Meadow and lake-sediment based reconstructions of Holocene fire histories for sub-alpine and montane ecosystems in Great Basin National Park

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Overview

Our study focused on providing resource managers at Great Basin National Park (GBNP) with a long-term perspective of the linkages that exist between climate variability and fire disturbance regimes central Great Basin of the western United States (Figure 1). We used WNPA funds to study lakes and meadows within Great Basin National Park (GBNP) and matching funds from the Department of Geography at The Ohio State University (OSU) to study lakes in the East Humboldt and Ruby Mountains. We proposed a multi-year, multi-disciplinary scientific and education project featuring two components: **1) development of long-term fire histories for Great Basin National Park that span the Holocene; and 2) linking this newly developed fire histories to known drivers of Holocene climate variability in the Great Basin.** The study involved numerous researchers, including: undergraduate students (10) - James White, Jillian Dyer, Julia Andreasen, John Morgan-Manos, Mary Grace Thibault, Kelsey Simmons, Emily Sambuco, Jack Csokmay, John Shaub, Nischay Soni; graduate students (2) - Stephen Cooper and Forrest Schoessow; Staff- Jim DeGrand; Professors- Bryan Mark, Dave Porinchu and Scott Reinemann. The proposed timeline of two-years was eventually extended to three years to accommodate the additional laboratory analyses, dissertation publication, and faculty relocation. The original project was slated to be finished in September 2018, but was pushed back to August of 2019, thus extending the submission of this final report to September 2019. Throughout this project we have kept Park staff appraised of our progress, producing progress reports in April (2016), April & September (2017), April & September (2018), and April (2019).

Background and Motivation

Over the past several years, wildfire has proven to be a persistent and serious concern in the western United States. Wildfires represent complex systems where specific drivers and mechanisms may not be immediately apparent. For this reason, it is useful to look at past wildfire regimes to determine how human effects may induce change to forest structure and composition.

The high-relief and associated elevation-dependent climate gradients that characterize Great Basin National Park result in an ecosystem that supports an impressive diversity of plant and animal communities, including those associated with desert, montane, sub-alpine and tundra environments. The convectional thunderstorms that occur from late spring to early fall produce lightning strikes that can result in fire ignition, which can significantly affect biotic communities within the Park. For example, the Black Fire, a lightning ignited-fire that burned over 4,600 acres, occurred at the Park boundary in July 2013. Given the significance of fire to the Great Basin ecosystem, and particularly within GBNP, it is important that we improve our understanding of local fire regimes. This understanding will help contextualize both historic and future changes in fire disturbance regimes and highlight the role of fire in maintaining healthy and resilient forest ecosystems.

Our research project was thus designed to provide new insights into the late Holocene history of fire in GBNP and vicinity by collecting and analyzing new meadow sedimentary records and use archived lake sedimentary records of both macroscopic charcoal and sediment geochemistry. In submitting this final report, we gratefully acknowledge the financial support of the WNPA, matched by OSU Geography. In the following

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sections, we summarize the key results from our analyses, and provide a concluding synthesis of our insights with a list of published and presented findings.

Results and Discussion

We proposed to enhance the interpretive mission of the Park by documenting long-term changes in fire histories (frequency, severity and extent) in the GBNP's montane and sub-alpine forest ecosystems and in doing so, expand the temporal context of our understanding of natural variability in fire regimes in the Park. We have contributed to a growing body of wildfire research by generating a paleo-ecological record of past wildfire activity within GBNP. Specifically, we extracted five sediment cores from three different wetlands and one lake within the park. Then, back in our lab facilities, we analyzed three of these cores (extracted in 2009, 2014, and 2015) to determine how sedimentary charcoal varied throughout each core. We have completed additional analysis on the lake core to identify fossil pollen and sediment geochemistry. Before conducting any of these analyses, we needed to establish chronologies based on radiocarbon dates from each core to allow fire activity to be extrapolated through time. Below we give some examples of this process, highlighting our most significant findings.

In order to construct the age models that are critical to developing fire histories, we obtained radiocarbon dates using material extracted from the cores (Table 1 and Table 2). We recovered large, visible charcoal fragments either directly from the core or from samples remaining after a sieving process to remove smaller fragments. Determining the age model for each core also required us to use sedimentary principles and computer modeling software to evaluate if the radiocarbon dates were accurate and consistent. These considerations resulted in different numbers of dates available for each core. For example, we obtained 12 radiocarbon dates to determine the age model for the core we recovered in the meadow adjacent to Dead Lake (core DLM15, shown in Table 1). The age model performs well for the mostly continuous middle section of the core, but in the upper section of the core we encountered dates that were out of sequence with the stratigraphy, so we excluded the upper 40 cm from further analysis. Similarly, due to the presence of several gravel lenses and a poorly constrained age model, the material below 140 cm was also excluded from further analysis. The continuous middle section of the core, however, provided a robust age model similar to the middle section of DLM 14, and allowed undergraduate student James White to conduct a charcoal frequency analysis for his Honor's undergraduate thesis in Earth Sciences at OSU. Analysis of sedimentary charcoal provided evidence of fire activity within the catchment via changes charcoal accumulation rates (CHAR). A key outcome of his thesis has been quantifying rates of fires during the middle Holocene (5000-9000 years ago) (Figure 2).

One of the key outcomes exemplifying our project has been our record of fire history and vegetation change for Stella Lake in GBNP that comprises the research focus of a Master's thesis in Geography at the University of Georgia being completed by Stephen Cooper. This record covers the past two millennia, and includes analyses of **fossil pollen**, **sedimentary charcoal,** and **sediment geochemistry** (including total %C, total % N, and stable isotopes of N and C [δ^{15}N and δ^{13}C]). The analysis of fossil pollen has provided evidence of vegetative changes within the Stella Lake catchment via pollen percentages and the ratio of arboreal to non-arboreal pollen (AP/NAP; Morris et al 2013). Geochemical analyses of bulk sediment has provided additional evidence of how the terrestrial and lacustrine ecosystems have reacted to past disturbances. While still in process, we summarize below some of our interpretations about fire and ecology over the last 2000 years based on these analyses.

The 1st millennia of the Common Era (CE, formerly A.D.) was characterized by a period of relative ecological stability at Stella Lake. Proxy evidence suggests that there were no fires ($CHAR_{max}$ < 1 per cm^2/yr^{-1}) or erosional events within the catchment during between 0 CE and 800 CE. The sub-alpine forest surrounding Stella Lake was dominated by pine and spruce (*Pinus*/*Picea* co-dominant) during this interval (Figure 3). The first evidence of change occurred at ~750 CE with an increase in the relative abundance of grasses (*Poaceae).*

The abundance of grasses reached a maximum of 48% at 850 CE. A reduction in arboreal taxa occurred at this time as arboreal taxa reached their minimum percentages of the 1st millennia at ~850 CE. CHAR and $\delta^{15}N$ values began to increase after 800 CE, suggesting the occurrence of low intensity fires within the catchment between ~ 800 and ~1370 CE. From 1370 CE to 1600 CE, drastic changes took place in the catchment as fire activity increased (Figure 4). Evidence suggests that two major, catchment-wide fire events occurred during this period of time. At ~1490 CE the first of those events occurred. Sedimentation rates increased, suggesting increased erosion in the catchment. Maximum values of CHAR and $\delta^{15}N$ occurred following this fire event. Carbon flux to the lake sediment was significantly reduced and $\delta^{13}C$ dropped to its 2000 year minimum. Pollen production from arboreal taxa reduced following this event, but not to their lowest levels. AP/NAP values fell below zero (favoring non-arboreal taxa) for the first time in nearly 500 years. At ~1570 CE, CHAR again increased significantly. This increase suggests the occurrence of a second major fire event. Similar to the previous event, $\delta^{15}N$ increased as $\delta^{13}C$ fell. Following this event, AP/NAP dropped to the lowest values of the entire record. Arboreal pollen production was at the 2000 year minimum at ~1575 CE, while *Poaceae* represented >50% of total pollen at that time. Evidence suggests that these two fires are the most significant disturbances to have occurred in the Stella Lake catchment over the last 2000 years. Moreover, the AP/NAP values show that the forest structure at Stella Lake has not yet recovered fully from these two fires.

Interpretive Product

As a prototype, we envision featuring the results of this study and the produced figures, images, and text on a poster and/or a story map to display at GBNP. This product could be reproduced and disseminated as directed by Park staff, e.g. online or in one of the two visitor centers. This interpretive product does differ from the originally proposed informative video on the research approaches and methodologies utilized to develop fire histories. We justify this change based on our inability to find a suitably skilled student. The idea of a “Story Map” or poster would be of interest to the park as a tangible product of the research we have finished.

Conclusion

Results from this study are two fold; **(1)** our Holocene meadow records indicate a fire return interval of approximately one major fire every 200 years. There appears to be a period of high fire activity roughly 6800 years ago. The return interval before this point appears much longer than two hundred years, signaling a rapid, sustained shift in the ecosystem 6800 years ago. This shift may be linked to major local scale drought events seen in other paleoclimate record around this time. **(2)** A 2000 year record using a multiproxy analysis of organic geochemistry (%C, %N, $\delta^{13}C$ and $\delta^{15}N$) and sedimentary charcoal, at multi-decadal resolution, reveals that a major disturbance occurred in the Stella Lake catchment between CE 1480 and CE 1510. Sedimentary charcoal suggests that this disturbance was likely a large, severe, catchment-scale fire. The geochemical evidence and preliminary charcoal data generally track well with the chironomid-inferred T (°C) at the site (Reinemann et al. 2014), suggesting that the aquatic community in Stella Lake had been responding primarily to climate until ~1500 CE; however, the sediment geochemistry suggests that following 1500 CE the aquatic biota likely responded to the fire event, rather than to changes in MJAT. During the modern era (1850-2009), sediment geochemistry suggests a shift toward higher lake productivity and C_4 (grass and sedge) vegetation, which agrees with the midge-based inference of increasing MJAT during this interval (Reinemann et al. 2014). As a note towards future research a broader geographic diversity in the core sites would allow researchers to test if fire frequency was regionally consistent throughout the park. On a larger scale, the wider Great Basin region would benefit from further charcoal analysis in order to better understand the geographic variation in fire response. Paired with other paleo-environmental research, this analysis can be used to help understand the drivers of wildfire activity through time.

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Table 1 DLM Radiocarbon dates

Core	Depth (cm)	δ13C(^{0}/00)	^{14}C age years BP	Date Error (+/-)	Calibrated years BP
DLM14	13	-21.4	1090	25	975
DLM14	77	-24.9	5290	30	6005
DLM14	131.5	-23.5	6710	30	7580
DLM15	10	-24.6	4450	20	5050
DLM15	14.5	-24.71	3740	20	4135
DLM15	26.5	-24.88	3450	40	3695
DLM15	30	-24.12	3590	40	3890
DLM15	39.5	-23.99	4710	30	5465
DLM15	40	-23.05	940	20	830
DLM15	61	-24.18	5010	25	5740
DLM15	65	-29.02	0	N/A	N/A
DLM15	88.5	-23.4	6180	30	7030
DLM15	104.1	-23	6830	35	7670
DLM15	139.3	-23.8	7430	30	8210
DLM15	164.8	-20	8110	30	9020
SFB	55.5	-24.85	7720	30	8520
SBC	60	-27.15	1300	25	1270

Table 2 Stella Lake radiocarbon dates

UGAAMS#	Sample ID	core depth	Material	δ^{13}C, ‰	^{14}C age years, BP	±	pMC	±
29940	GB-SL-09 PT1 1	11.5 cm	needle	-25.09	modern		122	0.34
29941	GB-SL-09 PT1 2	32 cm	needle	-24.3	70	25	99.17	0.29
29942	GB-SL-09 PT1 3	40.75 cm	needle	-21.76	200	25	97.55	0.3
29943	GB-SL-09 PT1 4	45.75 cm	twig	-23.08	310	25	96.21	0.29
29944	GB-SL-09 PT1 5	62.5 cm	needle	-23.37	480	25	94.23	0.28
38784	GB-SL-09 LC1A 7	72.25 cm	wood	-25.16	1110	20	87.09	0.24
29945	GB-SL-09 LC1A 6	83 cm	wood	-23.57	2130	25	76.67	0.23

Figure 1. Location of study site.

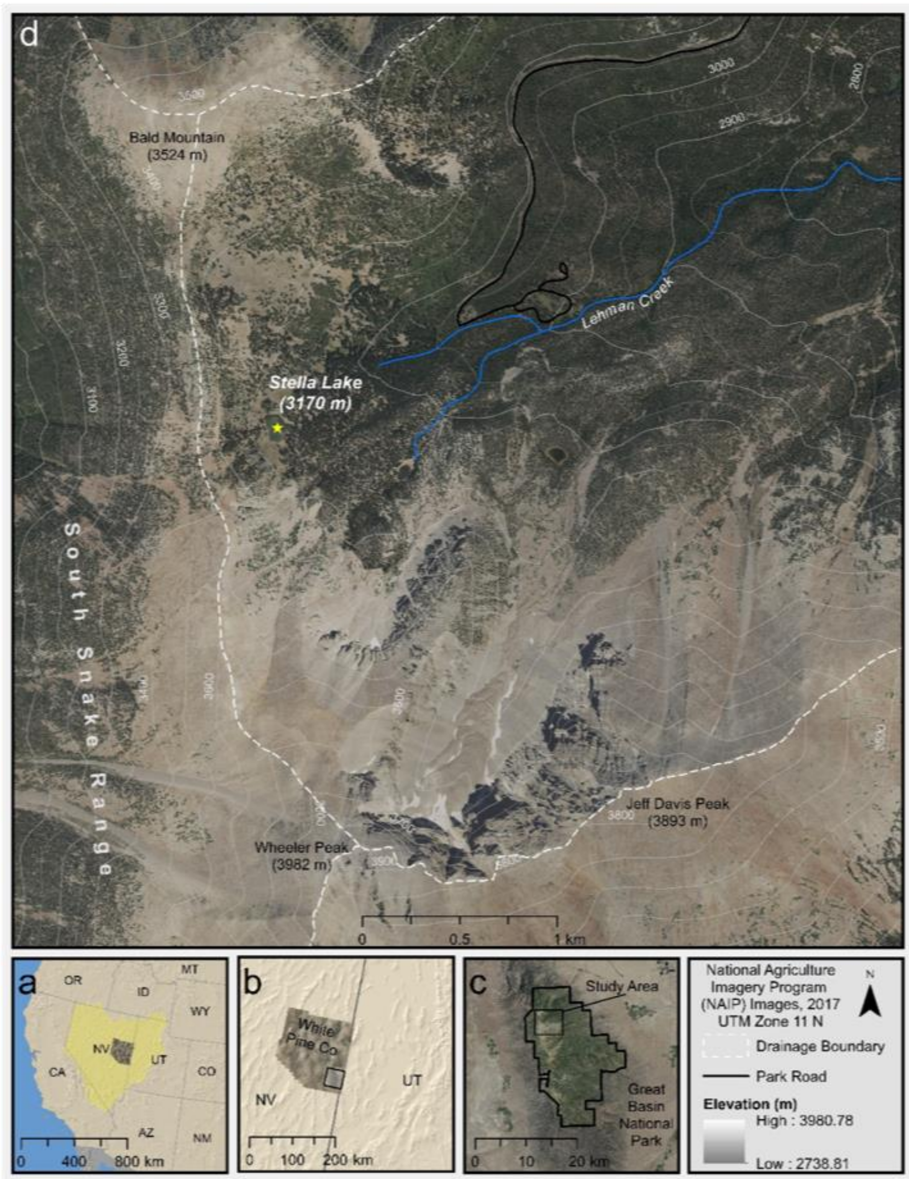

Figure 2. Calculated fire frequency for DLM14 on the left and DLM15 on the right. Both show a generally active regime in the past followed by a dip in fire activity and then a second rise but with an offset timing between the two.

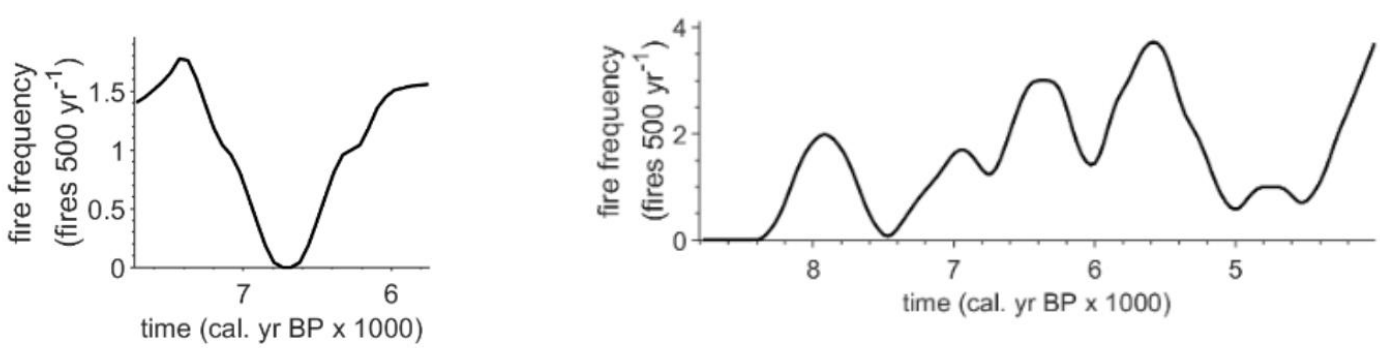

Figure 3. Fossil Pollen diagram from Stella Lake.

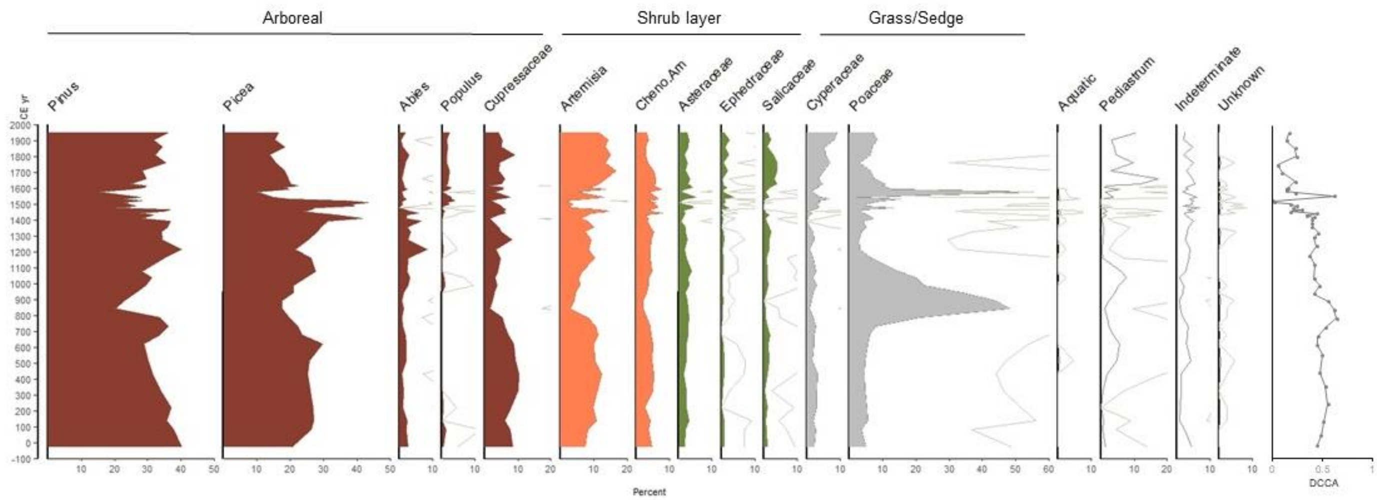

Figure 4. Charcoal accumulation rates from Stella Lake