Effects of produced water and hydrocarbon releases on vegetation at site A of the Osage-Skiatook petroleum environmental research project, Osage County, Oklahoma

Bobby D. Keeland, John W. McCoy

U.S. Geological Survey, Lafayette, LA 70506
Voice: 337-266-8663, FAX: 337-266-8592

and

James K. Otton

U.S. Geological Survey, Denver, CO 80225
Voice: 303-236-8020, FAX: 303-236-0459

ABSTRACT

To examine the impacts of past oilfield operations on forest stands of the "A" Site (Osage-Skiatook petroleum environmental research project northwest of Tulsa, OK) we sampleed the vegetation along 4 transects through an eroded salt scar caused by produced water disposal. Transects began and ended within the forest matrix on either side of the impact area, and 100 m^2 study plots were located at 15-m intervals along each transect. All trees greater than 2.5 cm in diameter in each plot were identified to species and measured. Saplings and shrubs within each plot were counted by species, while herbaceous species were counted in two 1 m^2 subplots. Tree ages were estimated from increment cores to provide a general age or age structure of the forest.

The forest matrix around the salt scar was composed predominately of post oak and blackjack oak with smaller amounts of hickory and very low numbers of black willow, ash, and American elm. Nine species, plum, eastern red cedar, buttonbush, red bud, honey locust, hackberry, buckbrush, winged sumac, and chittim wood (buckthorn bully), were found in the small tree/sapling/shrub layer. Vines included Virginia Creeper, catbrier, blackberry and grape. Nine of the 62 plots established, mostly in the salt scar area, contained no trees.

Age analysis indicates that many of the larger post oaks are greater than 100 years old while only a few of the blackjack oaks approach 100 years in age. Prior to oilfield operation the area was probably savannah with scattered post oak. The majority of trees currently in the area invaded during or after operation of the oil field, possibly as a result of fire exclusion.

INTRODUCTION

The Cross-Timbers ecosystem of eastern and central Oklahoma forms a broad transitional boundary between the eastern deciduous forest and the grasslands of the Southern Great Plains. The distribution and character of the area is controlled by a combination of climate, soils, and bedrock type. The post oak-blackjack oak forest that dominates the area is generally underlain by coarse sandy soils derived from the underlying sandstone parent material. Upland deciduous forests dominate the hillslopes while ridges are vegetation with grasslands and small stands of oaks. Glades (small treeless areas) are abundant throughout the area (1). Slow growth of the trees is due in part to the relatively low rainfall in this marginal climate zone, and because the porous sandy soils tend to be infertile with little water holding capacity (2). Due to the poor form and generally small size of most trees, large-scale industrial logging has not been a major disburbance in the area. The post oaks that dominate the canopy rarely exceed 15m in height or 60cm in diameter, but may be over 250 years old (3). Historically the area has been used for hunting and grazing of cattle.

A portion of the Cross-Timbers ecosystem can be found in the rolling hills of southeastern Osage County, northwest of Tulsa Oklahoma. The area is dissected with modest relief and is underlain by interbedded shale, mudstone, siltstone, and sandstone of the Pennsylvanian Wann Formation. Thick, resistant sandstone units typically form the hillcrests, whereas shale, mudstone, siltstone, and thin sandstone beds underlie hillslopes (4). Locally, a layer of eolian sand of variable thickness covers the bedrock.

Oil extraction has been a major industry in Osage County since the early 1900s. Oil production fluids typically consist of a brine/crude oil mix that is stored in tanks to allow separation of the two fluids and recovery of the oil. Historically, the oil was transported to a refinery while the produced water was simply released to drain down slope. Current practices require reinjection of the brine, however spills occur. The impacts of long-term oilfield operations on vegetation and soils are evident throughout the region, especially in areas where oil/water separation tanks were located.

We conducted a study of the forest in and around an impact site to determine the effects of past oilfield operations, produced water disposal, and oil spills on the vegetation. Our specific objectives were to examine the age structure of the trees to determine if they had survived the disturbance or if they had invaded after oilfield operations had ceased.

STUDY SITE

Our study was conducted at the Lester Lease (OSPER 'A' site) that is located west of the town of Skiatook on the shoreline of Lake Skiatook (figure 1). The site is situated in a topographic saddle between two low hills on a small peninsula extending southward into the lake. The main body of the lake, along the old channel of Hominy Creek, forms the southern and western shorelines of the peninsula while the Cedar Creek arm of the lake forms the eastern and northeastern shoreline. The site is underlain by 1) a surface layer of eolian sand or mixed eolian and slopewash sand ranging from 0 to 1 m thick; 2) sandy or clayey colluvium that ranges from a thin layer of granule-pebble weathered sandstone-clast conglomerate to large boulders of sandstone; 3) weathered shale, mudstone, siltstone, clayey sandstone, and sandstone; and 4) unweathered bedrock (4). The eolian sand, colluvium, and the uppermost part of the weathered bedrock are exposed in a deeply eroded area that runs downhill through the middle of the site.

The lease was originally drilled in 1912 with production beginning in 1913. The productive unit was the Bartlesville Sand (local name) at depths of 450-425 m (1475-1395 feet) below the surface. A battery of four oil tanks and a central power unit were situated near the top of the site. During the early part of the 1900s, produced water released from the tanks drained into two pits and either infiltrated into the ground or was released from the pits downslope. The impact or salt scar area consists of two contiguous areas. The uphill portion of the site, above an access road, contains the tank battery and pits where produced water (a Na-Ca-Cl brine) and oil sludge were released. This portion of the site is covered with grass, scattered trees, and shrubs. In many locations, weathered asphalt provides evidence of past oilfield operations. Below the access road the soil has eroded away to depths of as much as 2 m. Some vegetation grows on remaining islands of soil, but little to nothing grows in the gully bottom. Increased salt accumulations can be found in the bedrock to depths greater than 4.5 m and below the present elevation of Skiatook Lake.

METHODS

Study Plots

We conducted vegetation surveys during the fall of 2002 and spring of 2003. Four transects were established across the impact area, and 100 m^2 study plots were established at 15 m intervals along each transect (figure 2). Transects began and ended within the forest matrix on either side (east and west) of the salt scar. A total of 62 plots were established along the four transects. In each plot all trees greater than 2.5 cm in diameter at 140 cm above the soil surface (dbh) were identified to species and measured for diameter. Shrubs and saplings (less than 2.5 cm dbh) were counted by species, and the percent cover of herbaceous vegetation was visually estimated in two quadrats (1 m^2 each). Importance values (IV300) were calculated for trees in all plots combined, for all plots per transect, and for all plots east and west of the salt scar.

Soil depth, bedrock type

Soil depth and bedrock type was determined in 59 of the 62 vegetation plots. A 5-cm diameter soil auger was augered into the soil to refusal and the material brought to the surface was laid out in sequential piles on a tarp for examination. A metric ruler was then used to measure the depth of excavation.

Age Determination

Two increment cores were extracted at 50 cm above the ground surface from each of the two trees nearest plot center for age estimation. Particularly large or old-looking trees in the vicinity of each transect were also cored for comparison with trees located within the plots. Cross sections were cut from a few particularly small or recently dead trees with a chainsaw. Increment cores were stored in straws (courtesy of McDonalds Corporation) for safe transport back to the lab where they were dried at 45 °C for 48 hours. One side of each straw was slit to facilitate drying. Cores were then glued to hardwood mounts, sanded with progressively finer sandpaper (120, 220, 320, 400, and 600 grit), and examined under a binocular dissecting microscope. The age of hollow trees was estimated by multiplying the average number of rings per centimeter counted on the extracted core by the measured radius, after allowing for bark thickness and core shrinkage caused by drying.

Statistical Analysis

The relationship between tree ages versus soil depth and tree density was tested with a 2-way analysis of variance (ANOVA), and the relationship between stem density and soil depth was tested with a 1-way ANOVA. Both analyses were conducted using PROC GLM in SAS (5)(6).

RESULTS AND DISCUSSION

A total of 53 taxa were encountered on the site (Table 1). These included 22 woody and 31 herbaceous taxa. Many grasses and forbs (22) were not identified to species because they were not in flower at the time of our site visit. In addition, 8 woody taxa were only identified to genera due to a lack of flowering parts. The total list of species for the site is therefore probably higher, but a relatively low diversity might be expected for vegetation in the Cross-Timbers area.

Overall, the forest matrix around the salt scar was composed predominately of post oak (IV300 = 136.8) and blackjack oak (115.9), with smaller amounts of hickory (42.1) and very low numbers of willow (2.3), American elm (1.5), and ash (1.4)(Table 2). Nine species were found in the small tree/shrub layer. These included plum, red cedar, buttonbush, redbud, honey locust, hackberry, buckbrush (Indian currrant), winged sumac, and chittim wood (buckthorn). Vines included poison ivy, Virginia Creeper, catbrier, blackberry and grapes. Prickly pear, a somewhat woody cactus, was also found on site. Although black locust is included in Table 1, it had been planted as part of an impact recovery experiment and was not found growing naturally on the site. Nine of the 62 plots contained no trees and a few were devoid of any vegetation. These empty plots were mostly within the highly eroded salt scar area of transects C and D.

Both species of oak were found along the entire hillslope (Table 3). Blackjack oak importance was highest along the B transect with decreasing importance both up and down slope. The importance of post oak decreased with increasing elevation along the hillslope. There were no differences in oak distribution between the east and west sides of the salt scar. Differences in the importance of these two oak species may be related to moisture and/or nutrient concentrations along the elevation gradient, but data that could support or refute that relationship were not collected. Recent fires, as indicated by the abundance of fire scars on many of the trees and cross-sections (figure 3), could also have had an effect on species distributions.

Very few individuals of the other tree species were encountered and so conclusions cannot be drawn with regard to their distribution. A few tree species, such as honey locust, red cedar, plum, redbud and hackberry were only found in the seedling and sapling (shrub) layers. The presence of these species may indicate a subtle shift in the species composition of the forest, but it is also possible that these additional species may only rarely attain canopy status at this site.

Age analysis indicates that only a few of the trees on this site are greater than 100 years old (figure 4). Although blackjack oak trees were the most abundant, most were small in size and all were less than 100 years old. Post oak trees occurred over a wider range of ages. Some post oak trees were less than twenty years old while others were greater than two hundred and sixty years in age. A few of these older post oak trees predate oilfield operations by more than a century. Only a very few blackjack oaks were present at the time when the lease was first occupied. Many smaller post oak and most of the blackjack oaks became established during the past 65 years. A few oaks have invaded into the salt scar area, including areas immediately adjacent to the produced water and oil pits. Some of the smallest blackjack oaks became established in the upper portion of the salt scar area as recently as the early 1980s, presumably after oilfield operations ceased on this site.

Soil depth across the transects varied over a range of almost a meter (figure 5). In some areas of the lower salt scar, where erosion has been greatest, exposed bedrock was visible. Bedrock consisted of sandstone, weathered clayey sandstone, or sandy claystone. In a few plots a thin gravel, colluvial gravel or a thin sandy clay was found immediately above the sandstone bedrock. No obvious relationship between bedrock type and soil depth was observed. Likewise, comparisons between tree ages versus soil depth ($F_{1, 35}$=0.74, P=0.3946), tree density ($F_{15, 35}$=0.63, P=0.7902), and the interaction of soil depth and tree density ($F_{10, 35}$=0.55, P=0.8417) were not significant. There was a significant relationship between stem density and soil depth ($F_{1, 72}$=4.18, P=0.0446), but 94.6 % of the variation in stem density was explained by variables other than soil depth.

CONCLUSIONS

These data and some limited anecdotal information from a past lease operator indicate that prior to oilfield operations the area consisted of grassland with scattered post oak trees. The open, savannah nature of the area was probably a result of several factors that most likely included low precipitation, poor quality soils, and frequent fires. With settlement of the area, fire prevention would have become a priority to protect people's houses and oilfield equipment. Fire prevention combined with the introduction of cattle grazing would have allowed the invasion and survival of more trees, while the low precipitation and poor soils would have limited the number of tree species.

A slight shift in precipitation patterns toward greater rainfall could also have resulted in the invasion of woody species and development of a closed canopy forest. We do not, however, have any data to support or refute that hypothesis. Very few weather records that extend back 100 years are available and longer records (as would be needed to determine if a precipitation shift had occurred) do not exist for the project area.

Most likely, oilfield operations had little direct effect on what little forest occurred in the Osage County area during the early part of the 20^{th} century. Although scattered trees existed at this site 100 years ago, the present forest community, in general, is recently established and therefore mostly unaffected by oilfield activities. The majority of environmental damage caused by oilfield operation was probably related to effects on wildlife, herbaceous vegetation, soils, and the regional water table. The greatest effect on the pre-existing vegetation was related to an increase in forest cover that probably resulted from fire suppression and cattle grazing. The primary direct impact of production operations is related to the ability of trees to establish in the salt scar area. Although some trees are invading into the upper portion of the salt scar area, the young age of those trees suggest that recovery will be a slow process. It will be many decades before the lower, more highly eroded area will become forested through natural processes.

REFERENCES

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Table 1. Plant species encountered at the OSPER 'A' site.

Tree Species	Scientific Name[1]
American elm	*Ulmus americana* L.
Ash	*Fraxinus* sp.
Black Locust	*Robinia pseudoacacia* L.
Blackjack Oak	*Quercus marilandica* Moench.
Hackberry	*Celtis occidentalis* L.
Hickory	*Carya.* sp.
Honey Locust	*Gleditsia triacanthos* L.
Plum	*Prunus* sp.
Post Oak	*Quercus stellata* Wang.
Redbud	*Cercis canadensis* L.
Red Cedar	*Juniperus virginia* L.
Black Willow	*Salix nigra* Marshall

Shrub Species	Scientific Name
Buckthorn Bully	*Sideroxylon* sp.
Button bush	*Cephalanthus occidentalis* L.
Indian Currant	*Symphoricarpos orbiculatus* Moench.
Prickly Pear Cactus	*Opuntia* sp.
Winged Sumac	*Rhus copallina* L.

Vine Species	Scientific Name
Blackberry	*Rubus* sp.
Cat Briar	*Smilax* sp.
Grape	*Vitus* sp.
Poison Ivy	*Toxicodendron radicans* L.
Virginia Creeper	*Parthenocissus quinquefolia* (L.) Planchon

Grass Species	Scientific Name
Bluestem	*Andropogon* sp.
Bullrush	*Scirpus* sp.
Flat Sedge	*Cyperus* sp.
Panic grass	*Panicum* sp.
Sedge	*Carex* sp.

Forb Species	Scientific Name
Annual Ragweed	*Ambrosia artemisiifolia* L.
Aster	*Aster* sp.
Bush-Clover	*Lespedeza* sp.
Carolina Coralbead	*Cocculus carolinus* (L.) DC.
Corn salad	*Valerianella* sp.
Cranesbill	*Geranium* sp.
Dock or sorrel	*Rumex* sp.
Milkweed	*Asclepias* sp.
Milfoil	*Achillea millefolium* L.
Pepperwort	*Lepidium* sp.
Plantain	*Plantago* sp.
Pussy toes	*Antennaria* sp.
Queen Ann's Lace	*Daucus carota* L.
Scorpion-Weed	*Phacelia.* sp.
Sericea Lespedeza	*Lespedeza cuneata (Dumont) G.*
Skullcap	*Scuttelaria* sp.
Small Venus'-Looking-Glass	*Triodanis biflora* (Ruiz & Pavón) Greene
Spoon-Leaf Purple Everlasting	*Gamochaeta purpurea* (L.)
Spruge	*Euphorbia* sp.
Stonecrop	*Sedum* sp.
Tick-Trefoil	*Desmodium* sp.
Violet	*Viola* sp.
Wild lettuce	*Lactuca* sp.
Wild onion	*Allium* sp.
Windowbox	*Oxalis rubra* St.-Hil.
Wood Sorrel	*Oxalis* sp.

[1] The study site was visited only once in early May, 2003 so many of the plant species observed were not in flower and could not be identified to species. This should not be considered a complete listing of all plant species on the site.

Table 2. Stand table for the 'A' site, all transects and plots combined. Frequency represents the number of plots (out of 60) in which each species occurred. Density is the total number of stems for each species. Dominance is the total basal area (in cm^2) across all plots per species. The importance value (IV300) is the sum of the relative frequency, relative density and relative dominance.

Species	Frequency	Density	Dominance	IV300
Ash	1	1	13.9	1.4
Hickory	19	50	3684.7	42.1
Blackjack Oak	37	128	20464.2	115.9
Post Oak	34	157	28789.7	136.8
Black Willow	1	3	175.3	2.3
American Elm	1	1	91.6	1.5

Table 3. Importance values of each species by transect, east of the salt scar, and west of the salt scar.

Species	**A**	**B**	**C**	**D**	**East**	**West**
Ash			5.4	35.6		3.4
Hickory	80.4	41.3	14.0		47	43.3
Blackjack Oak	113.6	192.7	94.0	57.8	126.6	110
Post Oak	99.8	57.8	186.6	206.6	120.9	139.6
Black Willow		8.1			5.5	
American Elm	6.2					3.7

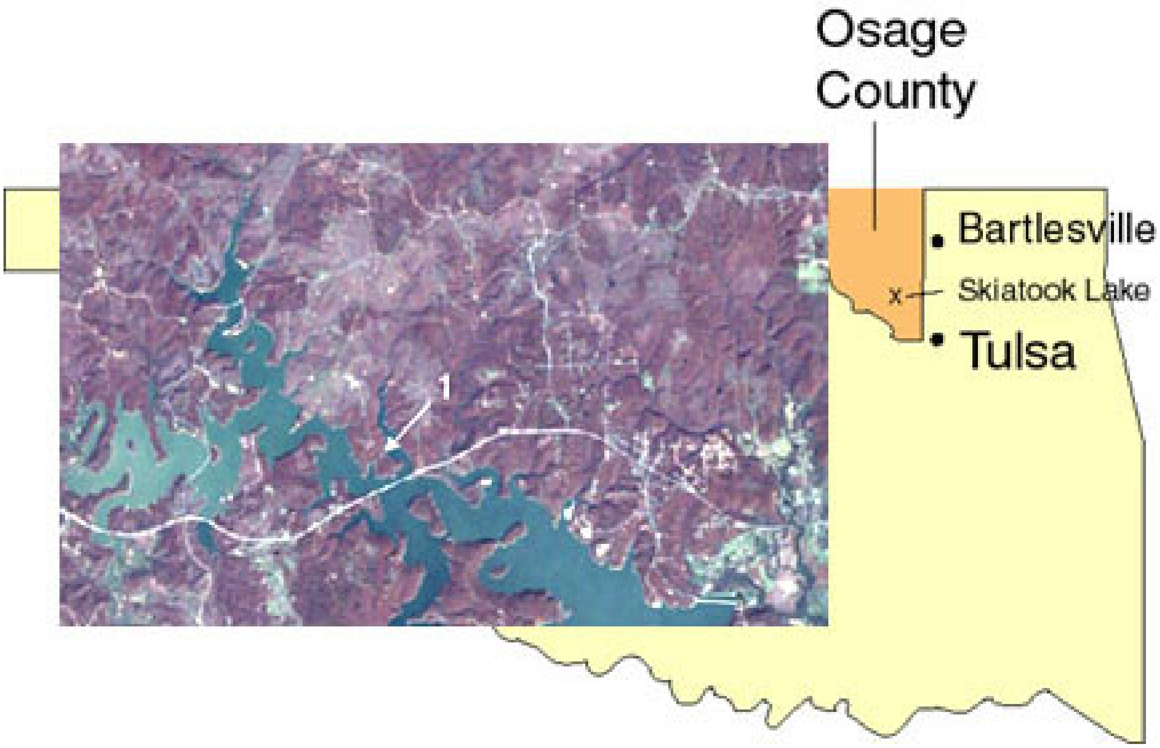

Figure 1. Location of the study site on Skiatook Lake, in Osage County, northwest of Tulsa Oklahoma. The town of Skiatook can be seen on the right side of the picture with Hwy 20 crossing the photo to the left. (1999 Landsat image of Skiatook Lake).

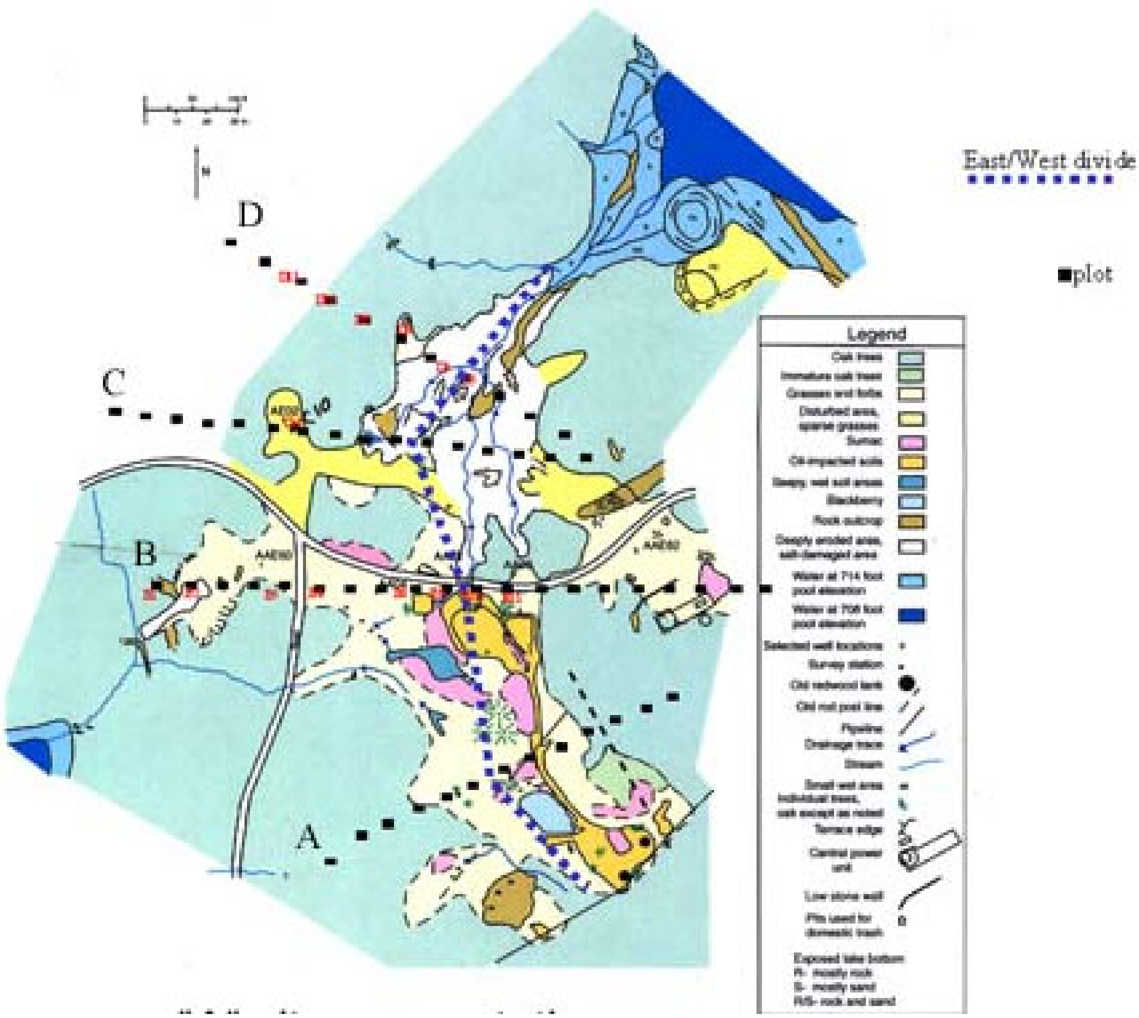

Figure 2. Vegetation map and location of the transects. Transect A is at the highest elevation, near the southern end of the site. Transects B, C, and D are progressively lower on the hillslope.

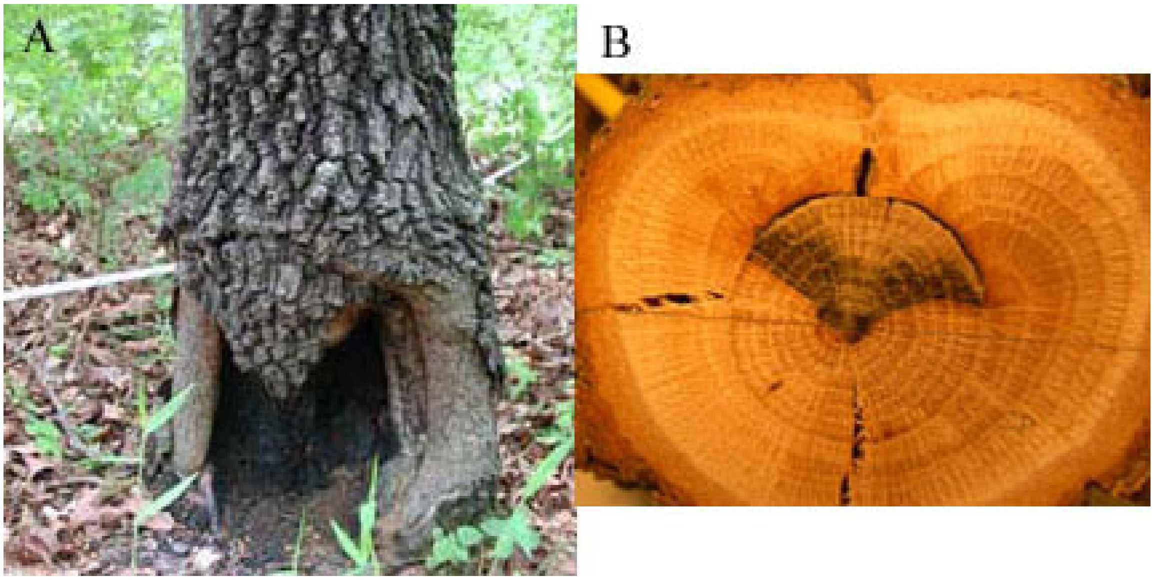

Figure 3. Fire scars; A) at the base of a canopy oak tree, and B) on a cross section of an oak stem. The fire scar in photo A was too large to heal over. When the sapling in photo B was eight years old, during the fall of 1995 or winter of 1996, the cambium around about 1/3 of the stem was destroyed by fire. The callous formed in response to the wound can be seen curling around both sides of the fire scar over the next several years.

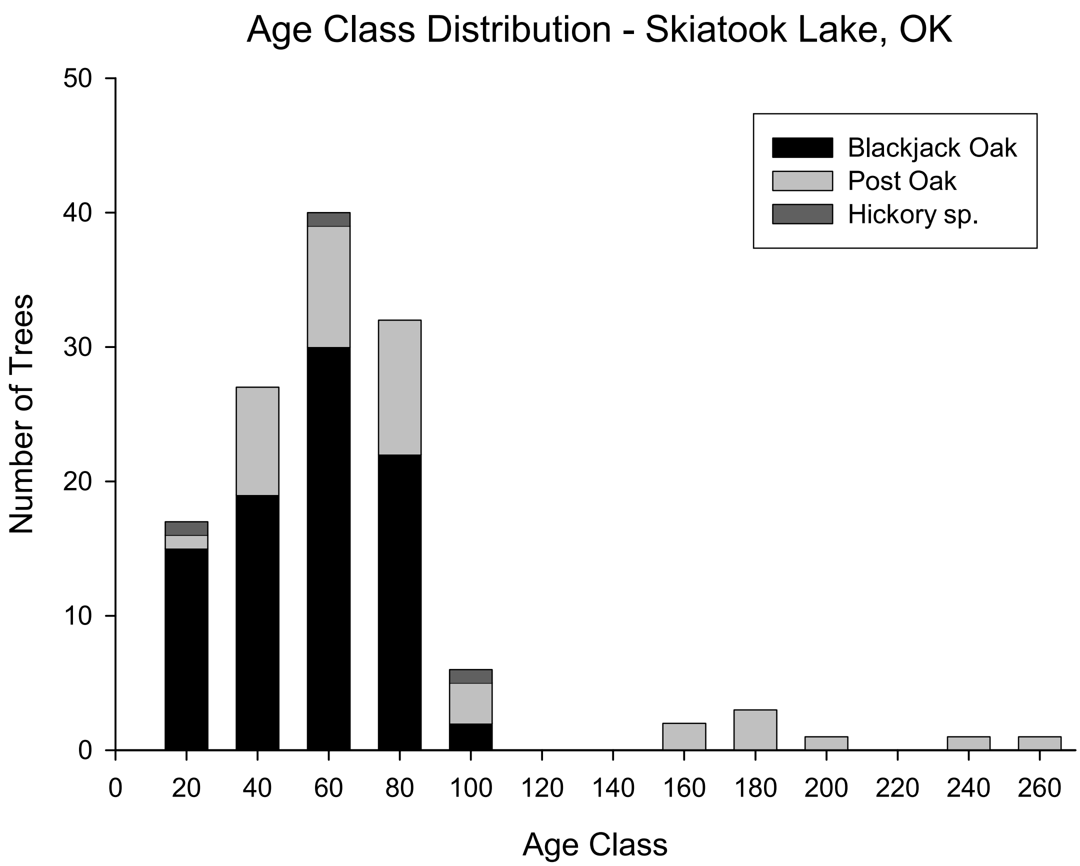

Figure 4. Age class distribution of canopy trees. Age data are given in years.

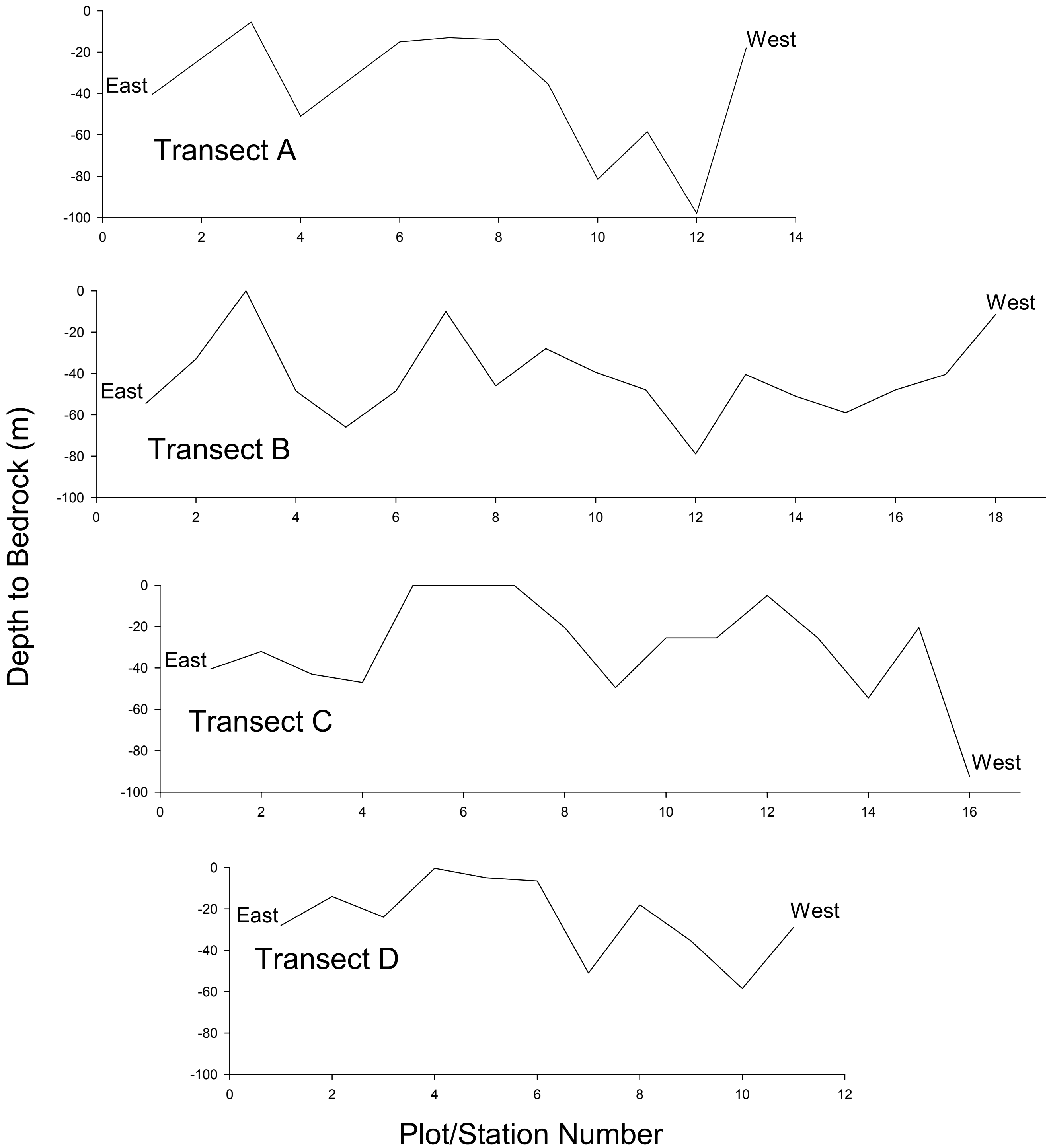

Figure 5. Depth to bedrock along each of the four transects. See figure 2 for transect locations.