# Table of Contents

## Front Matter

UW-NPS Research Center Personnel ................................................................. v
Director’s Column .......................................................................................... vi

## Research Project Reports

### Geology

Shallow Seismic Investigation of the Teton Fault
Glenn Thackray, Mark Zellman, Jason Altekruse, Bruno Protti, and Harrison Colandrea .................................. 2

### Hydrology

Measuring the Morphology and Dynamics of the Snake River by Remote Sensing
Carl J. Legleiter and Brandon T. Overstreet ...................................................... 12

### Ecology

Kelly Warm Springs Historical Data Summary: Progress Report
Paige Anderson, Aida M. Farag, and David D. Harper ................................... 22

Simulating Expected Changes in Pollinator Resources as a Function of Climate Change
Diane M. Debinski, Kim Szcodronski, and Matthew Germino ........................ 29

Spatio-temporal Ecological and Evolutionary Dynamics in Natural Butterfly Populations (2014 Field Season)
Zachariah Gompert and Lauren Lucas ............................................................... 34

Water Flow and Beaver Habitat in Grand Teton National Park: Adaptation to Climate Change
William J. Gribb and Henry J. Harlow ............................................................. 38

Succession Effects on Mammal and Invertebrate Communities 26 Years after the 1988 Huckleberry Mountain Fire
Hayley C. Lanier, Andy J. Kulikowski, R. Scott Seville, Zachary P. Roehrs, and Meridith A. Roehrs .................. 49

Dendrochronological Assessment of Whitebark Pine Response to Past Climate Change: Implications for a Threatened Species in Grand Teton National Park
Kendra K. McLauchlan and Kyleen E. Kelly ..................................................... 58

Evaluating the Effects of Projected Climate Change on Forest Fuel Moisture Content
Kellen N. Nelson and Daniel B. Tinker .............................................................. 65

A Non-invasive Population Study of Moose in Northern Yellowstone National Park
Ky B. Koitzsch, Lisa O. Koitzsch, Jared L. Strasburg, and Tessa Tjepkes ................. 70
Cultural Resources

Archaeology and Social Geography of the Sunlight Basin, Wyoming
Laura L. Scheiber and Amanda Burtt ................................................................. 85

The Upper Snake River Headwaters: Photo, Video and Audio Documentation
Michael Sherwin .................................................................................................. 97

The Teton Archaeological Project: Report from the 2014 Inaugural Field Season
Matthew A. Stirn and Rebecca A. Sgouros .......................................................... 99

Human Dimensions of Resource Management

Assessing the Potential of the River Otter to Promote Aquatic Conservation in the Greater Yellowstone Ecosystem:
A Unique Approach for Developing a Long-term Aquatic Flagship
Kelly J. Pearce and Tom L. Serfass ...................................................................... 108

INTERNSHIP REPORT

Water Resources Internship Report: Grand Teton National Park
Matthew Rouch ................................................................................................... 115

CLASSES

Field Research and Conservation Class: Clayton High School, Clayton, MO
Chuck Collis, Clayton High School, Clayton, MO .................................................. 118

Inquiry-based Geology Field Course for In-service Educators
David Harwood and Kyle Thompson, University of Nebraska-Lincoln ................. 124

Outdoor Studio Class: University of Wyoming Visual Arts Department
Patrick Kikut, University of Wyoming .................................................................. 126

Biology Field Studies: Grand Teton National Park
John S. Scheibe and James H. Robins, Southeast Missouri State University ........... 128

Utah State University Watershed Sciences Graduate Student Induction Course
Joseph M. Wheaton and Patrick Belmont, Utah State University ......................... 133

CONFERENCES AND MEETINGS

INBRE Network Retreat at UW-NPS Research Station in Grand Teton National Park
R. Scott Seville, University of Wyoming ............................................................ 136
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HAROLD L. BERGMAN ✤ DIRECTOR
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During the period of this report the University of Wyoming-National Park Service (UW-NPS) Research Center supported and administered research in the biological, physical and social sciences and cultural resources performed in national parks, national forests and surrounding areas in the Greater Yellowstone Ecosystem. The UW-NPS Research Center solicited research proposals from university faculty, governmental research scientists and non-governmental research organizations throughout North America via a request for proposals. Research proposals addressed topics of interest to National Park Service scientists, resource managers, and administrators as well as the academic community. Studies conducted through the Center dealt with questions of direct management importance as well as those of a basic scientific nature.

The Research Center continues to consider unsolicited proposals addressing applied and basic scientific questions related to park management. Research proposals are reviewed and evaluated by the Research Center’s proposal review committee. This committee is composed of university faculty and National Park Service representatives and is chaired by the Director of the UW-NPS Research Center. Research contracts are usually awarded by early April.

The UW-NPS Research Center also operates a field research station at the AMK Ranch on Jackson Lake in Grand Teton National Park. The research station provides researchers in the biological, physical and social sciences and cultural resources an enhanced opportunity to work in the diverse aquatic and terrestrial environments and the cultural resources of Grand Teton National Park and the surrounding Greater Yellowstone Ecosystem. Station facilities include housing for up to 60 researchers, wet and dry laboratories, a library, herbarium, boats, and shop accommodations. The research station is available to researchers working in the Greater Yellowstone Ecosystem regardless of funding source, although priority is given to individuals whose projects are funded by the Research Center.

More information about the UW-NPS Research Station, including facilities and housing, past research, seminars and other current events, and location information, can be found at the station’s web site: http://uwnps.org/.

Research Project Reports

The following project reports have been prepared primarily for administrative use. The information reported is preliminary and may be subject to change as investigations continue. Consequently, information presented may not be used without written permission from the author(s). Reports from past research at the station (1954–present) are available online and full-text searchable from here: http://repository.uwyo.edu/uwnpsrc_reports.
SHALLOW SEISMIC INVESTIGATION
OF THE TETON FAULT

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SUMMARY

Preliminary results from seismic data collected at two sites on the Teton fault reveal shallow sub-surface fault structure and a basis for evaluating the post-glacial faulting record in greater detail. These new data include high-resolution shallow 2D seismic refraction and Interferometric Multi-Channel Analysis of Surface Waves (IMASW) (O’Connell and Turner 2010) depth-averaged shear wave velocity (Vs). The Teton fault, a down-to-the-east normal fault, is expressed as a distinct topographic escarpment along the base of the eastern front of the Teton Range in Wyoming. The average fault scarp height cut into deglacial surfaces in several similar valleys and an assumed 14,000 yr BP deglaciation indicates an average postglacial offset rate of 0.82 m/ka (Thackray and Staley, in review). Because the fault is located almost entirely within Grand Teton National Park (GTNP), and in terrain that is remote and difficult to access, very few subsurface studies have been used to evaluate the fault. As a result, many uncertainties exist in the present characterization of along-strike slip rate, down-dip geometry, and rupture history, among other parameters. Additionally, questions remain about the fault dip at depth.

Seismic data were collected using highly portable equipment packed into each site on foot. The system utilizes a sensor line 92 m long that includes 24 geophones (channels) at 4 m intervals. At both the Taggart Lake and String Lake sites, P-wave refraction data were collected spanning the fault scarp and perpendicular to local fault strike, as well as IMASW Vs seismic lines positioned on the hanging wall to provide Vs vs. Depth profiles crossing and perpendicular to the refraction survey lines.

The Taggart Lake and String Lake 2D P-wave refraction profile and IMASW Vs plots reveal buried velocity structure that is vertically offset by the Teton fault. At Taggart Lake, we interpret the velocity horizon to be the top of dense glacial sediment (possibly compacted till), which is overlain by younger, slower, sediments. This surface is offset ~13 m (down-to-the-east) across the Teton fault. The vertical offset is in agreement with the measured height of the corresponding topographic scarp (~12 - 15 m). Geomorphic analysis of EarthScope (2008) LiDAR reveals small terraces, slope inflections and an abandoned channel on the footwall side of the scarp. At String Lake, the shallow buried velocity structure is inferred as unconsolidated alluvium (till, colluvium, alluvium); this relatively low velocity zone (<1000 m/s) is spatially coincident with the center of a gully, and appears to be vertically offset 10 – 14 m across the Teton fault. Scarp heights adjacent to the gully to the north and south are ~35 m.

Final interpretations are forthcoming pending additional data processing and analysis. This project was funded by a grant awarded by the University of Wyoming-National Park Service Research Center.
STUDY AREA

This study evaluated a total of five sites within GTNP using shallow seismic survey methods (Figure 1). At the Taggart Lake and String Lake sites, P-wave refraction and IMASW Vs data were collected across the Teton fault scarp to evaluate vertical offset and image the fault structure in the shallow subsurface. These sites were selected because they 1) are located on the main trace of the Teton fault, 2) exhibit simple fault geometry where all or most slip appears to be accommodated on a single strand, 3) have sparse or open vegetation cover, 4) are within hiking distance from the nearest trailhead, and 5) are likely to be locations where velocity contrasts created by slower alluvium in the hanging wall directly juxtapose crystalline bedrock of the footwall and could be imaged with seismic data. The 3 remaining field sites were located adjacent to the Craig Thomas Discovery & Visitor Center, Jackson Lake Lodge, and Signal Mountain Lodge. At these sites IMASW Vs surveys were conducted as close as possible to the park facility structures, in order to determine specific site characteristics, without causing disturbance for the park guests and within the substrate in which each facility is founded.

Teton Fault Sites

Taggart Lake

The Taggart Lake study site is located at the mouth of Avalanche Canyon, where a distinct north-striking scarp formed by the Teton fault offsets Taggart Lake basin sediments and the bounding lateral moraines (Figure 2). The basin is bounded to the north, south and east by lateral and end moraines, which formed around the toe of the Pinedale-age alpine glacier that flowed eastward out from Avalanche Canyon. Inferred sedimentary deposits within the basin include: dense glacial sediment (denoted here as till), Taggart Creek fluvial deposits, lacustrine deposits, colluvium, and organic soil. The glacial deposits are juxtaposed against layered gneiss and migmatite basement rocks (Love et al., 1992) exposed in the footwall. Cosmogenic ages from Licciardi and Pierce (2008) at Jenny Lake (Figure 1) indicate glacial retreat from the range front 13,000-15,000 years ago.

Within the vicinity of the Taggart basin the Teton fault has a northerly strike (~6°) and a distinct east-facing scarp. The fault vertically offsets the lateral moraines to the north and south of Taggart Lake and the basin floor to the west of Taggart Lake. North of Taggart Creek, most of the post-glacial slip appears to have been concentrated on a single fault trace, and to the south of Taggart Creek the fault appears to be segmented and left-stepping as it passes through the large lateral moraine (Figure 3). Small antithetic faults are visible near the crests of the lateral moraines to the north and south but are not evident in the Taggart Lake basin floor.

Figure 1. Location map showing five sites within GTNP studied with shallow seismic survey methods.

Figure 2. Oblique view of Taggart Lake basin from Google Earth. Yellow arrows show the Teton fault scarp on bounding lateral moraines. Red arrow shows the approximate location of Taggart Lake seismic survey location. Yellow arrows indicate scarps in moraine crests.
Figure 3. Taggart Lake site

The large moraine between Taggart and Bradley Lakes is vertically offset along a very distinct 35 m scarp, which indicates a longer record of surface faulting than the basin sediments or the faulted moraine south of Taggart Lake. The smaller moraine to the south is vertically offset 12 m (Thackray and Staley (in review)). The basin floor is vertically offset 12 - 15 m.

String Lake

The String Lake shallow seismic survey site is located to the south of Leigh Lake and west of String Lake (Figure 1 and 4) at the mouth of a steep debris flow gully at the point where the gully crosses the trace of the Teton fault (Figures 5 and 6) and over an alluvial fan deposited on the hanging wall. At this location the fault has a strike of approximately 20° and a scarp height of approximately 35m. Detailed scarp analysis by Thackray and Staley (in review) measured scarps in the area as high as 40 m suggesting a fault offset-based age estimate of 45-55,000 years. Antithetic faults are visible in EarthScope (2008) LiDAR to the south, but are apparently buried by the alluvial fan, sourced from the gully, in the vicinity of the seismic survey.

Figure 4. String Lake site
Figure 5. Looking west at the String Lake shallow seismic survey site (red arrow). Teton fault scarp is expressed as a green vegetation lineament, as indicated by the yellow arrows. The fault scarp becomes less apparent to the north of the seismic survey site.

Figure 6. Looking west at the String Lake field site. The dashed line indicates the approximate trace of the SL-01 and SL-02 seismic lines. The yellow arrow indicates the approximate location where SL-02 intersected the fault. Note fan development on hanging wall.

Shear Wave Velocity at Park Facilities

Three park facility sites (Jackson Lake Lodge, Signal Mountain Lodge and the Craig Thomas Discovery and Visitor Center; Figure 1) were surveyed with IMASW Vs methods. Sites were chosen that were in close proximity to the structure of interest, on relatively flat terrain in the sediment in which each building is constructed, and in locations that would cause minimal or no disturbance to park guests and staff.

Jackson Lake Lodge

The Jackson Lake Lodge IMASW Vs site (JLLVs-01) was located approximately 325 m north-northeast of Jackson Lake Lodge (Figure 7) and on the same Pleistocene terrace surface on which the Jackson Lake Lodge complex is constructed. At this site a gravelly terrace deposit (Qtg) is inset into Jackson Lake moraine related drift deposits (Qg4j) and overlies the Teewinot Fm, which outcrops on the bluff below the lodge (Love et al. 1992).

Figure 7. IMASW Vs survey location (JLLVs-01) at Jackson Lake Lodge.

Signal Mountain Lodge

The Signal Mountain Lodge IMASW Vs site (SMLVs-01) was located approximately 25 m east-southeast of the primary lodge structure (Figure 8) over Jackson Lake moraine related drift deposits (Qg4j) (Love et al. 1992). The survey utilized a power line clearing within a wooded area adjacent to the parking lot.

Figure 8. IMASW Vs survey location (SMLVs-01) at Signal Mountain Lodge.

Craig Thomas Discovery and Visitor Center (Moose Visitor Center)

The IMASW Vs site at the Moose Visitor Center (TVCVs-01) was located approximately 150 m north of the visitor center structure (Figure 9) in Snake River flood plain deposits (Qa) (Love et al. 1992).
METHODS

Seismic data were collected using a DAQ Link-II seismograph with 24 10Hz geophone channels spanning 92 m and 10 Hz geophones at 4 m spacing. The energy source consisted of an aluminum strike plate and 12-lb dead-blow hammer. This highly portable system was packed into each site on foot.

Seismic data collection utilized refraction lines oriented orthogonal or near-orthogonal with local fault strike and spanning the fault scarp. IMASW Vs lines were collected on the hanging wall and oriented sub-parallel to local fault strike and intersecting the refraction lines. The refraction lines are intended to image the 2D cross section of the fault and offset geologic units, and the IMASW Vs lines are intended to constrain the fault depth on the hanging wall, and thus, fault dip.

At the Taggart Lake site, we collected a single refraction line (TL-01), extending across and perpendicular to the ~12 - 15 m high topographic scarp formed by the Teton fault. An extended survey line was precluded by marshy ground to the east of TL-01. Two IMASW Vs lines were positioned sub-parallel to the scarp on the hanging wall and intersecting the refraction line. IMASW lines TLVs-01 and TLVs-02 were 28 m and 44 m from the base of the scarp, respectively.

At the String Lake site, we collected two overlapping refraction lines along the axis of a gully slightly oblique to the fault scarp – line SL-01 was entirely on the footwall and line SL-02 was centered on the fault zone with a six-geophone (20m) overlap and extended down an alluvial fan at the mouth of the gully onto the hanging wall. One IMASW Vs line (SLVs-01), 38 m from the base of the scarp on the hanging wall, was oriented sub-parallel to local fault strike and perpendicular to refraction line SL-02.

RESULTS

Shallow 2D P-wave refraction profiles and IMASW Vs vs. Depth plots from both the Taggart Lake and String Lake sites imaged subsurface velocity structure that reveal down-to-the east vertical offset across the Teton fault and provide a basis for assessing the fault at depth. The subsurface is not constrained with borehole data at these locations, so interpretations are based on geologic and geomorphic context and correlation charts for relating Vp and Vs to material (Table 1).

Table 1. Correlated P-wave and S-wave velocities for material types. Modified from Bourbie et al. (1987).

<table>
<thead>
<tr>
<th>Type of Material</th>
<th>P wave velocity (m/s)</th>
<th>S wave velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scree, Vegetal soil</td>
<td>300-700</td>
<td>100-300</td>
</tr>
<tr>
<td>Dry sands</td>
<td>400-1200</td>
<td>100-500</td>
</tr>
<tr>
<td>Wet sands</td>
<td>1500-2000</td>
<td>400-600</td>
</tr>
<tr>
<td>Granite</td>
<td>4500-6000</td>
<td>2500-3300</td>
</tr>
<tr>
<td>Gneiss</td>
<td>4400-5200</td>
<td>2700-3200</td>
</tr>
</tbody>
</table>

Taggart Lake

The single Taggart Lake 2D P-wave refraction profile spanned the Teton fault scarp and imaged both the hanging wall and footwall to depths of approximately 10 - 20 m (Figure 10). The refraction profile shows a layered velocity structure that vertically offsets the Vp 2000m/s iso-velocity surface ~13 m down-to-the east across the Teton fault. Each IMASW Vs vs. Depth plot (TLVs-01 and TLVs-02) (Figures 11a and 11b) shows a clear Vs increase from ~500 m/s to ~1000 m/s at ~5 m below the ground surface (bgs). TLVs-01 also shows a Vs increase to ~1500 m/s at ~70 m bgs and another increase to ~2000 m/s at ~130 m bgs and TLVs-02 shows a Vs increase to ~1500 m/s at ~110 m bgs.
Figure 10. Taggart Lake 2D P-wave refraction profile (TL-01). The approximate location of the Teton fault is shown, and the black arrows indicate the relative vertical motion. Locations where IMASW Vs surveys TLVs-01 and TLVs-02 intersects the refraction survey are indicated.

Figure 11a. IMASW Depth vs. Vs plot for TLVs-01

Figure 11b. IMASW Depth vs. Vs plot for TLVs-02

Figure 11c. IMASW Depth vs. Vs plot for SLVs-01

At Taggart Lake, we interpret the shallow, slow (Vp <1500 m/s / Vs ≤ 500 m/s) velocity zone to be unconsolidated post-glacial sediments overlying glacial till. The measured vertical offset of the velocity structure is approximately 13 m, which is very similar to the measured vertical height of the topographic scarp at this location, inferred by Thackray and Staley (in review) to have developed since deglaciation, ca. 14,000 years ago. The P-wave and IMASW Vs geophysical data were interpreted in context with the geomorphology and geology to develop a more detailed understanding of the fault structure at depth. Shown in Figure 12 are two topographic profiles (one of the faulted moraine between Taggart and Bradley Lakes and another of the Taggart Lake basin scarp at the survey site), simplified representations of the IMASW Vs surveys in a 1:1 scaled profile view, and preliminary structural interpretations.
Figure 12. Structural schematic based on new seismic data collected as a part of this study, geomorphology from EarthScope (2008) LiDAR and geology as presented in Love et al. (1992). The green line is a topographic profile on the moraine marking the northern boundary of the Taggart Lake basin, while the black line is a topographic profile at the geophysical site in Taggart Lake basin. Teton fault (Note A) is projected through moraine scarp, valley floor scarp and IMASW Vs increases in TLVs-01 and TLVs-02 (Note B, See Figures 11a and 11b). Blue lines represent an approximate range of dips for bedrock/alluvial contact based on geologic map (Love et al. 1992), projection of nearby outcrops from LiDAR and Google Earth and velocity horizon in TLVs-01 (Note C, See Figure 11c).

Figure 13. String Lake 2D P-wave refraction profile (SL-01 and SL-02). The approximate location of the Teton fault is shown, and the white arrows indicate the relative vertical motion. Locations where IMASW Vs survey SLVs-01 intersects the refraction survey is indicated.

String Lake

The two overlapping 2D P-wave refraction profiles collected at the String Lake site are displayed as a single 2D profile and imaged the hanging wall and footwall to depths of 20 to 60 m (Figure 13). The velocity structure of the refraction profile infers relatively deep (~40 m) deposits of unconsolidated sediment (till, colluvium, and alluvium) on both the hanging-wall and footwall, based on moderate to low P-wave velocities, and the overall geomorphic context observed in the Lidar imagery. The refraction data show a relatively low velocity zone (<1000 m/s) that is spatially coincident with the center of the gully and appears to be vertically offset 10 - 14 m across the Teton fault (Figure 13). Scarp heights adjacent to the
gully to the north and south are ~35 m (Figure 4). This offset measurement is intriguing, given the site context. The 10 - 14 m subsurface offset is similar to post-glacial offset of 14,000 year old deglacial surfaces on the floors of the main valleys (e.g., our Taggart Lake site). However, this site has not been glaciated since ca. 130,000 years ago (Licciardi and Pierce 2008, Thackray and Staley, in review). The offset, dense sediments must therefore be a non-glacial deposit derived from the unglaciated gully itself. As glacial climates throughout the region tended to activate hillslope processes and fan aggradation, the subsurface sediment may be a bouldery fan deposit or debris flow deposit.

The Vs vs. Depth plot from the single IMASW Vs profile (SLVs-01) on the hanging wall side of the fault (Figure 11c) shows a Vs of 500 - 700 m/s to a depth of 60 m, a Vs increase to 1000 - 1200 m/s at 60 m and a Vs increases to >1500 m/s at 100 m.

Structural interpretations of this site are pending further analysis.

**Park Facility Sites**

Vs30 was calculated for each of the 3 Grand Teton National Park facility sites from the IMASW Vs survey data. The Vs30 values for each site are presented in Table 2. The Vs vs. Depth plots for each site are presented in Figures 14 a, b, and c.

**Table 2.** Calculated Vs30 values for park facility sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Line ID</th>
<th>Vs30 (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson Lake Lodge</td>
<td>JLLVs-01</td>
<td>574</td>
</tr>
<tr>
<td>Signal Mountain Lodge</td>
<td>SMLVs-01</td>
<td>560</td>
</tr>
<tr>
<td>Moose Visitor Center</td>
<td>TVCVs-01</td>
<td>413</td>
</tr>
</tbody>
</table>

**CONCLUSION**

This project imaged the Teton fault in the shallow subsurface at two sites (Taggart Lake and String Lake) through P-wave refraction and IMASW shear-wave (Vs) survey techniques. At three other sites (Jackson Lake Lodge, Signal Mountain Lodge, and the Moose Visitor Center) 30 m depth-averaged shear wave velocities (Vs30) were determined through IMASW Vs surveys. Because the equipment is light and portable, these surveys were performed in remote locations with very minimal environmental impact.

The Taggart Lake site provides an ideal setting for structural analysis of the fault. The basin floor is relatively flat on both the hanging wall and footwall sides of the fault and provides a good setting for geophysical surveys. Slower post-glacial sediments overlie higher velocity glacial deposits to create a stratified velocity structure, which can be used for measuring vertical offsets caused by faulting. The
fault has a relatively consistent northerly strike through the basin and bounding lateral moraines. The site is accessible via existing trails.

Preliminary analysis of the Taggart Lake seismic data suggests that the P-wave refraction and IMASW Vs data provide a basis for assessing the structure of the Teton fault at the Taggart Lake site. Figure 13 depicts a preliminary structural analysis based on the geophysical data collected in this study, site geology, and geomorphology. The schematic shows that the Teton fault plane, projected through the moraine crest scarp to the north of Taggart Lake and the Taggart basin fault scarp, is correlative with Vs increases (Figure 11a and 11b) in both of the Taggart Lake IMASW Vs surveys (TLVs-01 and TLVs-02). In addition, the Vs increase to ~2500 m/s in TLVs-01 (Figure 11a) could likely represent the bedrock/alluvial contact, as inferred from velocity and material correlations in Table 1 and geologic context.

The P-wave refraction profile shows vertically offset velocity structure (Figure 10). The measured offset (13 m) of dense subsurface sediment (inferred to be glacial till) is very similar to the surface fault scarp measurement of 12-15 m, indicating that the surface scarp height faithfully reflects total offset since deglaciation, and supports an average fault offset rate of 0.82 m/ka determined by Thackray and Staley (in review).

The Taggart Lake site also contains numerous alluvial surfaces on the uplifted footwall that are suggestive of uplift-driven creek incision. These features hold promise for independent determination of fault offset event frequency and magnitude, and deserve closer scrutiny.

At the String Lake site, the overall length of the seismic refraction survey line was not long enough to clearly image the hanging wall and Teton fault zone to greater depth. The single IMASW Vs survey shows velocities that correlate with crystalline bedrock, so it is plausible that we have imaged the bedrock/alluvial contact at this site. However, the fault geometry is more complex than at Taggart Lake. The fault trace geometry changes a short distance north of the data collection site, and antithetic faults are present that have an unknown impact at the geophysical survey site. Additional data collection is necessary to resolve the subsurface structure at this location.

These results are preliminary in nature, based on new shallow seismic data collected at two sites. These data require additional analysis and interpretation. Additional geophysical and geomorphological investigation will further constrain these results and further improve understanding of the specific characteristics of the Teton Fault, its seismic hazards, and its impact on the evolution of the Teton landscape.

**ACKNOWLEDGEMENTS**

This research was funded by the University of Wyoming (UW) – National Park Service (NPS) Research Station small grants program and by in-kind contributions from Fugro Consultants Limited and Idaho State University. David Rodgers, Amie Staley, and Nick Patton (ISU) assisted with data collection, and Glen Adams, Dan O’Connell, Dean Ostenaa, and Jamey Turner (FCL) assisted with project design and geophysical data analysis.

**LITERATURE CITED**


RESEARCH PROJECT REPORTS

HYDROLOGY
The Snake River is a prominent, central feature of Grand Teton National Park, and this dynamic fluvial system maintains diverse habitats while actively shaping the landscape. Although the riparian corridor is relatively pristine, the Snake River is by no means free from anthropogenic influences: streamflows have been regulated since 1907 by Jackson Lake Dam. Among dam-controlled rivers in the western U.S., the Snake River is unique in that tributaries entering below the dam supply sufficient coarse bed material to produce a braided morphology. As a result of tributary inputs, sediment flux along the Snake River has been relatively unaffected by Jackson Lake Dam, but flow regulation has reduced the magnitude and altered the timing of streamflows. In this study we are coupling an annual image time series with extensive field surveys to document channel changes occurring on the Snake River. Our objective is to quantify how snowmelt runoff events and flow management strategies influence patterns of sediment transfer and storage throughout the river system, with a particular focus on tributary junctions. More specifically, we are using the image sequence to identify areas of erosion and deposition and hence infer the sediment flux associated with the observed changes in channel morphology. This analysis will improve our understanding of the river’s response to flow management and enable us to generate hypotheses as to how the system might adapt to future anthropogenic and/or climate-driven alterations in streamflow and sediment supply. In addition, our research on the Snake River involves an ongoing assessment of the potential to measure the morphology and dynamics of large, complex rivers via remote sensing. A new aspect of this investigation involves estimating flow velocities from hyperspectral images that capture the texture of the water surface. Extensive field measurements of velocity and water surface roughness are being used to develop this innovative approach and thus increase the amount of river information that can be inferred via remote sensing.

Figure 1. The Tetons tower over researchers as they survey the topography of the Snake River channel.
**INTRODUCTION**

The Snake River in Grand Teton National Park (GTNP) is a highly dynamic gravel-bed river that represents an important Park asset as well as an iconic component of the Jackson Hole landscape. In addition, frequent channel changes along the river create a rich diversity of habitat for aquatic and terrestrial species. The Snake River’s scenery, fishery, and wildlife draw thousands of river users each year, making the river a key element of the local tourist economy.

Regionally, the river is a prime source of irrigation water for agriculture on Idaho’s Snake River Plain. Flows on the Snake have been regulated since 1907 by Jackson Lake Dam (JLD), which was constructed at the outlet of the preexisting, Pleistocene-aged Jackson Lake (Love, 2003). The Snake River in GTNP is distinct from most other dam-regulated gravel-bedded rivers in that abundant coarse sediment supplied from tributaries downstream of the dam allows the river to maintain a braided morphology that is typically associated with a sediment surplus.

While the sediment supply to the Snake River has been unaffected by JLD, flow regulation at the dam has reduced the magnitude and altered the timing of peak streamflows in an effort to prolong late summer flows to meet downstream water demands (Erwin et al. 2011, Marston et al. 2005). Within GTNP, a balanced approach to flow management is critical to the health of the riparian ecosystem. A complete understanding of the river’s sediment budget also is crucial to effective flow management. Climate change and associated shifts in the timing of water demands might necessitate corresponding adjustments in flow regulation by JLD. A refined understanding of the geomorphic effects of such flow regulation will inform managers seeking to maintain the physical and ecological integrity of the Snake River within GTNP while also meeting downstream water demands.

In this study we are coupling remote sensing data with extensive field surveys to closely monitor the geomorphic changes occurring on the Snake River. This study seeks to track how annual runoff events and flow management strategies influence patterns of sediment transfer and storage throughout the river system, with a particular focus on tributary junctions. More specifically, we are using an image time series to identify areas of erosion and deposition and hence to infer bed material transport from the observed changes in channel morphology.

In addition, the consistent, clear late-summer releases from JLD make the Snake River an ideal location for testing remote sensing technology and developing new techniques for deriving various kinds of river information attributes from image data. In addition to tracking geomorphic change on the Snake River, we are also developing new techniques for extracting channel attributes from the water surface, water column, and bed from hyperspectral image data.

**STUDY AREA**

The remotely sensed data available to support this investigation provide complete coverage of the Snake River from JLD to Moose (Figure 2a). To be consistent with previous sediment budget studies (Erwin et al. 2011), we are initially focusing on the area between Pacific Creek and Deadman’s Bar. In this reach, the river alternates between a relatively stable, single-channel configuration and a highly dynamic multi-channel pattern. In addition to quantifying the overall dynamics of this river segment, we are working to characterize in greater detail the channel changes occurring at confluence zones associated with Pacific Creek, Buffalo Fork, and Spread Creek, as well as two meander bends, referred to as Rusty Bend (Figure 2b) and Swallow Bend (Figure 2c), where we are focusing on understanding the relationships among point bar growth, the flow field within the channel, and bank erosion.

**METHODS**

Our research group has obtained an extensive dataset to monitor geomorphic changes occurring on the Snake River that includes: 1) an annual time series of aerial images from 2009-2014; 2) LiDAR-derived digital elevation models from 2007, 2012, and 2014; and 3) field measurements of bathymetry and hydraulics collected annually from 2010-2014. This combination of optical image data, LiDAR, and field data allows us to precisely measure annual channel...
changes and associate these changes with specific run-off events. The six consecutive years of imagery encompass a range of flow regulation strategies, as well as natural runoff events on Snake River tributaries, that include both high magnitude flow events and the second lowest peak discharges observed on the Snake River in 111 years of record.

In 2013 and 2014, we continued to build upon these extensive remote sensing and field data sets. In the past two years we have greatly expanded the types of field measurements we can obtain from large rivers such as the Snake by acquiring new instrumentation for measuring various river attributes and by building new platforms for deploying these sensors. These new measurement capabilities, coupled with new image processing techniques, help to expand the utility of remotely sensed data for river management.

**Remotely sensed data collection**

In August of both 2013 and 2014 we acquired hyperspectral imagery deploying our CASI 1500H hyperspectral imaging system from a Cessna Caravan fixed-wing aircraft operated by contractor Quantum Spatial. This specialized instrument has allowed us to adjust the sensor’s configuration to meet the unique requirements for imaging river environments. For example, in 2013 and 2014, we collected imagery with a higher spatial resolution than has been previously collected on the Snake River. The 2013 and 2014 hyperspectral images are important additions to the database of hyperspectral, multiband satellite, and publically available imagery that we have compiled for the Snake River.

LiDAR data collection was planned for both 2013 and 2014. LiDAR uses laser pulses to precisely map surface topography. Traditional LiDAR systems emit near-infrared (NIR) laser pulses to measure surface topography. While NIR LiDAR create accurate maps of terrestrial surfaces, the NIR wavelength pulses are rapidly attenuated in water; hence it cannot be used to map river bathymetry.

The classified LiDAR point cloud in Figure 3 produced from 2012 NIR LiDAR at Rusty Bend illustrates the 3-dimensional view of the riverscape that LiDAR provides. While vegetation (green points) and terrestrial features (brown points) are accurately mapped, the only in-channel points (black) returned to the sensor are from laser pulses reflected from the water surface. In 2014 NIR LiDAR was collected during hyperspectral image acquisition using a Leica ALS50 system mounted on the Cessna Caravan.

Bathymetric LiDAR systems have recently been developed which are capable of mapping both terrestrial and aquatic topography. Bathymetric LiDAR systems use green wavelength lasers which are less susceptible to attenuation in water. Bathymetric LiDAR was collected along the Snake River in August 2012 by the National Center for Airborne Laser Mapping (NCALM) and by Quantum Spatial in August 2013. Topography and bathymetry derived from bathymetric LiDAR point clouds (Figure 4) are being compared to NIR LiDAR and image derived bathymetric maps to test the validity of this new technology. A sensor malfunction occurred during the 2013 bathymetric LiDAR acquisition. Despite extensive efforts to resolve the error during data post-processing, the data could not be reconciled.

**Field data collection**

Our study also involved extensive field work to calibrate and validate remote sensing algorithms and to support our geomorphic research. Our previous field campaigns have been coordinated with image acquisitions occurring in August when late summer flows are low and water clarity is high. In 2013 and 2014 we conducted additional field work in June to take advantage of higher water levels and a greater range in turbidity between the clear water released
from JLD and highly turbid snowmelt runoff from tributaries (Figure 5). The strong contrast in turbidity between the Snake River and tributaries provide a unique opportunity to study the effects of suspended sediment on the optical characteristics of the river. Additionally, the higher flows measured during the June data collection were more representative of geomorphically significant flow events.

**Figure 4.** Bathymetric LiDAR point cloud color coded by elevation from Rusty Bend on the Snake River (A). A cross-section through the data (red box in A. shown in B.) shows the topographic, bathymetric and water surface points collected by the sensor.

**Figure 5.** Sediment laden water from the Buffalo Fork (left side of photo) slowly mixes with clear, sediment-free water of the Snake River (right side of photo).

During June field data collection a suite of instruments were deployed from a cataraft along downstream profiles to measure the optical properties of the water column and the bathymetry of the channel.

The concentration and size distribution of suspended sediment were measured in real-time using a Sequoia Scientific LISST-100X. Spectral absorption and attenuation coefficients, inherent optical properties that control the distance light can travel through water, were measured by continuously pumping river water through a WetLabs ac-s Spectrophotometer. A second WetLabs instrument, the EcoTriplet, provided observations of the scattering coefficient, turbidity, and concentrations of chlorophyll and colored dissolved organic matter (CDOM). A Eureka Environmental Manta 2 multi-probe was used to measure blue-green algae concentrations as well. Reflectance spectra were recorded above the water surface using an Analytical Spectral Devices (ASD) FieldSpec3 spectroradiometer. A 100% reflectant Spectralon calibration panel was used to establish a white reference regularly during the downstream profile. A Trimble RTK GPS receiver was coupled with a SonarMite echo-sounder to map depth and water surface elevations. Time stamps from all of the instruments were used to define the GPS locations of all measurements.

**Figure 6.** In 2014 a larger cataraft was built to accommodate the additional instruments used to map the physical and optical properties of the Snake River.

SonTek acoustic Doppler current profilers (ADCP) were used to collect hydraulic and bathymetric data during both June and August field data collection. These instruments were deployed from kayaks outfitted with a specialized mounting system and recorded flow velocities in a series of cells distributed vertically throughout the water column. The ADCP measured streamwise, cross-stream, and vertical velocity components at a sampling frequency of 1 Hz and thus provided a very detailed characterization of the flow field. We also used the ADCP to measure river discharge by integrating the product of depth and velocity as we moved across the
channel. In addition to cross-sections located in our two primary study sites at Swallow and Rusty Bends, we recorded velocities along profiles oriented down the river. The ADCP also recorded flow depths and thus provided an additional source of field data for evaluating remotely sensed bathymetry.

To advance our goal of extracting other kinds of hydraulic information from remotely sensed data, we developed a new system for mapping water surface roughness. During the August 2014 field campaign we used a downward-facing ultrasonic distance sensor deployed from a spar mounted on the front of a kayak. This small sensor sampled the distance to the water surface at a frequency of 5 Hz. Data was collected along streamwise oriented transects. Water surface roughness data collected with the ultrasonic sensor was paired with simultaneous ADCP measurements using GPS timestamps on both instruments.

**Preliminary Results**

**Implications of flow management for hydrology and geomorphology of the Snake River in GTNP**

The Bureau of Reclamation (BoR) manages flow releases from JLD and is faced with the challenge of balancing a wide range of environmental, agricultural, and recreational water demands. The BoR’s highest priority is to ensure that Snake River flows are sufficient to meet irrigation needs downstream in Idaho. Irrigation water is conveyed to agricultural lands on the Snake River Plain through a number of reservoirs and canals comprising the Minedoka project. JLD is the highest dam on the Snake River and allows the BoR to store late spring snowmelt high in the basin and deliver water to Palisades Reservoir, 160 km downstream, as needed later in the summer. Therefore, flow releases at JLD are dictated by irrigation demands in Idaho and water levels in Palisades Reservoir. Variables such as local and regional snowpack, timing and duration of runoff, temperatures in Idaho, as well as water deficits carried over from previous years all factor into the timing, magnitude, and duration of flow releases from JLD.

In spring 2012, snowpack in the Snake River basin was 53% of average. While snowpack in upper basin tributaries such as Pacific Creek and the Buffalo Fork were closer to average, lower basin tributaries such as the Salt, Greys, and Hoback Rivers had below-average snowpack (NRCS, 2012). Low snowpack, especially in tributaries feeding directly into Palisades, lead to significant drawdown of Palisades and increased demand for water stored in Jackson Lake.

After the 2012 irrigation season, storage in Palisades was only 56% of average for that time of year.

The drought-like conditions continued in 2013. In June of that year the snow water equivalent in the Snake River Basin was 46% of normal (NRCS, 2013). Two consecutive years of low snowpack placed significant stress on the water storage in the Snake River system. In June 2013, Palisades Reservoir was 75% of average. Later in the summer, low water levels in Palisades, along with persistent irrigation demands, led to a management decision to release higher than normal flows from JLD throughout the summer, causing significant depletion of storage in Jackson Lake itself. Despite increased releases from JLD, storage in Palisades Reservoir and Jackson Lake were drawn down to 50% and 43% of average, respectively, for that time of year (USDA NRCS, 2014). As of January 2014, Jackson Lake was only 20% of total capacity (Figure 7).

![Figure 7. Water level in Jackson Lake was less than 20% capacity in January 2014 due to two consecutive years of below average snowpack in the Snake River Basin.](image)

The dry conditions of 2012 and 2013 thus depleted both Palisades Reservoir and Jackson Lake and left managers with a storage deficit that had to be remedied in order to continue to provide water for downstream users. Above average snowfall during the winter of 2013 – 2014 provided a much needed respite from the drought. Snowpack in the Snake River basin was 140% of average in June 2014. Snowpack in the Salt and Greys Rivers, which directly feed Palisades Reservoir, were 257% and 342%, respectively (NRCS, 2014). The deep snowpack in the lower basin implied that less water needed to be released from JLD. In an attempt to refill Jackson Lake, releases from JLD were kept very low during runoff in May and June.
The hydrographs in Figure 8 illustrate the differences between the regulated Snake River and the unregulated, snowmelt-driven Pacific Creek, which joins the Snake River 8.8 km downstream from JLD. This confluence marks the first significant sediment input to the Snake River below the dam and thus represents an ideal location to investigate the impact of flow regulation on the morphology of tributary junctions. On a year-to-year basis, the dynamics of confluence zones depend on the relative magnitudes of stream flows along the mainstem channel and the tributary, summarized in Figure 8 for 2012-2014.

One strategy managers use to satisfy downstream water demands while conserving reservoir storage is to minimize reservoir releases while tributary flows are high. This strategy is evident in the hydrographs from the 2013 season (Figure 8). As snowmelt runoff increased on Pacific Creek in May and June, releases from JLD were drastically reduced to conserve water in the reservoir. This management strategy resulted in overall flows in the river that remained consistent while Pacific Creek delivered a higher proportion of the flow in the river.

Figure 8. Hydrographs for the Snake River and Pacific Creek. Flows in the Snake River above Pacific Creek reflect dam operations at Jackson Lake Dam, whereas the tributary is unregulated.

In an attempt to replenish storage in Jackson Lake, peak flows released from the dam in 2014 were the second lowest in 111 years of record, even though a substantial snowpack contributed to high flows on Pacific Creek. For two consecutive years, this tributary delivered sediment to the Snake River while flows on the main channel were low, possibly less than what would be required to transport the sediment supplied from Pacific Creek. If this were the case, we would expect sediment to accumulate at the Pacific Creek confluence. This hypothesis was evaluated by inspecting channel changes that occurred between 2012 and 2014 (Figure 9). Differences between the digitized 2012 wetted channel (blue line, Figure 9) and the 2014 channel (background image) shows a narrowing of the main channel from 35 meters in 2012 to 24 meters in 2014 even though discharge at the time the two images were acquired was similar. In addition, a large mid-channel bar has been created downstream of the confluence, further evidence that sediment is accumulating and being stored at this confluence.

Figure 9. Channel changes observed at the confluence of Pacific Creek with the Snake River are highlighted by overlaying the 2012 channel boundary on an image acquired in August 2014.

While the planform changes observed between 2012 and 2014 are consistent with our hypothesis that sediment is being stored at tributary junctions, a more thorough analysis of annual changes occurring throughout our image time series is necessary to more fully understand how flow regulation impacts confluence zone dynamics. Additional image acquisitions scheduled for 2015 may also yield insight as to how the two years of sediment stored at the Pacific Creek tributary junction is routed.
downstream, provided that this year’s JLD releases are capable of transporting the sediment.

In addition, channel bathymetry derived from optical image data will be fused with LiDAR topography to produce continuous maps of tributary junctions. These maps will allow us to relate annual geomorphic changes to volumes of storage and evacuation of sediment (Figure 10).

Figure 10. Image data (upper panels) will be used to derive bathymetric maps of tributary junctions. When image-derived bathymetry is coupled with LiDAR topography (lower panels) we will be able to map volumetric changes at tributary junctions.

Isolating sun glint and mapping water surface roughness

Sun glint, which occurs when light reflects from the water surface directly to the remote sensor without entering the water column, results in anomalously bright pixels that can severely degrade the quality of an image. In addition to clarifying the signal associated with the water column and bed of the river, isolating sun glint could unlock important hydraulic information related to water surface topography. Radiant energy reflected from the water surface does not interact with the water column; therefore, surface reflected light resembles the solar spectrum. Conversely, light that enters the water column is subject to strong absorption of near-infrared (NIR) wavelengths; therefore, light that has interacted with the water column has little NIR signal. The reflectance in a NIR wavelength thus serves as an indication of the amount of sun glint for each pixel.

Building upon glint removal procedures created for shallow marine environments (Hedley et al. 2005), we have created a river-specific method to isolate and remove sun glint (Figure 11). In panel A, strong sun glint overwhelms much of the in-channel information in the image. The glint removal procedure isolates the sun glint component of the image (Panel B). Panel C is the final de-glinted image produced by subtracting the glint image from the original image. In the new de-glinted image, water depth is the primary control on image brightness. As a result, removal of sun glint increased the agreement between field-measured depths and image-derived depths from an $R^2$ of 0.65 to an $R^2$ of 0.8.

Figure 11. 2014 hyperspectral image from Swallow Bend was contaminated by sun glint (A). We used a glint removal procedure to isolate sun glint (B) so it could be removed from the original image which produced a new glint-free image (C).

As water surface roughness (WSR) increases, a greater number of surface facets are oriented so as to reflect the direct solar beam, implying that the texture
of the water surface exerts a primary control on the amount of sun glint in an image. WSR in rivers is affected by flow depth and velocity, but this relationship has not been quantified due to the lack of an established method for mapping WSR in the field.

To identify the relationship between surface roughness, sun glint, and channel hydraulics we identified a reach of the Snake River upstream of Rusty Bend that had strong contrasts in WSR (Figure 12). In this reach, the river transitions from a deep, slow moving pool with a smooth surface to a shallow, high gradient, high velocity riffle with high surface roughness. At the end of the riffle the river transitions back into a deeper, slower flowing pool (Figure 12 A). We used a NIR wavelength (851 nm) in the radiance image ($L_{851}$) as metric for glint intensity (Figure 12 B). The patterns of sun glint closely match patterns of surface roughness with low surface roughness pools corresponding to areas with minimal glint (blue colors, Figure 12 B) and high surface roughness riffles corresponding to areas with strong sun glint (red colors, Figure 12 B). These results indicate that sun glint is strongly related to WSR.

![Figure 12](image)

**Figure 12.** 2014 hyperspectral image of a pool-riffle sequence on the Snake River upstream of Rusty Bend (A). The sun glint intensity is well represented by plotting the intensity of the 851 nm band (B). Low roughness pool corresponds to regions with minimal sun glint and high roughness riffles correspond to regions with high sun glint.

Image-derived sun glint (black line, Figure 13A) is strongly correlated to the field-measured WSR (red line, Figure 13B). The longitudinal profile shown in Figure 13C highlights the relationship between WSR and geomorphic and hydraulic conditions. The water surface elevation (blue line) was derived from NIR LiDAR surface returns. The bed elevation (brown line) is the difference between the LiDAR WSE and field-measured depth. The filled points in 13C are the field-measured mean velocity corresponding to the color bar at the bottom of Figure 13C.

![Figure 13](image)

**Figure 13.** A) Image-derived sun glint (represented by radiance of the 851 nm wavelength) along a downstream profile of the pool-riffle sequence in figure 12. B) Field measured water surface roughness along the profile. C) Water surface elevation (blue line), bed elevation (brown line) and field-measured mean current velocity (filled points corresponding to color bar) along the downstream profile.

The spike in the image-derived sun glint and WSR both occur as water surface slope increase, depth decreases, and velocity increases. As the water surface slope decreases the roughness and glint also decrease. These initial results imply a relationship between sun glint, WSR, and flow velocity that might enable river hydraulics to be inferred from remotely sensed data. Image-derived sun glint also could be used to identify hydraulic biotopes distinguished on the basis of WSR.

**+ MANAGEMENT IMPLICATIONS**

This ongoing study directly contributes to the current management priorities of the National Park Service and could provide a powerful tool for assessment and monitoring of riverine resources throughout the region. The 2009 Craig Thomas Snake River Headwaters Act designated the river above...
Jackson Lake as a Wild River and the segment from Jackson Lake Dam to Moose, along with the Pacific Creek and Buffalo Fork tributaries, as Scenic Rivers in recognition of their ecological, aesthetic, and recreational value. This legislation provides these streams with protected status as part of the National Wild and Scenic Rivers System and ensures the free-flowing condition of these waterways. Along with this designation comes the task of determining how best to preserve this remarkable fluvial system. Accordingly, the Park Service has set out to develop a new river management plan, which will involve documenting these unique natural resources and identifying effective strategies for their protection. Park managers are thus obligated to characterize the form and behavior of the Snake River, along with the associated habitat conditions and recreational opportunities. Our primary objective is to derive such information from remotely sensed data; this continuing project will thus directly inform the Park's river management plan.

Regionally, the Snake River is a prime source of irrigation water for agriculture on Idaho’s Snake River Plain. Climate change and associated shifts in the timing of water demands might necessitate corresponding adjustments in flow regulation by JLD. A refined understanding of the geomorphic effects of such regulation will allow managers to devise a strategy for maintaining the physical and ecological integrity of the Snake River within GTNP while also meeting downstream water demands.

Although remote sensing clearly offers significant potential to facilitate a number of river-related applications, this potential has not been realized in practice, and the capabilities and limitations of a remote sensing-based approach must first be established. By demonstrating the utility of these methods, and also acknowledging their deficiencies, this study of the Snake River could lead to more widespread, effective use of remote sensing in river research and management.

**ACKNOWLEDGEMENTS**

In addition to logistical support from the UW-NPS Research Station, this project received funding from the Office of Naval Research. Field work along the Snake River would not have been possible without the able assistance of Chip Rawlins, Carlin Gerard, Steve Bradebura, Toby Stegman, Devin Lea, Lincoln Pitcher and Annie Toth. Remotely sensed data were acquired through collaboration with NCALM and Quantum Spatial.

**LITERATURE CITED**


**Figure 14.** 2014 field crew at Deadman’s Bar on the Snake River. From left to right: Lincoln Pitcher (UCLA), Toby Stegman (UW), Brandon Overstreet (UW), Carl Legleiter (UW), Chip Rawlins (UW), Devin Lea (UW).
RESEARCH PROJECT REPORTS

ECOLOGY
KELLY WARM SPRING HISTORICAL DATA SUMMARY: PROGRESS REPORT

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U. S. GEOLOGICAL SURVEY ♦ JACKSON, WY

ABSTRACT

Kelly Warm Springs is a unique geological feature located within Grand Teton National Park, Wyoming. The Kelly Warm Springs area is used extensively by park wildlife, for recreation by park visitors, and is a place of educational interest. It has also been the site of historic non-native fish releases. The current work was initiated to gather historical information and to begin systematic documentation of temperatures in and around Kelly Warm Springs. Historic information that was not published but considered valid was included. Non-native fish presence was first documented in the 1960s. Concerns about non-native fish and habitat loss for native species were discussed by researchers in the 1980s. The temperature ranges recorded at several sites October – December 2014 approached 0°C at the lower section of the outflow channel, but remained above 20°C in the spring pond. While these range below the preferred temperature range for goldfish, research has documented survival in near zero temperatures. All sites located below Mormon Row where temperature loggers were initially deployed were either dewatered or frozen by mid-November.

INTRODUCTION

Kelly Warm Springs, located in Grand Teton National Park (43° 38’ 21.8”N, 110° 37’01.9”W), are perennial warm springs located near Kelly, Wyoming. The springs create a shallow pond, with a maximum depth of about 4 feet, and maximum width of about 350 feet (Baldwin and Franta 1960). These unique springs have been subject to multiple surveys and studies to evaluate water chemistry, temperature, toxicity, species present, and discharge. Fish surveys have shown that Kelly Warm Springs has been the recipient of non-native fish disposal/planting, which likely resulted from the disposal of aquarium specimens. Surviving non-native fish could have negative implications for native fish living in Kelly Warm Springs and could impact the stability of the food web structure and function within the springs and surrounding water outlets (Hotchkiss and Hall 2009). Along with non-native fish, non-native invertebrates (e.g., snails) have increased in population. This increased presence of non-native species can lead to competition, disease, and habitat degradation for the native species within Kelly Warm Springs (Hotchkiss and Hall 2009).

Kelly Warm Springs is easily accessed and receives frequent recreational use by park visitors. Its unique features and easy access make it a place of interest for science education and study. Though many visiting scientists, student educational groups, and others have conducted studies on Kelly Warm Springs, those data were not always published, and have not been centralized for access by park resource managers.

As park resource managers become increasingly aware of thriving non-native aquatic species in the Warm Springs, they have become concerned about their existence within a National Park, and the potential movements of these non-natives out of the springs and into surrounding waters. These concerns were realized when a goldfish was collected within 400 meters of the mainstem Snake River (Whaley 2014). Though it has long been believed that cold water temperatures in the Snake River would inhibit goldfish establishment, no studies to systematically document temperatures from Kelly Warm Springs to the Snake River have been conducted.
There are two goals for the current project:

1.) Gather all pertinent aquatic resource data (1969-2013) related to Kelly Warm Springs, summarize where possible, and include the findings in this one report.  
2.) Monitor water temperature in and around Kelly Warm Springs, leading to the Snake River. Meeting these goals will provide park resource managers and others one source to find historical data collected on Kelly Warm Springs and define actual temperature fluctuations in waters leading from Kelly Warm Springs to the Snake River. These data can be used for science-based management decisions about the fate of non-native fish in Kelly Warm Springs and can boost educational awareness about the potential impacts of introducing non-native species into the Warm Springs.

**METHODS**

**Historical data compilation**

In order to compile historic data on the Kelly Warm Springs several resources were utilized. Data were gathered from the Grand Teton National Park Natural Resource Management records and representatives from the Wyoming Game and Fish Department (WGFD), and academic institutions were queried. Reports and information were considered valid when they had been peer-reviewed and/or published, or when the document was created by an official park service, governmental agency or academic institution. The goal of this summary was to gather all available information on Kelly Warm Springs and compile it in one place. Therefore some of the information may not generally be considered scientifically publishable but remains relevant.

**Temperature monitoring**

In order to conduct temperature monitoring in the Kelly Warm Springs, Hobo® Pendant® temperature/light data loggers (UA-002), were deployed in the Kelly Warm Springs and its coinciding outlet1. Ten temperature loggers were initially deployed into the warm springs and its outlet leading into the Snake River on July 10th 2014 (Figure 1). On July 29th three more temperature loggers were added to certain areas along the Kelly Warm Springs and its outlet. On July 31st initial data were gathered from the deployed temperature loggers still present within the Kelly Warm Springs and its outlet. On August 11th all deployed temperature loggers were pulled due to a recall from the manufacturing company. Eight temperature loggers were re-deployed on October 6th. Data from the loggers was downloaded on November 6th, and it was noted that all discharge downstream of the headgate located above the Ditch Creek crossing was directed into Ditch Creek. Consequently, 3 loggers located north of Ditch Creek near Mormon Row were pulled because all irrigation channels containing loggers were de-watered.
RESULTS AND DISCUSSION

Historic data compilation

Since 1966 Kelly Warm Springs has been studied frequently. Data gathered includes temperature, water chemistry, and species collection. The following tables present the classifications and common names of native and non-native fish species captured in Kelly Warm Springs and throughout Ditch Creek.

In the summer of 1968 the native fish species found in the Kelly Warm Springs included the Utah Sucker (*Catostomus ardens*), Utah Chub (*Gila atraria*), Redside Shiner (*Richardsonius balteatus*), and Longnose Dace (*Rhinichthys cataractae*) (Baldwin et al. 1968). Guppies (*Poecilia reticulate*) were the only non-native aquarium species collected. By the 1970s, surveys found no Utah Suckers present in the springs. Baldwin et al. (1968) and WGFD (personal communication) suggested that the initial introduction of guppies into the Kelly Warm Springs occurred in the 1960’s when this species presence was first documented. Baldwin et al. (1968) raised concerns about human presence and its potential negative influence on habitat (e.g., documented trash in the area). During sample collections in July, 1984, 37 specimens of Utah Chub and 2 Speckled Dace were caught. No Utah Suckers were observed. Non-natives captured included 65 guppy specimens and 203 Green Swordtail. Green Swordtail has not been recorded elsewhere in Wyoming (Courtenay 1984). These findings suggest that non-native fish are being deposited into Kelly Warm Springs from aquarium sources. Temperatures remained an almost constant of 25-27°C throughout the summer of 1984, however dates were not specified. Along with fish, many birds and some mammal species were also observed around the warm spring area (Courtenay 1984).

It appears that additional invasive species have been introduced since 1998 because of the increase in variety of species found in the Kelly Warm Springs since 1998 (Table 1) compared to the results found by C. Whaley and B. Hall sampled in 2009-2012 (Tables 2 and 3).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Family</th>
<th>Genus Species</th>
<th>Preferred Temperature Range</th>
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<tr>
<td>Swordtail</td>
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<td>Gila ataria</td>
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<td>Redside Shiner</td>
<td>Cyprinidae</td>
<td>Richardsonius balteatus</td>
<td>20 -21°C (68-70°F) (Minckley and Marsh 2009)</td>
</tr>
<tr>
<td>Long Nose Dace</td>
<td>Cyprinidae</td>
<td>Rhinichthys cataractae</td>
<td>18-24°C (65-75°F) (Alderman, 2014)</td>
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<td>Green Sword Tail</td>
<td>Poeciliidae</td>
<td>Xiphophorus helleri</td>
<td>19 - 29°C (66.2-84.2°F) (Hemdal 2003)</td>
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</tbody>
</table>
Goldfish prefer water temperatures of 20 – 24°C (68 - 75°F) (Table 2). However, Goldfish can survive in water temperatures down to 0.3°C (33°F) and as high as 40.6°C (110°F) (Ford and Bellinger 2005). These temperature tolerances can be highly dependent on the diet consumed. Goldfish that feed on high fat foods can more easily adapt and survive extreme temperature changes (Hoar and Cottle 1952). Tarkan et al. (2010) report that the Goldfish is a robust species able to withstand, thrive, and reproduce under environmental stress conditions including but not limited to increased turbidity, decreased dissolved oxygen, wide temperature fluctuations, and ecosystems disturbances. The upper lethal limit for Goldfish survival is 41°C, and a lower lethal limit of near 0°C has been documented (Fry et al. 1941, Ford and Bellinger 2005). Cichlid temperature tolerances are also extensive. Rantin (1986) documented Cichlid survival at a high temperature range of 32.9°C - 38.5°C and low temperatures of 7.8°C. The wide ranges of temperature tolerance for Goldfish and Cichlids suggest they have an ability to survive in some areas outside of Kelly Warm Springs.

There has been an increase in the species present in Kelly Warm Springs from the early 1970's. However the increase in diversity is due to non-native species that may be harmful to the Kelly Warm Springs ecosystem. There also appears to be an increase in the abundance of non-native fish and invertebrate species in the Kelly Warm Springs and surrounding outlets (e.g., Ditch Creek) (Tables 1, 2, 3, and 4).

Table 3. Species collected by Erin Hotchkiss and Bob Hall, June 2010 (Hotchkiss 2011).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Family</th>
<th>Genus Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah Chub</td>
<td>Cyprinidae</td>
<td>Gila atraria</td>
</tr>
<tr>
<td>Redside Shiner</td>
<td>Cyprinidae</td>
<td>Richardsonius balteatus</td>
</tr>
<tr>
<td>Long Nose Dace</td>
<td>Cyprinidae</td>
<td>Rhinichthys cataractae</td>
</tr>
<tr>
<td>Green Sword Tail</td>
<td>Poeciliidae</td>
<td>Xiphophorus helleri</td>
</tr>
<tr>
<td>Convict Cichlid</td>
<td>Cichlidae</td>
<td>Amatitlania nigrofasciata</td>
</tr>
<tr>
<td>Tadpole Madtom</td>
<td>Ictaluridae</td>
<td>Noturus gyrinus</td>
</tr>
<tr>
<td>Guppy</td>
<td>Poeciliidae</td>
<td>Poecilia reticulate</td>
</tr>
<tr>
<td>Goldfish</td>
<td>Cyprinidae</td>
<td>Carassius auratus</td>
</tr>
<tr>
<td>Bullfrog</td>
<td>Ranidae</td>
<td>Lithobates catesbeianus</td>
</tr>
</tbody>
</table>

Table 4. Species collected by Chad Whaley, June 2012 (Whaley 2012).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Family</th>
<th>Genus Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speckled Dace</td>
<td>Cyprinidae</td>
<td>Rhinichthys osculus</td>
</tr>
<tr>
<td>Utah Chub</td>
<td>Cyprinidae</td>
<td>Gila atraria</td>
</tr>
<tr>
<td>Redside Shiner</td>
<td>Cyprinidae</td>
<td>Richardsonius balteatus</td>
</tr>
<tr>
<td>Green Swordtail</td>
<td>Poeciliidae</td>
<td>Xiphophorus helleri</td>
</tr>
<tr>
<td>Convict Cichlid</td>
<td>Cichlidae</td>
<td>Amatitlania nigrofasciata</td>
</tr>
<tr>
<td>Guppy</td>
<td>Poeciliidae</td>
<td>Poecilia reticulate</td>
</tr>
<tr>
<td>Tadpole Madtom</td>
<td>Ictaluridae</td>
<td>Noturus gyrinus</td>
</tr>
</tbody>
</table>

Table 5. Temperature data from Kelly Warm Springs and the outlet Ditch Creek, collected by the U. S. Geological Survey (Cox 1972).

<table>
<thead>
<tr>
<th>Warm Springs Date</th>
<th>Temp.(°C)</th>
<th>Ditch Creek Date</th>
<th>Temp.(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/13/69</td>
<td>26</td>
<td>5/13/69</td>
<td>7</td>
</tr>
<tr>
<td>7/22/69</td>
<td>27</td>
<td>7/22/69</td>
<td>22</td>
</tr>
<tr>
<td>9/26/69</td>
<td>25.5</td>
<td>9/26/69</td>
<td>5</td>
</tr>
<tr>
<td>11/11/69</td>
<td>25.5</td>
<td>11/12/69</td>
<td>2.5</td>
</tr>
<tr>
<td>5/3/70</td>
<td>27.5</td>
<td>8/5/70</td>
<td>18.5</td>
</tr>
<tr>
<td>10/16/70</td>
<td>27</td>
<td>10/16/70</td>
<td>0</td>
</tr>
<tr>
<td>9/17/71</td>
<td>26</td>
<td>6/7/71</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 6. Temperature data collected from Kelly Warm Springs by the National Park Service (Grand Teton National Park 1972).

<table>
<thead>
<tr>
<th>Date</th>
<th>Temperature(°C)</th>
<th>Discharge (CFS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/13/69</td>
<td>26</td>
<td>16</td>
</tr>
<tr>
<td>7/22/69</td>
<td>27</td>
<td>12.8</td>
</tr>
<tr>
<td>9/26/69</td>
<td>25.5</td>
<td>9.76</td>
</tr>
<tr>
<td>11/11/69</td>
<td>25.5</td>
<td>7.86</td>
</tr>
<tr>
<td>5/3/70</td>
<td>27.5</td>
<td>5.96</td>
</tr>
<tr>
<td>10/16/70</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>9/17/71</td>
<td>26</td>
<td>11.03</td>
</tr>
</tbody>
</table>

There was less than a 3°C temperature range over three years of spring, summer, and fall monitoring (Tables 5 and 6). The mean temperature of these measurements is 26°C. However, it should be
noted that these measurements were in the Kelly Warm Springs proper, and that winter sampling data was not collected. Also, there was no continuous monitoring; these were one-time measurements.

Discussions about eradicating non-native species in the Kelly Warm Springs were held in the 1980’s. Courtenay (1984) observed that “there should be no non-native pets within the boundaries of a National Park,” however he also stated that the “tropical fish” were are no harm to the indigenous species residing within the springs. However, the disappearance of Utah Sucker concurrent with the increase in non-native fish may suggest non-native fish have had an impact. The comments by Courtenay (1984) represent the thought that Kelly Warm Springs be left in its current status until further study was conducted to determine whether it was plausible to take action. Necessary actions to remove non-native species may be quite extensive and expensive, especially if the goal was to rid the Warm Springs and its outlets of non-native species.

Along with concern about non-native species in the Kelly Warm Springs, there have been efforts to rehabilitate the springs itself. These included cooperative efforts by private landowners and the National Park Service to modify the shape of the springs along with the outflows and inflows. These efforts were initiated due to private landowner concerns related to irrigation issues. The National Park Service views this project favorably because of concerns related to non-native species competition with native species and disease introduction.

Current temperature monitoring

Table 7. Preliminary temperature data gathered from October 6-December 14, 2014.

<table>
<thead>
<tr>
<th>Hobo Name</th>
<th>Mean Temp (°C)</th>
<th>Maximum Temp (°C)</th>
<th>Minimum Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KWS 4</td>
<td>8.6</td>
<td>19.7</td>
<td>0.12</td>
</tr>
<tr>
<td>KWS 5</td>
<td>12.8</td>
<td>23.9</td>
<td>1.2</td>
</tr>
<tr>
<td>KWS 6</td>
<td>15.4</td>
<td>26.4</td>
<td>2.6</td>
</tr>
<tr>
<td>KWS 7</td>
<td>20.4</td>
<td>28.3</td>
<td>10.8</td>
</tr>
<tr>
<td>KWS 8</td>
<td>23.9</td>
<td>30.9</td>
<td>16.1</td>
</tr>
</tbody>
</table>

By mid-November, 3 of 4 sites downstream of Kelly Warm Springs proper experienced minimum water temperatures approaching 0°C (Table 7). All sites located below Mormon Row, where temperature loggers were initially deployed, were either dewatered or frozen by mid-November.

The Kelly Warm Springs is a popular area for recreational visitation. Visitors frequent the Warm Springs to observe terrestrial and aquatic life, boat, picnic, swim, etc. It appears that some visitors started depositing non-native fish into the springs as early as the 1960s, which has been a cause for concern (Baldwin and Franta 1968). The National Park Service is currently gathering visitor count data but suggest visitor numbers in the thousands each year (K. Melander, NPS personal communication). Heavy visitor use is linked to erosion around the Kelly Warm Springs (Figure 2). Footpaths have been been created by the traffic around almost the entirety of the springs. This traffic appears to have caused damage to vegetation with land erosion at the surface of the springs (Figure 2). The human and animal traffic in the warm springs may have also elevated the presence of algae and sediment in the area (Figure 3). In addition to land traffic from humans and animals around the springs, there is also high traffic in the water from swimmers, waders, kayakers, etc. (Figures 3 and 4). The National Park Service has begun an educational program to teach the public about potential issues related to Kelly Warm Springs (Summer 2014). During educational events, the public was invited to participate in citizen science (Figure 5) where they worked with park personnel to identify fish caught in minnow traps. Bullfrog tadpoles and Swordtails were identified and the data were recorded to follow fish species and amphibian presence within the warm springs (Figures 6, 7, and 8). This capture helps the National Park Service compile data as well as provides an opportunity for the public to learn proper sampling and observation techniques while they catalog and record the information. To further educate the public, the National Park Service recently posted signs (Figure 9) that request the public refrain from releasing aquarium fish and other specimens into Kelly Warm Springs.
In summary, research and monitoring has occurred in the Kelly Warm Springs since the 1960s and concern about non-native species and potential ecological damages have continued to grow since their initial discovery. The abundance and diversity of non-native species present within the springs, along with high human traffic threatens to erode, contaminate, and potentially introduce disease. Studies and observations pertaining to these potential threats are ongoing and in continuous review by the National Park Service and the U.S. Geological Survey.

**Figure 2.** Human traffic path to and from the warm springs. Photographer unknown.

**Figure 3.** Image of the Kelly Warm Springs with swimmers. This is a frequent occurrence year around creating heavy traffic not only around but in the springs. Photographer unknown.

**Figure 4.** Image displaying algae growth.

**Figure 5.** Image of a minnow trap placed in the north end of the Warm Springs and used for an educational program to identify and sample species in the springs. Photo by Paige Anderson.

**Figure 6.** Image of sample of native and non-native species taken from the warm springs. Photo by Paige Anderson.

**Figure 7.** An image of species being sampled and observed from the Kelly Warm Springs. Photo by Paige Anderson.

**Figure 8.** Specimens placed in ziploc bag for identification. Photo by Paige Anderson.
Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

**LITERATURE CITED**


Keifling J. 1999. Kelly Warm Springs Fish Samples. Wyoming Game and Fish Department, Cheyenne, WY.


ABSTRACT

Ecological effects of climate change can include advancement of spring events, shifts in species distribution patterns, and phenological changes. Studying these responses under field conditions can require decades of research. In 2010, we established an experimental field study designed to mimic the effects of predicted climate change using snow removal and passive heating in montane meadows. Here, we use this same experimental set-up to examine nectar production relative to pollinator emergence in two important nectar sources: Arrowleaf Balsamroot (Balsamorhiza sagitatta) and Wild Buckwheat (Eriogonum umbellatum). Preliminary results indicate that there was lower nectar volume for Balsamorhiza sagitatta in the heating compared to either the control or snow removal. The heating + snow removal was also lower in nectar volume than snow removal only. Preliminary results for Eriogonum umbellatum showed a lower sugar content in the control as compared to the heating + snow removal.

INTRODUCTION

Increasing evidence predicts that global climatic patterns are changing rapidly as a result of anthropogenic production of greenhouse gases, including CO₂ (Field et al. 2014). Global climatic patterns have shown increased temperatures since the 1970s (Field et al. 2014) and Atmosphere-Ocean General Circulation Model (AOGCM) simulations for the Intergovernmental Panel on Climate Change (IPCC) estimate a 1.4°C–5.8°C temperature increase during the period from 1990–2100 (Cubasch et al. 2001, Notaro et al. 2006). Changes in ecosystems at higher altitudes and latitudes may be subject to larger, more rapid changes (Harte and Shaw 1995, Kim et al. 2002, Thuiller et al. 2005). During the period from 2003–2007, the western United States had an average increase of 3°C when compared to the 20th century average (Saunders et al. 2008). Montane systems are some of the regions of the globe that may be most sensitive to climate change. Regional models of global climate change for the northern Rocky Mountains predict warmer temperatures, diminished amounts of precipitation, and decreased snowpack (Reiners et al. 2003, Zimmerman et al. 2006, Adam et al. 2009). It is likely that the impact of these changes will be significant throughout many ecosystems.

In 2010, we initiated a research project to simulate climate change in montane meadows of the
Rocky Mountains (Figure 1, Sherwood 2013). We used a replicated block design of snow removal (SR) and passive heating (H+), both treatments (SR and H+) and a control (CT) to examine the effects of temperature, snow removal and their potential interactions on soil conditions, plant growth, and insect responses. In 2014 we added a new dimension: assessing how snow removal and warming affect nectar resources for pollinators. Our hypothesis was that reduced soil moisture from reduced snowpack and passive heating would be correlated with lower nectar volume and/or sugar content in nectar plants.

**Methods**

**Study organisms and study site**

The study area for this study is a sagebrush (Artemisia sp.) meadow at an elevation of 2100 meters. This area has relatively flat, homogeneous topography and is located in Grand Teton National Park, WY. The meadow is approximately 2 x 0.5 km in size (Auckland *et al.* 2004) and is just south of the University of Wyoming-National Park Service Research Station, where our research team is housed during the field season. For this project, we monitored *Balsamhoriza sagittata* (Arrowleaf Balsamroot, below left) and *Eriogonum umbellatum* (Wild Buckwheat, below right). These two nectar resources are particularly valuable to the butterfly *Parnassius clodius* (butterfly in photo at right) found within this system.

**Field methods**

The experimental design includes three replicated blocks of four 2.5 x 2.5 m plots with the following treatments: snow removal (SR), passive heating (H+), both treatments (SR and H+) and control (CT). Each plot is separated by 5 m and is laid out in a regular pattern within the meadow. The plots were set up in 2010, with landscape edging buried to delineate plot edges.

Snow is removed manually using shovels at the end of April/early May. Assuming 53 cm/yr of precipitation (Shaw 1958), mostly as snow, with a spring snowpack that is about 50% water by volume (California Department of Water Resources [n.d.]), removing 50 cm of the snowpack (i.e., all snow still present in early May) can reduce the annual precipitation by approximately one half. As we have developed these techniques, we have determined that snow depth should be maintained at ~2 cm in treatment plots to minimize the possibility of vegetation damage. New or wind-driven snow is removed when present after the initial snow removal. Snow depth in control plots is also measured and recorded during the sampling period.

We utilized a louvered Open-Sided Chamber (OSC, Figure 1) to warm our plots, placed on the site when snow is removed in late April/early May and left there through the growing season. OSC’s passively increase the downwelling infrared (longwave, or thermal) radiation to plant and soil surfaces, thereby increasing minimum nighttime temperatures by several degrees Celsius (Germino and Smith 1999). There are a variety of both active (e.g., infrared lamps or heating cables) and passive (e.g., open-top chambers, shelters, or covers) methods available for creating warming conditions (Kennedy 1994, Convey and Wynn-Williams 2002, Bokhurst, *et al.* 2008). Each method has advantages and disadvantages for changing light or moisture regimes or altering of wind patterns or atmospheric exposure (Beier *et al.* 2004), and most of these approaches have been used to increase maximum daily temperatures (i.e., Kennedy 1994, Convey and Wynn-Williams 2002, Bokhurst, *et al.* 2008). It is important to evaluate ways to experimentally simulate increased minimum temperatures given that the daily minimum temperatures are increasing faster than daily maximum temperatures (Kukla *et al.* 1994, Alward *et al.* 1999).

Temperature and soil moisture are measured and recorded at 25 cm depth using soil moisture meters buried in the soil (Sherwood 2013). Debinski (unpublished data) showed that snow removal in early May can affect soil moisture at 25 cm depth through the growing season. Dataloggers record daily at 12:00 hrs through the summer.

**Extracting nectar**

During the flowering season, nectar was collected from each plant within the plot as it reached peak flowering time. We extracted the nectar using
icrocapillary pipettes, placed into the flower where the nectar pools. Once the nectar was extracted from the flower, we measured the length (in mm) of nectar within the tube, the size of the microcapillary pipet, and the temperature and relative humidity. We used a refractometer (with a Brix scale). Because buckwheat has very small flowers, we pooled samples from five flowers.

**Calculating nectar volume**

Nectar volume was calculated using the following equation:

\[
\text{Nectar volume (µL)} = \frac{\text{microcap size (µL)} \times \text{mm length of nectar in pipet}}{\text{mm length of pipet}}
\]

**Determining sugar concentration**

We converted the percent sucrose (Brix value) to concentration of sugar (mg/mL) (Kearns and Inouye 1993). Nectar sugar concentration is calculated using the following equation:

\[
\text{Nectar volume (µL)} \times \text{concentration of sugar (mg/mL)} \times \frac{1}{1000} \text{µL} = \text{Amount of Sugar}
\]

**RESULTS**

We compared both nectar volume and sugar content of each plant species relative to treatment (Tables 1 and 2). Preliminary analysis show that for *Eriogonum umbellatum* nectar volume was lower in the heating compared to either the control or snow removal and that heating and snow removal was also lower than snow removal only. The sugar amount did not show much variation among treatments. For *Balsamorhiza sagittata* there were no differences among treatments in the nectar volume, but there were differences in the sugar amount. Preliminary results show that the control was lower in sugar volume than the heating + snow removal.

**CONCLUSIONS**

These data show that there could be changes in nectar resources associated with warming and/or reduced snowpack. They also show that the responses could vary among plant species. Such changes could have important implications for the pollinator community in Grand Teton National Park.

| Table 1. 2014 GTNP nectar results: Sulphur Buckwheat (*Eriogonum umbellatum*) |
|-----------------------------|------------------------|------------------------|
|                            | Nectar Volume (µL) | Sugar Amount (mg) |
| Treatment                  | Average | Standard Deviation | Average | Standard Deviation |
| Control (n = 54)           | 0.68    | 0.46               | 344.66  | 169.07             |
| Heating (n = 60)           | 0.52    | 0.22               | 335.90  | 131.16             |
| Snow Removal (n = 57)      | 0.75    | 0.57               | 401.25  | 323.42             |
| Heating + Snow Removal (n = 57) | 0.57    | 0.29               | 353.02  | 170.11             |

| Table 2. 2014 GTNP nectar results: Arrow-leaved Balsamroot (*Balsamorhiza sagittata*) |
|-----------------------------|------------------------|------------------------|
|                            | Nectar Volume (µL) | Sugar Amount (mg) |
| Treatment                  | Average | Standard Deviation | Average | Standard Deviation |
| Control (n = 23)           | 0.32    | 0.17               | 163.15  | 65.88              |
| Heating (n = 20)           | 0.33    | 0.13               | 191.71  | 80.80              |
| Snow Removal (n = 28)      | 0.36    | 0.28               | 164.48  | 160.58             |
| Heating + Snow Removal (n = 19) | 0.37    | 0.21               | 225.73  | 107.04             |

**LITERATURE CITED**


SPATIO-TEMPORAL ECOLOGICAL AND EVOLUTIONARY DYNAMICS IN
NATURAL BUTTERFLY POPULATIONS (2014 FIELD SEASON)

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DEPARTMENT OF BIOLOGY  UTAH STATE UNIVERSITY  LOGAN, UT

INTRODUCTION

The study of evolution in natural populations has advanced our understanding of the origin and maintenance of biological diversity. For example, long-term studies of wild populations indicate that natural selection can cause rapid and dramatic changes in traits, but that in some cases these evolutionary changes are quickly reversed when periodic variation in weather patterns or the biotic environment cause the optimal trait value to change (e.g., Reznick et al. 1997, Grant and Grant 2002). In fact, spatial and temporal variation in the strength and nature of natural selection could explain the high levels of genetic variation found in many natural populations (Gillespie 1994, Siepielski et al. 2009). Long-term studies of evolution in the wild could also be informative for biodiversity conservation and resource management, because, for example, data on short-term evolutionary responses to annual fluctuations in temperature or rainfall could be used to predict longer term evolution in response to directional climate change. Most previous research on evolution in the wild has considered one or a few observable traits or genes (Kapan 2001, Grant and Grant 2002, Barrett et al. 2008). We believe that more general conclusions regarding the rate and causes of evolutionary change in the wild and selection’s contribution to the maintenance of genetic variation could be obtained by studying genome-wide molecular evolution in a suite of natural populations. Thus, we have begun a long term study of genome-wide molecular evolution in a series of natural butterfly populations in the Greater Yellowstone Area (GYA). This study will allow us to quantify the contribution of environment-dependent natural selection to evolution in these butterfly populations and determine whether selection consistently favors the same alleles across space and through time.

The focal species, *Lycaenidae idas*, is one of five nominal species of *Lycaenidae* butterflies that occur in North America (Figure 1; Nabokov 1949, Guppy and Shepard 2001, Gompert et al. 2006). These species are descended from one or more Eurasian ancestors that colonized North America about 2.4 million year ago (Vila et al. 2011). *Lycaenidae idas* hybridizes with a second species, *L. melissa*, in the GYA (Gompert et al. 2010, 2012). *Lycaenidae idas* is a holarctic species that is found in Alaska, Canada, and the central and northern Rocky Mountains of the contiguous USA (Scott 1986). *Lycaenidae idas* is univoltine and adults generally fly from mid-July to early August. In the GYA *L. idas* populations often occupy mesic forest and montane habitat at elevations ranging from 2000-3500 m above sea level. Most populations of *L. idas* in the GYA feed on *Astragalus miser* as larvae, but some populations feed on other native legumes (most notably, other species of *Astragalus* and *Lupinus*; Gompert et al. 2010). We selected *L. idas* as the focal species for this study because of our experience with this species, extensive data on the location and natural history of *L. idas* populations, the availability of genomic resources for this species, and several key aspects of this species’ natural history (e.g., *L. idas* have non-overlapping generations with one generation per year, well-defined populations, and modest genome sizes, and *L. idas* are found in various different habitats that might experience different environment-dependent selection pressures).

The specific goals of this study are to: (i) quantify genetic variation and molecular evolution in *L. idas* and their relationship with population size and environmental variation across space (i.e., different populations) and through time (i.e., from generation to generation), and (ii) test the hypothesis that the nature and strength of environment-dependent selection
varies among populations and over generations and that this variation is sufficiently large to contribute to the maintenance of genetic variation in *L. idas*. This report documents the results from the third year of this long-term study. The first year (2012) was a pilot study in which we collected *L. idas* for DNA sequencing and tested the distance sampling technique to estimate population sizes (population size is an important parameter for our evolutionary models). In our second year (2013) we collected *L. idas* and started distance sampling at four populations. This year we collected *L. idas* and used distance sampling at ten populations.

**Figure 1.** Photograph of a female *L. idas* butterfly perched above its host plant (*Astragalus miser*) on Blacktail Butte (BTB).

**METHODS**

We collected 596 specimens from twelve locations: the ten populations involved in this study (Figure 2, Table 1), as well as two other locations near Dubois, WY with which we are investigating putative current hybridization between two *Lycaeides* species. Four of the populations are within national park boundaries (BTB and RNV in GTNP and BNP and HNV in YNP). We are storing these whole adult butterflies at -80°C for later DNA extraction and sequencing. In addition, we used a distance sampling protocol to estimate adult population sizes in *L. idas*. Distance sampling involves counting individuals and recording their distance from a transect line or point (Buckland et al. 2001). This distance information is used to estimate a detection function that accounts for imperfect detection away from the transect line. We performed the distance sampling method one or two times per *L. idas* population over the course of four weeks (July 7 – August 3). For each population we randomly chose ten or fewer random points within a defined area of suitable habitat (we identified suitable habitat from ground surveys and satellite images). At each of these points, four trained observers (ZG, LKL and two USU Biology undergraduates, Robert Olsen and Peter Nelson) walked an approximately 100-meter transect, and: 1) counted the *L. idas* we saw along the way, recorded the sex and measured their distance from the transect line, and 2) quantified the abundance of butterfly host plants (Figure 3). We recorded a 0, 1 or 2 to denote whether there were no butterfly host-plants, less than 50% of the ground cover was host-plants, or more than 50% of the ground cover was host-plants within a meter of each transect line, respectively. The host-plant species recorded depended on the population: *Astragalus miser* (BCR, BTB, MRF, HNV, BNP, GNP, SKI, USL), *Astragalus bisulcatus* (USL), *Lupinus* sp. (PSP) or *Hedysarum* sp. (RNV). We only performed distance sampling between 10:00 am and 2:00 pm under sunny or partly sunny skies.

We estimated population densities (adult butterflies per square kilometer) using the `distsamp` function in the *unmarked* R package. We binned the detection distances of butterflies into 1 meter bins prior to analysis (e.g., 0 to 1 m, 1 to 2 m, etc.). We used a half-normal detection function and estimated the detection function and density model parameters using maximum likelihood (Royle 2004). This model assumes the latent transect-level abundance distribution is Poisson and that the detection processes is multinomial with a different detection probability for each distance class or bin. We then estimated population size by first multiplying density by the area of habitat (km²) and then by three because adult *L. idas* live for about a week but the population flies for about three weeks.

To preliminarily explore whether differences in population size across space (populations) can be explained by host-plant abundance and climate, we used 19 weather variables averaged over 1950-2000 (source: http://www.worldclim.org/bioclim), summarized as one variable via a Principal Component Analysis (PCA) using the `prcomp` function in R. We did a regression using the `lm` function in R.
RESULTS

Using data from the one visit out of the two to each population in which our census was higher, our estimates of adult *L. idas* population density using distance sampling were: 4813 butterflies per square km (standard error [se] 1511) at GNP, 4600 at BTB (se 1483), 6196 at BNP (se 1727), 4672 at BCR (se 1442), 3868 at PSP (se 1626), 4285 at USL (se 1234), 5010 at MRF (se 2023), 5144 at HNV (se 1668), and 4033 at SKI (se 1207). Our estimated population sizes ranged from 366.7 to 5291.4 butterflies (Table 1). We were unable to estimate the population size for RNV, as adult butterflies started flying much later than expected. When comparing estimates between 2013 and 2014, we observed that GNP and BTB stayed about the same, BNP increased, and BCR decreased (Table 1). The range of host-plant abundance across sites was 0.21 to 0.92, with the highest abundance at BNP and the lowest at MRF (Table 1). To collapse all 19 bioclim weather variables to one variable, we did a PCA and used the first principal component (PC1), which represented 52.6% of the variance in the original dataset. This climate variable ranged from 0.569 to -3.91 across sites. Negative numbers represent hotter and drier climates, whereas positive values represent colder and wetter climates. We found that PSP and BCR were the hottest/driest. PSP was -3.91 and BCR was -3.75. The coldest and wettest were RNV at 5.69 and GNP at 3.55 (Table 1).

![Map of the ten *L. idas* populations in the GYA involved in this long-term study.](image)

**Figure 2.** Map of the ten *L. idas* populations in the GYA involved in this long-term study.

![Photograph of a transect for distance sampling at Blacktail Butte (BTB). The two undergraduate researchers are recording host-plant abundance.](image)

**Figure 3.** Photograph of a transect for distance sampling at Blacktail Butte (BTB). The two undergraduate researchers are recording host-plant abundance.

<table>
<thead>
<tr>
<th>Population</th>
<th>2013 size</th>
<th>2014 size</th>
<th>Ave. host-plant abundance</th>
<th>Climate PC score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blacktail Butte (BTB)</td>
<td>1838.7</td>
<td>1978.5</td>
<td>0.5</td>
<td>-1.5</td>
</tr>
<tr>
<td>Bull Creek (BCR)</td>
<td>2382</td>
<td>1241.7</td>
<td>0.5</td>
<td>-3.8</td>
</tr>
<tr>
<td>Bunsen Peak (BNP)</td>
<td>633.9</td>
<td>1273.2</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Garnet Peak (GNP)</td>
<td>1119.9</td>
<td>1024.5</td>
<td>0.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Hayden Valley (HNV)</td>
<td>NA</td>
<td>5291.4</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Mt. Randolf (MRF)</td>
<td>NA</td>
<td>977.7</td>
<td>0.2</td>
<td>-1.5</td>
</tr>
<tr>
<td>Periodic Springs (PSP)</td>
<td>NA</td>
<td>366.7</td>
<td>0.6</td>
<td>-3.9</td>
</tr>
<tr>
<td>Rendenous Mountain (RNV)</td>
<td>NA</td>
<td>NA</td>
<td>0.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Ski Lake (SKL)</td>
<td>NA</td>
<td>1348.8</td>
<td>0.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Upper Slide Lake (USL)</td>
<td>NA</td>
<td>1708.2</td>
<td>0.5</td>
<td>-2.4</td>
</tr>
</tbody>
</table>

**Table 1.** Population names with abbreviations, population size estimates via distance sampling in 2013 and 2014, average host-plant abundance, and a representation of long term climate at each population.
Last, we found no relationship between 2014 population sizes and long-term climate and average host-plant abundance. Our p-values were 0.4648 (host-plant) and 0.2052 (climate), both of which are well above 0.05.

**DISCUSSION**

Because we have just begun this long-term study and we have not yet sequenced the DNA from the sampled butterflies, we cannot yet make any conclusions about the rates or causes of molecular evolution in these study populations. But we have already learned a few things from the distance sampling surveys and analyses over the past two years. Based on our moderate population size estimates we predict that both genetic drift and selection are important drivers of evolution in this system (Lynch 2007). The comparison of population size estimates in 2013 and 2014 are potentially interesting and could reflect demographic variability between years. The difference in habitat (i.e., host-plant) and climate across populations highlight the spatial variation in this study system. It is possible we would have seen a significant relationship between population size and weather specifically recorded from 2013 and 2014, but we currently don’t have these data; we only have the bioclim data that is an average of the weather from 1950-2000.

We will continue this study during the 2015 summer field season. During this and subsequent field seasons, we will collect samples and estimate population sizes at all ten sites listed in Table 1. We will also continue collecting habitat data that will be useful for fitting causal models of molecular evolution. We plan to begin DNA sequencing of the collected L. idas in 2015.

**LITERATURE CITED**


ABSTRACT

Beavers are a keystone species in Grand Teton National Park and are critical to the aquatic and terrestrial landscape. Modifications to their habitat by climate change impact multiple species. This study is designed to examine the current distribution and habitat of beavers in Grand Teton National Park and analyze the alterations to this distribution and habitat based on climate change. Field and aerial surveys were completed to determine the distribution of beaver colonies in Grand Teton National Park. Beaver habitat was constructed by integrating field surveys of vegetation, soils and hydrologic characteristics with satellite imagery classification. A model of climate change was utilized in an effort to distinguish potentially different rates of temperature and precipitation change into the 21st century. The results of the climate model were then integrated into a watershed assessment model to determine stream flow in the Snake River basin. The decreasing flow rates are critical to beaver habitat for cottonwoods and willow species and beaver settlement and movement and will limit their movement. In addition, the Snake River below Jackson Lake Dam is regulated for irrigation into Idaho and the decreasing flows on the Snake River below the Jackson Lake Dam will also impact water availability for beaver habitats. Decreases in precipitation availability will increase irrigation demand causing changes in the Snake River flow patterns. Management conflicts exist between preserving and maintaining beaver habitat in the national park and meeting the irrigation needs of Idaho irrigation agriculture.

JUSTIFICATION AND SCOPE

Climate change is manifested in alterations of temperature and precipitation on a global scale. In the Central Rocky Mountain region, warmer temperatures and large amplitude swings in precipitation patterns have been recorded on NOAA sites and throughout our national parks. Our proposed study will focus on beavers in Grand Teton National Park (GTNP), a keystone species. There are two distinct habitats utilized by beaver in GTNP. Populations include pond and river beavers. Pond beavers tend to inhabit an area for a longer time, several generations and create, preserve and restore their habitat by dam building and impoundment of water. River beavers in GTNP tend to traverse waterways such as the Snake River through the spring and summer and migrate away from the main river corridor in the fall. Over the last forty years the overall population of the GTNP beavers has decreased, with the most dramatic changes occurring on the river beavers.

Collins in 1975-1977 identified 112 colonies in the GTNP. Of this total, 45.5% were river beavers and 54.5% pond beavers. Gribb (2011) found overall decreases of 62% (42) and 48% (22), respectively, in subsequent censuses. River beavers experienced a decrease from 51 (1977) to 24 in 2006 and 8 in 2010. Pond beavers, however, remained relatively stable over this period with 18 surveyed in 2006 and only 14 in 2010. Interestingly, some ponds were abandoned while others were created with the abandoned ponds accounting for 18% of the total ponds, while 21% were created. Slough and Sadleir (1977) stated that reestablishment of abandoned lodges and ponds is a
continual process for beavers, and this spiral of II. creation, maintenance, abandonment, reutilization. III. maintenance is on-going throughout the beavers’ habitat. We are investigating this premise and comparing the dynamics of the process in beaver ponds and river channels.

This project will focus on modeling climate change impacts on the terrestrial and aquatic habitat of beaver utilizing ponds and rivers. The research project has five main objectives:

2. Determine the general habitat characteristics of beaver along the Snake River and the pond areas of GTNP.
3. Using the different climate change models create a scenario of temperature and precipitation changes in the Greater Yellowstone Ecosystem.
4. Utilizing the results of the models, examine the predicted climate change impacts to water resources in GTNP.
5. Analyze the beaver distribution based on the water resources impacted by the climate change models.

While ponds are fed from sub-surface water and tributaries, the lower Snake River is subject to controlled flow from the Jackson Lake reservoir. The results of this study will have management implications for GTNP when working with the Bureau of Reclamation to determine the seasonal water storage and release patterns into the Snake River. Recommendations for protection of ponds and translocation of beavers can be made depending upon the outcome of the climate modeling.

**SIGNIFICANCE**

This research is focused on the potential changes to the Snake River ecosystem based on a climate change model. An immediate impact to the ecosystem will be to those species that have habitat directly associated with the Snake River. The beavers in this area have had dramatic population changes in the last 40 years and with the model predictions there could be further changes to the river ecosystem. Policy strategies will be examined in response to the changing ecosystem and this will provide the GTNP with some options for wildlife management. A peer-reviewed research paper in River Research and Applications is anticipated. Further, research proposals to the Wyoming Water Development Commission, NSF and the Columbia River Basin Commission are forth-coming.

**METHODS**

This project will employ three research methods: an inventory and compilation of beaver habitat characteristics, field and aerial surveys of beaver lodge and den locations, and modeling of streamflow using climate change models. The first two methods are interrelated. Historic data on beaver locations will provide areas of past environmental conditions relating to vegetation and soils. This information will be incorporated into a more robust model of beaver habitat. Current beaver locations will be collected by field and aerial surveys. Vegetation and soil characteristics will be compiled from existing GIS-formatted spatial data to provide base data for the beaver habitat model. The aerial beaver census will provide base information on colony locations in a wider range of areas not covered by the ground field survey. The NOAA regional climate data center will provide historic data on temperature and precipitation for Region 2, the Central Rockies including Grand Teton National Park.

Beaver habitat characteristics were compiled from three different sources. First, the historic records of Collins (1977) and Gribb (2011) that provide vegetation and soils information at historic beaver lodges and bank dens. Second, current vegetation and soils data were collected and compiled from existing data sets from the US National Park Service, US National Resources Conservation Service, US Forest Service and the Wyoming Geographic Information Science Center (WyGISC). Finally, by utilizing high resolution WorldView2 satellite imagery from DigitalGlobe, an updated vegetation classification can be completed for areas inhabited by beavers as identified from the field and aerial survey.

Several different climate change modelling schemes have been developed to determine climatic conditions into the future. The US Forest Service in conjunction with ESSA have generated a model of general climate change that can be utilized for the central Rocky Mountain region, FVS. The model has the flexibility to incorporate several scenarios of change in temperature and precipitation. Thus, the model using the Global Circulation Model (GCM) with Regional Climate Models (RCM) developed by NOAA’s GeoPhysical Fluid Dynamics Laboratory (NOAA-GFDL_CM2.1) at a higher spatial resolution will be incorporated following the 21st Century A1B scenario (IPCC,2007). The USDA’s Soil and Watershed Assessment Tool (SWAT) will also be examined to determine if it can assist in analyzing the meteorological inputs at a watershed level. The combination of these models will allow this research...
to utilize model changes at a higher spatial resolution. For example, Jha and Gassman (2014) were able to model change at the sub-basin (HUC 12) unit level, creating hydrological response units (HRU).

Input into the SWAT model requires data on topography, soils, precipitation, temperature, solar radiation, wind speed, relative humidity and land use/land cover. The nine weather stations surrounding the study area will provide the climate and weather information required for this study along with the GCM-RM models. Land use will be classified using WorldView2 high resolution satellite data from DigitalSpace Imagery. Land use/land cover will be classified relative to beaver habitat parameters (Allen 1983, Gribb 2011). As examples relevant to our project, climate change models have predicted decreases in cottonwoods (Populus spp.) and willows (Salix spp.) in the Rocky Mountain region (Scott et al., 2013, Wood et al., 2013, and Kaczynski and Cooper 2013), major vegetation factors in beaver habitat. McWethy et al. (2010) provides a long term perspective on western U.S. climate change and their conclusions of incorporating the multi-millennial climate drivers into climate change models will be a fundamental concept in this study.

Modeling river discharge will follow the work of St. Jacques et al. (2013) and Dettinger et al. (2004) to estimate streamflow and its characteristics for river beaver habitat. Both studies use a generalized least squares regression model to determine flow rates for the mid-century scenario.

**PREVIOUS WORK**

The Co-PIs have conducted field surveys for beavers in GTNP since 2002. The work of Collins (1974-1977) identified 65 colonies along the Snake River and 112 throughout Grand Teton NP. Gribb and Harlow have conducted aerial surveys in 2006 and 2010 and have identified and mapped the decreasing beaver colonies in GTNP (Figure 1).

**ANALYSIS**

The first stage of this project had two parts, to field inventory beaver lodges and conduct an aerial census of beaver colonies. The field inventory of beaver lodges and bank dens was conducted through June and August, 2014. A total of 83 active lodges and dens were located across Grand Teton NP. These lodges and bank dens displayed activity by having recently browsed willow stems either at the lodge/den entrance or in close proximity or they were displayed on the top or side of the lodge. The second part of the inventory was an aerial census survey of beaver caches following the Snake River, Gros Ventre River, Cottonwood Creek, Buffalo Fork, Pacific Creek, and the upper Snake River above Jackson Lake Dam and the major tributaries going into Jackson Lake.

The aerial survey was conducted on November 3, 2014 and took approximately six hour to complete. Figure 2 illustrates the distribution of the caches that were located. A total of 76 caches were found throughout the park. Overall, 22 of the caches (28.9%) were pond or lake caches and the remaining 54 (71.1%) were along the major rivers or their back channels. The difference between the field observed lodge/bank dens and the aerial survey is that the field-
Figure 2. Beaver cache locations, aerial survey 2014.

observed lodges and bank dens represent areas that beavers utilized throughout the summer, but may not be lodges/dens that were used in the winter so they did not cache. Whereas, the caches represent lodges/bank dens that would be used during the winter because the beavers cached food that they could easily access from the lodge/bank den entrance.

The digital vegetation data came from the Grand Teton NP GIS Center and was part of a 2005 study of vegetation throughout the park extracted from USGS NHP imagery (2002). Overall, a total of 51 vegetation classes were identified in the park, of which seven categories were identified as potential vegetation communities associated with beaver habitat: willow shrubland, alder shrubland, mixed conifer-cottonwood riparian forest, mixed evergreen-poplar forest, cottonwood riparian forest, aspen forest, and artic willow dwarf shrublands.

Nicholas (2007) divided the lower Snake River (Jackson Lake Dam to Moose, WY) into 20 reaches. The reaches were classified by their geomorphic attributes, mainly sinuosity, braiding and erosion/deposition capacity. Utilizing the Nicholas reach classification and extending the process onto the upper Snake River (southern boundary of Yellowstone NP to delta of Snake River into Jackson Lake) seven additional reaches were delineated.

Combining the reach delineations with the vegetation classes, it was possible to determine the extent of beaver habitat within each reach. Table 1 provides a listing of the amount of potential beaver habitat within each reach. Overall, about 44% of the reach areas in Grand Teton NP have the potential to be beaver habitat. However, the maximum distance that a beaver will travel from water to acceptable vegetation browse is 60 m, thus percentage of potential habitat is then reduced to less than 15%. From Table 1 it is clear that there are some reaches that have very little beaver habitat because of a lack of vegetation cover, but this is also the result of a combination of soil characteristics (sand, gravel, and exposed bedrock), associated with sand bars, point bars and steep high slopes of gravel.

Figure 3 provides an overview of the density of beaver colonies by reach over the last 40 years, 1976-2014. By this diagram it is easy to determine that Collins counted the largest number of lodges and bank dens along the Snake River. This disparity in numbers can be attributed to the differences in definition of an active lodge or bank den. Collins counted an active lodge or bank den as any location that displayed any current activity at the time it was located. Thus, even if a lodge or bank den displayed any recent browse droppings when he located the dwelling it was counted as active. There was no differentiation between a location that was used temporarily during the summer or inhabited through the winter. In the aerial surveys of 2006, 2010 and 2014 an active lodge or bank den was counted in late October or early November if it had a food cache. This provided food for the lodge or bank den through the winter and would be a birthing location for the colony in the subsequent spring. The cache census would suffer an approximate 10-15% error in missing caches, but this would not account for the almost doubling of the difference between Collins’ counts and the three aerial surveys. Collins, though, believed that the beaver population during his study period, 1974-1976, was probably at the carrying capacity maximum.

The spatial differences between the four different counts displayed in Figure 3 can also be attributed to the fact that Collins did not complete as thorough a survey of beaver colonies in the upper Snake River region, from the southern boundary of Yellowstone National Park to the delta of the Snake River into Jackson Lake. The upper Snake River Reach #6 does display a consistency in having active lodges/dens through the four different censuses. Only three other reaches along the lower Snake River, from the Jackson Lake Dam to Moose, display the same
Table 1. Beaver habitat and vegetation by stream reach.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Area (ha)</th>
<th>Beaver Habitat (%)</th>
<th>% Reach Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>UpperSnake_Reach1</td>
<td>17.02</td>
<td>1.63</td>
<td>9.59</td>
</tr>
<tr>
<td>UpperSnake_Reach2</td>
<td>9.18</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>UpperSnake_Reach3</td>
<td>11.72</td>
<td>0.57</td>
<td>4.88</td>
</tr>
<tr>
<td>UpperSnake_Reach4</td>
<td>4.86</td>
<td>0.62</td>
<td>12.72</td>
</tr>
<tr>
<td>UpperSnake_Reach5</td>
<td>59.74</td>
<td>17.22</td>
<td>28.83</td>
</tr>
<tr>
<td>UpperSnake_Reach6</td>
<td>159.08</td>
<td>77.88</td>
<td>48.96</td>
</tr>
<tr>
<td>UpperSnake_Reach7</td>
<td>254.89</td>
<td>127.53</td>
<td>50.03</td>
</tr>
<tr>
<td><strong>Upper Snake Total</strong></td>
<td><strong>516.48</strong></td>
<td><strong>225.46</strong></td>
<td><strong>43.65</strong></td>
</tr>
<tr>
<td>LowerSnake_Reach1</td>
<td>85.81</td>
<td>31.82</td>
<td>37.08</td>
</tr>
<tr>
<td>LowerSnake_Reach2</td>
<td>72.23</td>
<td>12.23</td>
<td>16.93</td>
</tr>
<tr>
<td>LowerSnake_Reach3</td>
<td>131.75</td>
<td>29.95</td>
<td>22.73</td>
</tr>
<tr>
<td>LowerSnake_Reach4</td>
<td>63.31</td>
<td>6.35</td>
<td>10.02</td>
</tr>
<tr>
<td>LowerSnake_Reach5</td>
<td>10.68</td>
<td>2.34</td>
<td>21.93</td>
</tr>
<tr>
<td>LowerSnake_Reach6</td>
<td>14.62</td>
<td>1.12</td>
<td>7.67</td>
</tr>
<tr>
<td>LowerSnake_Reach7</td>
<td>9.23</td>
<td>2.05</td>
<td>22.19</td>
</tr>
<tr>
<td>LowerSnake_Reach8</td>
<td>109.25</td>
<td>15.86</td>
<td>14.52</td>
</tr>
<tr>
<td>LowerSnake_Reach9</td>
<td>3.91</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>LowerSnake_Reach10</td>
<td>118.53</td>
<td>26.39</td>
<td>22.27</td>
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<td>LowerSnake_Reach11</td>
<td>59.69</td>
<td>39.86</td>
<td>66.78</td>
</tr>
<tr>
<td>LowerSnake_Reach12</td>
<td>24.35</td>
<td>21.59</td>
<td>88.64</td>
</tr>
<tr>
<td>LowerSnake_Reach13</td>
<td>169.67</td>
<td>109.43</td>
<td>64.49</td>
</tr>
<tr>
<td>LowerSnake_Reach14</td>
<td>99.70</td>
<td>67.51</td>
<td>67.71</td>
</tr>
<tr>
<td>LowerSnake_Reach15</td>
<td>788.91</td>
<td>294.96</td>
<td>37.39</td>
</tr>
<tr>
<td>LowerSnake_Reach16</td>
<td>118.69</td>
<td>52.93</td>
<td>44.59</td>
</tr>
<tr>
<td>LowerSnake_Reach17</td>
<td>857.76</td>
<td>454.01</td>
<td>52.93</td>
</tr>
<tr>
<td>LowerSnake_Reach18</td>
<td>89.67</td>
<td>59.22</td>
<td>66.05</td>
</tr>
<tr>
<td>LowerSnake_Reach19</td>
<td>29.38</td>
<td>20.37</td>
<td>69.33</td>
</tr>
<tr>
<td>LowerSnake_Reach20</td>
<td>166.56</td>
<td>108.63</td>
<td>65.22</td>
</tr>
<tr>
<td><strong>Lower Snake Total</strong></td>
<td><strong>3023.70</strong></td>
<td><strong>1356.61</strong></td>
<td><strong>44.87</strong></td>
</tr>
</tbody>
</table>

The other reaches along the Snake River, both upper and lower reaches, provide intermittent access to the river during the winter period, either because the streamflow is so low that there is too much...
exposed land between the lodge/bank den and the water or the back channel in which the lodge/bank den is located has no flow during the winter months. Along the lower Snake River at the Moose gauging station the maximum spring runoff flow was 18,150 cfs in June, 1997. In comparison to the minimum winter flow of 641 cfs in March, 2014, a value of only 3.5% of the maximum flow. The radical shifts between spring runoff flows and winter flows make it difficult for beavers to maintain a year-long colony along the Snake River. This winter flow minimum is replicated in the upper Snake River with a maximum flow of 6701.0 cfs in June, 1996 and a minimum flow of 167.7 cfs in September 1994, a decrease of 97.5%.

Climate change will exacerbate this problem into the future. McWethy et al. (2010) has predicted that the middle Rocky Mountain region, which includes the Yellowstone/Grand Teton National Parks, will experience a warming trend and a decrease in winter snow precipitation levels resulting in lower river flows, using a combination of 22 different climate change models coordinated as part of the Coupled Model Intercomparison Project, Phase 3 (CMIP3). For the Central Rockies and the Greater Yellowstone Area, temperatures increased 1-2°C over the last half of the 21st century. Increased winter and spring temperatures have resulted in reduced snowpack, earlier spring snow melts and peak flows. However, the overall records show sizeable variability in temperature and precipitation trends.

This project used the NOAA-Earth System Research Lab’s climate base data from 1905-2014 for the climate region WY-Snake Drainage. Figure 4 is the yearly-average temperature for the region, while Figure 5 displays the annual precipitation levels. Though the hottest annual temperature occurred in 1934 at 4.39°C (39.9°F), temperature has slowly increased over this period. The least squares regression illustrating the change in temperature during this time is statistically significant (F=11.65, p=0.000); however, it is very weak in explaining the variability of the increasing temperature (r²=0.097). However, the trend it portrays has been verified in climate change models (McWethy et al. 2010, Westerling et al. 2011, and Shinker and Bartlein 2012).

A more detailed climatological breakdown of the temperature change by season reveals some difference in rates of change and types of change. The seasons are defined as Winter (Dec, Jan, Feb), Spring (Mar, Apr, May), Summer (Jun, Jul, Aug), and Fall (Sep, Oct, Nov). Figure 6 portrays the seasonal trends for the period of study and illustrates that all four seasons are trending with a slope increase in temperature, however slowly (Winter: 0.02; Spring: 0.014; Summer: 0.011; Fall: 0.002). Table 2 lists the change in temperature yearly as both an average change over the 110 year period and the average change for the last 30 years (1984-2014). In both the annual yearly changes and the seasonal yearly changes
there is a significant difference and increase in change between the 110 years and the last 30 years of record. This identifies the trend that temperature change is occurring at a faster rate in the last 30 years than as a trend for the last 110 years. Again, the GCM (Global Climate Model) multiple models have calculated a 1-4°C increase in temperature into the middle of the 21st century.

**Table 2.** Average yearly change in seasonal temperature, 1905-2014 and 30-year change 1984-2014.

<table>
<thead>
<tr>
<th>Ave.Chg 1905-2014</th>
<th>Annual</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>St.Dev.</td>
<td>1.594</td>
<td>3.106</td>
<td>3.291</td>
<td>1.949</td>
<td>2.405</td>
</tr>
<tr>
<td>30yr Chg 1984-2014</td>
<td>0.114</td>
<td>0.213</td>
<td>0.106</td>
<td>-0.026</td>
<td>0.163</td>
</tr>
</tbody>
</table>

Figure 5 displays the erratic precipitation levels over the last 110 years for the Snake River Region. The annual total precipitation has varied widely over the years. The highest amount recorded in 1997 at 1183.6mm (46.6in) to the lowest in 1939 at 568.9mm (22.4in). However, in the overall statistical realm precipitation is quite normal with a mean of 843.3mm (33.2in), a median of 833.1mm (32.8in), with a standard deviation of only 131.6mm (5.18in) and a mild skewness (0.194) and slight platykurtosis (-0.468). The sinuosity of the diagram makes it difficult to determine if there is a trend in precipitation, however it is a very slight positive trending slope of 0.0172. However, in the GCM inputs there is a slight decrease in precipitation as the temperature warms into the latter parts of the century (McWethy et al. 2010).

The precipitation seasons present the fact that seasonal precipitation levels are distinctly different (Figure 7). Summer precipitation is much lower than the winter precipitation, mean summer precipitation is 129.5mm (5.1in) while winter precipitation is 294.6mm (11.6in). Fall and Spring precipitation are relatively close, at 187.9mm (7.4in) and 231.1mm (9.1in), respectively. As the climate changes the form of the precipitation will also change. McWethy et al. (2010) and Westerling et al. (2011) have found that winter precipitation will change to less snow and more rain and there will be less summer rains increasing the drought potential.

There is a direct relationship between precipitation, runoff and streamflow (Wolman and Leopold 1957, Knighton 1984). In fact, both Vano, Das and Lettenmaier (2012) and Elsner et al. (2014) have demonstrated that temperature and precipitation together influence runoff and streamflow. So that as the trend in precipitation changes so will stream flows. In the Snake River basin the Snake River is divided into two sections, the natural flowing upper Snake River above Jackson Lake and the regulated lower Snake River below the Jackson Lake Dam. For this study, the upper Snake River will be represented by the U.S.G.S. Flagg Ranch gauging station (#13010065, 41°05’56”N, 110°40’03”W), while the lower Snake River will be represented by two gauging stations, one at the dam (Moran, #13011000, 43°51’30”N, 110°35’09”W) and at Moose, WY (#13013650, 43°39’14.6”N,110°42’55.7”W ). The Flagg Ranch gauging station has collected hourly data that can be obtained monthly from October, 1983 through September, 2014. Similarly, hourly readings for the Moran gauging station and the Moose gauging station have been acquired from October, 1995 through September, 2014. Figures 8-10 illustrate the monthly flow rates for the three gauging stations, respectively. There is some similarity in patterns of flow, but overall they are distinct. The year 1997 provides the most obvious similarity with high flows at all three locations. This also corresponds to one of the highest years for precipitation (Figure 7).

*Figure 7. Seasonal precipitation, Wyoming Region 2, 1905-2014.*

The upper Snake River represents the natural flow of the Snake River because it has no human interference by diversion, dams, or other storage structures. The average flows by season illustrate a consistent pattern difference with normal variations (Figure 8.). Table 3 lists the major statistical characteristics of the upper Snake River demonstrating the differences between the seasons on the river. Summer is the only season that has a
The lower Snake River, on the other hand, is a regulated river controlled by the U.S. Bureau of Reclamation since the first dam was constructed in 1906-07. The Moran gauging station has recorded lake discharge from 1904 to the present (Figure 9). However, discharge from Jackson Lake changed in 1957 from a summer demand sequence to a more normal flow with spring and summer snow melt. In reviewing Figure 11 this change is evident by the increases in both winter and spring flows after 1956. Thus, any statistical analysis will only include the years 1957-2014 which are more representative of the flow patterns. Table 4 presents the descriptive statistics for the lower Snake River at Moran for both the annual and the seasonal flows. Summer flows are the highest (8981.2cfs) with winter flows being the lowest (1365.7cfs).

The lower Snake River is a regulated river by the capture and release of water from Jackson Lake. Since 1957 a more normal pattern of flow has been released from the lake, however, at times of repair or reconstruction of the dam flows have been changed. Figure 12 illustrates the changes in the overall storage capacity of Jackson Lake, with an overall capacity of 847,000 a-f. Between 1977 and 1989 the Lake level was lowered because of adjustments and reconstruction of the dam. The lake level follows a yearly cycle of release and storage which impacts on the flow and can be observed in the streamflow levels recorded at the Moran gauging station, just downstream from the Jackson Lake Dam.

The Moose gauging station on the lower Snake River is at the Grand Teton National Park headquarters and represents the lower Snake River before the influences of the city of Jackson. This gauging station, however, reflects the flow changes in the Snake River by recording the combined flows of the Snake River and its three major tributaries: Pacific Creek, Buffalo Fork and Cottonwood Creek. Figure 10 displays the flow rates from 1994-2014. The overall trend has been a steady decrease in the flows on the Lower Snake River. Two of the three natural streams coming into the lower Snake River have recorded decreases in their flows over the last two decades, Pacific Creek and Buffalo Fork (Figures 13-14). Even though their flows have decreased over the last two decades, they are still a major hydrologic impact on the lower Snake River.

statistically normal distribution, overall the variations in flows even within a season are somewhat erratic as interpreted by their coefficient of variation. The summer season has the highest percentage of variability, 86%. But, as Leppi et al. (2012) have found, August stream flows across the Central Rockies are decreasing with an increase in temperature over the last half of the 20th Century.
### Table 3. Descriptive statistics, upper Snake River, Flagg Ranch gauging station, 1984-2014.

<table>
<thead>
<tr>
<th></th>
<th>AnnualCfs</th>
<th>WinCfs</th>
<th>SprCfs</th>
<th>SumCfs</th>
<th>FallCfs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>10679.94</td>
<td>1037.76</td>
<td>4129.20</td>
<td>4477.98</td>
<td>993.50</td>
</tr>
<tr>
<td><strong>St. Error</strong></td>
<td>523.67</td>
<td>36.21</td>
<td>162.39</td>
<td>429.34</td>
<td>50.47</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>10404.40</td>
<td>977.60</td>
<td>4047.60</td>
<td>3884.40</td>
<td>968.50</td>
</tr>
<tr>
<td><strong>St. Dev.</strong></td>
<td>2915.67</td>
<td>201.62</td>
<td>904.17</td>
<td>2390.46</td>
<td>280.98</td>
</tr>
<tr>
<td><strong>Kurtosis</strong></td>
<td>0.24</td>
<td>2.35</td>
<td>1.33</td>
<td>-0.39</td>
<td>0.47</td>
</tr>
<tr>
<td><strong>Skewness</strong></td>
<td>0.59</td>
<td>1.43</td>
<td>0.46</td>
<td>0.62</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>12105.90</td>
<td>894.10</td>
<td>4500.60</td>
<td>8763.70</td>
<td>1323.20</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>6305.60</td>
<td>800.10</td>
<td>2146.00</td>
<td>1292.40</td>
<td>401.20</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>18411.50</td>
<td>1694.20</td>
<td>6646.60</td>
<td>10056.10</td>
<td>1724.40</td>
</tr>
<tr>
<td><strong>Coefficient of Variation</strong></td>
<td>27.30</td>
<td>19.43</td>
<td>21.90</td>
<td>53.38</td>
<td>28.28</td>
</tr>
<tr>
<td><strong>Count</strong></td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

### Table 4. Descriptive statistics, lower Snake River, Moran gauging station, 1957-2014.

<table>
<thead>
<tr>
<th></th>
<th>AnnualCfs</th>
<th>WinCfs</th>
<th>SprCfs</th>
<th>SumCfs</th>
<th>FallCfs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>17146.51</td>
<td>1365.70</td>
<td>3665.78</td>
<td>8981.22</td>
<td>3128.76</td>
</tr>
<tr>
<td><strong>St. Error</strong></td>
<td>612.366</td>
<td>92.366</td>
<td>359.971</td>
<td>288.152</td>
<td>139.173</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>16161.35</td>
<td>1234.90</td>
<td>3146.30</td>
<td>8843.00</td>
<td>2921.85</td>
</tr>
<tr>
<td><strong>St. Dev.</strong></td>
<td>4663.64</td>
<td>703.44</td>
<td>2741.46</td>
<td>2194.50</td>
<td>1059.91</td>
</tr>
<tr>
<td><strong>Kurtosis</strong></td>
<td>0.150</td>
<td>5.932</td>
<td>-0.366</td>
<td>0.041</td>
<td>0.655</td>
</tr>
<tr>
<td><strong>Skewness</strong></td>
<td>0.512</td>
<td>2.034</td>
<td>0.803</td>
<td>-0.116</td>
<td>0.509</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>22416.4</td>
<td>3966.3</td>
<td>9816.5</td>
<td>10089.7</td>
<td>5327.4</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>8208.8</td>
<td>414.0</td>
<td>229.2</td>
<td>3857.3</td>
<td>1117.1</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>30625.2</td>
<td>4380.3</td>
<td>10045.7</td>
<td>13947.0</td>
<td>6444.5</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>994497.5</td>
<td>79210.4</td>
<td>212615.4</td>
<td>520910.7</td>
<td>181468.1</td>
</tr>
<tr>
<td><strong>Count</strong></td>
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<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td><strong>Coeff. of Variation</strong></td>
<td>27.20</td>
<td>51.51</td>
<td>74.79</td>
<td>24.43</td>
<td>33.88</td>
</tr>
</tbody>
</table>
Overall, the hydrologic characteristics of the Snake River basin are currently changing and will continue to change into the future. The climate models have found that the temperatures will be increasing into the middle and later parts of the century and this change will be most noticeable with warmer winter temperatures. This coincides with the fact that precipitation levels will also change and winter snows will decrease while winter rain will increase. This change will impact the flow regime of the Snake River and its tributaries by changing the spring snow-melt runoff. In addition, the climate and hydrologic models have calculated that summers will be warmer and summer streamflows will be less.

The impact of the differences in the Snake River streamflows will have long term effects on beaver spatial ecology. Beavers rely on water as their medium for movement and access to food. If there is no water for beavers to travel to food sources they move to locations that provide that water access. As demonstrated in the work of Collins and found from the aerial beaver census, a slight majority of the beaver lodges/bank dens (60%) are found off the Snake River in back channels and ponds. The Snake River’s ebb and flow through summer, fall and winter and then the spring melt-off produces a radical difference in streamflow. This difference between high and low flow changes the distance between lodge/bank dens and the water’s edge or depth, increasing the success rate of predators if the water is not deep enough or that distance exposes too much dry land. As the climate changes into the middle of the 21st century, beavers will have to migrate to areas that have permanent water to the bank’s edge and depth enough for them to travel, approximately 0.3-0.4m minimum flow depth.


SUCCESION EFFECTS ON MAMMAL AND INVERTEBRATE COMMUNITIES 26 YEARS AFTER THE 1988 HUCKLEBERRY MOUNTAIN FIRE

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† ABSTRACT

Fires are an important and increasingly common driver of habitat structure in the intermountain West. Through an ongoing study of burned and adjacent unburned areas along the John D. Rockefeller, Jr. Memorial Parkway, we examine the long-term effects of the 1988 fire season on community assembly, succession, and ecological processes. We collected mark/recapture data on rodents, removal data for insectivorous mammals and invertebrates, and habitat measurements on four grids in 2014 and combined these results with previous survey data. In 2014, 4,800 trap nights yielded 13 species of small mammals, comprising 618 individuals. Macroarthropod abundance was higher on burned grids, but diversity was higher on unburned grids. In contrast, springtail (Collembola) diversity was higher on burned grids, but abundance was highest in unburned grids. Since the beginning of this long-term study, the total number of mammal species has increased across all sites, and relative abundance in burned areas has shifted from early successional species (Peromyscus maniculatus) to those more associated with old growth forests (such as Myodes gapperi). Other than in 1991, the burned grids have harbored more diverse small mammal communities than the unburned control grids. Significant, long-term differences in vegetation based upon burn history were observed, including different ground cover, less canopy cover, and more coarse woody debris in burned sites. This work provides a unique long-term picture of the interrelationships of small mammal and invertebrate communities and correlated habitat variables as these ecosystems undergo post-fire succession.

‡ INTRODUCTION

On 20 August 1988, a wind-blown tree touched a power line in the John D. Rockefeller, Jr. Memorial Parkway (JDRMP) and sparked the Huckleberry Mountain Fire (Huck Fire; Swinford 1989). This fire was one of many that grew and merged as part of the 1988 fire season in the Greater Yellowstone Area (GYA). As the beginning of an upsurge of more severe fires in the western US, the 248 fires that burned ~570,000 ha in the GYA comprised one of the most severe fire seasons documented to date in the region both in scope and intensity (Romme et al. 2011). This event has provided a natural experiment for examination of the short- and long-term effects of fire disturbance on community assembly, succession, and ecological processes in previously burned regions.

While our understanding of the short-term (0–10 years post burn [YPB]) effects of fire on small mammals has reached a level of maturity that allows researchers to try and synthesize results from many studies, we have very little data on the long-term (>10 YPB) impacts of fire on forest communities (Fisher and Wilkinson 2005, Fontaine and Kennedy 2012, Kennedy and Fontaine 2009). Although few studies
have longitudinally characterized changes due to post-fire succession for more than 10 years, previous work has identified and summarized what is known about common transitions during these successional stages (Fisher and Wilkinson 2005, Lee 2002). Expectations based upon previous studies suggest many communities are initially dominated by the North American deermouse (*Peromyscus maniculatus*), which often responds positively to fire disturbance. Over time, the southern red-backed vole (*Myodes gapperi*) gradually invades burned areas, and generally this old-growth specialist will become the dominant species within the small mammal community (Fisher and Wilkinson 2005).

Several stages have been identified and characterized in this process (Lee 2002). Immediately after the fire, the initiation stage (0–10 YPB) is marked by a general absence of canopy cover, and an abundance of coarse woody debris (CWD). In the initiation stage small mammal response is highly variable based on fire severity and its effects on food and cover availability and other microhabitat characteristics. This phase is followed by the establishment stage (11–25 YPB), when shrubby and herbaceous vegetation increase as grasses decrease, and grainivore abundance decreases while red-backed voles, typically omnivores, increase. The third phase, and the current stage of succession from the 1988 fires, is the aggradation stage (26–75 YPB). During this phase tree density and canopy cover increase, while shrubs and herbs continue to decrease in burned areas. During the aggradation phase deermice are predicted to be the most abundant small mammal, and overall abundance of mammal communities is predicted to be lower than the preceding stages (Fisher and Wilkinson 2005).

Comparatively little is known about long-term community shifts of arthropods during post-fire succession. Arthropods fill numerous ecological roles during succession. Adult members of macroarthropod orders such as Lepidoptera, Coleoptera, and Diptera are essential to pollination. The larvae of many insects are also important in mediating flora via herbivory (Carson et al. 1999). Arthropods represent an abundant food source for vertebrate colonizers, such as bats, during succession (Loeb et al. 2006). Particularly important are the ecosystem services provided by the mesoarthropods that occupy leaf litter and soil. These small but highly abundant organisms create a system of complex trophic interactions involving mycorrhizae, detritus, nematodes, and bacteria (Rusek 1998). Springtails (order Collembola) are among the most ubiquitous and abundant arthropod members of this community and can reach numbers up to a 100,000 per m² (Hopkin 1997). Their diverse diet of fungi, bacteria, detritus, and other soil organisms coupled with sheer abundance has ramifications for larger ecosystem processes such as mitigation of nematode plant parasites (Heidemann et al. 2014) and the formation of soil microstructure during succession (Rusek 1998). Springtail interaction with arbuscular mycorrhizae, endomycorrhizae, and other non-mycorrhizal fungi competitors can affect plant growth both negatively and positively depending on taxa (Lileskov et al. 2005). These ecologically important roles make springtails an integral component of post-burn succession (Chauvat et al. 2003).

Previous studies by Stanton et al. (1991, 1998), Spildie (1994), Seville et al. (1997), and Burt et al. (2009, 2011) have examined the responses of small mammal communities and corresponding habitat structure on the same burned and unburned sites at regular intervals (3, 4, 9, 10, 21, and 22 YPB) in the Huck Fire region of the JDRMP. As these data can provide us with a unique longitudinal picture of successional changes in this community since a stand replacing fire event in the summer of 2014, we continued the Huck Fire region series of investigations to maintain this long-term dataset and determine the impacts of post-fire succession and habitat change on small mammal and invertebrate communities as these burned sites enter the aggradation stage of stand succession. Our specific objectives were to:

1. Determine the composition of small mammal and springtail communities at 26 YPB in adjacent burned and unburned sites following the methodologies and locations established by previous investigations.

2. Investigate relationships between small mammal community structure, habitat variables, and invertebrate communities.

3. Provide an overall summary of the 26 YPB change in mammal communities and habitat structure since the 1988 fire.

**METHODS**

**Trapping procedures**

To match previous study design and effort, we sampled the same 4 trapping grids, 2 burned and 2 unburned, at similar times of the year to previous studies during the summer of 2014. Trapping grids are located in Teton County, Wyoming, in the JDRMP,
10.5 north of the junction with Leeks Marina Road along Highway 287. Specific UTM coordinates for each grid (all in zone 12) are: east facing burn (EFB) 44 3.210 N, 110 41.568 W; east facing control (EFC) 44 2.953 N, 110 41.260 W; west facing burn (WFB) 44 2.992 N, 110 41.348 W; west facing control (WFC) 44 3.105 N, 110 41.624 W. Each grid consisted of a 1 ha area of burned or unburned forest. One of each treatment grid type was on the east facing slope of Steamboat Mountain (EFB, EFC) and the west facing slope of Huckleberry Mountain (WFB, WFC), as originally established by Stanton et al. (1991, 1998), and used by Spildie (1994), Seville et al. (1997), and Burt et al. (2009, 2011). All grids were assessed simultaneously from 1–4 June, 6–8 and 9–12 July, and 2–6 August 2014. During each 4-night trapping period, grids of 100 Sherman traps were placed (100 stations/ha, 10 m apart) and baited with rolled oats and peanut butter. Cotton bedding was placed in each trap for insulation/nest material. Traps were opened between 1600–2000 h and checked between 0500–0930 h the following day. Traps were closed during the day, and then reopened and re-baited (if necessary) the same afternoon. Animals captured in live traps were uniquely ear tagged and classified by species, sex, age class (juvenile or adult) and reproductive condition, weighed to the nearest gram and released where caught. Trap efforts (number of traps/grid, trap nights, and location) followed protocol from previous work at these locations.

Arthropods and insectivorous mammals were collected concurrently with live trapping during each of the trapping periods, using the same sites and grids. Pitfall traps were placed every 40 m within the 4 grids, with a total of 25 pitfall traps per grid, 100 traps per month, and 300 traps total for the survey. Traps consisted of plastic cups filled with 15.24 cm of propylene glycol/ethanol/water mixture (commercially available “pet safe” RV antifreeze), and buried so their rims were flush with the ground. Arthropods were all allowed to accumulate for 4 days per month and frozen until they could be processed. After invertebrate collection, the propylene glycol mixture was replaced with 70% ethanol for long-term storage and preservation of invertebrate specimens. Invertebrates were sorted and counted, with all arthropods identified to order and Collombola further identified to family based upon Christensen and Bellinger (1998) and sorted to morphospecies. Small mammals captured in pitfall traps were processed as described above, preserved as voucher specimens, and will be deposited in the University of Wyoming, Vertebrate Museum.

Habitat data were collected from 100 trap stations (25/grid) evenly spaced throughout the grid. Data gathered at each trap station included distance from trap to nearest tree, nearest sapling, nearest seedling, and nearest shrub (within 10 m of trap station), as well as diameter at breast height for nearest tree and sapling. A 5 m tape was laid down in the 4 cardinal directions (N, S, E, W), and at any point where CWD (>7.5 cm in diameter) crossed the tape, distance was measured from the trap station and the diameter, height above ground, and decay state of the debris was recorded. Cover class data gathered at each trap location included percent ground cover using a 1 m² square frame for herbs, grasses, woody plants, CWD, bare ground, leaf litter, and (where applicable) pitfall trap. Cover class categories were scored 0–4, with cover category 0 not represented, 1 representing 1–25% ground cover, 2 representing 26–50% cover, 3 representing 51–75% cover, 4 representing 76–100% cover.

Because these data are non-normal, and in many cases nonparametric, Kruskal-Wallis tests were used to examine vegetation community differences based upon fire history and year. Diversity among sites and between years was estimated using the Shannon-Wiener Index ($H' = \sum p_i \log p_i$). Recursive, nonparametric conditional inference trees implemented in the R package ‘Party’ (Hothorn et al. 2006) were used to examine the relationship between habitat variables and capture history for M. gapperi and P. maniculatus. Analyses were run in the R statistical package (version 3.0.2; R Core Team 2013).

RESULTS

Current mammal community composition

Thirteen species of mammals and 618 individuals were captured in 2014, including 322 M. gapperi, 71 Sorex monticolus, 67 P. maniculatus, 27 Tamias amoenus, 24 Sorex cinereus, 10 Zapus princeps, 5 Thomomys talpoides, 4 Phenacomys intermedius, 3 Microtus longicaudus, 3 Microtus montanus, 1 Microtus pennsylvanicus, 1 Neotoma cinerea, 1 Lemmiscus curtus, 1 Microtus sp. and 78 Sorex spp. Total numbers of species by grid are provided in Table 1. Reported values are out of 4,800 trap nights. As in previous years, M. gapperi and P. maniculatus accounted for the majority (63%) of captures (Figure 1).

The east ($H' = 1.33$) and west ($H' = 1.51$) facing burned grids harbored more diverse small mammal communities than the east ($H' = 1.04$) and
west ($H' = 1.13$) facing unburned control grids. As it is difficult to definitively identify shrew species without examination of the skull, diversity indices were calculated with all species of shrews lumped together (Sorex spp.) to accommodate unknown live species and facilitate comparison with previous years investigations in which shrew species data is not available.

Table 1. Total number of each species captured per grid in 2014. EFB = east facing burn; EFC = east facing control; WFB = west facing burn; WFC = west facing control.

<table>
<thead>
<tr>
<th>Species</th>
<th>EFB</th>
<th>EFC</th>
<th>WFC</th>
<th>WFB</th>
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<tr>
<td>Myodes gapperi</td>
<td>58</td>
<td>96</td>
<td>109</td>
<td>59</td>
</tr>
<tr>
<td>Peromyscus maniculatus</td>
<td>25</td>
<td>14</td>
<td>6</td>
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</tr>
<tr>
<td>Sorex monticolus</td>
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<td>18</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Sorex cinereus</td>
<td>2</td>
<td>8</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Tamias amoenus</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Zapus princeps</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Thomomys talpoides</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Phenacomys intermedius</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Lemmiscus curtatus</td>
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<td>0</td>
<td>0</td>
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<td>Neotoma cinerea</td>
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<tr>
<td>Microtus sp.</td>
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<td>1</td>
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</tr>
<tr>
<td>Sorex spp.</td>
<td>18</td>
<td>19</td>
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</table>

Current invertebrate community composition

Burned grids yielded 18,278 total macroarthropods, while 8,456 were collected from unburned grids. All major arthropod orders were included in the samples, with the most abundant captures coming from Hymenoptera (11,157 burned, 2,794 unburned, primarily ants), Diptera (1,009 burned, 598 unburned), Coleoptera (909 burned, 1,040 unburned), and Araneae (675 burned, 775 unburned). Burned grids had significantly higher abundance overall ($p = 0.0374$; Figure 2). However, unburned grids had higher diversity ($H' = 1.58$) than burned grids ($H' = 1.03$; Figure 2).

Over 5,470 Collembola were collected in the EFB, while 49,164 were collected in EFC (west-facing samples are still being identified). Across these grids, a total of 18 morphospecies from 4 different Collembola families (Entomobryidae, Isotomidae, Hypogastruridae, and Sminthuridae) were collected throughout the study area on burned and unburned grids. Individual stations within unburned grids exhibited much higher abundance ($\bar{X} = 664.38$ individuals/trap) than burned grids ($\bar{X} = 72.93$ individuals; $p = 0.0495$). Burned grids, had higher diversity ($H' = 1.139$) than unburned grids ($H' = 0.617$; Figure 3), and this effect was most pronounced in June and July. Differences among family abundances in burned and unburned sites were also observed. Hypogastruridae were more abundant in unburned sites, whereas Sminthuridae and Entomobryidae were more abundant in previously burned habitats (relative to their abundances in unburned habitats; Table 2).

Figure 1. Relative abundance of most common small mammal species in (A) east-facing sites and (B) west-facing sites based upon burn history.

Figure 2. Boxplot of macroarthropod abundance over the entire survey period (note y-axis is square root transformed). Kruskal-Wallis test indicate a significant trend ($p = 0.0374$), with greater abundance in burned grids.
Table 2. Average (above) and range [below] of collembolans from particular families collected per pitfall trap in June, July, and August in 2014.

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Changes in mammal communities since the fire

Over the past 26 years, the number of mammal species trapped has increased across all sites (both burned and unburned), and relative abundance has shifted. Initially, *P. maniculatus* dominated burned sites whereas *M. gapperi* was dominant in unburned sites (Figures 4 and 5). Gradually the community composition in burned sites has shifted, so that relative abundance more closely resembles control sites. *M. gapperi* became dominant in the WFB between 1998 and 2009 (Figure 4), and in EFB between 2010 and 2014 (Figure 5).

Trends for other species are more difficult to discern, due to low capture rates or difficulties with identification of live individuals. Shrews have become more abundant in both burned and unburned areas, and constitute 25–30% of captures on all grids (Figures 4 and 5). *Tamias* has been present on both burn grids in low numbers shortly following the fire, but is more abundant on the WFB (Figures 1, 4 and 5). Recently, *Tamias* has become more common in the control grids especially on the WFC (Figure 1). *Zapus princeps* and *Thomomys talpoides* have been captured on all grids, but are most abundant on the WFC grid (Figure 1). Other species with ≤5 individuals captured are generally scattered among different grids (Table 1).

Small mammal community diversity has increased in the 26 YPB history in both burned and unburned sites, but it appears to be impacted by annual fluctuations as well as slope aspect. Diversity indices for burned sites have been consistently higher than adjacent unburned areas beginning the 4th YPB (Figures 4 and 5). In most years, there have been more rare species on burned sites than unburned sites, contributing to the persistent differences in diversity.

![Figure 3](image-url) Macroarthropod and Collembola diversity, as measured by the Shannon-Weiner index. Macroarthropod diversity was greater in unburned grids relative to burned grids, whereas collembolan diversity was greatest in burned grids.

![Figure 4](image-url) Diversity, abundance, and species composition in: (A) the west facing burn sites, and (B) the west facing control sites. Initially, deer mice (*Peromyscus maniculatus*) were predominant in the burned sites, whereas red-backed voles (*Myodes gapperi*) have consistently dominated the adjacent unburned sites. Across most years, abundance has been higher in unburned grids whereas diversity has been higher in burned grids.
Figure 5. Diversity, abundance, and species composition in: (A) the east facing burn sites, and (B) the east facing control sites. Deer mice (*Peromyscus maniculatus*) were initially predominant in the burned sites, whereas red-backed voles (*Myodes gapperi*) have consistently dominated the adjacent unburned sites. Generally, shrews and other small mammals have increased in frequency and abundance over time in both sites.

**Microhabitat differences**

Persistent and significant differences were observed between burned and unburned sites in terms of habitat, ground cover, canopy cover, and CWD. Previously burned areas have significantly less canopy cover (50% closure burned vs. 71% closure in unburned grids), fewer shrubs, more bare ground and more grasses than unburned areas (Figure 6). There was also significantly more CWD in burned areas, but that CWD was more decayed and closer to the ground than CWD in unburned areas (height from ground $\bar{X}_{\text{burned}} = 4.5$ cm, $\bar{X}_{\text{unburned}} = 7.8$ cm; Figure 8). Differences in standing vegetation around traps are also evident, with trees, seedlings, and shrubs closer to traps in unburned areas relative to the distances in burned areas (Figure 7).

While microhabitat differences are evident over time, many habitat changes captured by our data have not been linear with respect to burn history or time period. Not surprisingly, trees and saplings were significantly closer to traps in burned sites than in past years (results not shown). In terms of ground cover, herbaceous cover has increased in burned sites (Figure 9), while the amount of bare ground has decreased (Figure 10).

The regression tree approach indicated the best explanatory variable for capturing *M. gapperi* was the presence of shrubs near the trap site (Figure 11), without considering burn history. For the subset of sites where we captured *P. maniculatus* and measured habitat variables, none of the habitat characteristics we examined (or combinations of those characteristics) significantly explained capture probability, despite the significantly higher number of deer mice captured in previously burned habitats and the significant differences observed among habitats based upon burn history (Figures 6–10).

Figure 6. Persistent differences in ground cover surrounding trap sites exist between burn and control sites, with fewer shrubs and more grasses and bare ground in unburned areas.

Figure 7. Differences in vertical habitat between burn and control sites. Trees, seedlings, and shrubs are all closer to traps in unburned (control) areas relative to previously burned habitat.

Figure 8. Coarse woody debris (CWD) is more prevalent in previously burned sites than in control sites, but CWD is higher off the ground in control sites.
Figure 9. Herbaceous ground cover has generally, and significantly increased in burned sites over time on both (A) east facing and (B) west facing grids.

Figure 10. Bare ground cover has generally, and significantly decreased in burned sites over time on both (A) east facing and (B) west facing grids.

Figure 11. Recursive partitioning identifies distance to nearest shrub as the most important factor impacting capture success for *Myodes gapperi*, with more animals captured when shrubs are less than 109 cm from the trap, regardless of burn history.

**DISCUSSION**

Our findings speak to broadscale patterns in succession occurring as the areas impacted by the 1988 Yellowstone fires transition into the aggradation phase (26–75 YPB). While 26 years have passed since the Huck Fire, persistent differences remain among burned and unburned sites in terms of mammal communities, invertebrate communities, and vegetation structure. In terms of major changes in mammalian communities, *M. gapperi* have increased in abundance in burned sites, and have become the most numerically abundant species in all 4 grids. *Peromyscus maniculatus*, which was initially dominant in burned sites, is no longer most abundant, but still makes up 17% of captures, and shows a preference for previously burned areas. Similar shifts in small mammal abundance during successional processes have been documented (e.g., Fisher and Wilkinson 2005); however, some of the hallmarks of those transitions, such as the dominance of deermice 26–50 YPB, are not supported by our results. In our sites, shrew species have become more abundant, now accounting for 24–35% of captures in burned sites and 26–28% of captures in adjacent unburned areas.

We also observed significant differences in macroarthropods between burned and unburned grids, suggesting habitat differences due to burn history are shaping abundance at the aggradation stage of succession, though the higher abundance in the burned grids (Figure 2) does not translate to greater diversity at the ordinal level (data not shown). Given the predominance in the number of ants collected in burned areas, it is possible that predation by ants, which were highly abundant in previously burned areas, are shaping community structure of the burned grids by limiting overall arthropod diversity. To thoroughly investigate differences in abundance and diversity further analysis of the macroarthropod community will need to be performed at the level of genus and species.

Differences in Collembola abundance were also observed to be significant between burned and unburned grids but interestingly trends in diversity were inverse from macroarthropods (Figure 3). Collembola appear to be more diverse in burned areas, and less diverse, but more abundant, in unburned areas. This may be due to observed mixed vegetative structure allowing for a broad range of canopy cover in burned areas, selecting for species with the ability to handle dryer and patchier climates. Comparisons by family suggest that differences in abundance exist which might be explained by the habitat tolerances of
each family (e.g., some species and some families may be better at traversing open habitat). However, further study is needed to examine whether functional differences in collembolan traits may be underlying these differences in abundance.

**Trends in succession over time**

Successional trends observed in our sites are similar to those observed in other burned areas. During the early phases of succession (Lee 2002), deermice dominate community abundance on burned sites; chipmunks correspondingly tended to be more abundant than in adjacent unburned habitat (e.g., Barmore et al. 1976, Wood 1981, Zwolak and Foresman 2007). More than a decade after a fire, during the establishment stage (11–25 YPB; Lee 2002), voles and shrews have increased on previously burned sites (Figures 4 and 5). However, the abundance of red-back voles and masked shrews continues to be greatest in old-growth areas compared to nearby burned areas (Figure 1; Roy et al. 1995), similar to the trend observed previously on the Huckleberry Mountain sites (Burt et al. 2009, 2010).

One other commonly observed trend is that abundance of small mammals increases with stand age after a fire (Fisher and Wilkinson 2005). In our sites, abundance has generally increased. However, fluctuations in abundance are evident across all 4 grids (Figures 4 and 5). The number of rare species has increased in all 4 grids, suggesting a potential regional impact of the succession across the GYA.

**ACKNOWLEDGEMENTS**

We would like to thank the UW-NPS Research Station and Wyoming INBRE (NIH NIGMS P20GM103432) for financial support; Ashkia Campbell, Ed Campbell, Kevin Crouch-Jacobs, Delina Dority, James Erdmann, Jennifer Forrester, Samantha Haller, Dominique Schlumpf, and Kayla Wilson for their hard work in the lab and field; Sue Consolo-Murphy and John Stephenson for facilitating collecting permits; Harold Bergman and Celeste Havener for assistance with station housing.

**LITERATURE CITED**


DENDROCHRONOLOGICAL ASSESSMENT OF WHITEBARK PINE RESPONSE TO PAST CLIMATE CHANGE: IMPLICATIONS FOR A THREATENED SPECIES IN GRAND TETON NATIONAL PARK

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KANSAS STATE UNIVERSITY ✦ MANHATTAN, KS

† ABSTRACT
One of the keystone tree species in subalpine forests of the western United States – whitebark pine (Pinus albicaulis, hereafter whitebark pine) – is experiencing a significant mortality event (Millar et al. 2012). Whitebark pine occupies a relatively restricted range in the high-elevation ecosystems in the northern Rockies and its future is uncertain. The current decline of whitebark pine populations has been attributed to pine beetle infestations, blister rust infections, anthropogenic fire suppression, and climate change (Millar et al. 2012). Despite the knowledge that whitebark pine is severely threatened by multiple stressors, little is known about the historic capacity of this species to handle these stressors. More specifically, it is unknown how whitebark pine has dealt with past climatic variability, particularly variation in the type of precipitation (rain vs. snow) available for soil moisture, and how differences in quantity of precipitation have influenced the establishment and growth of modern stands. We propose to study the past responses of whitebark pine to paleoclimatic conditions, which would be useful to park ecologists in developing new conservation and regeneration plans to prevent the extinction of this already severely threatened high-elevation resource.

The purpose of this study is to determine in great temporal and spatial detail the demographics of the current stand of whitebark pine trees in the watershed surrounding an unnamed, high-altitude pond (known informally as Whitebark Pine Moraine Pond) located approximately 3.06 miles NW of Jenny Lake in Grand Teton National Park (GTNP). The main objectives of this study were:

1.) To obtain the precise GPS locations of the current stand of whitebark pine trees in the watershed to generate a GIS map detailing their locations.
2.) To obtain increment cores of a subset of the trees in the watershed to estimate age and date of establishment for the current stand of whitebark pines, with particular attention to fire history.
3.) To analyze ring widths from core samples to identify climatic indicators that may influence the regeneration and survival of whitebark pine.

INTRODUCTION
Whitebark pine is a long-lived, early seral species found only at high elevation sites occurring in subalpine ecosystems of the Northern Rocky and Cascade Mountains in the United States (Keane and Parsons 2010). While whitebark pine historically occupied 10-15% of forests in the western United States, it has been suggested that it has experienced as much as a 90% decrease in population throughout its native range and is now considered functionally extinct in more than 30% of its modern range (Keane 2001, Mohatt et al. 2008, Tomback et al. 2001, Schrag et al. 2008). In addition to biotic factors such as blister rust and pine beetles, there is preliminary data indicating this recent mortality event is due in part to a warming climate, more specifically a significant warming in growing season temperatures (Bower and Aitken 2008). Historical climate data, based on records obtained from NOAA (the Moran 5 weather station, elev. 6798 ft.) dating from 1931-2008, indicate that the
average annual temperature in GTNP is increasing, while the annual amounts of both overall precipitation and snowfall are decreasing (Figure 1). It has been suggested that only a slight increase in global atmospheric temperature (4.5° C) would completely remove whitebark pine from the Greater Yellowstone Area and GTNP ecosystems (Schrag et al. 2008) (Figure 1).

Figure 1. The current range and distribution of whitebark pine in GTNP and GYA (left), and the predicted range and distribution of whitebark pine in GTNP and GYA given a projected 4.5°C temperature increase (right). From Schrag et al. 2008.

Whitebark pine is considered to be a keystone species of the particular ecological niche it occupies in the United States for three reasons. First, more than one hundred animal species, including the endangered grizzly bear (Ursus arctos horribilis), depend on its high-energy seeds for survival (Felicetti et al. 2003). If whitebark pine should vanish from its niche, endangered species would be forced to lower elevations in search of food, thus increasing the potential for contact with humans and human-caused casualties. Second, the presence of whitebark pine in subalpine ecosystems helps to slow the melting of accumulated snow, resulting in reduced flooding occurrences. And third, by slowing the melt of snow, whitebark pine provides a high quality source of water to plants and animals during the summer melting season (Keane and Parsons 2010).

In addition to its importance as a keystone species, whitebark pine also has value as a recreational resource. Whitebark pine has many aesthetic qualities that make it a potential attraction to park visitors. Tree species that thrive at high altitudes generally have unusual morphological characteristics resulting from the harsh conditions provided by high altitude conditions. One of the most striking characteristics of high altitude species, including whitebark pine, is the twisted formations of trunks and branches. Additionally, whitebark pine has value as a recreational resource because communities tend to form very open, park-like forests ideal for adventurous hikers (Keane and Parsons 2010). Lastly, whitebark pine forests offer value as a recreational resource for avid birdwatchers. Whitebark pine is the only species of pine in North America that does not disperse its seeds utilizing wind. Rather, whitebark pine relies on a mutualistic relationship with a bird – the Clark’s nutcracker – to disperse its seeds. In the late summer and fall, Clark’s nutcrackers harvest seeds from the whitebark pinecones and carry them up to ten kilometers away and bury them (Tomback 1982). The nutcrackers will eventually return for the seed stocks, but those seeds left unclaimed will eventually begin to germinate (Tomback et al. 2001). This mutualistic relationship with the Clark’s nutcracker would provide avid birders the opportunity to see this high-altitude bird in action during the summer and fall months that, without the presence of whitebark pine, they would likely never see.

We have conducted preliminary research on the history of whitebark pines in Paintbrush Canyon. We reconstructed a long paleoecological record of 8,000 years from a 1.5 meter sediment core obtained from Whitebark Moraine Pond (by Sarah Spaulding, Alex Wolfe, and Jill Baron). We analyzed the sediment core for pollen, charcoal, and macrofossils to reconstruct Holocene-scale vegetation and fire history records. Our data indicate that the site has predominately been occupied by whitebark pine with brief periods of vegetation dominated by non-arboreal taxa, and that the site historically experienced frequent, low-intensity fire episodes. However, fire episodes have been decreasing in frequency and increasing in intensity towards the present. In addition to sedimentary data, we collected a set of increment cores from whitebark pine trees at the site in 2013 to identify how climate has impacted the growth of the modern stand. The average age of establishment for the 20 trees we cored in this stand is, with the oldest individual dating to 1300 C.E. Our dendrochronological results indicate that increasing growing season temperatures are correlated with a recent decline in whitebark pine growth, thereby highlighting the need for further dendrochronological studies examining the role of climate on the growth and survival of whitebark pine stands in GTNP.

Obtaining additional increment cores from the higher-elevation Holly Lake site (Figure 2) and oxygen isotope data from annual tree rings at both study sites has provided two key pieces of evidence. First, by obtaining a complementary set of increment cores from whitebark pine at Holly Lake, we have made
comparisons regarding establishment dates and site-specific responses to climate between the two study sites. Because the study sites vary primarily in elevation, we examined how relatively small shifts in elevation affect annual growth of whitebark pine trees.

Second, results from the oxygen isotope analysis portion of this study would identify the type of precipitation utilized by whitebark pine for the 700 years of the dendrochronological record. This, in turn, would allow for inferences to be made about how precipitation source influences the growth and stability of whitebark pine populations. As both precipitation quantity and type (snow vs. rain) are predicted to shift in the future, it is important to know how whitebark pine has responded to past precipitation variability. By understanding how two different populations of whitebark pine responded to past climate change, park ecologists can formulate more effective conservation and management plans to prevent the disappearance of whitebark pine from GTNP with current and future climate change.

Much of the high-elevation wildlife and scenery in GTNP exist because of whitebark pine as a keystone species. Understanding how climate change has affected, and continues to affect, this threatened and disappearing species will help park conservationists develop new strategies for maintaining and restoring the current stands of whitebark pine. This increased conservation effort would ultimately lead to both an enhanced recreational and educational experience for park visitors. Our proposed research will provide information critical to the survival of whitebark pine stands by using the long-term paleoecological perspective to gain new insight on the resilience or vulnerability of whitebark pine to past climate change.

**STUDY AREA**

Holly Lake, a glacially moraine dammed lake, is an ideal comparison site to Whitebark Moraine Pond (Figure 2) because of its similar vegetation composition, relative proximity, and higher elevation. The purpose of choosing site locations in Paintbrush Canyon is to match high-resolution dendrochronological records with the previously-mentioned sediment record of fire and vegetation history for the area.

The modern vegetational ecosystem of the study area can be characterized as a subalpine conifer forest. Canopy species dominate the watershed and consist primarily of whitebark pine (*Pinus albicaulis*) and subalpine fir (*Abies lasiocarpa*).

![Figure 2. Topographic map with study sites circled in black. Holly Lake is located to the north, while Whitebark Moraine Pond is the site located to the south.](image)

**METHODS**

Where necessary, project methods have been approved by the respective permitting authority or oversight committee.

**Increment cores and response to modern climate**

A subset of 20 living whitebark pine trees were cored to establish ages and dates of establishment in the watershed surrounding Holly Lake. Cores from 20 trees were taken using standard dendrochronological techniques with a 5.15 mm diameter increment borer 30 cm above the soil surface (Elliot 2011). Diameter at breast height (dbh) was also recorded. GPS coordinates of all trees were recorded to assess the role of microsite and topography in placement of whitebark pine trees. Once the cores were in a laboratory setting, they were sanded and scanned, and rings on each individual core were counted to establish chronologies, using cross-dating protocols and software (Coo Recorder, C Dendro). Pith estimators and age-to-coring-height equations were applied as in Elliot (2011).

Ring widths were analyzed to understand the magnitude of climate change events experienced by each cored tree, as well as how climate change events impacted the growth and stability of each tree on a local scale. Methods generally followed those of a larger study of climate and local-scale factors on upper treeline in the Rocky Mountains (Elliot 2012). Because climate stations are rare at higher elevations in the Rocky Mountains, Precipitation-elevation Regressions...
on Independent Slopes Model (PRISM) data was used to make inferences regarding how the trees responded to past climates (Daly et al. 2008). This climate analysis allows for comparisons to be made between climate conditions in the past and the current climates in order to predict the response of the current stand of whitebark pine. We sampled, processed, and analyzed tree cores from Whitebark Moraine Pond in 2013 using the same methods outlined here.

Role of historical precipitation

To assess the history of precipitation source in the Holly Lake and Whitebark Pine Moraine watersheds, we measured the composition of the carbon and oxygen isotopes in the wood for at least 200 years of the dendrochronological record on a decadal temporal scale. Briefly, a chemical digestion procedure was used to purify the wood into cellulose at the University of Arizona, and the stable oxygen and carbon isotopic composition was then analyzed using standard mass spectrometry techniques at Washington State University. To calibrate the wood \(^{18}O\) proxy, we sampled snow, ice, and water from the two watersheds for preliminary interpretations (Anderson 2011).

† PRELIMINARY RESULTS

Demography of current stands

The average date of establishment for the current stand of whitebark pine at Whitebark Moraine Pond is 1751 C.E. (Figure 3), while the average date of establishment for the current stand of whitebark pine at Holly Lake is much younger, with the majority of trees averaging a date of establishment around 1895 C.E. Older trees located at Holly Lake appeared to be significantly affected by mountain pine beetle infestations. No trees at the Whitebark Moraine Pond site were affected by pine beetles.

Ring widths and modern climate

Average yearly ring widths at Whitebark Moraine Pond ranged from 1.23 mm in 1950 to 0.60 mm in 2011 for the period of available climate data (1895-2012) (Figure 4A). A breakpoint analysis confirmed the presence of change point at 1949 (±4.5 years) and further indicated that average ring widths increased until 1949, and then began to decline to their current widths.

Average July minimum temperature (Tmin) was identified as the most statistically significant variable affecting annual ring widths (p < 0.001) (Figure 4B). Other temperature and precipitation variables had no significant effect on the growth of whitebark pine at this site. Until 1991 (±2 years), average July Tmin values experienced no significant variation and remained relatively constant through time. A maximum value of 37.38 F was reached in 1945, with a spread in data of 8.07 F. After 1991, however, average July Tmin values exhibited more variability and increased to temperatures higher than any other time during the record. Values reached a maximum in 2011 with an average July Tmin of 45.7 F with a spread of 13.34 F from 1991-2011.

Average July Tmin values were plotted against average annual ring widths to determine the effect of climate on tree growth (Figure 4C). Analyses indicated that average July Tmin values were a significant (p < 0.001) predictor of whitebark pine growth. The resulting relationship between the two variables reveals that the modern decline in whitebark pine growth at the study site can be attributed to increasing July minimum temperatures.

Increasing July minimum temperatures have aided in the displacement of whitebark pine by subalpine fir. The initial onset of declining ring widths around 1949 may have been triggered by an unknown ecological event which subsequently increased the stand’s sensitivity to later temperature changes beginning in 1991, thereby amplifying its effect on the population. *Abies* and *Picea*, competitors of whitebark pine, are better adapted to survive in warmer climates than whitebark pine. While July minimum temperatures were discovered as the most significant

![Figure 3. Trends in estimated dates of establishment for all cored trees at Whitebark Moraine Pond.](image-url)
variable at this site, Perkins and Swetnam (1996) observed a significant inverse relationship between ring widths and May temperatures in the Sawtooth-Salmon River region of Idaho. This discrepancy in climate variables may be caused by the geographic difference in site locations. In both cases, increased growing season temperatures have resulted in altered subalpine conifer communities by allowing warm temperature-adapted species to invade the niche normally occupied by whitebark pine. Because subalpine fir tends to grow much faster than whitebark pine, it acts as a competitor for resources and ultimately restricts the growth of whitebark pine by out-shading.

Figure 4. (A) Average ring widths by year. (B) Average July minimum temperatures by year. (C) Relationship between ring widths and July minimum temperatures (p<.001).

Annual growth trends of the whitebark pine stand at Holly Lake show an altogether different growth trend. Whitebark pine trees at Holly Lake showed a definite cyclical growth trend not observed at Whitebark Moraine Pond, as well as an overall increase in annual growth towards present (Figure 5); however, annual growth has declined in the last five years. Similar to Whitebark Moraine Pond, growth trends observed at Holly Lake also show a statistically significant relationship with minimum growing season temperatures, particularly during time periods of growth decline. It is important to note that the overall increasing growth trend at Holly Lake may be an artifact of the relatively young age of trees sampled due to a high mortality resulting from pine beetle infections.

Figure 5. Ring width results from the Holly Lake stand of whitebark pine trees showing the cyclic nature of the data. Comparable to Figure 4.A.

Historical precipitation

Oxygen isotope data were analyzed from snow, lake water, and stream water in Paintbrush Canyon in an effort to aid in the interpretation of oxygen data resulting from processed tree rings (Figure 6). There did not appear to be a pattern related to the elevation at which water and snow samples were collected, but there was an observable difference in the isotopic signatures of snow vs. liquid water when compared to the global meteoric water line (GMWL) which will aid in our interpretation of final tree ring isotopic data.

Purified alpha-cellulose samples are currently being processed at Washington State University’s Stable Isotope Lab and final isotopic data are expected to be received during the summer of 2015. We suspect that we will be able to use collected snow and water samples to interpret these results and determine, quantitatively, the role that different moisture sources play in the growth trends of whitebark pine trees at these two sites.
The central challenge associated with mitigating this modern decline of whitebark pine is that climate change (the main driver of this decline) is not an environmental problem with a simple solution. Climate change is a global phenomenon acting on a long timescale. Because this driver of whitebark pine decline is not easily managed, the best management option will be to focus on more locally-driven processes contributing to the decline, such as fire suppression.

**ACKNOWLEDGEMENTS**

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**LITERATURE CITED**


EVALUATING THE EFFECTS OF PROJECTED CLIMATE CHANGE ON FOREST FUEL MOISTURE CONTENT

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PROGRAM IN ECOLOGY ♦ UNIVERSITY OF WYOMING ♦ LARAMIE, WY

OVERVIEW

Understanding how live and dead forest fuel moisture content (FMC) varies with seasonal weather and stand structure will improve researchers’ and forest managers’ ability to predict the cumulative effects of weather on fuel drying during the fire season and help identify acute conditions that foster wildfire ignition and high rates of fire spread. No studies have investigated the efficacy of predicting FMC using mechanistic water budget models at daily time scales through the fire season nor have they investigated how FMC may vary across space. This study addresses these gaps by (1) validating a novel mechanistic live FMC model and (2) applying this model with an existing dead FMC model at three forest sites using five climate change scenarios to characterize how FMC changes through time and across space. Sites include post-fire 24-year old forest, mature forest with high canopy cover, and mature forest affected by the mountain pine beetle with moderate canopy cover. Climate scenarios include central tendency, warm/dry, warm/wet, hot/dry, and hot/wet.

YEAR 1 ACTIVITIES

Our first year progressed well and our work is on track. Field data from 2014 have been entered and checked for accuracy. Laboratory work related to the moisture content of foliar and surface dead fuel particles is being completed by student workers at the University of Wyoming and will be complete by June 2015. Kellen Nelson will fully analyze these data this year. We augmented our sampling design and field data collection methods to address several additional objectives: (1) With the help of NPS staff (Stacey Gunther and Roy Renkin), we selected three 1x1 km study sites on the Yellowstone Plateau that reflect important forest development stages to demonstrate the effects of forest development and stand structure on live and dead fuel moisture. Targeted forest development stages include 24 year post-fire, mature forest with high canopy cover, and mature forest affected by the mountain pine beetle with moderate canopy cover. (2) We added several fuel components including dead surface woody fuel particles, litter, and duff fuel and live understory plant fuels (herbs and graminoids) to investigate how changing weather conditions may alter these fuel components and expand the impact of the study. (3) 15 low-cost, open-source weather stations were developed by Kellen Nelson. These stations reduce costs by ~10 times of commercial systems while maintaining accuracy and reliability. Weather stations were deployed across the three study sites. Designs will be published in an appropriate peer-reviewed journal and assembly instructions will be available on Kellen Nelson’s website. (4) Erick Larsen, a field crew member and student at the University of Washington, completed an independent study project that met the requirements for a senior thesis that investigates how stand structure influences seedling recruitment and growth in the three development stages mentioned in the objectives.

To accomplish the study objectives outlined in the proposal and support the additional objectives mentioned above, the Boyd Evison Fellowship was supplemented with grants from the UW/NPS Research Station (AMK Ranch—Research Station) and the American Alpine Club. Additionally, Kellen N. Nelson (student PI) and Daniel B. Tinker (faculty PI) have been awarded a ‘Graduate Innovation grant’ from the Joint Fire Sciences Program to expand the extent of this study to the entire Yellowstone Plateau. Research funded by the 2014 Boyd Evison fellowship (and other 2014 grants) provide the foundation for this new investigation and will enable us to be the first investigators to fully incorporate feedbacks and interaction between climate, vegetation, and fire across the Yellowstone Plateau landscape.
RESULTS TO DATE

Weather station development

Weather stations were developed using the Arduino open-source prototyping platform and designed to measure the most relevant meteorological factors affecting forest fuel drying (Figure 1). An Arduino pro microcontroller was paired with an Adafruit Datalogger shield and powered using an AA battery pack. Data was logged to an SD card. Sensors were soldered directly to the Adafruit Datalogger shield and included temperature/humidity (SHT-15/75 sensor), soil water potential (Watermark 200ss), and soil and litter temperature (Vishay NTC Thermistor--NTCLE100E3). Measurements were logged during the fire season at 15 minute intervals.

Fuel moisture across three stages of forest development

Dead FMC varied through the season depending on the fuel particle and the stand development stage (Figure 2). Understory vegetation increased in FMC in the young stand but did not change in the mature stands. Duff FMC trended upward through the season in the mature stands but did not change appreciably in the young stands—perhaps because very little duff was observed at this site. Litter FMC was higher in the mature stands early in the season but all stands had similar FMC at the end of the season. One-hour fuel particle (woody material <0.25” diameter) FMC increased in the young forest site but did not in the mature sites. Ten-hour fuel particle (woody material 0.25”—1.00” diameter) FMC trended positively through the season.

Preliminary analysis of live FMC shows differences in FMC with needle age (Figure 3). From this preliminary analysis, there does not appear to be any statistical differences between sites; however, only one-third of the data has been processed in the lab.
Figure 2. Mean (±1 Standard Error) FMC for dead fuel particles.

Figure 3. Mean live FMC on August 20—22 for each site by the year of needle development. Note: Results are preliminary and reflect approximately one-third of the data collected.

Stand structure across three stages of forest development

Tree density significantly differed between mature forest with high canopy cover, mature forest with moderate canopy cover, and the young post-fire forest. Sapling density, sapling basal area, total basal area, and all measures of quadratic mean diameter did not differ between the two mature study sites but did differ between the young, post-fire site and the two mature sites (Table 1). This data will be further analyzed and FMC models will be implemented during the next year.
Table 1. Mean and 95% confidence intervals for a selection of forest structure by site

<table>
<thead>
<tr>
<th>Stand Attribute</th>
<th>Structure</th>
<th>Site 1: Mature forest with moderate canopy cover</th>
<th>Site 2: Mature forest with high canopy cover</th>
<th>Site 3: 25 year old post-fire forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree density (ha(^{-1}))</td>
<td>725 (627-822)</td>
<td>1300 (1099-1500)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Tree basal area (m(^{2}))</td>
<td>40 (34.5-45.5)</td>
<td>46.9 (38.9-54.8)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Tree quadratic mean diameter (cm)</td>
<td>25.8 (24.1-27.6)</td>
<td>23.1 (21.5-24.7)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Sapling density (ha(^{-1}))</td>
<td>2274 (1792-2755)</td>
<td>1991 (1417-2565)</td>
<td>7417 (5896-8938)</td>
<td></td>
</tr>
<tr>
<td>Sapling basal area (m(^{2}))</td>
<td>2.1 (1.6-2.7)</td>
<td>2.8 (1.9-3.6)</td>
<td>13.3 (10.4-16.2)</td>
<td></td>
</tr>
<tr>
<td>Sapling quadratic mean diameter (cm)</td>
<td>3.0 (2.6-3.4)</td>
<td>4.0 (3.4-4.6)</td>
<td>5.2 (4.5-6.0)</td>
<td></td>
</tr>
<tr>
<td>Total basal area (m(^{2}))</td>
<td>42.1 (36.7-47.6)</td>
<td>49.6 (41.5-57.7)</td>
<td>13.1 (10.4-16.2)</td>
<td></td>
</tr>
<tr>
<td>All quadratic mean diameter (cm)</td>
<td>14.7 (13.1-16.2)</td>
<td>15.4 (14.0-16.7)</td>
<td>5.2 (4.5-6.0)</td>
<td></td>
</tr>
<tr>
<td>Seedling density (ha(^{-1}))</td>
<td>11341 (7812-14871)</td>
<td>6343 (3614-9072)</td>
<td>8980 (5824-12135)</td>
<td></td>
</tr>
</tbody>
</table>

The density of seedlings, saplings, and trees varied by species and site (Table 2). Mature lodgepole pine (*Pinus contorta*) tree density was highest in the high canopy cover site and lowest in the young, post-fire forest site. Lodgepole pine seedlings were highest on the moderate canopy cover site that was affected by the mountain pine beetle and lowest on the high canopy cover site. Subalpine fir (*Abies lasiocarpa*) trees and saplings were most dense on the moderate canopy cover site and absent from the post-fire site. Subalpine seedlings were highest on the high canopy cover site and decreased with reductions in canopy cover. Whitebark pine (*Pinus albicaulis*) trees were the same in both mature forest stands but were absent from the post-fire stand. Whitebark pine saplings and seedling density were highest on the moderate canopy cover site and lowest on the post-fire site. Englemann spruce (*Picea Englemannii*) tree, sapling, and seedling density was highest on the high canopy cover site and lowest on the post-fire site.

Table 2. Species specific stand structure by site

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>Tree density (ha(^{-1}))</th>
<th>Sapling density (ha(^{-1}))</th>
<th>Seedling density (ha(^{-1}))</th>
<th>Basal area (ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Abies lasiocarpa</em></td>
<td>68.1±24.8</td>
<td>355.8±149.8</td>
<td>732.2±247.3</td>
<td>2.3±0.9</td>
</tr>
<tr>
<td></td>
<td><em>Pinus albicaulis</em></td>
<td>5.6±4.1</td>
<td>714.6±143.1</td>
<td>1092.9±255.8</td>
<td>0.6±0.1</td>
</tr>
<tr>
<td></td>
<td><em>Pinus contorta</em></td>
<td>619.6±58.3</td>
<td>1157.9±282.1</td>
<td>9354.5±2877.9</td>
<td>38.8±2.5</td>
</tr>
<tr>
<td></td>
<td><em>Picea englemannii</em></td>
<td>37.5±11.3</td>
<td>57.4±27.2</td>
<td>278.9±125.9</td>
<td>0.9±0.3</td>
</tr>
<tr>
<td>2</td>
<td><em>Abies lasiocarpa</em></td>
<td>67.4±25.4</td>
<td>279±116.4</td>
<td>1180.9±353.6</td>
<td>2±0.7</td>
</tr>
<tr>
<td></td>
<td><em>Pinus albicaulis</em></td>
<td>5.6±5.6</td>
<td>214.1±63.9</td>
<td>512.2±106.1</td>
<td>0.3±0.1</td>
</tr>
<tr>
<td></td>
<td><em>Pinus contorta</em></td>
<td>1101.1±203.5</td>
<td>1329.9±303</td>
<td>4329.5±2385.6</td>
<td>41.3±5.7</td>
</tr>
<tr>
<td></td>
<td><em>Picea englemannii</em></td>
<td>125.5±37.6</td>
<td>168.2±54.3</td>
<td>320.9±111.3</td>
<td>6±2.2</td>
</tr>
<tr>
<td>3</td>
<td><em>Abies lasiocarpa</em></td>
<td>0±0</td>
<td>0±0</td>
<td>7.6±5.2</td>
<td>0±0</td>
</tr>
<tr>
<td></td>
<td><em>Pinus albicaulis</em></td>
<td>0±0</td>
<td>0±0</td>
<td>22.9±13.6</td>
<td>0±0</td>
</tr>
<tr>
<td></td>
<td><em>Pinus contorta</em></td>
<td>0±0</td>
<td>7417.2±969.9</td>
<td>8934±2633.8</td>
<td>13.3±1.5</td>
</tr>
<tr>
<td></td>
<td><em>Picea englemannii</em></td>
<td>0±0</td>
<td>0±0</td>
<td>15.3±6.9</td>
<td>0±0</td>
</tr>
</tbody>
</table>
The growth rate of seedlings and saplings varied with site (Figure 3). Linear models were fit for each site. The highest growth rate (~0.3 m yr\(^{-1}\)) occurred on the post-fire site with no surviving overstory trees (R\(^2\)=0.62, p<0.001). Mature forest were significantly lower than the post-fire stand. The mature forest site with moderate canopy cover had a growth rate of ~0.03 m yr\(^{-1}\) (R\(^2\) = 0.53, p<0.001) and the high canopy cover site had a growth rate of ~0.02 m yr\(^{-1}\) (R\(^2\) = 0.35, p<0.001).

**PRODUCTS**

A NON-INVASIVE POPULATION STUDY OF MOOSE IN NORTHERN YELLOWSTONE NATIONAL PARK

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Two bull moose in Round Prairie, Yellowstone National Park, December, 2013

PROJECT SUMMARY

North American moose (Alces alces) populations are declining across much of their southern distribution from the Canadian Maritimes to the Rocky Mountain range of the Shiras moose subspecies (Alces alces shirasi). Shiras moose population declines have been documented in Montana and Wyoming with reduced productivity reported from Utah and Colorado. These declines are due to a combination of factors including the natural succession, loss, and degradation of habitat; predation by wolves and bears; disease caused by infection from artery worm; and parasitism by moose ticks. The effects of heat stress may also contribute to chronic malnutrition and a reduction in female fertility.

Significant reductions in Montana and Wyoming moose populations adjacent to Yellowstone National Park (YNP) are indicative of regional moose population declines and suggest that moose numbers may be decreasing in YNP as well. In the northern portion of YNP, also known as the Northern Range (NR), significant loss of riparian willow browse due to overgrazing by elk for decades and by bison more recently, the reduction of mature and old-growth conifer forests from the fires of 1988 and from disease more recently have reduced both winter habitat quality and quantity for moose. Several moose with cropped ears, an external sign of the disease Elaeophorosis, or artery worm, have been observed over the past few years on the NR suggesting that the disease may also be present in YNP. Northern Range estimates of moose have decreased from almost 400 in 1970 to possibly fewer than 100 today. Despite evidence suggesting moose decline in YNP, no current population data exists.
Knowledge of population demographics serves as a critical baseline for evaluating and understanding factors leading to population declines. However, because moose are solitary, prefer densely vegetated habitats, and are present at low densities, collecting population data is challenging. Traditional methods of studying moose that require capture, radio-collaring, and aerial surveys are costly, sometimes produce unreliable results, can be harmful to the study animal, and are discouraged in some jurisdictions such as national parks. Non-invasive sampling, the collection of data without having to capture, handle, or in any manner physically restrain study animals, has proven to be a valuable tool for acquiring accurate population data from free-ranging ungulates when using traditional methods is neither feasible nor practical.

In December 2013, we initiated a three-year non-invasive moose population study in YNP with the main objective to estimate population demographics of NR moose. For three consecutive winters we will be systematically collecting fecal pellets from the extent of NR moose wintering habitat. We are extracting DNA from epithelial cells on the pellet surface and through genetic testing will be able to identify individual moose and their genders. Female pellet samples will be analyzed for pregnancy hormone concentrations to make inferences on pregnancy rates. Because fecal pellet size is directly related to moose size, and therefore to moose age, we will use various pellet measurements to differentiate between age classes. These data will be used in capture-recapture modeling to estimate population abundance and vital rates.

**STUDY OBJECTIVES**

The ultimate goal of our study is to demonstrate the use of non-invasive methods to estimate population abundance and age and sex specific vital rates of northern YNP moose. To this end, we have the following objectives:

1. Systematically survey NR wintering moose habitat over three winter field seasons to collect fecal pellets from as many individual moose as possible as a source of DNA and pregnancy hormones.

2. Determine the genotype of individual moose using microsatellite analysis of fecal DNA for estimating minimum population size.

3. Identify individual moose gender through PCR-based fecal DNA analysis to identify females for analysis of pregnancy hormone concentrations. After genotypes are determined, gender will be used to estimate population sex ratios and sex specific vital rates.

4. Determine pregnancy hormone concentrations in female moose using enzyme-immunoassay. Comparing our data to thresholds for pregnancy of known-pregnant moose from Wyoming and Montana we will be able to make inferences on study population pregnancy rates.

5. Explore the use of moose pellet morphometry to differentiate between calf, yearling, and adult age classes. Age class data will be used to estimate age-specific vital rates.

6. Use robust design capture-recapture (CR) analysis of microsatellite genotypes to estimate population parameters including census population size and gender- and age-specific rates of recruitment, survival, and population change.

Moose in Barronette willows, Soda Butte drainage, December 22, 2013. Moose abandoned this area only weeks later when snow depth exceeded 110 cm (~43 inches).
BACKGROUND

Moose in Yellowstone National Park

When YNP was established in 1872, moose sightings were extremely rare and moose may not have appeared on the NR until the early 1900’s. In 1925, the U.S. Forest Service conducted surveys in several northern YNP drainages and reported a count of 65 moose. By 1936, an estimated 193 moose were found in the Hellroaring, Buffalo Fork, and Slough Creek drainages. In 1945, the Montana Fish and Game Department issued 40 permits to hunt moose in the area just north of YNP because of concern that willows were being over-utilized by wintering ungulates including moose. Northern range estimated spring maximums were recorded of 292 moose in 1968, 385 in 1969, and 383 in 1970. Aerial counts of moose were conducted between 1968 and 1992 and range from a high of 100 in 1972 to only four observed in 1986. Since the counts were not closely correlated with other index data, the flights did not produce complete survey data, and the cost of survey flights could not be justified, aerial censuses for moose in the Park were stopped after 1992. The most recent moose research in YNP was conducted by Dan Tyers between 1987 and 2001. His work focused on moose winter ecology on the NR and the use of population indices for monitoring demographic trends. He documented the importance of mature and old growth conifer forests for wintering moose. He also had the opportunity to study YNP moose before and after the devastating 1988 fires. He demonstrated that the 30% reduction of mature and old growth conifer forest caused a significant decline in moose numbers in the Park and that effect is still evident today. Currently, there is no population data for the NR moose population.

Non-invasive sampling

Estimating reliable population parameters is essential for the conservation and effective management of wildlife species. However, for species such as moose that are present at low density, occupy large home ranges, are solitary, and prefer heavy cover, acquiring such information can be challenging.

The most common methods of gathering moose population data include aerial surveys, physical capture, and the use of radio collars. However, these methods have limitations that can affect both their use and the quality of the data that are gathered as they are weather dependent, time consuming, logistically challenging, and often cost prohibitive. In addition, these methods are often discouraged in national parks because they are likely to alter the visitor’s experience of observing animals in their natural environment.

Physical capture and the restraint of moose for processing, as well as the subsequent collection of biological data, can be extremely invasive and can cause injury and physiological stress to the animals, which in turn can lead to capture-induced death. Aerial surveys, which require the use of sightability correction factors, can sometimes produce biased estimates of abundance as their accuracy depends on many factors including snow cover, type of aircraft, moose density, forest canopy closure, topography, and observer experience.

An alternative to these traditional methods is non-invasive sampling, the collection of biological data without having to capture, handle, or in any manner physically restrain study animals. Such methods are useful and often preferred in wildlife studies because they reduce costs while at the same time produce dependable population data, and they provide researchers with a tool to study animals that cannot otherwise be studied using traditional methods. Biological samples collected in this manner include hair, feces, urine, and saliva. Non-invasive genetic sampling (NGS) was introduced in 1992 to obtain genetic data from rare European brown bears and has emerged as one of the most accurate, efficient, and versatile tools for monitoring wildlife populations and for studying population demographics. Using DNA extracted from non-invasively collected samples, researchers can determine a study animal’s individual genotype and gender, and from these, estimate population parameters using capture-recapture (CR) models.

One of the most common sources of DNA for NGS studies is feces. DNA is extracted from epithelial
cells found on the surface of fecal pellets that have been sloughed off from the intestinal wall. The sampling of feces is not only easy and inexpensive, but also allows for the collection of large sample sizes.

**STUDY DESIGN**

**Study area**

Much of the NR (Figure 1) landscape below 2,000 meters (m) is open, treeless and covered by sagebrush and grassland vegetation. Mid-elevations are dominated by Douglas fir and lodgepole pine forests and upper elevations, between 2,200 m and 3,000 m, are dominated by Engelmann spruce, subalpine fir and whitebark pine. Willow occurs along streams and rivers and in wet forested areas. Scattered aspen stands, which represent <2% of the area, dot the landscape at mid elevations.

![Yellowstone National Park](image)

**Figure 1. Yellowstone's Northern Range**

Research conducted between 1987 and 1991 in northern YNP found that the cover types most used by wintering moose were lodgepole pine and Engelmann spruce/subalpine fir forests over 300 years old, and concentrations of tall and low willow species. One-hundred to three-hundred year-old conifer forests with associated willow were also important. Most moose were found in riparian habitats that supported late-winter, and in higher elevation mature and old-growth conifer forests that supported regenerating subalpine fir during mid-winter. Much of this mid-winter habitat on the NR was lost when the fires of 1988 burned approximately 30% of the mature conifer forest.

Our study area encompasses the portion of the Northern Yellowstone Elk Winter Range, located inside YNP, as well as some contiguous creek drainages located north of the Park (Figure 2). Specifically, moose winter habitat within our study includes those drainages containing willow, and willow associated with mature conifer forests. These include Glen, Fawn, Panther, Blacktail Deer, Oxbow, Geode, Hell Roaring, Elk, Lost, Tower, Slough, Crystal, Cache, Pebble, Amphitheater, and Soda Butte Creeks. In addition, we are sampling from portions of the Gardiner, Lamar and Yellowstone rivers. The drainages north of the Park in the Gallatin National Forest include the upper Hellroaring, Coyote, Buffalo, and Slough Creeks. Our study area covers approximately 1,000 km².

**Sampling design**

Our sampling design fits the requirements of Robust Design CR analysis (see ‘Capture-Recapture Analysis’). We will sample for three consecutive winters; 2013, 2014, and 2015 (called sampling periods), and collect samples during two distinct intervals from December 15 - January 15 and April 1 - April 30. These are termed ‘early-winter’ and ‘late-winter’ sampling sessions. Sampling during each of these two sessions will require 25 to 28 days or occasions. Assuming there are approximately 100 moose in our study area, we will need to collect 125 samples during each sampling session in order to generate reliable population parameter estimates.

We chose the sampling session dates for several reasons: to allow comparison between all early- and late-winter data; to have snow on the ground, which is helpful for tracking moose and finding samples, and to allow for efficient ski travel; to ensure that temperatures are below freezing to preserve DNA in samples; to sample moose at times of the year when they are most concentrated; and to allow for initial assessment and reassessment of moose pregnancy status.
Figure 2. Study area showing early winter moose survey flight and historic moose winter range.

We also will collect pellets opportunistically between January 16 and March 31, which we term our ‘mid-winter’ sampling session. In combination with snow depth measurements, genotype data from these samples will be useful in evaluating temporal and spatial shifts within winter habitat as well as evaluate individual winter home range sizes. All mid-winter samples will be used for morphometric analysis, female samples will be analyzed for pregnancy hormone concentration, and all genotypes will be used to estimate minimum population size.

Data collection

Fecal pellets were located by following fresh moose tracks (determined by the age of the tracks as compared to the date of the most recent snowfall).

Collecting moose pellets from track
Consistent with ethical data collection, moose were back-tracked so as not to disturb the animal. To ensure sterile sample collection, disposable gloves were worn to collect pellets. Thirty pellets were collected for each individual moose: 10 each for DNA analysis, pregnancy hormone analysis, and pellet morphometrics. The three samples of 10 pellets were double-bagged with a label displaying the field identification number in the outside bag, stored in a quart-sized bag containing the field ID number, and frozen at -20°C until they could be analyzed. Frozen pellet samples were delivered to the University of Minnesota-Duluth (UMD) for genotype and gender analysis and to the Smithsonian Conservation Biology Institute in Front Royal, Virginia, for pregnancy testing. K2 Consulting in Waitsfield, Vermont analyzed morphometrics and will conduct future CR analyses.

**ANALYSES**

**DNA extraction and amplification**

The first steps of our genetic analysis are the extraction of DNA from epithelial cells on the surface of fecal pellets and the amplification of DNA using a process called polymerase chain reaction or PCR. To overcome the challenges of using low quality and quantity DNA common in fecal samples, we have tested and optimized each step of our genetic methodology, from field sampling to PCR conditions. Overall, the results from this first year have been very positive, and the time and resources spent this year will improve the efficiency and success of the study moving forward. Different extraction kits and protocols resulted in varying levels of DNA extraction success and DNA purity. Therefore, we tested multiple extraction kits and protocols to find the pairing that produced the best results. From these tests we have chosen to extract DNA using the QIAamp DNA Stool Mini Kit.

From the 270 samples collected, including 36 samples that resulted in poor (< 2.0 ng/µl DNA product) or failed extractions, DNA concentrations average 21.11 ng/µl, which is well over what is required for PCR amplification for genotyping. Many of the 'poor' or 'failed' extractions were from older pellet samples which were collected purposely to determine what age pellets still contained viable DNA. We found difficulty extracting DNA from pellets older than ~4-7 days, particularly if the pellets were collected in direct sunlight and had dried up, and when late-winter pellets were saturated with water or had undergone repetitive freezing and thawing.

PCR amplification of the SE primer pair (SE47/SE48) is done immediately post-extraction and is used to verify extraction success and determine gender. Even with successful DNA extractions, we found our initial PCR amplifications to be inconsistent, likely because of PCR inhibitors common in fecal material. To remedy this we refined our PCR process by adding bovine serum albumin (BSA), which has been shown to limit the effects of PCR inhibitors. For a comparison of visualized PCR product with and without the inclusion of BSA see Figure 3.
In addition to including BSA, we have modified other PCR conditions for optimal amplification of each microsatellite (Table 1). Finally, we have included a multiplex pre-amplification step which is designed to increase the quality and quantity of the desired DNA template. In this step, an initial large-volume PCR containing all primers for the loci to be genotyped is conducted. Product from this pre-amplification step is then used in individual PCRs for each locus or smaller subsets of loci. This method requires additional effort and is not beneficial for all loci; therefore it is only used for loci that are not amplifying consistently using traditional single step PCR (Table 1). Refinement of our genotyping process has resulted in an increased genotyping success rate from 58% to 88%, after removal of non-working and monomorphic microsatellites. Continued modification will still be attempted to increase this rate, and any missing data can be filled in by data replication.

### Determining gender

Identification of individual gender is required for estimating population sex ratio and sex-specific population parameters, and for monitoring gender-related population trends. For our study, it will also be necessary for separating female from male pellet samples for pregnancy analysis. The most common method for determining gender in moose is the identification of sexually dimorphic characteristics. Males are identified by the presence of antlers or pedicels on adults or antler buds on calves, and females by the presence of a white vulva patch. However, when sightability of moose is limited, these methods are not useful. In the last 15 years, PCR analysis of fecal DNA has become an important tool for studying gender in moose.

Determining gender in mammals involves the identification of X- and Y-chromosome-specific DNA sequences. The method we chose, validated for a number of North American ungulates including moose, uses the SE47/SE48 primer pair to amplify common X- and Y-linked gene markers on the amelogenin gene. Amplified products are short, which is important when

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**Table 1.** Characteristics of 1 sex-linked (SE47/SE48) and 27 autosomal microsatellites. They are either PCR amplified using single step PCR (S) or pre-amplified (P) as indicated in PCR plex column, along with specific multiplex. Also shown are the fluorescently labeled primers (M13 label) and optimal annealing temperatures.

<table>
<thead>
<tr>
<th>PCR plex</th>
<th>Locus</th>
<th>Size range (bp)</th>
<th>M13 label</th>
<th>Ann. Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S,Uniplex</td>
<td>SE47/SE48</td>
<td>224, 259</td>
<td>-</td>
<td>53</td>
</tr>
<tr>
<td>S,MP1</td>
<td>RT23</td>
<td>160-170</td>
<td>VIC</td>
<td>54</td>
</tr>
<tr>
<td>S,MP5</td>
<td>RT5</td>
<td>151-161</td>
<td>FAM</td>
<td>54</td>
</tr>
<tr>
<td>S,MP2</td>
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working with low quality and quantity of DNA, and differ in length so they can be easily separated using gel electrophoresis. Electrophoresis displays a single band for females and a double band for males (Figure 4).

We determined definitive genders, based on distinct X- and Y-linked product bands using gel electrophoresis, for 234 (86%) of the 270 samples. Of those, 111 (47%) were female and 123 (53%) were male. Of the remaining 36 samples, 23 (8%) showed no PCR product and 13 (5%) showed questionable results in that the bands were not distinctive. Of the 23 that showed no PCR products, 19 were collected in late-winter when snow was melting, snow events were less frequent, and the age of the samples became difficult to determine. Some of these samples were aged at one week or older and others were collected assuming they were mid-winter samples just to see if the DNA was still viable.

We collected pellets from 43 known-sex moose based on visual identification and identified 100% of the genders correctly. These results helped to validate our gender determining methodology using the PCR-amplified SE primer pair.

Figure 4. Gender signature on agarose gel showing a single band for females and double band for males

Determining genotype

Individual genotypes are required to estimate population abundance and vital rates and are determined through the analysis of DNA microsatellite markers. A number of genetic markers have already been developed for North American and European moose populations and at least 30 variable microsatellite markers have been characterized for moose in the Molecular Ecology Resources Primer database (http://tomato.bio.trinity.edu/). Many more have been developed for other ungulate species that also amplify in moose.

The number of microsatellites needed for genetic determination of NR moose was established in a pilot study. We tested 27 autosomal primers for microsatellites previously developed for moose on 14 pellet samples (Table 1). We have since discarded five of these, four of which did not amplify consistently (INRA003, RT27, FCB193, and NVHRT34), and one that was monomorphic in the YNP moose population (NVHRT01) and thus provided no information for genetic differentiation. We found low genetic diversity in our pilot study, which requires more loci to be considered for genotyping, so we chose to use all of the remaining 22 microsatellites for further analysis.

For the 16 microsatellites that have been analyzed thus far, we found 2-6 alleles per locus and calculated expected and observed heterozygosity, two measures of the amount of genetic variation in the NR moose population (Table 2). In comparison, a genetic study of Alaskan moose, using many of the same microsatellites, showed the number of alleles per locus to range between three and 12. The microsatellite locus (RT 30) containing 12 different alleles in the Alaskan study only showed three allelic variants in our study population so far. We also observe both lower and higher number of alleles in YNP moose at other loci compared to similar studies on moose, although some of these differences could be due to varying sample size. Data from additional sampling seasons will help clarify this question.

The total number of unique individuals sampled in the first year will be determined by creating a genotypic fingerprint for each sample using data from the 22 microsatellites. The number of unique fingerprints will represent the minimum number of individuals sampled in the population. Samples collected in following years will be used to improve the minimum population size estimate and to estimate census population size (Nc) using the mark-recapture method and Program MARK. Genotype determination for the first year is expected to be completed by the end of 2014, after which the minimum number of individuals will be determined.
Table 2. Number of alleles (N_A) and heterozygosity (expected H_E and observed H_O) at 16 autosomal microsatellite loci.

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Estimating pregnancy rates

Knowledge of the reproductive status of individuals in a population can provide information about age specific fertility, population reproductive potential, and trends in population size. Traditional methods of assessing pregnancy, which are all invasive and require capture, include drawing blood, performing trans-rectal ultrasound, and palpation of the reproductive tract. In the past two decades, however, non-invasive methods of assessing pregnancy using analysis of fecal hormones have been developed and used for moose. The method we are using, and the one most commonly used in ungulates, is enzyme-immunoassay (EIA) of progestagen hormones. Progestagens are a group of hormones that function to maintain pregnancy in mammals and increase throughout the pregnancy cycle.

Pregnancy is determined based on a threshold level of progestagen concentration. Researchers in Alaska found concentrations above 7,000 ng/g for captive pregnant moose and in the southern Greater Yellowstone Ecosystem, researchers reported fecal progestagen concentrations >10,600 ng/g for 21 known-pregnant moose and <2,600 ng/g for four non-pregnant moose. Where pregnancy rates for moose have averaged ~84% across North America, researchers of declining moose populations have reported much lower pregnancy rates. In on-going studies of Shiras moose, pregnancy rates ranging from 48% to 74% have been reported for Wyoming’s Sublette moose herd and 75% to 80% for Montana moose.

It is important to note when making inferences about pregnancy rates of free ranging populations using non-invasive methods that pregnancy hormone concentrations can vary between regions and populations and that pregnancy rates can also vary for a number of reasons including habitat quality, moose density, and population age structure.

Progestagen concentrations for our early winter samples varied from 168 ng/g to 5,227 ng/g (N=60) and 13 of the lowest 21 concentrations were from calves. We submitted calf samples (based on visual observation and/or pellet, track and bed size) to determine baseline hormone concentrations as compared to adults, which is useful for differentiation between calf and yearling age-classes. Concentrations of our late winter samples varied from 131 ng/g to 9,191 ng/g (N=42). With this batch we included three known males in order to get baseline concentrations, which will help to differentiate between cows and bulls. Whereas these males did not have the lowest three concentrations, they did fall in the lowest 14 values ranging between 197 ng/g and 467 ng/g.

We compared our concentrations to mid- and late-winter samples of known pregnant-moose from on-going studies in Montana and Wyoming that identified thresholds for pregnancy of 1,130 ng/g and 2,100 ng/g, respectively (Figure 5). Because pregnancy hormone concentrations increase throughout the pregnancy cycle, we used our late-winter concentrations in comparison to generate a more reliable estimation of pregnancy rate. After removing the three known bulls (N=39) from our late winter samples, 25 (64%) were above the Montana threshold and 24 (62%) were above the Wyoming threshold. Assuming threshold concentrations for pregnancy of northern Yellowstone moose are similar to those of Shiras moose in neighboring regions, it would suggest that between 62% and 64% of our late-winter samples were from pregnant females.
Age class determination

Ages of study animals are used to determine the age structure of wildlife populations, which in turn are used to estimate population growth rates and for estimating age-specific vital rates. Common methods of aging cervids include counting cementum annuli on extracted teeth, analyzing tooth wear or replacement, and weighing and measuring the animal, all of which entail physical capture. A non-invasive alternative to these traditional methods is fecal pellet morphometric analysis in which the age class of animals is determined by pellet size. Application of these analyses requires a positive relationship between animal live-weight, age, and pellet size.

Researchers studying reindeer in Norway differentiated between calf, yearling, and adult age classes of females. They found adult pellets were longer than calf pellets, and adult and yearling pellets were wider than calf pellets. In addition, they showed that pellet volume, based on pellet length, width, and depth measurements, could differentiate between calf, yearling and adult age classes 91% of the time. Researchers in Denali National Park correctly identified 91% of known-age and -sex moose based on pellet volume estimates. Combining pellet age class data with other non-invasive genetic and hormonal techniques will improve population monitoring of ungulate species.

Our goal in conducting morphometric analysis of moose pellets is to differentiate between calf, yearling, and adult age classes. In each group of pellets we collected, ten to twelve pellets were oven dried at 60°C in a convection oven for 48 hours. After drying, partial pellets and equal numbers of the largest and smallest pellets were discarded from each sample, leaving the eight most representative in size and shape of the original sample. Using digital calipers with a precision of 0.01 mm, each pellet was measured for maximum length (Lp), width (Wp), and depth (Dp) at 90° rotation from Wp. Using the product of the mean values of the three measurements, we calculated a volume index for each sample; \( V_s = L_p \times W_p \times D_p \). Volume index was then converted to cm³.

Two-hundred and twenty samples of both genders combined, 120 from early winter and 100 from late winter, were measured. Volume indices, and pellet average widths and lengths ranged from 3.2 cm³ to 11.6 cm³ (Figure 6), 12.4 mm to 20.9 mm, and 19.2 mm to 33.5 mm, respectively. Using the same methodology we also measured 57 known-age pellet samples from female moose provided by Montana Fish Wildlife & Parks from an ongoing study. Montana samples were collected during mid- and late-winter moose capture and late-winter/early-spring ground surveys. Average pellet volume for each age class is shown in Figure 7. We used one-way ANOVAs to identify variation in pellet measurement means between age classes. We found significant differences in pellet mean volume between calves and yearlings (P=0.002) and between calves and adults (age 2.5-12.5) (P=0.00002) but no difference between yearlings and adults. We also found significant differences in pellet mean width between calves and yearlings (P<0.001) and between calves and adults.
Figure 6. Frequency distribution of YNP pellet volume (P<0.001) but no difference between yearlings and adults.

No differences in mean pellet length were detected between age-classes (Figure 8). As our data set builds we hope to be able to separate between yearling and adult cohorts.

These data will be used for future estimation of age-groups for our female samples using discriminant function analysis. We are also exploring the use of cluster analysis to group our male samples into age-classes. Cluster analysis will be particularly useful for our study of free-ranging moose because unlike discriminant function analysis, it does not require a priori age-class data.

Capture-recapture analysis

Capture-Recapture (CR) analysis compares the relative proportions of marked to unmarked animals in successive samples to estimate population abundance. In the last 15 years, the use of fecal DNA-based CR analysis of microsatellite genotypes to estimate population parameters and trends has become common place. In addition to population abundance, such analysis can provide estimated rates of fecundity, recruitment, survival, temporary emigration and immigration, and population change.

Figure 8. Box plots showing average pellet width, volume, and length of known-age MT moose. There were no significant differences in pellet length between age classes.

We will use Robust Design models in Program MARK, a Windows-based computer program to estimate census population size and gender- and age-specific rates of recruitment, survival, and population change. Robust Design models analyze two levels of sampling (primary and secondary) in order to generate estimated population parameters. We chose MARK because it is commonly used and highly versatile and it offers a full complement of Robust Design models. MARK has also been used in recent population studies of Sitka black-tailed deer, mountain goats, and caribou. Once individual genotypes have been determined we will begin creating capture histories of each moose which are the input data for our CR analysis. Capture-recapture estimates of NR moose vital rates will be compared to those from other populations of Shiras moose.

FIELD SUMMARY

Pellet samples and sampling effort

Over the course of our 2013 field season (December 15, 2013 to April 30, 2014) we collected 270 fecal pellet samples: 125 early-winter, 114 late-winter, and 31 mid-winter. Pellet samples were collected in all study area drainages with the exceptions of Hellroaring,
Coyote, Buffalo, Panther, Glen, Crystal, and Cache Creeks where we did not find any moose.

During our early-winter sampling, our field crew, Ky and Lisa Koitzsch, skied 687 km to survey 304 km of study transect over 29 field days and conducted one moose survey flight of 569 km. Two multi-day trips of five and three days were taken to sample moose in the Frenchy’s Meadow area of upper Slough Creek and Miller Creek, respectively. During our late-winter sampling, the field crew skied 553 km to survey 357 km of transect over 20 field days (Figure 9). No multi-day trips or survey flights were taken during the late-winter session due to deteriorating snow conditions and chronically poor flying conditions (wind and/or poor visibility). Sampling effort was directly correlated to daily weather. We did not sample during snow storms because moose tracks and pellets were covered, visibility was poor, and avalanche conditions were potentially dangerous. The state of the snow pack also dictated how much area we could cover. When snow was deep and unconsolidated it took more effort to break trail which slowed our progress and when the snow was crusted and supported our weight we could sample more efficiently.

Habitat use

Similar to earlier studies of northern YNP moose, we found two different patterns of habitat use by moose on the NR depending on the occurrence of mature conifer forests. In much of the western and central portion of our study area, such as the Blacktail Deer Plateau, where most of the mature conifer was burned in the 1988 fires, moose spent the early-winter in upper creek drainages feeding on willow. As snow depths increased, thereby making willow unavailable, moose moved downstream towards the Yellowstone River where snow depths were moderate and there they fed on small pockets of willow in steep drainages. By late winter, some moose were found at ~1,740 m (~5,600 ft.) elevation along the Yellowstone River. In contrast, moose in the eastern portion of our study area, such as the Soda Butte Creek drainage, fed on willow in the early winter but moved to higher elevations when snow depths made this food source unavailable. Here, the mature conifer canopy offered thermal cover, lesser snow depths allowing easier travel, and available browse primarily in the form of regenerating subalpine fir. We sampled from one moose that had been feeding and bedding at 2,430 m (~8,000 ft.). We found the highest concentrations of wintering moose in the Soda Butte Creek drainage because of its abundant willow stands and mature lodgepole pine/Engelmann spruce/subalpine fir forests.

The Soda Butte Creek drainage supports the highest densities of moose on the NR because of the abundant willow and mature conifer forests.
Subalpine fir saplings in understory of mature lodgepole forest (above). Heavily browsed subalpine fir (below).

Blacktail Deer Plateau. All of the drainages shown (Blacktail Deer, Oxbow, Geode Creeks) flow north into the Yellowstone River.

Field observations

From our observations it appears that northern Yellowstone moose are relatively healthy. Of the 43 animals we observed closely enough to determine gender, we did not notice any tick induced hair loss, abnormal behavior, or unhealthy looking animals. Over the course of the winter we also did not find any ticks in the hundreds of beds we examined. Other than two individuals with cropped ears, we didn’t see any other physical evidence that would suggest that artery worm is having a significant impact on YNP moose. Perhaps because moose in northern YNP occupy higher elevation habitats than other populations of Shiras moose, the associated prolonged winters make them more immune to tick infestations and a relatively lower mule deer density keeps them isolated from chronic artery worm infection.

There appeared to be a fair number of recruited calves in the population based on our observations over the course of the winter. In addition, we observed one pair of twin calves, one pair was reported to us, and another was identified based on tracks and beds during sampling. We recovered two moose carcasses in our study area that we had likely collected fecal pellets from. One female calf was killed by wolves in March and an adult cow drowned in a lake in October. From these carcasses we were able to obtain tissue samples for DNA genotype analysis that we will compare to genotypes of previously sampled moose. These ‘dead recoveries’ of moose are important for aspects of our CR modeling and for validation of our genotyping and gender methodology.

We observed a difference in pellet size and form between early winter and late winter and between the two habitat types used by wintering moose. In general, moose that fed primarily on willow deposited pellets that were large in volume, oval in shape, light in
color, and sawdust-like in consistency. Those moose that utilized old growth conifer deposited pellets that were smaller in volume, angular in shape, black in color, and smooth in consistency. Those moose that utilized both habitats deposited pellets intermediate in both size and form. In general, early-winter pellets were larger than late-winter pellets.

We believe these differences were due to variation in forage quantity and quality between the two habitat types. The more abundant and coarser woody stems of willow contributed to the larger oval pellets while the less coarse and less abundant understory twigs, buds, and leaves of subalpine fir and Ribes spp. (among others) contributed to smaller, angular pellets. We also noted an increase in late winter consumption of arboreal lichen (Old Man’s Beard) within the mature conifer forests. Numerous studies have documented moose eating arboreal lichen during the winter as a supplementary food source and some researchers believe moose may use it as a source of free water during the cold and dry winter months. Because moisture content of the forage is often the most important factor in determining pellet form and shape, it seems likely that those moose ingesting large volumes of arboreal lichen would deposit less formed, smoother, and moister pellets. Future microhistological analysis of YNP moose pellets may provide insights into these differences.

FUNDING AND SUPPORT

We greatly appreciate all those who have helped fund and support our project. We received funding from a UW-NPS Research Grant, the Campfire Club of America Conservation Fund, Andrew B. Heath, and Dick and Karen Koitzsch. We thank Yellowstone National Park for providing housing and the Yellowstone Center for Resources for daily logistical support. We especially thank the University of Minnesota-Duluth for providing funding for genetic analyses.

ACKNOWLEDGEMENTS

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PROJECT STAFF

Ky and Lisa Koitzsch own K2 Consulting, LLC and live in Waitsfield, Vermont. They are wildlife biologists who have been specializing in winter studies of predators and their prey. They have recently been working on the Isle Royale Wolf/Moose Project and the Yellowstone Wolf Project. Ky received a Master’s degree from the University of Vermont where he quantified moose habitat suitability of Vermont Wildlife Management Units. He is especially interested in moose winter ecology. Lisa has a background in avian studies and is currently working on a study of wolf predation in YNP using GPS cluster analysis to locate wolf kills.

Jared Strasburg is an assistant professor at the University of Minnesota-Duluth who specializes in evolutionary and population genetics. He works with a range of organisms, including moose, wolves and other carnivores, and sunflowers.

Tessa Tjepkes is a graduate student at the University of Minnesota-Duluth who is conducting our genetic analysis under the direction of Jared Strasburg. In addition to her work applying non-invasive techniques to study Northern Yellowstone moose genetics she is also studying population genetics of northeastern Minnesota moose.
RESEARCH PROJECT REPORTS

CULTURAL RESOURCES
ARCHAEOLOGY AND SOCIAL GEOGRAPHY IN THE SUNLIGHT BASIN, WYOMING

LAURA L. SCHEIBER  AMANDA BURTT
INDIANA UNIVERSITY  BLOOMINGTON, IN

ABSTRACT

Painter Cave (48PA3288) is a dry rockshelter in the foothills of the Absaroka Mountains of northwestern Wyoming that has deeply stratified deposits. Archaeological materials were disturbed several decades ago by looters, who reportedly took a number of perishable Native American artifacts including moccasins and a cradle board, as well as numerous other unidentified objects. Preliminary assessment by Shoshone National Forest Service personnel in 2011 suggested that the site might still be partially intact. Indiana University’s Bighorn Archaeology project conducted a pilot study at Painter Cave and the surrounding area in 2014 in an effort to identify and recover any additional cultural deposits. Artifact recovery addressed local landscape use, cultural chronology of the area, subsistence strategies, and environmental conditions. The looter activity unfortunately proved to be extensive. Although team members identified numerous archaeological signatures at different sites in the study area, primary deposits in the shelter itself were disturbed in such a way that investigation into the use of Painter Cave by past peoples was challenging.

INTRODUCTION

Painter Cave is a recently-recorded archaeological site located in Sunlight Basin in northwestern Wyoming at an elevation of approximately 2268 m (7,440 ft.) above sea level. Sunlight is a resource-rich high altitude basin, 24 km east of Yellowstone National Park. It is located on the road between Cody, Wyoming, and Cooke City, Montana, via the Beartooth and Chief Joseph Scenic Byways. The Beartooth Highway (U.S. Hwy 212), which opened in 1937, is a National Scenic Byways All-American Road through southwestern Montana and northwestern Wyoming from Red Lodge, Montana, to the Northeast entrance to the Park. The road is partially closed in winter due to snow accumulations, leaving sole access to the eastern side of the Park via the Chief Joseph Scenic Byway from Cody that travels through Sunlight Basin. The Chief Joseph Scenic Byway (Wyoming Hwy 296) follows the route taken by Chief Joseph as he helped guide a group of eight hundred Nez Perce Indians fleeing the U.S. Calvary in 1877. The highway was built in the late 1800s to offer support to miners and railroad interests in the area. The route crosses the Shoshone National Forest through the Absaroka Mountains to the Clarks Fork Valley and was not paved until 1995. The Beartooth and Chief Joseph Highways are still heavily traveled today. The project area is located 15 km west of the highway just north of Sunlight Road, as it bisects and drops into Sunlight Basin. Archaeological evidence suggests that this travel corridor has been in use for thousands of years, linking the Wyoming Bighorn Basin to Yellowstone and the Montana Plains.

The Sunlight Basin environmental context is a combination of sagebrush grasslands, mixed conifer forest, and mountain meadows (Figure 1). It is a natural habitat for many species of animals including elk, mule deer, moose, bighorn sheep, black bears, mountain lions, and coyotes (Buskirk 2016). Birds such as blue and ruffed grouse, mourning doves, songbirds, and some duck species also spend time here. Previously extirpated animals such as wolves and grizzly bears have returned to the basin, while bison continue to graze in other areas of the forest closer to the park.
Although referred to as a cave, Painter Cave is technically a dry rockshelter (Figures 2-3). It has the potential to contain deeply stratified deposits of multiple cultural and natural layers. The extensive use of the shelter by packrats (also called bushy-tailed woodrats, *Neotoma cinerea*) informs us about local animal species present through time. Size-sorted debris identified at the entrance of the shelter additionally provides evidence of previous looting activity and could mean that stratified deposits were impacted by the looters.

The Shoshone National Forest Service District Archaeologist Kyle Wright along with archaeologist Dr. Larry Todd documented the looter activity when they recorded the site in 2011. They drew preliminary maps of the cave floor and determined the depth to be multiple meters. The probability of finding perishable materials was thought to be high due to the protected nature of the cave, as well as previous reports from local community members. Perishables are rarely recovered in open air sites and thus are significantly understudied. The conspicuousness of the location and the former looting make Painter Cave susceptible to further vandalism by artifact collectors. This concern continues to be shared by the local community, indigenous groups, the Shoshone National Forest District Archaeologist, and the Forest Service Law Enforcement Rangers. Studying this cave was an attempt to preserve the histories that this site and its contents represent.

**BACKGROUND AND SIGNIFICANCE**

Cave sites are known to be “extraordinary data sources for two fundamental reasons: they repeatedly provided permanent shelter for human groups, and they serve as fairly permanent post-depositional containers for the material residues of those human occupations” (Straus 1979:332-333). Closed sites in this area are usually classified as one of four features: caves, rockshelters, overhangs, and boulder shelters (Kornfeld 2007:58). Within the mountain regions that comprise the adjacent Bighorn Basin, at least 49 closed archaeology sites have been examined, with over 130 known (Finley et al. 2005, Kornfeld 2007). These sites have been used for thousands of years, and some deposits date to as old as the first inhabitants of the North American continent. They have the potential to inform us about long-term cultural processes in these environmental contexts. Stratified open air sites, while rare, have been documented and contribute valuable information about technologies and variations in lifeways over time. However, closed sites offer opportunities for the understanding of temporal cultural change and reconstructing past environments though stratified deposits in protected conditions (Finley et al. 2005, Walthall 1998). These sites are distinctive because they have “escaped to varying extents the geological processes of weathering and stream scouring and transport, so that in situ archaeological components were preserved in stratigraphic sequences that can extend over long periods of time” (Kornfeld et al. 2010:70).
Although numerous Native groups used this area through time, it is perhaps most known for the Mountain Shoshone or Sheepeater occupants. Shoshone people occupied this area for many thousand years (Larson and Kornfeld 1994, Nabokov and Loendorf 2004). A large late precontact Shoshone campsite is located at Sunlight Creek, just two kilometers south of Painter Cave (Kornfeld et al. 2010). Archaeologists and others have long recognized the relatively unique bighorn sheep hunting features in northwestern Wyoming as remnants of Mountain Shoshone “Sheepeater” bands (Frison et al. 1990, Norris 1881), but it has only been since 2004 that recognition of associated camp and butchering sites dated the hunting features to the contact period ca. AD 1750-1850 (Eakin 2005, Scheiber and Finley 2010). Both archaeologists and historians have a poor understanding of the first encounters between these Indians and Euroamericans, and rare records of culture contact in the mountains east of Yellowstone National Park informs both intellectual communities about Native responses to colonial encounters beginning with the Upper Missouri and Rocky Mountain fur trade and ending with forced settlement on the Wind River Reservation in central Wyoming. The Shoshone likely continued to travel north to the Yellowstone area through the 1870s and possibly beyond (Stamm 1999). The archaeological record from Painter Cave could supply additional insights about changing patterns of Shoshone subsistence, settlement, exchange, territoriality, and ethnic identity both pre and post contact (Scheiber and Finley 2010, 2011a, 2011b, 2012).

Sunlight Basin was Crow territory in early historic times (Medicine Crow 2000). It was part of the Crow Indian Reservation until 1868, when it was reduced to a fifth of its size and constrained to the state of Montana during the Fort Laramie Treaty. Yellowstone National Park was established in 1872, effectively shutting Native people out of park lands. In an effort to present Yellowstone National Park as an unaltered landscape, early officials effectively removed Native communities from regional histories (Nabokov and Loendorf 2004, Scheiber and Finley 2010). Mining in the late 1860s and 1870s brought white settlers to the Sunlight area. It is clear that the Crow were still regularly traveling south to Wyoming during this time. As quoted by the Mountain Crow spokesperson Sits in the Middle of the Land in 1873, “We used to go up the Yellowstone, and cross to the lake, and go through to Heart Mountain on the Stinking Water. That was our country. This summer we intend to go to Heart Mountain to get skins for our lodges” (Wright 1874:130). The route from the agency to the Stinking Water would likely have taken them through Sunlight Basin and near vicinity. In 1882 and again in 1891 the Crow lost the area near Cooke City, Montana, just north of Sunlight, largely due to mining interests. Euroamericans settled more extensively in the basin starting in the 1880s, although the Crow continued to travel through the area at least into the early 1900s (Dominick and Chivers 2004).

The Crow continue to tell stories about Sunlight Basin today. According to Grant Bulltail, Crow tribal historian whose grandfather grew up in the region, it was known as Yellow Crane’s land. “A little further up from the Red Hills (Shichishe) is the location known to whites as Sunlight Basin but to the Crow as Yellow Crane’s Land (Apitshihilishasawe) for a leader who regularly took his band there to hunt elk, bighorns, and buffalo in the winter” (Nabokov and Loendorf 2004:43). Yellow Crane was likely born around 1850, and he was a tribal leader at the turn of the century (Hoxie 1995, U.S. Congress. Senate 1908, U.S. Congress. Senate. Committee on Indian Affairs 1886).

In 1877, Chief Joseph and eight hundred Nez Perce journeyed through this area as they were pursued by the U.S. Calvary (Lang 1990). Although they may not have traveled directly through Sunlight Basin, their attempts to avoid confinement by trying to flee to Canada contributes to the landscape of Native-white relationships in this area of northwestern Wyoming. The exact routes of both the Nez Perce and two Army units continue to be investigated by archaeologists and historians.

The research project at Painter Cave is significant in multiple dimensions across space and through time: 1) it contributes to the scientific study of regional rockshelters potentially offering a prehistoric “master sequence” of long-term cultural occupations and environmental histories in the basin uplands, 2) hundreds of recently identified high-altitude single-component surface sites may be tied into this potential master sequence, 3) it is located on a drainage between historic conical lodge structures and one of the largest known precontact Shoshone winter campsites and thus has enormous potential to contribute to knowledge about Shoshone landscape use across different elevations, 4) it is informed by the voices of local descendant tribal groups. The site is vulnerable because it is not protected. Although the sub-surface of the cave likely has not been disturbed in decades, the shelter was recently referenced on a local resident’s blog, and other people are aware of its location. Studying this cave is crucial to protect and preserve the site for the future. Additionally, the site is
located in an unburned forested area. Providing baseline data for the forest pre-burn is an important tool for resource management. In fact, Sunlight Basin is adjacent to the boundary of the 1988 Yellowstone (Clover Mist) fire.

**ARCHAEOLOGY OF SUNLIGHT BASIN AND THE EASTERN YELLOWSTONE AREA**

The project area is in the vicinity of several key archaeological sites, many that are essential for understanding the regional prehistory, including Mummy Cave, the Dead Indian Campsite, Bugas-Holding, and the Sunlight Sheep Trap. This work ties directly into these regional chronologies and provides more information to connect the valleys to the mountain contexts, which is now almost completely lacking. Painter Cave presents a unique opportunity to study long-term change and continuity in hunter-gatherer use of the Rocky Mountains, including subsistence strategies, resource exploitation, technological change, seasonality, climatic fluctuations, and cultural identity and migration. Investigating the variability of human occupation in this area is crucial for studying the duration and intensity of remote mountain landscape use as well as for tracking the movements of particular groups of people who came to occupy this area in historic times. Recovery of faunal remains also links ecological histories and fine-tunes environmental climatic fluctuations.

Several archaeological sites have been documented in the near vicinity, many through cultural resource management projects for road and building construction. Thirty-three archaeological sites have been recorded in a 9.6 km (6 mile) radius around the research area. Two-thirds are prehistoric sites, and one-third are historic sites. Most of these are located within a short distance from the water source of Sunlight Creek. This pattern is likely as much due to discovery efforts as past peoples’ preferences.

Other important sites in the area were investigated several decades ago (primarily in the 1960s, 1970s, and 1980s). Dating from 5,000 to 500 years ago, the Dead Indian Campsite (48PA551), is located 10 km south/southwest of Painter Cave (Frison and Walker 1984). It has been listed on the National Register of Historic Places since 1974 and is one of only three prehistoric archaeological sites listed on the register in Park County, along with the Horner site (48PA29) and Mummy Cave (48PA201). The most intensive occupation at the Dead Indian site is the Middle Archaic (4,500 years ago) winter pithouse camp with evidence of extensive deer processing. The Bugas-Holding site (48PA563), just two km south of Painter Cave, is a large Shoshone fall/winter campsite dated to AD 1400-1600 (Rapson 1990). It, along with Mummy Cave, demonstrates the most extensive evidence for sheep procurement in the region.

Mummy Cave is a large rockshelter containing one of the prehistoric master sequences discussed above (Husted and Edgar 2002, Wedel et al. 1968). It is thirty-three km southwest of Painter Cave almost at the East entrance to the Park. Containing thirty-eight occupation levels, it spans human occupation in the region from more than 10,000 years ago to several hundred years ago. The Sunlight Sheep Trap (48PA1040) is an excellent example of a preserved sheep trap, with a wood catch pen and wooden drivelines (Frison et al. 1990). It is located five km west of the site. Painter Cave has the potential to tie together these important sites as well as bring innovations and advances through the use of 21st century technology and recovery methods not possible fifty years ago.

This research also builds on the recent experiences of numerous archaeological teams working throughout the high-elevation wilderness areas of the Greater Yellowstone Ecosystem (GYE). Although a limited number of wooden features associated with sheep traps (drivelines, catchpens, structures) as well as conical pole lodges have been known throughout the area since the late nineteenth century, associated artifacts are rare or absent at these sites so that archaeologists were unable to document the daily lives of those participating in the communal sheep hunts. Based on the preservation of the wood and a few preliminary dendrochronology dates, archaeologists assumed that most of these sites were created and used during the early 1800s (Frison et al. 1990). Much of the work during the next fifteen years in the region was conducted as part of Section 106 compliance for cultural inventories such as the fourteen-season project associated with the upgrade to the North Fork highway between Cody and Yellowstone (Eakin et al. 1986). Most of the identified sites are still in the valley. During the last decade however, several archaeologists realized this gap in knowledge and initiated new research projects specifically targeting high-altitude sites (Adams 2010, Morgan et al. 2012, Scheiber 2015, Todd 2015, Todd and Scheiber 2012). Hundreds of new sites have been identified and recorded as a result of this renewed interest. It was not until the Boulder Basin II wildfire in 2003 that the full extent of mountain archaeological
resources started becoming clear, as site visibility rose dramatically in fire-altered contexts.

The objective for the social geography part of this project was to respond to previous work conducted by Peter Nabokov and Larry Loendorf for the National Park Service in the mid-1990s and published in their book Restoring a Presence (Nabokov and Loendorf 2004). They found that many Native groups continue to tell compelling stories about the Yellowstone area. They also wished for better archaeological data, describing an “inadequate archaeological database on which to build ethnographic data” (Nabokov and Loendorf 2004:28). This situation is rapidly changing. Archaeologists and other scholars need to continue to involve Native people in investigations about the past, in responsible participatory research. Other efforts in this regard include the Heart Mountain Pipe Ceremony, sponsored by the Wyoming Humanities Council and the Park County Library, which is now in its fifth year of welcoming Crow people back to northwestern Wyoming to tell stories about their homelands (Keller 2014).

METHODS AND PRELIMINARY RESULTS

The project employed archaeological methods that were best suited to investigate this type of environment, including surveying the surrounding area in a systematic fashion to assess the use of the broader landscape, mapping surrounding sites, conducting test excavations in the shelter to investigate the depth of deposition, and stratigraphic profiling to examine the cave’s use over time. In addition to archaeological investigation, the research team met with descendant community members and stakeholders. The team also used innovative resources to investigate the Painter Cave site, including a three-dimensional laser scanner to digitally capture the cave interior. Widespread packrat activity extended throughout the shelter, with nests (branches, leaves, pine needles, sticks, and bones) and droppings covering the current surface. The packrat middens were not only pervasive throughout the shelter but extended for several meters below the surface as well. Rodent occupation may have predated temporary past human occupations. Several meters of rat urine and excrement were observed in exposed interior walls. In creating these middens, packrats brought hundreds of animal bones to the cave.

Archaeological survey

Several important archaeological sites have previously been recorded in the Painter Cave vicinity, including Bugas Holding, the Sunlight Basin Sheep Trap, and the East Fork of Painter Gulch lodges (48PA305). The first few days were spent systematically surveying for previously unidentified sites and visiting known site locations. Landforms varied from open alluvial terraces along the creek drainages to wooded foothills. The primary method was a standard archaeological survey inventory using pedestrian transects with 10 meter interval spacing. The field crew visited the Sunlight Basin Sheep Trap and the East Fork of Painter Gulch lodge site, to access the integrity of these rare and unique sites (Figure 4).

Figure 4. Sunlight Basin Sheep Trap catchpen.

Because they are constructed of perishable wood material and have been impacted by harsh elements, they likely are no older than two or three hundred years (Scheiber 2015). As part of the field school training, the crew mapped the collapsed lodge structures and used GPS units to locate the sheep trap. Observing both features informed the students’ understanding of high-altitude occupation and subsistence strategies.

A systematic survey was also conducted in the area surrounding Painter Cave, including a crawl survey of the 20 meters surrounding the cave opening with a 50 cm interval spacing. Five new sites and site isolates were recorded, including several lithic scatters and a Late Paleoindian (ca. 8,000 year old) projectile point. In total, the crew surveyed 938,000 square meters, or 232 acres.

Excavation and mapping

East Fork of Painter Gulch Lodge Site:

The East Fork of Painter Gulch lodge site is a campsite with several fallen lodge structures. Often
referred to as war lodges or wickiups, these features are more appropriately called conical pole lodges that were primarily residential structures (White and White 2012). The site was originally recorded over 30 years ago as two lodge structures, one of which was still standing. The standing structure was excavated, revealing a central fire pit and burned bones. The site was re-identified by then Forest Service District Archaeologist Molly Westby and Larry Todd in 2010. They recorded four features, all collapsed and were unable to determine which structure had previously been excavated.

Our team re-visited the site as part of the 2014 project (Figure 5). We re-identified the four collapsed lodge structures, drew scientific illustrations of each, and metal detected the site. Because the site is unburned and located in a forested environment, the mountain duff and pine needles are several cm thick throughout the site, making surface artifact visibility nearly impossible.

![Figure 5](image.png)

**Figure 5.** Collapsed lodge at the East Fork of Painter Gulch site.

Most of the identified metal artifacts were food cans, horseshoes, round nails, beverage pull tabs, a gum wrapper, and unidentified metal, which speak to the site’s historic and modern impacts. The most interesting item was a .53 caliber lead musket ball that was found on the edge of Lodge 2 (Figure 6). It was likely fired from a smooth bore musket and dates to the nineteenth century. This size musket ball was popular in many hunting guns of the early historic era, although they technically could still be used today. The musket ball might be associated with the residential structure, given their similar ages and their proximity to one another.

![Figure 6](image.png)

**Figure 6.** Musket ball at edge of lodge under thick forest duff.

**Painter Cave:**

The interior of Painter Cave is approximately 20 meters in length by 8 meters in width. With an area of 160 square meters of floor space and an unknown depth of at least several meters, the cave deposits had the potential to contain a rich assemblage of material culture dating from recent times to several thousand years ago. An abandoned 1/2” mesh screen with a 1969 date and a shovel in the back of the cave indicate that it was likely looted in a somewhat methodical manner decades ago. Other modern cultural items such as beverage pull tabs and cigarette butts speak to the cave’s ongoing visitor presence. Although no obvious looting pits were present, piles of size-sorted rocks and dirt since overgrown with vegetation near the drip line of the cave likely represent these efforts. Forest Service personnel estimated that looters may have impacted approximately 5-10 cubic meters of the cave floor. The sediments on the floor of the shelter were extremely loose and unstable, and it was difficult to walk from the entrance to the back of the cave without disturbing the unconsolidated soft dry cave sediments.

The initial stages of investigation began by screening the backdirt through a 1/8” mesh dry screen, to try to recover a sample of what may have been removed by the looters. In dozens of buckets of screened backdirt, we recovered a handful of chipped stone flakes and debitage and hundreds of faunal remains. No lithic tools, ceramics, trade goods, or organics were recovered. The looter activity was prolific and presumably robbed the site of many artifacts, especially those that were greater than one-half inch.

Two other areas were also excavated in horizontal levels, with different strategies. Two 50x50 units were excavated from the deepest and most undisturbed part of the cave. Another large unit
approximately 1x2 m revealed the posterior wall of what appeared to be a disturbed ledge possibly left by looters. The small test units recovered no archaeological material while the possible edge of the looter’s pit showed packrat midden stratigraphy and bones with varying degree of modification, both cultural and natural. Chipped stone debitage and one small Late Prehistoric (ca. 300-500 years ago) projectile point were also recovered. All units were dug to sterile levels, which in the case of the larger unit was several meters deep. The stratigraphy of the deep unit informed us more about taphonomic (packrat) disturbances than about improving our understanding of cultural deposits (Figure 7). No obviously cultural perishable materials were recovered, although denning materials from the packrats were present throughout the levels.

![Figure 7. Interior of Painter Cave, showing large excavation unit with stratified packrat midden.](image)

Packrats have likely been present for millennia, and their activities have obviously impacted the site. Packrats urinate on their middens, which crystallizes into a material known as amberat. This process of hardening the midden was obvious in the stratigraphic profile of the large unit, with evidence of layer after layer of packrat midden through time. The middens may be several thousand years old, as they decay slowly from the amberat and the dry shelter environment (Davis 1990). While few artifacts were recovered, we were able to assess the local faunal environment based on the presence of bones both on the surface and sub-surface. The bones were likely the result of packrat occupation, while some were culturally modified.

With the help of staff from the Idaho Virtualization Laboratory of the Idaho State University Museum, we were able to obtain a complete digital image of the inside of Painter Cave. The shelter was scanned with a FARO Focus3D LS120, producing detailed measurements of the cave’s interior and surrounding landscape. Five separate scans produced a three-dimensional video that seamlessly captured the topography and features of the land and cave.

**Social geography**

Social geography includes empirical studies of the role of space, place, and culture in relationship to social issues, politics, daily practices, and identity. Our understanding of the cultural history of Sunlight Basin was informed by Apsaalooké tribal elder Grant Bulltail from the Crow reservation in Montana. Interview questions included stories about Sunlight Basin, the Bighorn Basin, the Cody area, Yellow Crane, and movements by the Crow during the early reservation period.

**ANALYSIS**

Artifact analysis focused on the hundreds of faunal remains that were recovered from Painter Cave, as well as basic analysis of the lithic materials and of the lead musket ball described above. We hoped to include information about the artifacts that were previously removed from the cave but were unable to obtain additional information about their current whereabouts. The faunal material was analyzed following standard zooarchaeological methodology. The total number of identified specimens (NISP) is 1207. This number represents specimens, i.e. number of bones, not individual animals. Taxonomic assessment was determined with the aid of the comparative collection at the William R. Adams Zooarchaeology Laboratory at Indiana University. Taxonomic lists are important to determine which animals lived in the vicinity of the site through time and possibly which animals were procured by past peoples. Bone surface modification was also recorded, including burning, rodent gnawing, and carnivore modification. Burning is a sign of cultural activity, as bones were likely burned during cooking or when discarded in fire hearths. Rodent gnawing suggests the degree to which the packrats impacted the assemblage and possibly which bones were introduced to the site. Carnivore modification also suggests that the bones were impacted after primary deposition, either when animals were killed by humans, killed by other animals, or died naturally. Cutmarks, digestion, and pathologies were also observed on a few bones.

**Fauna identified taxa**

Twenty-three taxa were identified to various levels, including both mammals and birds, and large and small animals (Figure 8). Eleven of these could be
narrowed down to genus/species-level: bighorn sheep (Ovis canadensis) (n=179 identified specimens), deer (Odocoileus spp.) (n=39), rabbits (both Lepus spp. and Sylvilagus spp.) (n=28), pronghorn (Antilocapra americana) (n=4), bison (Bison bison), (n=1), coyote (Canis latrans) (n=1), cow (Bos taurus) (n=1), elk (Cervus canadensis) (n=1), mountain lion (Puma concolor) (n=1), and porcupine (Erethizon dorsatum) (n=1). The vast majority of the bones belong to bighorn sheep, possibly as many as 40% of the assemblage. The minimum number of bighorn sheep recovered from throughout the shelter is six, as determined using right astraguli (ankle bones).

<table>
<thead>
<tr>
<th>Taxa</th>
<th>NISP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bighorn Sheep (Ovis canadensis)</td>
<td>179</td>
</tr>
<tr>
<td>Bison (Bison bison)</td>
<td>1</td>
</tr>
<tr>
<td>Canidae (wolf, dog, coyote, fox)</td>
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</tr>
<tr>
<td>Carnivora</td>
<td>1</td>
</tr>
<tr>
<td>Cow (Bos taurus)</td>
<td>1</td>
</tr>
<tr>
<td>Cricetidae (rats and mice)</td>
<td>61</td>
</tr>
<tr>
<td>Coyote (Canis latrans)</td>
<td>1</td>
</tr>
<tr>
<td>Deer (Odocoileus spp.)</td>
<td>39</td>
</tr>
<tr>
<td>Elk (Cervus canadensis)</td>
<td>1</td>
</tr>
<tr>
<td>Leporidae (Lepus spp. and Sylvilagus spp.)</td>
<td>28</td>
</tr>
<tr>
<td>Mountain lion (Puma concolor)</td>
<td>1</td>
</tr>
<tr>
<td>Porcupine (Erethizon dorsatum)</td>
<td>1</td>
</tr>
<tr>
<td>Pronghorn (Antilocapra americana)</td>
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<tr>
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</tr>
<tr>
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<tr>
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<tr>
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</tr>
<tr>
<td>Small Bird</td>
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<tr>
<td>Medium Bird</td>
<td>6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1207</td>
</tr>
</tbody>
</table>

**Figure 8.** Fauna taxa identified from Painter Cave. NISP = Number of Identified Specimens.

In broader terms, 1043 (86%) bones were identified to the order of Artiodactyla (prey-animals common throughout the region). Almost half of these are medium-sized artiodactyls, including bighorn sheep, deer, and pronghorn. A small number are large-sized artiodactyls, including bison, elk, and cow. All of these animals, except for the bison, are currently present in the area. Relatively smaller numbers of other animal groups are represented, some in higher values than others. Over 60 rodents were identified, from mice and rats to porcupine. Many of these belong to the family Cricetidae. Nearly 30 rabbit specimens were found at the site, both jackrabbits and cottontails. A relatively small number of carnivores were identified, which includes mountain lion, coyote, and possibly a wolf.

Animals that are not represented or poorly represented include birds, fish, reptiles, and amphibians. Mammal species that are not present are small carnivores such as badgers, weasels, otters, skunk, and raccoons, and other small mammals such as squirrels and pocket gophers. Bears, bobcats, moose, and beaver were also not recognized in the assemblage.

**Fauna modification**

A selected sample of the total faunal assemblage (n=538) was examined for bone surface modification. Not surprisingly, 301 (56%) of the study set were impacted by rodent gnawing, both light and heavy, sometimes obliterating identification landmarks on the bones. Rodents such as packrats constantly gnaw on objects such as bone or wood in order to keep their incisors from growing too long and piercing their skulls. Packrats carry these items for several dozen meters to create their nests or middens. Some of the bones that were gnawed by the packrats could have been food remains left in the cave by human occupants.

Thirty-eight bones (7%) were gnawed by carnivores, such as coyotes or wolves, which are also known to chew, break, and digest animal bones. This number is relatively low and may suggest that these species did not have direct access to many of the dead animals, either due to human deposition or rodent taphonomy. One calcaneus or heel bone of a jackrabbit showed signs of digestion through acid etching, likely when eaten by a carnivore. Two bones displayed evidence of pathologies (Figure 9). A coyote tibia was broken and re-healed during life, and a bighorn sheep metatarsal had an abscess that infected the bone with evidence of remodeling.
Some of the faunal remains showed signs of possible cultural modification. Ninety-four (17%) of the bones were burned, with various levels of severity. Burning is not always caused by human cooking and discard activities, but often is, especially since there is no evidence of forest fires in the area around the cave. The presence of burned bone indicates primary deposition of people living in or near the cave. Almost all of the burned bones are medium artiodactyls such as bighorn sheep. In addition to burning, several bones (n=10) showed signs of cutmarks, created during past butchery activities. Although this number is not high, the rodent gnawing could have obfuscated the cutmarks.

**Lithics**

All of the units in the front part of the shelter as well as from the surface contained chipped stone lithic materials. The small units in the back and middle of the shelter did not. A total of 208 flakes and angular debris and one projectile point were recovered. The majority of these were made of a clear translucent chert. The lithics were found distributed throughout the levels from the surface to several meters below the surface but without specific changes in stratigraphy. Most of the flakes (84%) measured under 2 cm, which is consistent with the half-inch screen size found in the back of the cave (0.5 inch = 1.27 cm). The flakes found in the deeper larger units may not have previously been disturbed, but the stratigraphy did not support an argument for tracing temporal change in that part of the shelter. No other tools or artifact types were found.

One small nearly complete projectile point was recovered from the large deep unit along the possible edge of the looter area. It is a clear chert trinotched arrow point, measuring approximately 1x1 cm. It might have passed through the half-inch screen used by the original looters. This type and size of arrow point is common in the late precontact (Late Prehistoric) period and dates to between about A.D. 1500 and A.D. 1800. They are often called desert trinotched points and have been found at several Mountain Shoshone sites in the region (Scheiber and Finley 2010).

**CONCLUSIONS**

This project lead to a number of conclusions about Sunlight Basin, past and present. First, this resource-rich basin has been inhabited by past peoples for thousands of years, and many archaeological sites have not yet been identified or recorded. The 2014 Bighorn Archaeology crew located several new sites and site isolates, ranging from 8,000 years old to several hundred years old. These materials contribute to the broader understanding of past Native American life ways in the Greater Yellowstone Ecosystem (GYE). Second, fragile and perishable wood features in the form of sheep traps and conical pole lodges are still present in the area but are disappearing and are threatened by forest fires. They should be monitored on a regular basis. The lead musket ball found in one of the collapsed lodges during metal detecting of the East Fork of Painter Gulch lodge site provides additional details about these sites. Third, this research contributes to more robust and interdisciplinary scientific endeavors. Incorporating Native informants and perspectives in archaeological research is a critical part of “Restoring the Presence” of Native peoples in the Greater Yellowstone Area. Fourth, closed sites like Painter Cave have the potential to add important details about long-term environmental histories, chronology, technology, and subsistence in the past. They can provide master cultural sequences that can tie together single-component sites. Unfortunately, most of the cultural materials, and certainly diagnostic time-sensitive ones, were systematically removed by looters. The shelter is deeply stratified with packrat middens, but not necessarily with cultural materials. Fifth, over 1200 faunal materials left behind at the cave represent both cultural cooking activities and natural packrat accumulations. The multiple taxa that are present and the ones that are absent tell interesting stories about the diversity of animal species in the area through time.

This project should serve as a cautionary tale for the importance of protecting archaeological sites and educating the public on the importance of archaeological resources. The information this site could have provided will never be known. Moving forward we hope to continue our commitment to public outreach and working with communities regionally and beyond.
ACKNOWLEDGEMENTS

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THE UPPER SNAKE RIVER HEADWATERS: PHOTO, VIDEO AND AUDIO DOCUMENTATION

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BACKGROUND

On March 30, 2009, passage of the Craig Thomas Snake Headwaters Legacy Act added the Snake River Headwaters to the National Wild and Scenic Rivers System. The Snake River Headwaters is unique in that it encompasses a connected watershed, rather than just one river or isolated rivers across a region. It includes 14 rivers and 25 separate river segments totaling 414 river miles (Figure 1).

UPPER SNAKE RIVER WATERSHED EXPLORATION

In early August 2014, I spent 10 days attempting to visit all 14 rivers and creeks in the recently protected Upper Snake River Watershed. My father, John Sherwin, joined me as an assistant on the expedition. My goal was to make photographs of each river/creek, while also documenting the journey and the surroundings. I also made video and audio recordings of each of the waterways. I will be sharing my observations in an immersive installation as part of a three-person exhibition titled, The Upper Snake River, Three Photographic Approaches to the Snake River Watershed, at The Art Museum of Eastern Idaho, May 21-August 15, 2015.

The first leg of the trip, August 3-9, was spent in the central and southern sections of the watershed using Jackson, WY as our home base. During this portion of the expedition we visited the Snake River, Gros Ventre River, Crystal Creek, Hoback River, Granite Creek, Bailey Creek, Wolf Creek and Willow Creek. We also attempted to find Shoal Creek, but were deterred by heavy thunderstorms and miles of difficult bushwhacking. We accessed each of the waterways at multiple locations and acquired a total of 20 gigabytes worth of data. During this initial phase, I also visited The Art Museum of Eastern Idaho in Idaho Falls, ID and met with the director of the museum and the other two artists participating in the exhibition to discuss the details of the gallery and installation plans.

The second leg of the trip, August 10-13, was spent in the northern portion of the watershed using the University of Wyoming National Park Research Station, or AMK ranch, as our home base. During this portion of the expedition we visited Pacific Creek,
Blackrock Creek, the Buffalo Forks, Lewis River and the Snake River. Once again, each waterway was accessed in multiple locations and I gathered an additional 20 gigabytes of data for the project. My good friend, George Leys, who has been a resident of the valley for close to 50 years, led our Buffalo Forks trek. We covered 12 miles, or more, with heavy gear bags in order to visit the confluence of the North and South Buffalo Forks.

The UW NPS Research Station, ideally located in the northern portion of the Upper Snake River Watershed along the banks of Jackson Lake in Grand Teton National Park, was the perfect home base for this second segment of the project. It enabled us to spend more time in the field, rather than on the road. I also did quite a bit of photographing and recording, both video and audio, right on the grounds of the Research Station. With the exception of an occasional airplane, the sounds collected around the Research Station, including approaching thunderstorms, rain, wind, squirrel banter, etc., were some of the cleanest recordings made throughout our journey. The library at the Research Station was also an inspiring resource. I collected numerous new titles to read and browsed a few of the many excellent guidebooks. I also enjoyed meeting the other residents conducting research at the Station and sharing our respective projects. Although my project was more artistic than scientific, I felt tremendous support from the other researchers and staff of the Station. It is truly an inspiring location for anyone looking for a quiet retreat to focus and renew.

In total, our travels took us throughout the Bridger Teton National Forest, Grand Teton National Park, Yellowstone National Park and Teton, Sublette, Lincoln and Park counties, an estimated 800 miles of driving (many of which were dirt, or gravel). We also hiked roughly 30 miles, most of which consisted of unmarked trails, overgrown access roads, or game trails. In addition to the usual critters, we spotted numerous elk, pronghorn, and black-tailed deer, a beaver, moose, sandhill cranes and evidence of a large grizzly bear along the Buffalo Fork.

**ART MUSEUM OF EASTERN IDAHO
UPPER SNAKE RIVER EXHIBIT**

I am currently editing the imagery and recordings and working on several pieces for the *Upper Snake River* exhibit at The Art Museum of Eastern Idaho. My portion of the show will consist of a large circular video projection of moving water captured at each of the waterways. The video will be projected on the ground and a corresponding audio component will surround the viewer. There will also be two large still image pieces hung on the walls. One piece consists of a photographic typology of rocks collected over the 10 days, while the other is a large “map” created from video stills placed in the relative geographical location they were captured. Several additional monitors will be scattered throughout the gallery showing various wind study footage and time-lapse sequences. Finally, a photo book titled, “Journey Water” that compiles my photographs in a loose visual narrative chronicling our adventures, will also be on display.
THE TETON ARCHAEOLOGICAL PROJECT:
REPORT FROM THE 2014 INAUGURAL FIELD SEASON

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ABSTRACT

In August and September, 2014, two eight-day archaeological surveys were conducted by the Jackson Hole Historical Society and Museum in Caribou-Targhee National Forest and Grand Teton National Park. This project, the inaugural season of the Teton Archaeological Project, investigated high-altitude passes, basins, and ice patches for prehistoric archaeological sites. In total, during the 2014 season 28 archaeological sites were recorded ranging from Paleoindian (9,000 BP) to Late-Prehistoric (1,000 BP) in age. The results of this field season investigation provide an enlightened understanding of prehistoric life in the high Tetons and will offer a solid foundation for future archaeological surveys and research questions.

INTRODUCTION

In the summer of 2014 the Teton Archaeological Project was launched with the goals of continuing archaeological research, interpretation, and education in the Teton Mountains. With the aid of five students from the University of Wyoming and University of Montana, the project team conducted two 8-day surveys of high elevation passes, basins, and ice-patches along the Teton Crest in Caribou-Targhee National Forest and Grand Teton National Park. In total, the team recorded 28 new prehistoric archaeological sites and reevaluated 5 sites previously recorded in the 1970’s. The results of this first season identified a dense and consistent occupation of the Tetons since the Paleoindian era (c. 9,500 − 10,000 BP) and provided new and parallel evidence of paleoeconomics and residential patterns in the high Tetons.

The Tetons

The Teton Range is located in northwest Wyoming and extends approximately 50 miles north to south along the Jackson Hole, Wyoming and Teton Valley, Idaho border. The alpine ecotone of the range is almost entirely located in wilderness areas with Caribou-Targhee National Forest/Jedediah Smith Wilderness on the Western slope and Grand Teton National Park on the Eastern slope. In 1942 photographer Ansel Adams forever epitomized the Tetons as inhospitable and extreme with his iconic photograph depicting towering spires and hanging glaciers. While the central Tetons do offer technically demanding peaks up to 13,770 feet in elevation, the majority of the range is composed of comparatively gentle alpine basins, meadows, and passes that reach an average elevation of 10,000 – 11,000 feet. There is, however, a distinct variability in terrain and accessibility between the eastern and western slopes.

The Wyoming side of the Tetons extending west from the base of Jackson Hole to the Teton Crest ascends rather abruptly from the valley floor at an average slope of 32 degrees. This steep rise is truncated approximately every 3.5 miles by glacially carved canyons that offer easier access to the divide. The Idaho side of the Tetons provides a less demanding approach with a series of gently sloping finger ridges that extend into Teton Valley and portions of the Snake River Plain. These ridges, along with a series of canyons, ascend towards the divide but stop short in large alpine basins that are mostly unique to the western slope. Unlike the steep canyons of the eastern slope, the basins in the western Tetons offer more suitable locations for extended living and rich subsistence opportunities.
For describing the terrain encountered during this inaugural survey, the geologic zones of the Teton Range were categorized into two generalized groups: sedimentary and granitic. The sedimentary category includes (but is not limited to) Paleozoic Madison Limestone and Bighorn Dolomite and is found primarily in the northern and southern portions of the Teton. The granitic category is composed of Precambrian Granite, Gneiss, and Monzonites and occurs primarily in the central to north-central portions of the Teton (Love, Reed, and Pierce 2000). In some circumstances Precambrian layers are topped with Flathead Sandstone — it is at this contact that steatite (a.k.a. soapstone), an important resource for prehistoric peoples, occurs and was routinely quarried for late-prehistoric bowl, pipe, and bead production (Adams 2003, 2004, 2006, 2010). Other prominent lithic resources in the Teton include several obsidian sources, ignimbrite, high quality chert, and occasional sources of Flathead sandstone and quartzites.

Previous research in the Tetons

Research focusing on the prehistoric utilization of the high Teton Range has occurred sporadically over the past 40 years. Due to the format of this research report we will not go into much detail regarding past work in the Teton, although this work played a crucial role in conceptualizing alpine archaeology on a global scale. In the 1970s, several high-altitude surveys and some excavations were conducted in the northwest Teton by Love (1972), Wright (1977, 1978, 1984, Wright, Bender, and Reeve 1980), Bender (1978), and Marceau (1978) to determine a basic chronology of alpine occupation and to develop a broad-spectrum subsistence model for the range (Bender and Wright 1988, Wright 1980, Cannon, Brindelson, and Cannon 2004, Connor 1989). This initial work was the first in the Teton and Wyoming to suggest that entire families resided seasonally in the alpine zone and that extreme vertical topography was not a hindrance to prehistoric mobility (Bender and Wright 1988, Wright 1984). This work, in particular Bender (1981), was also instrumental in identifying a dense plant-based resource pool in alpine basins that were previously thought to be low in subsistence opportunities.

After the work of Bender and Wright, only a few projects in Teton County have focused on high-altitude occupations. Some Section 106 compliance surveys were carried out by Connor (1991a, 1991b) and Reher (2000) which focused on the impact of alpine archaeological sites by modern hiking trails and campsites. Additionally, several of Bender and Wright’s sites have occasionally been monitored and revisited by Midwest Archaeological Center, Grand Teton National Park, and Caribou-Targhee National Forest archaeologists. In recent years, only a few question-oriented projects have been conducted in the high Teton which include studies on prehistoric steatite usage (Adams 2003, 2004) and site patterning on the Eastern slope of the range (M. Peterson, personal communication). As with the early work, the more recent projects have similarly concentrated on the northern portions of the range.

Altogether, the previous alpine archaeological research conducted in the Teton Range has demonstrated that family groups frequented the alpine ecotone for at least 10,000 years and utilized a wide range of lithic and subsistence resources. This research offers a detailed framework for understanding Teton prehistory and solid foundation for future research. However, given that only a small sample (approximately less than 30%) of the range has currently been surveyed, our knowledge and interpretations of past Teton usage remains in its infancy.

Teton Archaeological Project 2014 Season

In the summer of 2014, project directors from the Jackson Hole Historical Society and Museum along with five student volunteers from the University of Wyoming and University of Montana conducted two high-elevation surveys in the Teton Range. Unlike traditional archaeological projects, the remote nature of this wilderness survey necessitated small amounts of equipment and technology that are suitable for camping (see Adams et al. 2014, Morgan 2014, Stirn 2014a). With the aid of horses and professional outfitters the team was able to travel efficiently and investigate a variety of alpine basins, passes, and ice-patches in the southern and central Teton. In total the team covered 1,923 acres, recorded 28 new archaeological sites, reevaluated five previously recorded sites, and investigated 7 ice-patches for organic material culture. The results of this project will be presented chronologically by time period.

Survey Results and Interpretations

Paleoindian Period

During the 2014 survey, the team recorded two Paleoindian sites, 48TE1926 and 48TE1934.
TE1926 is a multicomponent site (see Late Prehistoric section) located just above tree line amongst alpine tundra, ample Whitebark Pine, and a series of alpine lakes. At this site the team collected the base of a James Allen type projectile point (c. 8,000 BP: Drager and Ireland 1986:587) and the midsection of a non-diagnostic obsidian point with ground margins and parallel oblique flake patterning. Site TE1934 is located on the southern slope of an exposed peak near 10,000 feet and here the team collected a single Alberta style Cody Complex projectile point (c. 9,000 BP: Drager and Ireland 1986:586; Figure 1).

Figure 1. Paleoindian Alberta Projectile Point From TE1934.

The three Paleoindian era projectile points recorded this season do not lend themselves to detailed interpretation. The Alberta point is among the earliest artifacts found in the high Teton but is not particularly surprising given the abundance of Cody complex sites in Jackson Hole, Wyoming (Connor 1988, Page and Peterson 2015) and Teton Valley, Idaho (Sgouros and Stirn 2015). According to Whitlock (1993:191) the period between 10,500 – 9,000 BP in the Teton region is characterized by the onset of warm-dry conditions and the generalized establishment of sub-alpine forests. It is likely that during this time, due to reduced snowpack, the Teton Range became more accessible and could have offered several routes between Wyoming and Idaho with a higher abundance of alpine plant and animal resources than was found in the Late Pleistocene. At this point in our research, however, not enough data on the Paleoindian use of the Teton has been acquired to move beyond basic speculation.

Archaic Period

In total, three Archaic era sites were recorded with projectile points dating from the Early Archaic (c. 7,500 – 5,000) and Late Archaic Periods (c. 3,000 – 1,400 BP). Site TE1928 contained one white chert Early Archaic Elko Corner Notch projectile point (Drager and Ireland 1986:591) located near 9,000 feet in a large, marshy alpine meadow on the Western slope of the Tetons. Site TE 1937 contained several pieces of groundstone, end scrapers, a quartzite Northern Side Notched style and quartzite Elko Corner Notch projectile point (Drager and Ireland 1986:587,591) located on a pass near 10,000 feet. Site TE1923 is located next to a large sub-alpine lake and contained several hundred non-diagnostic artifacts, two biface fragments, one obsidian Late-Archaic Pelican Lake style point (Drager and Ireland 1986:589) and Late-Prehistoric period artifacts (see below).

Bender (1983) and Wright (1984) recollect that the majority of sites they recorded in the northern Tetons were from the Archaic period. While the results of the 2014 Teton Archaeological Project do not display a higher number of Archaic sites, the preliminary data does suggest a broader utilization of the mountains during this time. Whereas every Paleoindian site recorded in the Teton high country thus far is characterized by isolated projectile points, many Archaic sites display superficial evidence of a longer-term occupation and wider activity range through the occurrence of fire-heaths, a variety of formal tools, groundstone, and denser lithic scatters (see also Bender and Wright 1988, c.f. K. Cannon, Bringelson, and Cannon 2004). In the nearby Wind River Range, the occurrence of groundstone at Archaic and Late-Prehistoric sites have been associated with the processing of Whitebark Pine nuts and as evidence of longer-term seasonal occupations (Adams 2010, Stirn 2011, 2014b). Whitlock (1993) notes that the period in the Tetons between 9,000 – 5,000 BP was characterized by drier conditions and a rise in the elevation of tree line (corroborated by our icepatch study results, see below). Given these climatic trends it is not surprising that the mountains experienced a more sustained utilization by humans during the Archaic period. The economic intensity and activities related to the Archaic period, however, remain uncertain and will require question-based testing and additional research.

Late Prehistoric Period

During the 2014 season the TAP team recorded eight new Late-Prehistoric sites (c. 1,400 – 250 BP) and re-evaluated one that was recorded previously by Marceau (1978). Of the newly recorded sites, TE1927 is located near an alpine lake at 9,000 feet and consists of a dense lithic scatter and single obsidian Late-Prehistoric side-notched projectile point. TE1923 (see previous section for environmental description) contains primarily Archaic artifacts with the exception of one Late-Prehistoric era soapstone
bowl preform (Figure 2). Sites TE1935 and TE1940 are located on an exposed alpine shelf at near 9,200 feet and consist of dense obsidian lithic scatters with one late-prehistoric side notched projectile point at each site.

Site TE1925 is located in an alpine basin just above treeline. This site covers over 500 square meters and consists of a dense lithic scatter of obsidian, chert, Wiggins Fork petrified wood, basalt, and quartzite. Several formal artifacts were recorded at this site including a late-prehistoric obsidian projectile point and pieces of at least three broken soapstone vessels. Additionally, two possible residential structures (a.k.a. lodge pads -- Adams 2010, Stirn 2014b) were recorded at the site.

Site TE1926 is located 1 km South of TE1925 and is located just above treeline near several springs and streams. This site provides evidence of several occupations including Paleoindian (see above section) and Late-Prehistoric. This large site covers approximately 6,000 square meters and consists of a dense lithic scatter of obsidian, chert, Wiggins Fork petrified wood, ignimbrite, basalt, and quartzite. Several formal obsidian tools were recorded including two bifaces and a Cottonwood Triangular projectile point. Additionally, the team recorded several pieces of soapstone debitage, one soapstone bowl fragment, and a complete soapstone vessel that was cached between two large granite boulders (See Figure 3). One possible residential structure was also recorded.

Site TE1942 is located in the central Tetons in a sub-alpine pine forest above 9,000 feet and covers 3.2 square kilometers along a mountain stream. This site consists of an extremely dense lithic scatter of various materials including obsidian, ignimbrite, quartz crystal, petrified wood, chert, quartzite, and basalt. The team recorded several formal tools including quartzite end-scrapers, quartzite and chert bifaces, basalt and granite groundstone, and two obsidian late-prehistoric side notched projectile points. The team also recorded two abraded soapstone pebbles and one nodule of red ochre.

Site TE1943 is located just upstream from TE1942 and consists of a small soapstone workshop located above 9,000 feet in a small alpine cirque. The team recorded fragments of four separate soapstone vessels including one with a repair hole (see Adams 2006, 2010), and, a preform of an unfinished soapstone vessel.

In addition to recording new Late-Prehistoric sites, the TAP team reevaluated TE 557 and TE 654 which had previously been recorded by Marceau (1978). Upon examination it was determined that both sites are not unique and are instead part of one large archaeological site located on an alpine shelf near 10,000 feet. Here, the team recorded a dense lithic scatter of obsidian, chert, quartzite, and basalt, and, an obsidian Archaic Pinto Basin style and obsidian Late Prehistoric side-notched projectile point. The team also recorded four pieces of burned non-diagnostic long bone and a ceramic scatter consisting of 18 pieces (representing at least three separate vessels) of Intermountain Style pottery (Finley and Boyle 2014, Mulloy 1958). This marks the first known example of pottery in the high Tetons (Figure 4).
The Late Prehistoric period at high-elevations in the Rocky Mountains and Great Basin is typified by the occurrence of residential structures and alpine villages (Adams 2010, Bettinger 1991, Morgan, Losey, and Adams 2012, Stirn 2014b, Thomas 2013). These features have been interpreted as evidence toward an intensification of mountain resources (Morgan, Losey, and Adams 2012) and in the Wind River Range display a site patterning likely related to the optimal procurement of Whitebark Pine nuts (Stirn 2014b). At several alpine villages the co-occurrence of residential architecture, Intermountain style pottery and soapstone artifacts have been interpreted as culturally affiliated to the Mountain Shoshone (Adams 2010, Stirn 2015b, c.f. Larson and Kornfeld 1994). Because only two possible village sites were recorded in the Teton, there is not enough data to approach questions related to site patterning or cultural affiliation. The discovery of several new Late Prehistoric sites, possible residential structures, soapstone workshops, and pottery does, however, provide a fresh perspective of Teton occupation between 2,000 BP and modern day. While the Teton have long been considered important to Late Prehistoric cultures for soapstone acquisition (Adams 2003, 2004, Marceau 1978), the extent of occupation and resource acquisition during this period has remained unclear. Because of the lack of Late-Prehistoric sites he identified, Wright (1984), for example, suggested that Jackson Hole and the Teton Range experienced a hiatus in utilization during this time. The discoveries made during the 2014 season offer a more detailed glimpse into the Late Prehistoric period and suggest that in a similar fashion to the nearby Absaroka and Wind River Ranges, the Teton were used intensively throughout the past 2,000 years. To more fully understand the economies underlying late prehistoric sites in the Teton, it will be necessary to conduct further question-based research such as site location modeling (see Stirn 2014b) and dietary analysis from lipid residue and archaeobotanical analyses.

**ICE PATCH SURVEYS AND RESULTS**

Throughout the past decade warming temperatures in the Rocky Mountains have led to the discovery of several preserved-organic artifacts (e.g. Andrews, Mackay, and Andrew 2012, Lee 2012, Lee et al. 2014, Reckin 2013) and paleobiological specimens (e.g. Benedict et al. 2008) thawing from permanent snow and ice patches. Whereas the majority of the prehistoric archaeological record in North America is represented by lithic artifacts, the rare occurrence of organic (wood, cloth, twine, etc.) provides a unique glimpse into obscure aspects of ancient life. Additionally, non-archaeological specimens (e.g. wood, trees, plants) offer valuable information regarding past environmental and ecological changes such as temperature, precipitation, and species development. Given the increase in seasonal temperatures worldwide during the past several decades, ice patches are melting at an unprecedented rate (Lee 2012, Lee et al. 2014). When organic artifacts or paleobiological specimens are exposed, they quickly begin to decompose due to increased oxidation and desiccation. As organic material is being exposed at an increasing rate, it is important that ice patches and permanent snowfields are continuously investigated for archaeological and paleobiological remains.

Following several years of productive research in Yellowstone and Glacier National Parks, Lee (2014) developed a predictive model for the Greater Yellowstone Ecosystem of ice-patches that are quickly thawing and are likely to contain cultural and/or paleobiological material. This model targeted areas that receive little solar radiation and are situated in areas likely to have been frequented by past humans (Lee et al. 2014). While this model has previously been tested and proven successful in the Absaroka and Wind River Ranges (R. Kelly - Personal Communication), its applicability for the Teton has remained unexplored. During the 2014 season, the TAP team investigated five ice patches and snowfields identified by Lee’s model, two of which contained organic specimens. Ice patch PL4 is located at 10,000 feet near an alpine pass and contained one non-diagnostic large mammal long bone. This specimen was photographed and recorded but was not collected for species identification or radiocarbon dating. Ice patch PL1 is located at 10,200 feet in Caribou-Targhee National Forest on an exposed alpine slope. Two pieces of wood were collected from the field of PL1 and were AMS dated to 6040+/−127 BP (D-AMS 008937) and 2749+/−25 BP (D-AMS 008938) (Figure 5). The Early Archaic specimen is non-cultural and is likely the bark of a high-altitude pine. The Late Archaic specimen appears to be modified (cut) but is not an obvious tool or artifact. Both specimens are currently being submitted for species identification or radiocarbon dating. Ice patch PL1 is located at 10,200 feet in Caribou-Targhee National Forest on an exposed alpine slope. Two pieces of wood were collected from the field of PL1 and were AMS dated to 6040+/−127 BP (D-AMS 008937) and 2749+/−25 BP (D-AMS 008938) (Figure 5). The Early Archaic specimen is non-cultural and is likely the bark of a high-altitude pine. The Late Archaic specimen appears to be modified (cut) but is not an obvious tool or artifact. Both specimens are currently being submitted for species identification or radiocarbon dating. Ice patch PL1 is located at 10,200 feet in Caribou-Targhee National Forest on an exposed alpine slope. Two pieces of wood were collected from the field of PL1 and were AMS dated to 6040+/−127 BP (D-AMS 008937) and 2749+/−25 BP (D-AMS 008938) (Figure 5). The Early Archaic specimen is non-cultural and is likely the bark of a high-altitude pine. The Late Archaic specimen appears to be modified (cut) but is not an obvious tool or artifact. Both specimens are currently being submitted for species identification or radiocarbon dating.

The results of this study are significant as they show that ice patches have remained preserved in the Teton for at least 6,000 years and, that Lee’s (2014) predictive model is successful in the Teton Range. The occurrence of pine (Pinus sp.) at 10,300
feet (above modern tree line) during the Early Archaic period coincides with Whitlock’s (1993; c.f. Mensing et al. 2012) palynological data which suggests that tree line rose substantially during this period. This data helps to place Archaic era sites in the high Tetons within a more accurate ecological context. As more organic cultural and paleobiological specimens are discovered in future seasons, the Tetons could become an important contributor to regional ice patch archaeological studies.

Figure 5. Icepatch PL_1 and Recovered Wood Specimens

Lipid residue analyses

A high resolution of data regarding diet and paleoeconomies in the Tetons is important to our interpretations and understanding regarding past life at high elevations. While there currently exist numerous hypothesis based upon theoretical patterns (e.g. Losey 2013, Morgan, Losey, and Adams 2012) and spatial modeling (e.g. Benedict 1992, Stirn 2014b), most interpretations of prehistoric alpine economies are preliminary and require additional scientific evidence. Lipid residues (fatty acid chains) offer an excellent marker for reconstructing past diets as they are species specific, can be analyzed as compounds, and often survive better than other biomolecules such as proteins or starches (see Regert et al. 2003). Moreover, recent developments in lipid residue analyses are non-destructive and can be accomplished through a solution bath and ultrasonic vibrations (M. Malainey — Personal Communication).

During the 2014 season, the TAP team collected eleven samples from Caribou Targhee National Forest consisting of groundstone, quartzite projectile points, and soapstone to be submitted for non-destructive lipid analysis at Brandon University. The goals of this study are to determine the survivability of absorbed lipid residues within surface artifacts and to test their effectiveness in identifying prehistoric food sources to the species level. The results from this testing remain incomplete and will be presented in a future publication. If successful it is believed that absorbed lipid residues will provide a detailed dietary record for the prehistoric occupants of the Teton Range.

✦ CONCLUSIONS

During the 2014 field season the Teton Archaeological Project recorded 28 archaeological sites along the Teton Crest in Caribou-Targhee National Forest and Grand Teton National Park. The data acquired from these preliminary surveys provide congruent evidence towards previous research in the Teton Mountains and suggest that the alpine zone in this region was utilized extensively and consistently from at least 9,000 BP. The identification of several new Late Prehistoric sites, soapstone workshops, and Intermountain-style ceramics offer new information regarding recent occupations of the Tetons and suggest that they were utilized to a similar extent as other mountain ranges in Northwestern Wyoming. The recovery of two pieces of Archaic era wood from a high-elevation ice patch demonstrate that snow fields and ice patches in the Tetons have remained intact for at least 6,000 years. The data acquired from these specimens also support existing paleoenvironmental models of the Tetons suggesting that tree line rose substantially during the Archaic period and few sites at this time would have been located in the true alpine zone. In total the archaeological and paleobiological information acquired during the 2014 season offers a fresh glimpse into the Tetons’ past and provide a foundation for future work. The TAP team looks forward to continuing work in the summer of 2015 with expanded objectives and hopes to further unravel the story of the Tetons.

✦ ACKNOWLEDGEMENTS

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RESEARCH PROJECT REPORTS

HUMAN DIMENSIONS OF RESOURCE MANAGEMENT
ASSESSING THE POTENTIAL OF THE RIVER OTTER TO PROMOTE AQUATIC CONSERVATION IN THE GREATER YELLOWSTONE ECOSYSTEM: A UNIQUE APPROACH FOR DEVELOPING A LONG-TERM AQUATIC FLAGSHIP

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ABSTRACT

Charismatic “flagship” species are used in many parts of the world to raise public awareness or financial support for conservation, both among local people living in the area and among potential donors living far away. Flagship species can serve as symbols to stimulate conservation awareness and action and have been particularly valuable because of their potential to change citizen behavior, including involvement in conservation and support of fundraising. For a flagship to be successful, however, the target audience and conservation objectives must be established and understood before implementing the concept. Researchers have suggested that a successful flagship should possess traits that endear it to the public, should not be feared or disliked, nor have been used to convey conflicting messages of conservation. Therefore, critical to the flagship approach is understanding attitudes, species preferences, level of wildlife knowledge of people living near and living far away for which support is sought. To determine if the river otter (Lontra canadensis) could be a successful flagship for the Greater Yellowstone Ecosystem (GYE), we conducted social science surveys with visitors to Grand Teton National Park who participated in guided-raft trips on the Snake River (n = 768), visitors of Oxbow Bend (n = 254), a popular turn-out for viewing aquatic wildlife, and visitors to Trout Lake in Yellowstone National Park (n = 298). Preliminary results showed that familiarity with the river otters is area dependent (e.g., Trout Lake visitors were more familiar with the species than those visiting Oxbow Bend or rafting the Snake River), river otters are not controversial, but education is needed to better inform the public about river otters’ occurrence and ecosystem function in GYE.

INTRODUCTION

Although a variety of approaches have been used in attempts to engender public support for conservation such as education, social marketing, and economic incentives, the need to actively engage stakeholders is still a fundamental problem in ecosystem preservation and new innovative methods are needed to achieve this goal. One technique that has been demonstrated to positively influence conservation intentions is the use of a flagship species (Smith and Sutton 2008, Skibins et al. 2013). The concept, definition and role of flagship species has been debated since its first inception in academic literature during the 1980’s (Myers 1983, Mittermeier 1986, Western 1987) and, currently, “flagships” are defined as “popular, charismatic species” that serve to attract attention to large-scale conservation issues (Heywood 1995) and “…have the ability to capture the imagination of the public and induce people to support conservation actions and/or to donate funds” (Walpole and Leader-Williams 2002).

Unlike other conservation surrogates, such as umbrella, indicator, or keystone species, which are selected for their ecological role, flagships are selected based on their ability to serve a socio-economic role,
by attracting attention and financial support to conservation goals (Leader-Williams and Dublin 2000, Walpole and Leader-Williams 2002). This distinction between flagship species and other conservation surrogates is critical to alleviating misconceptions over the term. Further, recent research by Verissimo et al. (2011) expands the definition of a flagship species to include a marketing aspect, and describes a flagship as “a species used as the focus of a broader conservation marketing campaign based on its possession of one or more traits that appeal to the target audience.” Often, flagships are charismatic megafauna, large vertebrates such as bears, big cats, whales and elephants, but research has also demonstrated that lesser-known, smaller species, such as chameleons (Calumma tarzan) (Gehring et al. 2010) and the axolotl (Ambystoma maxicanum) (Bride et al. 2008) can also serve as successful flagships.

The potential to increase participation in support and fundraising (Leader-Williams and Dublin 2002) as well as affect citizen pro-conservation intentions (Smith and Sutton 2008) and behavior (Skibins et al. 2012) makes the flagship approach valuable to conservation. Further, flagships can serve a multitude of roles such as increasing conservation awareness, fundraising, promoting ecotourism, protection of species/habitat, and influencing policy (Barua et al. 2010). The flagship approach is especially important given the current rate of biodiversity loss (SCBD [Secretariat of the Convention on Biological Diversity] 2008), and what researchers indicate as the wide-scale reliance on charismatic megafauna (Kontoleon and Swanson 2003) (e.g., In the United States ≥50% of wildlife funding is used for conservation of ≤2% of those species listed as endangered [Metrick and Weitzman 1996]). Specifically, the most well-known conservation flagships of the United States, including the Florida panther (Felis concolor coryi), California condor (Gymnogyps californianus) and the northern spotted owl (Strix occidentalis caurina), are in the top 10 species by total spending on endangered species (metric and Weitzman 1996).

Research has indicated a variety of characteristics and criteria that make a flagship successful depending on the organization’s intended conservation outcome (e.g., local vs. global conservation awareness, fundraising, influencing policy). Generally, a species should be well-liked, recognizable, viewable, and associated with a particular habitat (Bowen-Jones and Entwistle 2002). Other factors that have been hypothesized as important in selecting a flagship species include body size (Ward et al. 1998), conservation status (Gunnthorsdottir 2001), and biological group (e.g., part of an ecological guild; Krüger 2005) (see Barua et al. 2010 for overview of specific criteria depending on context and purpose). Selecting the most effective flagship for a conservation campaign involves understanding the target audience and certain contexts (e.g., social, cultural, political, economic), that affect their knowledge and attitudes and shape their interactions with the species (Kellert 1985, Hills 1993, Schlegel and Rupf 2010). Assessing attitudes, perceptions and preferences in regard to wildlife can be elucidated via a variety of tools such as workshops, focus groups, surveys and interviews (Jacobson 1999) and understanding the target audience’s perception of and attitudes towards a species is critical when assessing the species’ potential as a flagship for a particular region (Stevens 2011).

The objective of this study is to assess the potential of the river otter (Lontra canadensis) to serve as an aquatic flagship species for the Greater Yellowstone Ecosystem (GYE). The river otter, a semi-aquatic mammal has a variety of characteristics that endear them to the general public, such as being described as playful (e.g., Park 1971) and charismatic. The obligate use of aquatic habitats by river otters (Kruuk 2006) may lead to the species being associated with locally important habitats, a component of a successful flagship species.

Two different surveys were conducted during summer 2014 at 3 locations within Grand Teton (GRTE) and Yellowstone National Parks (YELL). The first survey (hereafter referred to as the “Guided-raft Trip Wildlife Viewing Survey”) was designed specifically to investigate the opinions and preferences regarding GRTE and its wildlife among participants on guided Snake River trips in GRTE. Place-based surveys were conducted among these participants to assess aquatic recreation frequency in GRTE, priority of participating in specific activities on the river trip, knowledge, and motivations on several potential flagship species, including the river otter.

The second survey (hereafter referred to as the “River Otter Viewing Survey”) was conducted at Oxbow Bend in GRTE and Trout Lake in YELL. These locations are popular wildlife viewing areas, specifically for the otter because of the aquatic components of each site (i.e., Oxbow Bend is a large bend in the Snake River, an ideal area for river otters, and Trout Lake is a lake connected to smaller streams, with populations of both cutthroat and rainbow trout). The goal of the Oxbow Bend and Trout Lake surveys...
was to assess visitors’ intent for visiting those sites, determine if they knew the river otter could be viewed at the site, and if so, determine if the potential to view the river otter was the primary reason for visiting the site on that day, and finally, assess frequency of visitation to primarily view the river otter.

**METHODS**

To determine attitudes and preferences of the target audience (visitors and residents of the GYE) we conducted place-based social surveys with visitors to GRTE and YELL from 3rd June - 17th July 2014. A non-random intercept sampling method was used for survey collection (Davis 2012) at all three survey locations. Although this was a non-probabilistic sampling method, efforts were made to ask every visitor (over the age of 18) encountered to take the survey. In approaching every visitor, we increased the chances of a true representative sample because every member of the population had an equal chance of being selected.

**Guided-raft trip wildlife viewing survey**

Surveys were conducted with visitors who participated in guided-raft trips on the Snake River (*n* = 768) at the commercial boat pick-up location in Moose, WY. Participants were asked to complete the survey prior to participating on the river raft trip. The survey consisted of 15 questions (14 closed and 1 open-ended). A mixed-method approach was applied for the raft trip surveys, using both paper-and-pencil and electronic tablet (e-tablets) for survey administration. A response rate of 72% was attained. The surveys were designed to assess familiarity, knowledge and motivation to see 9 wild animal species while participating on a guided-raft trip in the Snake River in GRTE.

**River otter viewing survey**

Paper-and-pencil surveys were administered in the parking lot of Oxbow Bend (*n* = 254), and Trout Lake (*n* = 298). Participants were asked to complete the survey prior to their trip to Trout Lake. The survey consisted of 12 closed-ended questions.

**PRELIMINARY RESULTS**

**Guided-raft trip wildlife viewing survey**

The majority of respondents (76%; *n* = 580) indicated that seeing and connecting to wildlife was a priority on the day’s raft trip (Figure 1). Eighty-five percent (*n* = 638) of the participants knew what the river otter looked like, 35% (*n* = 271) considered themselves somewhat or very knowledgeable about the river otter (Figure 2), and 29% (*n* = 221) were motivated to participate in the rafting trip to see the river otter (Figure 3). Against other species, the river otter ranked 4th to other species (moose [*Alces alces*], bald eagle [*Haliaeetus leucocephalus*], and beaver [*Castor canadensis*] which ranked 1st, 2nd, and 3rd respectively) in motivation to participate in the raft trip. The species that ranked high in motivation (moose, bald eagle, beaver) also ranked high in “knowledge of” (bald eagle, moose and beaver were ranked 1st, 2nd, and 3rd respectively).

![Figure 1. Percent of respondents to the question “How would you rate the priority of participating in the following activities on your guided river trip today?” recorded on a 1-7 scale in our 2014 survey of aquatic recreationists in GRTE. Responses that were reported as 6 and 7 are displayed.](image1)

![Figure 2. Percent of respondents to the question “How knowledgeable are you about each of the animals listed below?” in our 2014 survey of aquatic recreationists in GRTE. Responses that were reported as “somewhat” or “very” are displayed.](image2)
A total of 254 Oxbow Bend visitors agreed to participate in the survey with a response rate of 75%. Most of the respondents (40%, n = 103) indicated this was not their first time visiting Oxbow Bend. On average, repeat visitors to Oxbow Bend visited 25.4 times (SD ± 109.5). The majority of people indicated viewing scenery was their highest priority (85%, n = 218), followed by photography (74%, n = 191), and solitude (73%, n = 187) (Figure 4).

Most of the visitors (79%, n = 199) did not know that river otters could be viewed at Oxbow Bend. Of the 20% (n = 53) who did know river otters could be viewed, 11% (n = 6) agreed or strongly agreed that the possibility of viewing the river otter was the primary reason for visiting Oxbow Bend. When asked how they learned the river otter could be viewed from Oxbow Bend, 15% (n = 8) indicated other park visitors and 15% (n = 8) indicated park employees (Figure 6). Most respondents (30%, n = 16) indicated they had
never been to Oxbow Bend to specifically view river otters in the past, and some (26%, n = 14) respondents indicated 1-2 times (Figure 5).

**MANAGEMENT IMPLICATIONS**

Flagship species have the potential to raise public awareness and financial support for conservation activities. To be a successful flagship, a species should be well-liked, identifiable, viewable, and associated with a particular habitat (Bowen-Jones and Entwistle 2002). Against other species, the river otter ranked 4th (moose, bald eagle, and beaver ranked 1st, 2nd, and 3rd respectively) in motivation to participate in a raft trip. The species that ranked high in motivation (moose, bald eagle, beaver) also ranked high in “knowledge of” (bald eagle, moose and beaver were ranked 1st, 2nd, and 3rd respectively). Many “well-known” species (moose, bald eagle, beaver) either “very much” or “extremely” motivated respondents to participate in the river raft trip. This could be because these animals have an intrinsic quality that appeals to tourists, or the species appeals to tourist because they consider themselves “very” or “extremely” knowledgeable about these species (Stevens 2011).

The results of the Oxbow Bend and Trout Lake surveys indicate that after people learn that river otters can be viewed there, many return to those sites for a chance to view river otters. This indicates that the river otter appears to be a popular species among tourists. Further, Trout Lake is a more popular viewing area for the river otter than Oxbow Bend. This is likely because Oxbow Bend is well-known for its view of the Snake River and Mt. Moran, and thus is more popular for viewing scenery and photography then Trout Lake.

The results from the first year of our study initially support the idea that the river otter could serve as aquatic flagship for the GYE. Overall, initial outcomes suggest that aquatic recreationists and visitors of aquatic habitats in GYE would support the river otter as a flagship. However, educational efforts are needed to enhance the familiarity of visitors to the region about the ecological function of the river otters and where they are most likely to be viewed.

**ACKNOWLEDGEMENTS**

Support for this study was provided by the Frostburg State University. Kendyl Hassler was of great assistance throughout the summer, and helped conduct all the surveys. Thanks to Mike from Teton Lodge Company who provided informal reports of river otter sightings. We would also like to thank Steven Cain from GTRE and Stacey Gunther from YELL for permit and logistical assistance and UW-NPS research station and Harold Bergman for the wonderful summer housing and weekly river kabobs.

**LITERATURE CITED**


INTERNSHIP REPORT
PROJECT SUMMARY

The objective of this project was to consolidate all previous work on water rights in the park into a single geodatabase that could be updated and built on in the future. Priority areas specifically for this project were Cottonwood and Spread Creeks, with the goal being to identify all water rights and associated ditches being diverted off of these creeks.

METHODS

The duration of this project was 8 weeks, from May-July of 2014. The first 4 weeks consisted of field work involving the mapping of irrigation ditches in priority areas. Miles of ditches were walked and mapped and compared to historical plat maps and previous mapping work done by the park. The last 4 weeks involved researching all associated water rights with priority areas using historical maps and the Wyoming State Engineer’s Office e-Permit website. In addition, all previous mapping work related to water rights was combined and edited in a single shapefile and placed in a geodatabase.

RESULTS AND DELIVERABLES

- GIS geodatabase with one primary layer for each water right feature, one line-file for ditch lines and one point-file for diversion structures. It includes all previous mapping work and current mapping work from this project.

- Excel database which combined all previous water rights data and newly identified water rights in this project which was combined with layers in the geodatabase.
**RECOMMENDATIONS**

It seems as though there had been a lot of good solid work done in the park over the last 15 years related to mapping irrigation ditches, however none of it was ever synthesized. This led to redundant mapping projects and unorganized data storage and management. The objective of this project was to alleviate some of the problems associated with scattered and cryptic data sources. It is highly recommended that the geodatabase created from this project be the primary source for water rights data in the park and that all future projects and users utilize this resource.
CLASSES
FIELD RESEARCH AND CONSERVATION CLASS:
CLAYTON HIGH SCHOOL, CLAYTON, MO

CHUCK COLLIS ✶ INSTRUCTOR
CLAYTON HIGH SCHOOL ✶ CLAYTON, MO

Figure 1. The 2014 Field Research & Conservation Crew:
Chuck Collis, Emma Chereskin, Jolena Pang, Marysia Hyrc, Sarah McAfee, and Jacob Youkilis

CLASS OVERVIEW

Field Research & Conservation emphasizes long-term field research experiences, examines ecosystem processes, and investigates the evolution of American perspectives about nature. Our time spent at the UW-NPS research station is divided between pursuing behavioral ecology research and exploring Grand Teton National Park and the surrounding area. These experiences help students gain understanding of how the region was shaped by geological, biological, and political processes that have been influenced by America’s evolving conservation ethic.

After the summer field experience, my students assist in data analysis and the development of a poster project. We present our findings at the Phi Sigma Research Symposium at Illinois State University and the St. Louis Ecology, Evolution, and Conservation Retreat at Southern Illinois University Edwardsville.

RESEARCH INTRODUCTION

The sagebrush cricket (Cyphoderris strepitans) is an Orthopteran insect of the family H Aglidae that inhabits high altitude sagebrush meadows and open stands of lodgepole pine and
subalpine fir. Soon after snowmelt, the breeding season is initiated by males as they secure calling perches in sagebrush and use tegmental stridulation to entice potential mates from dusk until midnight. Receptive females locate males acoustically and initiate mating by mounting a male and chewing on his fleshy underwings as an act of nonlethal sexual cannibalism (Figure 2). As the female ingests wing material and hemolymph, the male attempts to attach an external spermatophore to his mate. Although the damage incurred by males is permanent, this does not preclude them from securing additional instances of mating. Additionally, the post-copulatory degradation of male hindwings aids in determining their mating status in the field. The hindwings of virgin males are intact and milky-white while non-virgin male hindwings are tattered, withered, and visibly darkened (Figure 3).

Figure 2. A copulating pair of C. strepitans. (Photo courtesy of S. Sakaluk.)

Song is generated in C. strepitans when males stridulate their forewings, causing a plectrum to run along a series of teeth on the opposite wing. This generates sound in a fashion that is similar to raking a thumbnail along the teeth of a comb. Each closure of the forewings creates an individual acoustic pulse. A rapid series of pulses constitutes a train (Figure 4).

Our study was conducted on a population of sagebrush crickets at Lower Deadman's Bar, a level, four-hectare sagebrush meadow on the banks of the Snake River within Grand Teton National Park. The site’s northern boundary is delineated by a gravel road while the east and west borders are defined by areas of lodgepole pine and subalpine fir accompanied by steep terrain. The southern limit of the site is defined by a copse of trees and a topographical narrowing of level ground (Figure 5).

The aim of our study was to investigate the relationship between aspects of male calling behavior and the amount of time it takes males to secure a mate. Multiple studies have indicated that calling is an

Figure 3. Male C. strepitans underwings: virgin (left) versus old wounds (right) (Photos courtesy of S. Sakaluk.).

Figure 4. Male song is divided between periods of high and low activity. Each train is composed of multiple individual pulses bookended by periods of acoustic inactivity.
energetically expensive behavior and that males that invest more energy in calling have an advantage in securing mates (Sakaluk and Snedden 1990, Sakaluk et al. 2004, Leman et al. 2008, Ower et al. 2011). Based on these findings, we sought to determine if repeated measures of male calling behaviors in the field are predictive of mating success. More specifically, we hypothesized that high calling effort (time spent calling), long train durations, and short intertrain durations would decrease the time it takes for males to secure their first mate.

**METHODS**

We were fortunate to have dry and reasonably warm weather during our 2014 field research window from May 23 through June 3. Additionally, we found that our study site was just coming into mating season when we arrived. From May 23 – May 25 we caught only virgin males. All males used in the study were captured on May 25.

On the morning following their capture, each male in our study was tagged by using Loctite® SuperGlue Gel to affix a unique number, printed on vinyl paper, onto his pronotum. Males were also marked with fluorescent, acrylic paint on their femora and pronotum, outside of the numbered area (Figure 6). The paint aided in recapturing males with the help of UV flashlights.

Repeated measures of each male’s calling behavior in the field were made possible using pens fashioned out of aluminum flashing. The material for each pen measured approximately 3 m by 0.5 m. The ends of the flashing were joined together using duct tape to construct a circular pen approximately 0.5 meters in diameter. The pens were used to surround the “home sagebrush” of the males and were buried several centimeters deep into the soil (Figure 7), very similar to a previous repeated measures study on C. strepitans (Johnson and Hupton 2011). Before dusk, flash drive microphones were sealed in plastic baggies and dropped into pens to record calling behaviors on three nights: May 26, 27, and 28. The microphones were collected as calling wound down each night.

On May 29, about an hour before calling began, males were released by disassembling the pens. Over the next five nights (May 30 through June 3), males were recaptured to determine mating status by examining their underwings for damage.

**PRELIMINARY RESULTS**

Twenty-six of the thirty males were recaptured at least once. Time to mate was determined
as the number of nights from release until recapture as a non-virgin. Males that had not mated by their last recapture were included as “censored” observations. The fifteen males recaptured as non-virgins took from one to five nights to mate. Eleven males were last captured as virgins and were estimated to have taken from two to six nights to secure a mate.

Audio recordings were analyzed using the band limited energy detector function of Raven Pro 1.4 to determine the beginning and end time of each train. From these data, we determined nightly calling effort, mean nightly train duration, and mean nightly intertrain duration for each male.

Unfortunately, our intended sample size of 30 males was limited due to pen malfunctions (10 blew away), poor audio recordings (4), and failure to recapture males (4). This reduced our effective sample size to 17 males for whom we had good recordings all three nights, were released on May 29, and were recaptured following release. Adding to our data troubles, male calling behaviors were individually inconsistent over the three nights of recording (Figures 8 – 10).

Repeated measures ANOVA revealed statistically significant differences in mean nightly calling effort ($F_{2, 32} = 76.9, p < 0.001$), mean nightly train duration ($F_{2, 32} = 7.7, p = 0.02$), and mean nightly intertrain duration ($F_{2, 32} = 3.5, p = 0.04$) over the three nights of recording (Figures 11 – 13). We tentatively attribute the abrupt differences in behavior on May 28 to progression of the mating season.

May 28 was the warmest day in more than a week of warm days (daily highs from 22°C to 27°C) with no recorded precipitation. Field conditions at Lower Deadman’s Bar (LDB) ranged from 9°C to 14°C at 21:00 (onset of calling) from May 23 to May 27 which makes May 28 stand out with 16°C at onset of calling. It is worth noting that all seventy-four males collected from LDB between May 23 and May 25 were virgins and that on May 30, our first night of recapturing, the proportion of non-virgin males in our study (22%) was close to the proportion of non-virgin males who were outside of our study (38%) and free to mate from May 26 through May 28.

Because of individually inconsistent calling behaviors and various indicators that suggest calling data gathered on May 28 best represents behaviors exhibited on nights with high mating activity, we chose to use the May 28 calling data alone for the failure-time analysis instead of combining it with calling data from May 26 and 27. Thus, failure-time analysis (PROC PHREG in SAS) was used to examine the effect of calling effort ($X^2 = 1.75, p = 0.93$), mean train duration ($X^2 = 1.70, p = 0.53$), and mean intertrain duration ($X^2 = 2.06, p = 0.35$) recorded on May 28 on time to mate. The analysis revealed no effect for any of the calling behaviors on time to mating success (Figures 14 – 16).
While these results were not anticipated, they are hardly surprising considering the lack of individual calling consistency coupled with a less than ideal sample size. This could still prove to be an interesting avenue of field research, but is fraught with multiple, uncontrolled variables in a tight window of opportunity. A similar study in which audio recordings are made over a series of nights in the lab prior to field release would help to determine if calling is individually consistent under controlled conditions and correlated with mating success in the field. It may also be interesting to record the calling behavior of penned males in the field for a week or more while monitoring mating status of the field at large.

Figure 11. Significant differences in mean calling effort by night.

Figure 12. Significant differences in mean train duration by night.

Figure 13. Significant differences in mean nightly intertrain duration.

Figure 14. No effect of calling effort on time to mate.

Figure 15. No effect of mean train duration on time to mate.

Figure 16. No effect of mean intertrain duration on time to mate.
ACKNOWLEDGMENTS

We would like to thank Scott Sakaluk for his continued support in providing general research advice and assistance with data analysis. We thank Geoff Ower for his help with detector functions in Raven Pro. We thank the University of Wyoming and the National Park Service for lodging and research facilities. We also thank Harold Bergman and Celeste Havener for their assistance and support.

LITERATURE CITED


INQUIRY-BASED GEOLOGY FIELD COURSE FOR IN-SERVICE EDUCATORS

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DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES AND CENTER FOR MATH AND COMPUTER SCIENCE EDUCATION
UNIVERSITY OF NEBRASKA ✶ LINCOLN, NB

Figure 1. Eight educators in western Nebraska on their way to Wyoming to explore the geological history of the Rocky Mountains and new teaching methods of scientific inquiry.

CLASS OVERVIEW

Eight in-service teachers and two instructors engaged in an inquiry-based geology field course from June 14 to 29, 2014 through Wyoming, South Dakota, and Nebraska. This team of learners spent three days in mid-June working in the Grand Teton National Park area. The UW-NPS facilities provide an excellent opportunity for participants to discover the natural history of the Teton Range, as well as close-out a few projects while sitting in a real chair, at a real table, a welcome change from our usual campground setting.

COURSE BACKGROUND

The 3-credit graduate course at the University of Nebraska-Lincoln, Methods in Field-based Geoscience Instruction - GEOS 898, is a 16-day, inquiry-based field course offered for in-service teachers and pre-service education students to expose them to inquiry-based learning. This course comprises a science immersion and discovery experience in Wyoming, Nebraska and South Dakota. The primary aim of this course is to improve educators' ability to teach using scientific inquiry, to gain knowledge and an understanding of the geosciences, and to demonstrate effective teaching methods that can integrate geoscience into K-12 learning environments. This field course offers an opportunity to discover the
geological history of the Rocky Mountains and experience and discuss inquiry-based scientific methods. The group built upon their growing geological knowledge to investigate the geological evolution of the Teton Range. The spirit of the 2014 course was captured in a short video that aired as part of the Nebraska public television program “Nebraska Stories.” Please find this program at: http://video.netnebraska.org/video/2365367432/

Figure 2. A mirror-calm setting at the UW-NPS Research Center’s boat ramp welcomed our group.
OUTDOOR STUDIO CLASS: UNIVERSITY OF WYOMING VISUAL ARTS DEPARTMENT

Patrick Kikut
Department of Visual Arts
University of Wyoming • Laramie, WY

CLASS OVERVIEW

Art 4620: Outdoor Studio is an upper division course in the Department of Visual Arts. This course provides students with the opportunity to explore a wide range of media and approaches to art making in the field. Most of the course takes place in Albany County with the final week being a trip to the AMK Ranch in Grand Teton National Park.

The AMK Ranch is critical to this course as it provides students with access to the incredible variety of land formations, animals and plants in Grand Teton and Yellowstone National Parks. Also, the AMK allows for art students to work and live along with scientists that are conducting research projects. Ideally this interaction between science and art allows art students the opportunity to tie their work to a backbone of scientific content.
This time at the AMK is like a residency. It allows for students to have a fair amount of uninterrupted time to research their subjects and delve deeply into their work. It is critical to take full advantage of this time as well as the overwhelming landscape.

Along with the landscape, the Outdoor Studio course takes advantage of the many programs offered by the National Park. In particular, programs that address the native art collection has been of interest. Also, we benefited greatly from a docent tour of the National Wildlife Museum of Art in Jackson. The access to both of these collections of art is a great complement to all of the information available regarding the geology and biology of the Parks.

Students spend much of their time producing work in the field, the boathouse and the screened in porch of the Johnson Lodge. On the last night of the AMK stay, students display their work and participate in an open reception. This event is always fun and useful for both the art and science students as it provides an informal way to discuss their research and results.
BIOLOGY FIELD STUDIES:
GRAND TETON NATIONAL PARK

JOHN S. SCHEIBE ♦ JAMES H. ROBINS
DEPARTMENT OF BIOLOGY
SOUTHEAST MISSOURI STATE UNIVERSITY ♦ CAPE GIRARDEAU, MO

Students on trail above Jenny Lake, while scouting for yellow-bellied marmots and pikas in Grand Teton National Park.

CLASS OVERVIEW

Biology Field Studies is a regular 5-credit-hour summer field course offered through Southeast Missouri State University. Over the last few years, we have started the course in the Black Hills of South Dakota, followed by field work in Northern Idaho. This year for the first time, we are in the Tetons. The emphasis of the course has been to teach students modern faunal survey techniques (including passive acoustic sampling for amphibians, bats, birds and flying squirrels), techniques for behavioral studies of wildlife, floristic survey techniques, and in some cases specimen preparation for natural history collections. There is a strong emphasis on proper field notebook preparation, and the use of various analytical and modeling environments to aid both in the development of appropriate hypotheses for field projects, and to analyze results. We provide the students with instruction in the use of Songmeters and Anabats II’s
for passive acoustic and ultrasonic sampling, Reconyx trail cameras, wildlife callers and digital field recorders with shotgun microphones. Before getting into the field, students learn to use a variety of software programs including Presence, Distance, SPOMsim, SongScope, and Past. With these computational tools, they are ready to estimate population sizes of various species, but also to develop spatial patch occupancy models.

Our course is open to both undergraduates and graduate students. Of the 9 students in the course, 6 were graduate students, and all students were Wildlife majors.

**GRAND TETON NATIONAL PARK**

We arrived in the Tetons with a week of field work already completed in the Black Hills. Thus, students were acclimated to the course routine, and all students were involved in course projects. The first few days in the park were spent familiarizing the students with the park habitats and wildlife, and, importantly, where we were likely to observe species of interest. This involved numerous hikes, with spectacular scenic views, and observations of numerous charismatic mammal and bird species.

Several students were involved in a project designed to evaluate a model of vigilance behavior in social mammals. To do this, they video-recorded the above-ground activity of black-tailed prairie dogs at
Wind Cave National Park, and yellow-bellied marmots in the Northern Black Hills. In the Tetons, the yellow-bellied marmots above Jenny Lake and the Uinta ground squirrels on the AMK Field Station were video-recorded. This provided 2 graduate students with nearly 100 hours of archived video data for analysis, and important data for their master’s thesis research. The preliminary results suggest that colony size does influence scanning rates in smaller ground squirrels, but not in larger ground squirrels like marmots.

**Efficacy of Passive Acoustic Sampling for Detection of Northern Flying Squirrels**

Using both Anabat II and Songmeter ultrasonic detectors, several students set up recording stations within the Tetons in an effort to listen for northern flying squirrels. Before the start of field work, we developed a call library of southern and northern flying squirrels using captive colonies of animals housed at Southeast Missouri State University. We used these calls together with a bat call library obtained from the Museum of Southwestern Biology at the University of New Mexico to develop discriminant functions for classification of unknown calls. The model was applied using previously recorded calls from the Black Hills, Northern Idaho and from Prince of Wales Island AK to demonstrate efficacy. Once our calls were downloaded to computer, we were able to identify the presence of Northern Flying Squirrels within several habitat patches in the Tetons. The students working on this project plan to develop a survey protocol for northern flying squirrels that will not require trapping or handling this sensitive species.

**Estimation of Population Size in Elk and Pronghorn**

Using rangefinders, compass and GPS, several students embarked on an effort to estimate population sizes of elk and pronghorn, and, specifically, to compare pronghorn population sizes with those estimated for Custer State Park in the southern Black Hills. The surveys involved both vehicular transects and transects on foot. Clearly, the estimates are unreliable because the sample sizes are small and too restricted in terms of area, but the exercise provided valuable hands-on experience in the technique and an opportunity to use programs Presence and Distance in a real-world setting.

Elk observed while on a transect.

Barrow’s Goldeneye.

**Wildlife Observations**

Because most of our students have never been in the west, they are unfamiliar with many of the species we observe. Most have never seen a Barrow’s Goldeneye, Western Tanager or Crossbill, and for some of these students the world has suddenly grown much larger.

One reason this course has been so successful over the last 10 years is that we prepare our students beforehand. They come into the field with an idea of what they want to accomplish, and the tools necessary to be successful. The dramatic scenery and abundant wildlife we found in the Tetons reinforced in our students their commitment to careers in Wildlife Biology.

Observing elk as they establish their position in the social hierarchy, or pronghorn and moose as they forage is an experience that comes too rarely for most students.
Summary

Two of the students that participated in the field course at the AMK field station are finalizing the analysis of their data, and will defend their MNS theses in the spring. The data they collected in the Tetons is an integral part of their research. They will present the results of their work at the annual meetings of the American Society of Mammalogists in 2014. Because of her experience in the Tetons, one of the undergraduate students has decided to pursue graduate education in wildlife biology, and has applied for admission to several graduate schools. The course was a positive experience not only for the students, but for the instructors as well. We look forward to our next opportunity to return to the Tetons and the AMK field station.
Preparing for potential predation event by a red fox on yellow-bellied marmots.

After several days of field work, a chance to relax with a hike.

Two of the many views that made a return to the Midwest difficult.
CLASS OVERVIEW

Utah State University Department of Watershed Sciences runs an introductory course for all incoming graduate students (13 students in fall 2014) immediately prior to each fall semester. The course is an intense, five-day introduction to the fundamental concepts of Watershed Science, as well as the people of the Department of Watershed Science and the techniques they use in research. The course begins with one day focused on water quality and wetlands at Cutler Reservoir in Logan, Utah, then one and a half days focusing on collection of fish, remotely sensed data, and topographic surveys in the Logan River watershed, followed by one and a half days discussing landscape organization and evolution and making field
observations in the Grand Teton region. We use AMK Ranch for lectures, discussions, group dinners, sleeping quarters, and as a central base for Teton area activities, including rafting on the Snake River (photo above).

**CLASS OBJECTIVES**

The general objectives of the course are to help incoming graduate students get acquainted with the nearby landscape, the people in the Department of Watershed Sciences, some of the broader concepts and questions that define Watershed Science, and some of the techniques that USU faculty use to answer those questions.

A sampling of the techniques demonstrated:

- Terrestrial laser scanning,
- Real-time kinematic GPS,
- Collection of visible and IR aerial photography using drone aircraft,
- Field mapping,
- Soil evaluation,
- Collection and analysis of climate data,
- Fish and macroinvertebrate sampling, and
- Water quality monitoring.
CONFERENCES AND MEETINGS
INBRE NETWORK RETREAT AT UW-NPS RESEARCH STATION IN GRAND TETON NATIONAL PARK

R. SCOTT SEVILLE ✶ DEPARTMENT OF ZOOLOGY AND PHYSIOLOGY UNIVERSITY OF WYOMING/CASPER COLLEGE CENTER ✶ CASPER, WY

SUMMARY

September 11-13, 2014, Wyoming IDEAS Networks for Biomedical Research Excellence network participants met for the annual Wyoming INBRE Retreat at the University of Wyoming-National Park Service Research Station (AMK Ranch) in picturesque Grand Teton National Park.

Despite difficult travel conditions including icy roads, cold temperatures, and a treacherous snowstorm that hit the entire state of Wyoming on Thursday September 13th, attendance was outstanding. Regrettably a couple of participants from Gillette College were completely snowed in and could not attend but the majority put on their warmest winter gear to embark on a longer road trip than usual due to the dicey road conditions. Fifty-eight attendees from across Wyoming arrived safely at the AMK on Thursday September 11th 2014. Research teams composed of students and faculty from all the following WY institutions were in attendance at the retreat: Northwest College (Powell), Sheridan College, Central Community College (Riverton), Western Wyoming Community College (Rock Springs), Laramie County Community College (Cheyenne), University of Wyoming (Laramie), and University of Wyoming at Casper (Casper).

The schedule on Friday September 12 was full, somewhat eclectic and definitely interesting as all teams presented about their ongoing research programs (see list of presentations below). The evening keynote speaker was Dr. John Oakey from the Department of Chemical and Petroleum Engineering at the University of Wyoming (Laramie), who delivered a very well received lecture on biomedical engineering processes (Microfluidic Encapsulation for the Design of Intra- and Extracellular Niches). On Saturday Sept 13th, Wyoming INBRE Transition Fellows from UW Laramie opened the meeting by sharing their research experience with future INBRE Transition Fellows from WY junior colleges. A student poster session followed these presentations. The conference ended with an open discussion between all WY INBRE PIs and researchers to consider the state and direction of education and research activities as the program moves towards the next 5 year grant.

The formal meeting adjourned at noon on Saturday September 13th, and with better weather, most attendees participated in a group hike up Cascade Canyon to Hidden Falls.

PRESENTATIONS
(speakers are underlined)

INBRE Network Investigations of Coccidia in Wild Hosts. R. Scott Seville (University of Wyoming at Casper)
Production of Recombinant Spider Silk Proteins for Use in Generation of Biomaterials. Sean Henley, R. Scott Seville, and Florence Teulé-Finley (University of Wyoming at Casper)
Twenty-Five Years of Successional Change in Small Mammal Communities since the 1988 Yellowstone Fires. Hayley C. Lanier, Zachary P. Roehrs, Kevin M. Crouch-Jacobs, Samantha E. Haller, Kayla A. Wilson, Dominique C. Schlumpf, Ashkia L. Campbell, Andy J.
Kulikowski, II, Meredith A. Roehrs, and R. Scott Seville (University of Wyoming at Casper and Laramie County Community College)
Yellowstone’s Springtail Community 25 Years after the Fires. Andy Kulikowski and Hayley Lanier (University of Wyoming at Casper)
Soil Comparison Study: Germination and Growth of Artemisia tridentate. Brittany Elliott, Hayley Lanier, and Lynn Moore (University of Wyoming at Casper)
RBM20, a Potential Therapeutic and Prognostic Target for Progressive Heart Failure. Zhiyong Yin, Chaoqun Zhu, Jun Ren and Wei Guo (University of Wyoming, Laramie)
The Effect of Scavenger Diversity on the Rate of Carrion Decomposition. Stephanie Ashley and Will Clark (Western Wyoming Community College)
The Effects of Microclimates on the Invertebrates of the Trout Creek Waters and its Riparian Zones. Tiffany Simpson and Will Clark (Western Wyoming Community College)
Assessment of Cardiac Function Using Pressure-Volume Loops As Cardiac Hypertrophy Develops From Iron Deficiency. Jacquie Zadra, Ashley Weigel, Andrea Sanchez Walk, Denise DeLoera, and Bud Chew (Western Wyoming Community College)
INBRE Research at Northwest College 2013/2014. Allan Childs, Eric C. Atkinson, Elise Kimble, and Steve Harbron (Northwest College)
Antibiotic Producing Symbionts in Temperate Formicidae. Ryan Croft, Elise Kimble, and Eric Atkinson (Northwest College)
Adventures in Research, and Other Stuff at Laramie County Community College. Zachary P. Roehrs, Ami L. Wangeling, Meredith A. Roehrs, Kelsea N. Zukauckas, Samantha E. Haller, Meghan O’Brien, Alexis Lester, and Casandra B. Kertson (Laramie County Community College)
Faculty report from Central Wyoming College. Suki Smaglik and Steve McAllister (Central Wyoming College)
Biodetection Using Gas Chromatography-Mass Spectrometry. William Trebelcock, Mitch Helling, and Franco Basile (University of Wyoming, Laramie; transition fellow)
A Year as a Transition Scholar. James Edermann (University of Wyoming, Laramie; transition fellow)
Examination of Coccidia in Order Passeriformes. Zach Swope, Wyatt Fabrizio, Marcus Couldridge, Eric C. Atkinson, Allan Childs, and Elise Kimble (Northwest College; Poster)
Winged Arthropods as Sources of Antibiotic-producing Microbes: Is There a Taxonomic Pattern? Alison Winkler, Ryan Croft, Eric Atkinson, and Elise Kimble (Northwest College; Poster)