Indigenous impacts on North American Great Plains fire regimes of the past millennium

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Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved June 26, 2018 (received for review March 27, 2018)

Fire use has played an important role in human evolution and subsequent dispersals across the globe, yet the relative importance of human activity and climate on fire regimes is controversial. This is particularly true for historical fire regimes of the Americas, where indigenous groups used fire for myriad reasons but paleofire records indicate strong climate–fire relationships. In North American grasslands, decadal-scale wet periods facilitated widespread fire activity because of the abundance of fuel promoted by pluvial episodes. In these settings, human impacts on fire regimes are assumed to be independent of climate, thereby diminishing the strength of climate–fire relationships. We used an offsite geoarchaeological approach to link terrestrial records of prairie fire activity with spatially related archaeological features (driveline complexes) used for intensive, communal bison hunting in north-central Montana. Radiocarbon-dated charcoal layers from alluvial and colluvial deposits associated with driveline complexes indicate that peak fire activity over the past millennium occurred coincident with the use of these features (ca. 1100–1650 CE). However, comparison of dated fire deposits with Palmer Drought Severity Index reconstructions reveal strong climate–fire linkages. More than half of all charcoal layers coincide with modest pluvial episodes, suggesting that fire use by indigenous hunters enhanced the effects of climate variability on prairie fire regimes. These results indicate that relatively small, mobile human populations can impact natural fire regimes, even in pyrogeographic settings in which climate exerts strong, top-down controls on fuels.

anthropogenic burning | bison hunting | pyric herbivory | climate–fire relationships | hunter-gatherers

Fire is a significant earth system process that has shaped the ecological history of landscapes and biomes (1). Climate exerts significant top-down controls on fire regimes, thereby influencing the production of fuels and their drying for combustion (2). In fuel-limited grasslands and dry woodlands, wet periods are necessary to produce sufficient abundance and continuity of fuels to burn (3). This is particularly true for mixed, shortgrass, and fescue prairies of the North American interior, where fire activity correlates with wet phases (i.e., pluvial episodes) and corresponding increases in grassland productivity (4, 5). Despite a wealth of documentary evidence of fire use for a diverse range of purposes (6–10), the role of anthropogenic burning in the historical ecology of North American ecosystems remains controversial (11). This is particularly so for low-density hunter-gatherer populations, who are assumed to have minimally impacted ecosystems and their fire regimes (12). However, grassland burning by aboriginal hunters in Western Australia has measurable impacts on fine-scale biodiversity, even as the landscape-scale fire rotation is virtually identical between human-managed and unmanaged areas (13). Furthermore, these human-managed areas are less vulnerable to climate-driven extreme fire years, suggesting that hunter-gatherer burning can buffer impacts of climate variability on these fire regimes (14). This aligns well with fire history observations of human-managed landscapes in similarly grass-fuel–dominated forests of the American Southwest (15) and California (16).

In recent decades, two different narratives of human/climate fire relationships have emerged (17). For many fire scientists, human activities and climate are mutually exclusive influences on fire regimes. From this perspective, the primary human impact is to dampen climate–fire relationships, producing fire histories that deviate from the expected “natural” regime (18, 19). Human population size or density are often used as a proxies for the potential magnitude of human influence, with the assumption that smaller, mobile groups impact surrounding fire regimes less than larger, more sedentary populations (19). In this framework, demonstrable climate–fire correlations in paleofire records suggest that human activities had little or no influence on fire regimes (12, 18, 20, 21).

From an ethnographic and archaeological perspective, anthropogenic burning is abundant and diverse (6, 7, 22, 23), and both foragers and farmers can measurably impact surrounding fire regimes, largely by buffering the impacts of climate variability (13–15, 24, 25). This effect is mostly unintentional, as human decision-making in these contexts probably prioritizes social and economic concerns over suppressing climate effects (26, 27). Although this model acknowledges the abundant record of traditional fire uses, it is compatible with elements of the first perspective. Both suggest that human contributions to fire regimes involve a suppression or dampening of the climate–fire relationship. However, ethnographic research also indicates that indigenous peoples are keenly aware of climate impacts on fuels and may leverage this by lighting more fires when fuels are abundant (27).

By using an empirical approach, we demonstrate that at least some Native American and First Nations foraging groups used fire to manipulate the location of herds for episodic mass harvesting of

Significance

The relative importance of human activities and climate in shaping fire regimes is controversial. In North American grasslands, climate exerts strong top-down influences on fuels. For centuries before the introduction of the horse, Native American and First Nations hunters built and used landscape features on these grasslands to harvest bison en masse. Charcoal layers associated with drivelines indicate that fire was an important part of these hunting practices. Furthermore, correlation of dated fire deposits and climate records indicate that ancient bison hunters burned in response to favorable climate conditions. This study indicates that climate and human activities are not mutually exclusive factors in fire histories; even relatively small groups of hunter-gatherers can enhance climate impacts.


The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1805259115/-/DCSupplemental.
bison. This fire use was constrained by favorable climate conditions, thus aligning anthropogenic burning with the same climate processes driving natural fire regimes and enhancing climate effects on landscape fire activity. We demonstrate this by combining landscape archaeology with offsite geoarchaeology to reconstruct paleofire activity that is spatially isomorphous with the scale of ancient driveline hunting complexes and comparing these records vs. regional paleoclimate reconstructions.

Ecological and Archaeological Context

The northwestern Great Plains is characterized by shortgrass prairie dominated by fescue (Festuca spp.). These grasslands are fuel-limited (28) but provide ideal winter forage for American bison (Bison bison) (29). Historically, naturally ignited fires occurred during the summer, whereas anthropogenic fires occurred predominantly in the spring or the fall (SI Appendix, Fig. S9) (30). Lightning-strike densities in the fescue grasslands are among the lowest on the continent (<4 flashes per km$^{-2}$·y$^{-1}$; National Lightning Detection Network), with the rate of lightning fires less than 0.25 km$^{-2}$·y$^{-1}$ in neighboring shortgrass prairies (31). Nevertheless, lightning and anthropogenic fires are important in these ecosystems (30–32), with positive impacts on postfire grassland productivity. Even low ignition rates can produce substantial burn areas when climate produces sufficiently abundant, continuous, and dry fuel (33). Festuca hallii (formerly Festuca scabrella), the dominant grass species in these prairies, is most productive after early spring burns followed by wet conditions, and burned patches are more productive than unburned patches in dry years as well (28, 34).

In the northern Rocky Mountain foothills, fescue prairie uplands are dissected with river valleys that provide the ideal setting for a hunting strategy that involves driving herds of bison over steep bluffs along the valleys (29, 35). Three key landscape features of this hunting strategy are the bison grazing area (i.e., gathering basin) (29) and the linear arrangements of rock cairns (i.e., drivelines) that channel bison herds to the precipice (i.e., jump) (35). Together, gathering basins, drivelines, and jumps were part of a linked strategy to increase returns by harvesting bison en masse.

In the northern Plains, mass harvesting of bison by using stone-lined drives and wooden corrals is first associated with Late Archaic cultural complexes such as Bracken (800–100 BCE) (36, 37) and, more widely, with Besant (100 BCE to 500 CE) (37, 38), when it may co-occur with increased fire activity, increased carrying capacity, and ultimately population growth and expansion into new areas (39). However, specialized bison hunting by using drivelines is most characteristic of the Old Women’s phase (ca. 900–1750 CE) (38, 40). Old Women’s phase sites are found in southern Alberta, southwestern Saskatchewan, and north-central Montana (29, 35, 37, 40). Recent research on the Blackfeet Indian Reservation in north-central Montana has documented the timing and intensity of use of driveline complexes along the Two Medicine River (Fig. 1). Radiocarbon dates from bone beds span approximately 900–1650 CE. Peak driveway use from throughout the valley dates to 1400–1650 CE, although this record may be biased toward the latest periods of use (SI Appendix and SI Appendix, Fig. S1). Native populations in the region may have been impacted by European diseases in the 17th century, with strong evidence for smallpox epidemics in 1730 and 1781–1782 CE reducing some northern Plains populations by as much as 50% over this interval and causing temporary regional depopulation (41, 42). However, at the end of the 18th century, European traders observed 150 individuals per hunting band and as many as 2,000 in aggregated winter camps along the Rocky Mountain Front (43). These observations may provide a rough proxy for population in our study area during the Old Women’s phase.

Results

Two offsite stratigraphic exposures (KAP 2 and KAP 4; SI Appendix and SI Appendix, Table S2) from tributary drainages to the Two Medicine River have evidence of grassland burning associated with driveline complexes (Fig. 1). The drainage basin for each locality overlaps with the driveline and gathering basin for specific bison jump complexes (SI Appendix, Figs. S2 and S5). These localities are on the north (Two Medicine/Schultz complex) and south (Stranglewolf complex) sides of the Two Medicine River, so charcoal deposits in each locality represent fires overlapping specific driveline complexes and cannot represent fires that spread from one locality to the other. Each exposure had five to eight continuous charcoal layers interbedded within
alluvium or colluvium. Charcoal-rich layers that extended >3 m laterally (Fig. 2 and SI Appendix, Figs. S3 and S6) were sampled as evidence for elevated fire activity in the drainage basin for that locality (“fire deposit”). Eleven of these fire deposits were directly dated via accelerator mass spectrometry 14C assays of aggregated grass charcoal (44, 45). Four charcoal samples from sedimentary deposits or soils bracketing the fire deposits were also radiocarbon-dated to provide constraining ages on the earliest and latest deposition of charcoal layers at each locality. Final radiocarbon measurements were calibrated by using a Bayesian algorithm in BCAL (https://bcal.sheffield.ac.uk; ref. 46), with stratigraphic relationship between dated deposits used to further constrain the final posterior probability distributions. This Bayesian approach also permitted us to assign probabilities for the ages of two fire deposits from KAP 4 that could not be dated directly. Posterior probability distributions for directly and indirectly dated charcoal deposits were summed for each locality to generate a locality-specific history of enhanced fire activity (Fig. 2).

Dated fire deposits indicate that unusually high prairie fire activity occurred between 1100 and 1650 CE, approximately coeval with the Old Women’s phase archaeology of the Two Medicine valley (ca. 900–1650 CE; SI Appendix, Fig. S1). More than half of the 13 deposits date to the period of most intensive use of the driveline complexes between 1400 and 1650 CE. It is important to note that, at both localities, there are alluvial and colluvial deposits without distinct charcoal layers that postdate the Old Women’s phase through at least the late 19th century. Furthermore, stratigraphic evidence from both localities and a stratigraphic exposure adjacent to KAP 2 span at least 500 y before the Old Women’s phase but lack comparable fire deposits (SI Appendix). The absence of charcoal deposits in strata that predate and postdate the Old Women’s phase suggests that the fire regime was qualitatively different between 1100 and 1650 CE than centuries before or after. The absence of dense charcoal deposits after 1650 CE is particularly noteworthy because otherwise analogous alluvial and colluvial deposits are common at our localities.

Fires, both natural and anthropogenic, persisted after this date in the historic record (30), and charcoal is commonly dispersed in the alluvium, colluvium, and soils that postdate this time. However, the unique circumstances that promoted the formation of dense, continuous charcoal layers exclusively dates to the Old Women’s phase; these are not found in strata that predate or postdate this period in our records. Given the spatial proximity to driveline complexes and the timing of fire activity relative to their use, we interpret the radiocarbon and stratigraphic data as strong evidence for anthropogenic burning as part of Old Women’s phase bison harvesting technology.

Although it is possible that fire was used to initiate bison drives as well, we think it more likely that strategic grassland burning was used to lure bison to the gathering basins of particular driveline complexes. The seasonality of communal hunts, as indicated from bone bed faunal remains and ethnohistorical summaries (47), suggest that the drivelines were used from late fall to early spring. Spring burning (for a fall hunt) or fall burning (for a spring hunt) would have created attractive conditions for subsequent grazing by bison, who prefer to graze recently burned patches (30, 48). In contemporary practice, this use of fire to manipulate grazer behavior is called pyric herbivory (49). This practice would have increased the predictability of locating bison in the gathering basin for a particular driveline complex, effectively enhancing encounter rates (13) as hunters-gatherers do across the globe (22).

Although our radiocarbon records provide strong evidence for anthropogenic burning during the Old Women’s phase, they also show significant relationships with climate (Fig. 3). Six of the thirteen dated charcoal deposits coincide with decadal-scale pluvial episodes (50), as would be expected even under “natural”
conditions. However, the remaining seven charcoal deposits correspond to modest or short wet periods, which should have lower fire activity. Furthermore, although decadal-scale pluvial episodes persist after 1650 CE, comparable charcoal layers did not form at either of these localities. Together, these patterns suggest that anthropogenic burning during the Old Women’s phase leveraged pyric herbivory when there were sufficient fuels to use fire in communal hunts, even amplifying the effects of short or modest wet periods on grassland fire regimes.

The peak probabilities for individual fire layers for the two localities indicate that the associated driveline complexes may not have been used simultaneously. This supports the historical view that use of specific complexes may have been rotated across the landscape (51). Decadal-scale pluvial episodes were long enough to support burning at multiple driveline complexes (spaced at 8–15-km intervals along the river) over the course of most wet periods, so we would expect for the peak probabilities of more than 2 of the 13 fire layers to be synchronous if multiple drivelines were in use simultaneously at the decadal scale (Fig. 2). This evidence of bison kill-site rotation, pyric herbivory, and fire regime change before the emergence of horse culture in the 18th century has important implications for refining the ecological impact of bison hunters on northern prairie landscapes, which we discuss subsequently.

Discussion

Although many scholars treat climate and human activity as mutually exclusive influences on fire activity, our study indicates that human impacts on fire regimes are not so simple (52). Humans and fire both respond to climate influences, but not necessarily in the same way or to the same effect. Climate variability provides the context for human decisions to burn relative to some specific goal, and that agency may result in human activities enhancing (53) or buffering (14, 15) climate impacts on fire regimes at different scales. For example, communal bison hunts on the Great Plains may have primarily occurred during wet periods (54), meaning that human activity and fire responded to the same climate signals. In our study, the use of pyric herbivory in communal bison hunts enabled indigenous foragers to leverage even minor climate opportunities to burn, thus amplifying the effects that these wet periods had on prairie fire regimes and creating a stronger apparent climate–fire relationship. Within the annual cycle, communal bison hunts focused on bison wintering areas in the foothills (40, 55), contributing to differences in the seasonality between burning for pyric herbivory and natural fires (30).

Furthermore, our study indicates that hunter-gatherers can have a significant impact on fire regimes (56) even at relatively low population densities, suggesting that population estimates or modes of economic organization may be useful, but not necessarily sufficient, proxies for human influence on fire activity (19). In our study, distinguishing the human role in fire history is only possible because of linkages between the fire record and the archaeological record at comparable pyrogeographic scales (17, 52). The visibility of the anthropogenic fire regime may have been facilitated by the relatively low rates of lightning ignitions, creating greater opportunity for anthropogenic ignitions to generate distinctive fire patterns. Future paleofire studies should be mindful that the presence of a strong climate–fire signal does not rule out the possibility of human influence, nor should archaeologists expect that anthropogenic burning will necessarily be independent of climate effects on local fire regimes.

That relatively small populations of foragers can have impacts on fire regimes has important implications for assessing the Ancient Anthropocene hypothesis (24, 56, 57). In this hypothesis, fire use and land clearance associated with early agriculture generated ongoing, net-positive carbon releases to the atmosphere, stabilizing Holocene climates (58). In part, this hypothesis assumes that foragers before the invention or adoption of agriculture did not impact fire regimes or carbon cycles. Although the pyric herbivory we document for the Old Women’s phase was unlikely to produce carbon releases comparable to forest clearance, it indicates that hunter-gatherer burning can have meaningful impacts on fire regimes and needs to be considered as the Ancient Anthropocene hypotheses continue to be debated (56).

Ethnographic (13, 59, 60) and ethnological research (7, 22, 23, 26, 61) makes clear that there is no universal “hunter-gatherer” use of fire. Past and present foragers vary widely in their home environments, as well as their social, economic, and political structures (62, 63). However, ethnographic diversity likely...
underrepresents hunter-gatherer diversity in the deep past. Bison hunters occupied the Northern Plains before and after the Old Women’s phase. However, at our localities, they did not have the same impacts on prairie fire regimes. It is important to note that the Old Women’s phase involved intensified, communal bison hunting using stationary landscape features and was associated with seasonal aggregation of hunting bands. This temporarily elevated the population density, fostered increased ecological and political complexity (29, 35), and concentrated the impacts of anthropogenic burning. With the introduction of the horse in the early 1700s, hunters became much more mobile even as social and economic complexity persisted. Northwestern Plains foragers continued to use prairie fires as a tool and as a weapon but did not generate the same type of fire record as during the Old Women’s phase. The greater mobility of equestrian hunters, and probably of pedestrian hunters before the Old Women’s phase, meant that fire use would have been much more widely distributed on the landscape, rather than concentrated in association with drive line complexes. Extensive fire use by mobile foragers may be less easily distinguished from natural fires, particularly if it also leveraged climate opportunities to burn.

In this context, it is worth reiterating that changes in socio-economic organization can drive abrupt, climate-independent fire regime changes (17, 64, 65). This appears to have occurred in our study area first with the transition to intensive, place-based bison procurement and pemmican processing for trade (35, 66), followed by the adoption of the horse and transition to equestrian bison hunting (67). Although simple dichotomies between foragers and farmers may not be useful for interpreting human impacts on past fire regimes, closer attention to particular socioeconomic patterns and transitions may be useful for discriminating changes in human impacts on fire regimes. It is also important to stress that our records do not represent indiscriminate or broad, landscape-scale burning. Pyric herbivory for bison hunting would be useful only if the hunters could predict with a reasonable degree of certainty where bison were going to graze in the next hunting season. Burning too large an area or in areas too far from drive line gathering basins would undermine this goal. Therefore, it is likely that the fire patterns we have identified here are restricted to the uplands where drive line complexes occur: a fairly large but not necessarily continuous area from central Montana into southern Alberta and southwestern Saskatchewan. The asynchrony of dated fire layers from our two localities suggests that, even at the spatial scale of the Two Medicine River and the temporal scale of an individual pluvial episode, anthropogenic burning was not uniform across the area.

Finally, our study lends support to the growing body of work that indicates that coupled human–natural fire regimes should be understood as integral parts of food webs (27, 49, 68). Human uses of fire are largely, but not exclusively, related to their impacts on food resources (22). Changes in ecosystem structure associated with human uses of fire have important impacts on biodiversity (i.e., pyrodiversity) that have trophic consequences, only some of which have direct bearing on human economies and diets at the time (69). Because of these important trophic consequences and their impacts on the historical trajectories of fire-prone environments, it is important that we understand the full range of human influences on historical fire regimes, even if the entanglements of human activities and climate are not readily apparent at first glance. Understanding the full complexity of human experiences with fire and climate will be essential as contemporary communities plot a course to coexist with fire on a flammable planet (17, 52, 70).

**Methods**

From 2007 to 2012, M.N.Z. directed archaeological survey and excavations in the Two Medicine River upstream from the confluence with Badger Creek (Fig. 1). By using intensive survey methods, rock cairns were identified and mapped by using GPS (20). Alignments of rock cairns that formed drive line complexes were identified based on their spatial pattern, as distinct from other features for use of the two drive line complexes (1 m × 1 m) were conducted at four bone bed sites associated with drive line complexes (Badger, Racine, Stranglewolf, Two Medicine/Schultz) to supplement the regional survey. Stratigraphic excavations at the Kutoyis bone bed site and processing site revealed five thermal features (66) and at least three discrete layers of burned bone bone deposits. Bison bone, cane bone, charcoal, and blowfly pupae were radiocarbon-dated from the tested bone bed. Stratigraphic layers (Fig. Apendix, Table S1). Dates from these strata were calibrated by using a Bayesian algorithm in BCa (46) that used the radiocarbon dates and stratigraphic relationships as priors. Although the test excavations at regional bone bed sites are probably biased toward the younger deposits, the median probability distributions of these calibrated radiocarbon dates indicate that drive line and bone bed dates at the Two Medicine Valley spans at least 900–1650 CE with peak probabilities between 1400 and 1650 CE (SI Apendix, Fig. 5). Excluding a recent historic occupation, dates from the Kutoyis site are more representative of its total use and span 1200–1800 CE with peak probabilities between 1400 and 1650 CE (SI Appendix, Fig. 5). Luminescence dates from drive line cairns and rock rings demonstrate that drive lines, bone bed features, and campsites were coeval (71).

In 2010 and 2011, C.I.R. directed geoarchaeological fieldwork at four localities associated with three drive line complexes (Kutoyis, Two Medicine/ Schultz, and Stranglewolf). Two of these localities (KAP 2 and KAP 4) were selected for further analysis based on the presence of dense charcoal deposits that were interbedded within well-stratified alluvial (KAP 2) and colluvial (KAP 4) sequences. The stream terrace at KAP 2 is inset into an older terrace (KAP 3). Although it did not evince any charcoal deposits, samples were collected from KAP 3 to provide a longer-term context for KAP 2. In the field, erosional profiles were manually cleared by C.I.R. and K.L.H. to clarify the relationships between depositional strata and overprinted soils. Deposits were described, measured, and sampled for extracting charcoal for radiocarbon dating.

Deposits associated with elevated fire activity were identified based on continuous, laterally traceable (>3-m horizontal continuity), charcoal-rich deposits (elsewhere in this paper, “fire deposits”). Charcoal was dispersed in alluvium, colluvium, and soils at both localities superposed above and below the fire deposits. Although undoubtedly associated with prairie fire activity, dispersed or discontinuous charcoal deposits were treated as part of the background fire activity (30) and not as evidence of elevated fire activity that is the subject of this study. The glacial till that is parent material for the alluvial and colluvial sediments in our study includes inherited ancient charcoal, thereby potentially contaminating bulk and aggregated radiocarbon dates and making them artificially old (SI Appendix). Because of the potential for contamination by older carbon, the youngest dates on aggregated “grass” charcoal were preferred for developing the fire chronologies. The accepted charcoal dates were calibrated by using INTCaL 13 (72) in BCa (46) using traditional and Bayesian methods that intrinsically account for both stratigraphic relationships and the radiocarbon measurements as priors. Bayesian methods allowed us to estimate the probability of the ages for the two undated charcoal deposits from KAP 4, thus providing indirect dates. Traditional and Bayesian calibrations are presented in SI Appendix, Table S2. Posterior probability density functions for each dated fire deposit were summed by using annual probability values to generate the summed posterior probability density functions for each locality (Fig. 2) and for both localities together (Fig. 3). Summed probability distributions were then compared as time series vs. summed probability distributions from the regional archaeological sites (SI Appendix, Fig. 5) and vs. the Palmer Drought Severity Index (PDSI) reconstruction for grid point 83 in the North American Drought Atlas (NADA) version 2a (50), the nearest grid point in NADA to our study area (Fig. 18). As fire activity and fuels respond to previous moisture, decadal variability in the PDSI record was measured by creating a 10-y antecedent average of annual PDSI values (PDSI). For the analysis, decadal-scale pluvial episodes were identified as continuous periods with positive PDSI values for 10 y or longer.

**ACKNOWLEDGMENTS.** We thank Jesse Ballenger, who directed us to these localities; John Murray, who provided institutional support through the Blackfeet Tribal Historic Preservation Office; the Blackfeet Tribal Business Council and the Running Fisher family, who authorized archaeological research on their ancestral sites; and David Melzer, Tom Swetnam, and three anonymous reviewers for constructive comments on earlier drafts. This research was supported by National Science Foundation Awards BCS-0918081 and BCS-1266118 (to M.N.Z.); a Marj Scholarship at Southern Methodist University (M.M.M.E.H.); and University of Edinburgh, the Department of Anthropology, and the Dedman College of Humanities and Sciences at Southern Methodist University.