was such a wet year, it was surprising that bur oaks did not use more surface soil water. Trees that can switch between shallow and deep water typically respond to wet summers by using more shallow water during wet periods and deep water during dry periods (Chimner and Cooper 2004). However, many woody plants that utilize deep water cannot utilize summer rains (Elhringer et al. 1991). It appears that bur oaks use deep water consistently and do not switch to shallow water, even during wet years. This is similar to findings of white oak (*Quercus alba)* water use in savanna and woodlands in Iowa (Asbjornson et al. 2008).

Cub Creek could be a “losing” river and discharging water into the floodplain, or a “gaining” river and receiving groundwater into the river. Our data suggest that groundwater discharges into the river, creating baseflow at low stage. The river water differs both chemically and isotopically from the groundwater. The river water is more enriched than the groundwater because of the evaporative enrichment from the surface of the water and mixing with precipitation. The height of the groundwater is also out of sync with the river water. The river stage rises and falls with heavy precipitation, but the groundwater level does not show this flashy pattern. Instead the groundwater shows a distinctive seasonal pattern with high water in the summer and low water in the winter. This indicates that the bur oaks are getting deep water from groundwater, not from river water and that any lowering of the river is not having much of an impact on the water status of bur oaks.

The groundwater level at Homestead NM is very deep (6-7 m below the soil surface). However, bur oaks produce deep tap roots that can extend down to at least 6 m

(Johnson 1990). Therefore, the current level of the groundwater is probably not adversely affecting the mature bur oak trees. However, it is unknown how long it takes for juvenile bur oaks to grow a 6 m tap root or under what conditions successful bur oak regeneration occurs. Bur oaks are also very fire tolerant and have deep tap roots, which confer a competitive edge to this tree species in prairie ecosystems where fire and drought are major disturbances (Johnson 1990). The absence of fire has been implicated in the conversion of savanna ecosystems by allowing the encroachment by shade-tolerant, fire-sensitive species, converting them to dense woodlands (Nuzzo, 1986; Anderson, 1998; Asbjornsen et al. 2005).

In summary, we found that bur oaks in Homestead NM are using deep water sources, and are unlikely to be affected hydrologically by current regional downcutting of the river. Downcutting and alteration of the floodplain can have major affects on other ecological parameters such as floodplain vegetation communities and tree regeneration, but that is outside the scope of this study. Given that bur oaks do not appear to be water stressed and are known to be fire tolerant, we feel that allowing fire into the bur oak stands will probably not be detrimental to the adult bur oaks. However, we suggest that fire be reintroduced experimentally into the southern forested section first, not directly into the less disturbed, mature bur oak forest.

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