Holocene records of fire in the subalpine forests of Utah: Linkages to climate change, forest composition and beetle infestations.

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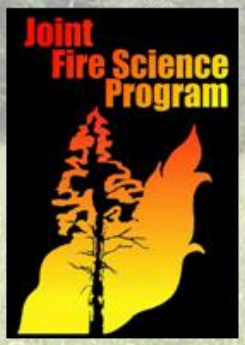

This research was sponsored by the Joint Fire Science Program. For further information go to www.firescience.gov

Photo Credit: Ghost forest of Engelmann spruce, Wasatch Plateau, 2005 (A. Brunelle)

I. Abstract

JFSP project # 06-3-1-31 intended to reconstruct the past vegetation and fire regimes for the high elevation spruce/fir ecosystems of central and southern Utah using lake sediment archives (pollen, charcoal and macrofossils). In conjunction with the vegetation and fire regimes, we also intended to determine if spruce beetle outbreaks occurred over the last 10,000+ years, and if so, the relative significance of this disturbance compared to fire. The results of this project indicated the most spruce beetle outbreaks do not leave macrofossil evidence in the sedimentary record. However, a new methodology to identify past outbreaks using pollen abundance was developed. It was discovered that spruce beetle outbreaks have occurred in the past, and they occur with an average frequency of an event every ~600 years. Fires occur approximately every 350-400 years. Fires and spruce beetle outbreaks were uncommon during the period of spruce parkland vegetation type, but became more common as the spruce/fir forest ecosystem evolved on the landscape. Less than one quarter of the spruce beetle outbreaks over the Holocene are coincident (within 100 years) with a fire episode. The most recent spruce beetle outbreaks appear to be greater in magnitude than any of the other outbreaks over the record. Three manuscripts have already been produced from the project results, with another to be submitted in the calendar year, and several others in progress. Interpretive materials (posters and handouts) are underway and arrangements have been made with the management units for posting. All published results will be posted on FRAMES website and the project website for dissemination to the management and scientific communities.

II. Background and Purpose

As a result of extensive research, it is given that fire regimes are best understood in conifer forests. However, "best" implies a relative scale, the base of which is no knowledge about a given environment. Although this study proposes to address fire in conifer systems, we argue that there is still much to learn about many evergreen systems and that this missing information can contribute to land management efforts related to wildfire and other disturbances.

This project reconstructed fire history records spanning the last 13,000 years for spruce-fir forests of Utah because such long-term histories are lacking for the subalpine spruce-fir ecosystem. There are some dendrochronological examinations of fire and disturbance in spruce-fir forests from Alaska and Colorado, however they encompass the last 500-1000 years at most. Because the wildfire-return interval in spruce-fir forest is long (200-400 years, Peet, 1981), even the dendrochronological records cannot provide sufficient insight into fire dynamics in this high elevation environment. Also, according to Kulakowski et al. (2003), using tree-rings to infer fire regime from a high-elevation spruce-fir forest where stand-replacing fires seem to be the norm, can lead to erroneous results because the trees are not left to be scarred.

Fire is not the only disturbance in the spruce-fir forests of the west. The impacts of insect infestations (especially bark beetles) are said to equal (Baker and Veblen, 1990) or exceed (Logan and Powell, 2001) those of fire. As the occurrence of fire and epidemic insect infestations are both strongly influenced by climate, in order to understand patterns of disturbance, climatic conditions preceding the event are extremely important (Hebertson & Jenkins 2008). In Utah, spruce beetle (SB), *Dendroctonus rufipennis* and mountain pine beetle (MPB), *D. ponderosae* outbreaks have affected millions of trees within the last several decades.

This project provides insight on the relative significance of fire and spruce beetle outbreaks in the spruce-fir forest of Utah.

Information on past fire, beetle, climate and vegetation dynamics was generated using lake sediment analyses. The first order deliverable for this project is the Holocene fire reconstructions. These fire reconstructions provide information on the fire regime that overlap temporally with those from dendrochronology, but also extend back in time through the Holocene. The Holocene records include periods of time both cooler and warmer than present, with early Holocene summer temperatures an estimated to be 2-4^{o}C warmer than today (Kutzbach et al. 1998). Fire reconstructions from this period provide an analog for climate and fire conditions expected as a result of global warming for the next century.

In addition to the information about past fire regimes, we also provide information on past SB infestations and their relationship to fire and climate. There is much debate about the role of fire in forest ecosystems that have been impacted by beetles, particularly in high elevation forests. Modern studies of SB infestations suggest that fire does not necessarily follow epidemic outbreaks, that drought and appropriate fire weather must occur during the outbreak when fine fuels are available or as the trees drop to the forest floor increasing the fuel loads which add to fire intensity (Jenkins et al 2008, Jorgensen & Jenkins, in press, Jorgensen & Jenkins, in review). Currently management strategies within spruce beetle affected forests consider this information. In addition, the dendrochronological records of SB only cover the last 300-500 years, which considering the modern frequency of SB outbreaks and fire does not provide a long enough record to evaluate the relationships between fire and spruce beetle affected forests. Recent research in western Colorado examines the 1940s White River spruce beetle outbreak and associated fire history (Kulakowski et al. 2003). However, this is only a short-term evaluation based on recent events, limited to west-central Colorado. Evaluating the relationships among beetle infestation, spruce, and fire during the early Holocene when climate was similar to that modeled for the next hundred years provides resource managers with valuable information associated with managing spruce-fir forests.

III. Study Description and Location

We present reconstructions of Holocene fire history from lakes on the Wasatch, Aquarius and Markagunt Plateaus (Figure 1). All three areas have experienced, or are experiencing spruce beetle mortality at landscape scales. Spruce beetle has significantly impacted the Wasatch Plateau where over 95 percent of the spruce greater than 10 inches diameter breast height has been killed by the insect (Dymerski et al. 2001). The forest type on the Wasatch Plateau was predominantly Engelmann spruce, (*Picea engelmanii*)with less than 22 percent of the basal area in subalpine fir, (*Abies lasiocarpa)* and minor amounts (<4 percent) of quaking aspen, (*Populous tremuloides),* Douglas-fir, (*Pseudotsuga menziesii)* and limber pine, (*Pinus flexilis).* We also reconstructed environmental histories from the Aquarius Plateau where a spruce beetle outbreak occurred in the 1920s and a site on the Markagunt Plateau where there was an outbreak in the 1990s (DeRose and Long 2007).

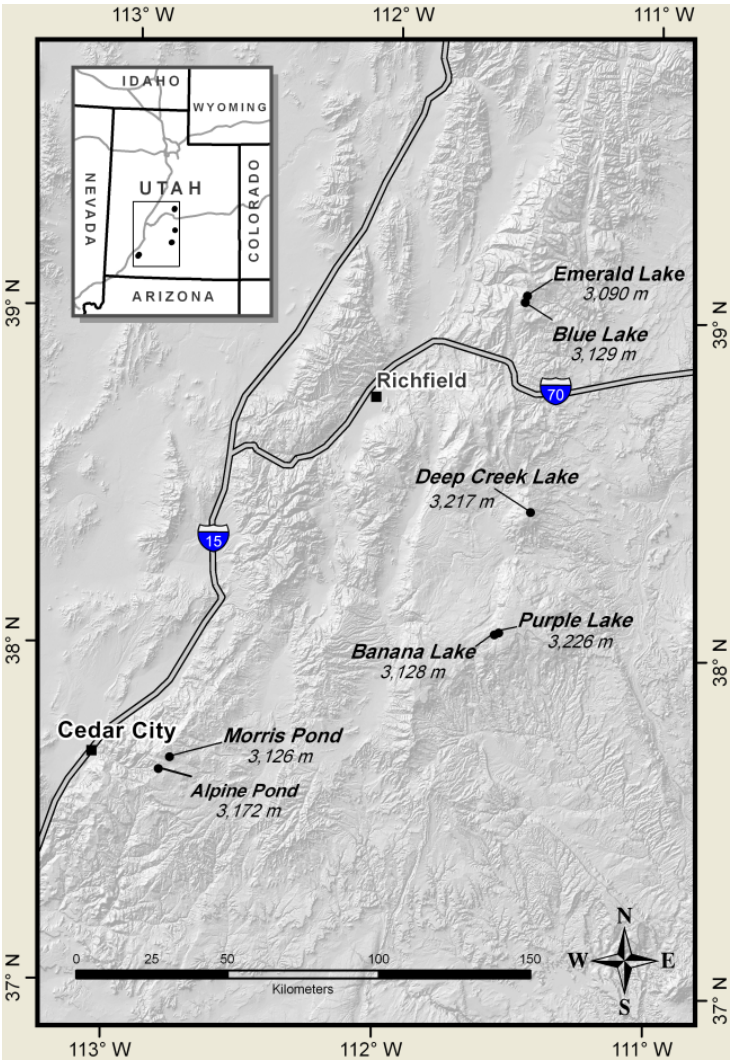

Figure 1. Site map of locations studied for this project. Emerald and Blue lakes are located on the Wasatch Plateau, Deep Creek Lake on Thousand Lakes Mountain, Purple and Banana lakes are on the Aquarius Plateau and Morris and Alpine ponds are on the Markagunt Plateau.

IV. Key Findings

1. Elytra are not commonly found in lake sediments associated with beetle outbreaks.
    a. Because elytra from mountain pine beetle were discovered and identified from lake sediments in the Northern Rocky Mountains (Brunelle et al. 2008), it was assumed that basins that had historic outbreaks would have identifiable elytra in the sediments from those events, and that earlier Holocene events would also be identifiable. However, in every case (Morris et al. 2010; Morris and Brunelle, in review; Morris et al., in review; Brunelle et al., in review) there were no spruce beetles identified from the stratigraphic layer associated with the outbreak. Part of this is attributed to lake chemistry (Morris et al. 2010), but part is also attributed to taphonomy and climate conditions at the time of beetle flight (Morris and Brunelle, in review).
2. Outbreaks are detectable using pollen.

a. Because elytra were not available from the sedimentary record, new methods for identifying outbreaks were sought. Because of the ecosystem response to a spruce beetle outbreak (loss of spruce, release of fir) it was thought that there would be a significant pollen signature associated with the outbreaks. This was identified, carefully calibrated and is reported in Morris et al. 2010 and Morris and Brunelle, in review. It was this multiple site, high resolution calibration that extended the timeline of the project. However, it has provided a new tool for other researchers to use to identify beetle outbreaks over Holocene time scales (see New Deliverables below).

3. The relationship between fire and spruce beetle outbreaks.
    a. Abstract from Brunelle et al. (in review)

    This research provides some critical insights into disturbance ecology for subalpine spruce/fir ecosystems. The Emerald Lake record demonstrates that spruce beetle (*Dendroctonus rufipennis*) outbreaks are an important part of the disturbance regime, with a recurrence interval of 615 years. Fires are also an important component of the disturbance regime, with mean fire return interval (MFI) for last 8000 years at 374 years, and the MFI for the entire 13,000 record at 391 years. The reconstruction also supports the dendroecological data which indicate that fires are not necessarily more likely following a spruce beetle outbreak. Of the 13 outbreaks of the last 8000 years, only 3 are followed by a fire within 100 years. The Emerald Lake record also demonstrates that forest composition is important in disturbance ecology. In the late Pleistocene/early Holocene portion of the record, the pollen data suggest that the ecosystem was a spruce parkland, and vegetation was open. During this time period fires are rare, and there is no indication of spruce beetle outbreaks. Once spruce/fir forest develops, outbreaks and fires become more common. This is significant as vegetation composition changes are likely to occur with climate change. And finally, the Emerald Lake record shows that the most recent SB outbreak in the 1980s is unprecedented in magnitude for the entire 13,000 year record. The intensity of this outbreak is likely associated with historic modifications of the landscape, including logging, grazing, and fire suppression.

4. The Holocene fire regime from 4 high plateau lakes
    a. The data from four sites (Purple Lake, Morris Pond, Emerald Lake and Blue Lake) are in the final phase of analysis. The fire histories from these sites represent the first Holocene fire history reconstructions from subalpine spruce:fir systems in the world (Global Charcoal Database (GCD), accessed September 2010). To provide context for the fire regimes in the spruce:fir sites, records from other sites in the GCD at varying elevations and in different systems will be compared. The manuscript for this finding will be complete and a copy of the draft submitted for review (International Journal of Wildland Fire) sent to JFSP by November 1, 2010.

V. Management Implications

The Forest Service operates under the mandate of facilitating a “multiple-use” approach to meet resource objectives across landscapes. Multiple-use includes a variety of resource objectives which include timber harvesting, recreation, grazing, wildlife, landscape aesthetics , minerals, soils, fisheries, water quality, wilderness etc. With such a diverse list of resource objectives

and often competing demands on a resource, it is important to have as much information about a particular ecosystem in question as possible. Often knowledge about a given forest ecosystem and patterns of disturbance are only available for the previous 100 years. However, many of the systems have processes and non-linear cycles that take centuries or millennia to occur thus making these patterns more difficult to discern. In the case of spruce beetles and wildfire, resource managers have speculated that increased wildfire risk occurs as a result of spruce beetle outbreaks. It has been reported in the tree-ring literature that this is not the case (Veblen et al. 1994; Bebi et al. 2003; Kulakowsi and Veblen 2007), and that the increased probability of wildfire ignition only occurs over a short period of time when dead needles remain on the tree. Because tree-ring records only record the last ~ 300 years, there has been uncertainly about the robustness of those data over the longer forest history. The long-term records obtained in this study corroborate the tree-ring records, indicating that wildfires are not usually associated with spruce beetle outbreaks, that beetle outbreaks have occurred every ~ 615 years over the last 8000 years, and fires occur (on average) every 374 years. While our record indicates that spruce beetle outbreaks are generally not associated with wildfire, of the 13 outbreaks in the last 8000 years, 4 have fire events occurring within less than 100 years following the outbreak. It should also be noted however, that impact of human disturbance (settlement logging; Morris et al. 2010) and the most recent spruce beetle outbreak (Brunelle et al. in review) seem to be greater in magnitude than other disturbance events that have occurred over the last 8000-12,000 years in the high elevation spruce-fir ecosystem where these studies were conducted.

VI. Relationship to Other Recent Findings and Ongoing Work

Research on spruce beetle outbreaks has been conducted using tree-ring records (e.g. Baker and Veblen 1990; Veblen et al. 1994; Kulakowski 2003; Kulakowski and Veblen 2007) and similar work continues today by Veblen, Kulakowski, Sherriff and others. Anderson et al. (2010) are also working on detecting past spruce outbreaks using pollen, and Brunelle and her research group are continuing to pursue the identification of past mountain pine beetle outbreaks using lake sediments as well.

Results from the funded project presented here are in agreement with the results from the tree-ring community. It does not appear that beetle outbreaks lead to increased incidence of fire, but that these high elevation fire events are more controlled by the unique climate conditions (unusual drought, stand conditions) that allow fuels to become susceptible to carrying fire (i.e. Bessie and Johnson 1995).

VII. Future Work Needed

The research here provides fire histories and the relationship between fire and spruce beetle outbreaks for several high elevation spruce/fir ecosystems in Utah. A critique of the originally funded proposal was that we as researchers needed to be careful to not take our geographically limited results and assume that they are relevant to similar systems across the western U.S. We agree with this statement and caution completely. The funded project reported here has provided the first Holocene history of fire and spruce beetle outbreaks and also provides a new, and much needed methodology for repeating this work in other locations. Additional studies looking at spruce beetle outbreaks, fire and vegetation should be conducted in other spruce ecosystems in the west, including Alaska to verify the relationships identified here.

VIII. Deliverables

Primary Deliverables (original)

1. Four Holocene fire reconstructions
    a. Morris et al. (in preparation, to be submitted by November 1, 2010)
2. Information on the relationship between fire and spruce beetles.
    a. Brunelle et al. (in review)

Secondary Deliverables (original)

1. Information on climate and spruce beetle outbreaks over the Holocene.
    a. Brunelle et al. (in review)
2. Information on how spruce beetle and fire affect forest composition.
    a. Morris et al. (2010), Brunelle et al. (in review)

Management Deliverables (original)

1. "Contribute to management strategies for high elevation spruce-fir forests in Utah and other western states."
    a. Working closely with Forest Health Protection/Forest Service collaborators. All publications being sent out to relevant FS field offices.
2. Provide a website with research findings.
    a. http://www.geog.utah.edu/red_lab_research/red_lab_fire_science.html (still under construction)
3. Link that website to FRAMES.
    a. Permission has been granted to link final results website (above) to FRAMES research website. The research project and publications will also be cataloged on FRAMES.
4. Attend workshops and meetings to disseminate information about beetle outbreaks and fire in Utah.
    a. Attended and presented 3 talks at 2 WFIWC (Western Forest Insect Working Conference) Meetings in 2007 and 2010.
        i. Brunelle, A., Morris, J., Munson, S. Long-term records of spruce beetles and fire from Utah. Western Forest Insect Work Conference, Boise, Idaho. (2007)
        ii. Brunelle, A., Rehfeldt, J., Bentz, B., and Munson, S. (2007). Lake Sediment Records of Mountain Pine Beetle Infestations. Western Forest Insect Work Conference, Boise, Idaho. (2007)
        iii. J. Morris, A. Brunelle, A.S. Munson . Using sedimentary proxies to infer past spruce beetle outbreaks. Western Forest Insect Work Conference, Boise, Flagstaff, Idaho. (2010)
    b. Attended and presented at the International Fire Ecology Conference in 2009.
        i. Brunelle, A. A Holocene record of fire from a subalpine Utah forest: linkages to climate change, forest composition and beetle infestations. Association of Fire Ecology, Savannah, GA.
    c. Presented at multiple Association of American Geographer (AAG) meetings.
        i. Morris JL and A Brunelle 2010.Calibration and application of sedimentary proxies in evaluating spruce beetle disturbances from the high plateaus of Utah. Association of American Geographers, April 14-18, Washington, DC.

ii. Morris JL and A Brunelle 2009. Inferring pre-historic spruce beetle outbreaks from lakes sediments. Association of American Geographers, March 22-27, Las Vegas, Nevada.
iii. Morris JL and A Brunelle 2008. Sedimentary evidence of spruce beetle outbreaks. Association of American Geographers, April 15-19, Boston, Massachusetts.
iv. Morris JL and A Brunelle 2007. Sedimentary signals of disturbance from the Wasatch Plateau, Utah. Association of American Geographers, April 17-21, San Francisco, California.
v. Morris JL and A Brunelle 2006. Climate dynamics, spruce beetle and forest disturbance regimes in central Utah. Annual Meeting of the Association of America Geographers, March 7-11, Chicago, Illinois.

d. Gave an invited talk at "Restoring the West" in Logan, UT (November 2009).
    i. Brunelle, A. An introduction to paleoecological data and their utility in ecosystem restoration.
e. Gave invited talk to University of Minnesota Geography Department (January 2009).
    i. Brunelle, A. Using Paleoecology to Understand Disturbance Ecology in Western Forests.
f. Gave invited brown-bag talk to University of Utah Museum of Natural History Docent group.
    i. Brunelle, A., Morris, J. and Munson, S. (2008). Beetles, Fire, and Humans- Evidence of Forest Disturbance on the High Plateaus of Utah.
g. Gives annual talks to the Environmental Studies program, University of Utah.

New Deliverables (in addition to those promised in proposal)

1. Methodology to detect spruce beetle outbreaks from pollen
    a. When the elytra were not discovered in the sediments of any of the lakes that had known, historic bark beetle outbreaks, a new method needed to be developed to identify these disturbance patterns in the past. Using high resolution pollen analysis we were able to devise a way to identify the known outbreaks (Morris et al. 2010, Morris and Brunelle, in review)
2. Providing public information documents to Cedar Breaks National Monument
    a. Providing signage for the trailhead to Alpine Pond, in Cedar Breaks National Monument, Markagunt Plateau. To be installed early summer 2011.
    b. Providing pdf version of poster installed in Cedar Breaks National Monument which will be available on the Parks website. Early summer 2011.
    c. Providing trifold information pamphlets for all regional Forest Service offices proximal to the Wasatch, Aquarius, or Markagunt plateaus. To be distributed by December 2010.

IX. Publications Resulting from JFSP #06-3-1-31 (*copies attached*)

Morris, J.L., Brunelle, A., Munson, A.S. (2010). Pollen Evidence of Late Holocene Disturbance on the Wasatch Plateau, Utah. *Western North American Naturalist* 70(2):175-188.

Brunelle, A., Morris, J.L, Munson, A.S., and Power, M.J. **(***In Review*). A Holocene record of spruce beetles, wildfire and vegetation from a high elevation basin from the Wasatch Plateau, Utah, USA. *Forest Ecology and Management.*

Morris, J.L., Brunelle, A., Munson, A.S., Power, M.J., Bares, R., and Spencer, J. (*to be submitted by November 1, 2010).* Sedimentary records of Holocene fire regimes from four spruce/fir basins in subalpine ranges of the Colorado Plateau, USA . *International Journal of Wildland Fire.*

Morris, J.L. and Brunelle, A. (*In Review*). Pollen records of historic spruce beetle (*Dendroctonus rufipennis*) disturbance: A calibration study from the subalpine ranges of southern and central, Utah, USA. *The Holocene*.

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Jorgensen, C.A. and Jenkins, M.J. Predicted fire behavior in selected spruce beetle infested Engelmann spruce stands. *Forest Science* (In review).

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