UNIVERSITY OF WYOMING - NATIONAL PARK SERVICE RESEARCH STATION

38th ANNUAL REPORT 2015

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TABLE OF CONTENTS

PAGE

UW – NPS RESEARCH STATION INFORMATION

RESEARCH PROJECT REPORTS

Geology

Ecology

2015 UW-NPS Research Station Personnel

HAROLD BERGMAN ✦ DIRECTOR
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DIRECTOR'S COLUMN

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During the period of this report the University of Wyoming-National Park Service (UW-NPS) Research Station 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 Station 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 Station dealt with questions of direct management importance as well as those of a basic scientific nature.

The Research Station continues to consider unsolicited proposals addressing applied and basic scientific questions related to park management. Research proposals are reviewed and evaluated by the Research Station'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 Station. Research contracts are usually awarded by early April.

The UW-NPS Research Station operates a field station facility 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, Yellowstone National Park and the surrounding Greater Yellowstone Ecosystem. Station facilities include housing for up to 60 researchers, wet and dry laboratories, a library with internet access, an herbarium, boats, and shop facilities. 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 Station.

A summary of the 2015 users and activities at the Station is included below. And additional information about the UW-NPS Research Station, including the current year's Request for Proposals, housing and facilities request forms, summaries of past and current research, upcoming seminars and other events, and location information, can be found at the station's web site: http://uwnps.org/.

AVAILABILITY OF 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 Research Station (1954–present) are available online and full-text searchable from here: **http://repository.uwyo.edu/uwnpsrc_reports**

2015 UW-NPS RESEARCH STATION USERS AND ACTIVITIES SUMMARY (3655 total user-days)

Classes and Field Research Courses

11 classes on Field Ecology, Geology, Social Science and Art from UW, LCCC-Cheyenne, CWC-Riverton, UW-Casper, NWCC, Nebraska, Oklahoma, California, Pennsylvania, Texas and Utah – 959 user-days

- Field Geology – Laramie County Community College - Cheyenne
- Field Geoscience – Chadron State University
- Field Ecology – Oklahoma City University
- Outdoor Studio Art Class – UW Art Department
- Field Geoscience – Mt. San Antonio College, CA
- Human Dimensions of Wilderness Use – S. F. Austin University, TX
- Field Geoscience – University of Nebraska
- Field Ecology/Geology – University of Pittsburgh
- Watershed Science Graduate Student Field Course – Utah State University
- Field Geology – Central Wyoming Community College - Riverton
- Wildlife Photography – Northwest Community College - Powell

Workshops and Meetings

13 workshops and meetings on climate and butterflies, international energy and environmental security, historic building restoration, ecophysiology, landscape painting, international wildlife issues and biomedical topics from UW and WY Community Colleges, Iowa, Germany, Botswana, Jackson Hole, regional game and fish agencies and GYA federal and state agencies – 513 user-days

- Iowa State University Debinski Ecology Lab Workshop/Retreat
- Grand Teton NP Science and Resource Management Division Staff Meeting
- UW Energy-Environment Security Workshop
- WY/ID/MT Game and Fish Agency Annual Tri-State Meeting
- Greater Yellowstone Coordinating Committee Meeting
- Alliance for Historic Wyoming Workshop and AMK Historic Building Tour
- GYA Revegetation Science Meeting and Tour
- Teton Plein Air Painters – Landscape Painting Session
- UW Dillon Ecophysiology Lab Workshop/Retreat
- UW INBRE Planning Workshop – UW & WY CC Instructors and Students
- Bavarian Forest National Park, Germany, Education Program Tour
- Wildlife Summit at Jackson Lake Lodge
- Atlas of Wildlife Migration: Wyoming's Ungulates

Research Projects with Residence at the Station (* = funded by UW-NPS/GRTE)

37 research teams of from 1 to 12 researchers studying diverse topics in Ecology, Geology, Water Quality, Fish and Wildlife Biology, Social Sciences and Cultural/Historic Resources from UW, WY Community Colleges, and 17 other colleges and universities from all over the US and 6 federal or state agencies – 1966 user-days

- Butterflies and Climate Change – Iowa State University
- Avian Biomechanics – Harvard University
- Cultural History of Snake River Rafting – Idaho State University
- * Small Mammals and Fire Ecology – UW-Casper/LCCC
- River Otter – Frostburg State University/University of Maryland
- Avian Ecophysiology – University of Wyoming
- *Historic Building Conservation – University of Pennsylvania
- Cricket Ecology – St Louis Schools Biology Class
- *Beaver Ecology – University of Wyoming
- *Human Response to Acoustic Environment – Penn State University
- Avian Biodiversity – University of California Los Angeles
- Fire and Climate Change – University of Wyoming
- *Geomorphology of Snake River – University of Wyoming
- Aquatic Ecology – University of Wyoming
- Aquatic Invasive Species and Ecology – University of Wyoming

- Aquatic Community Ecology – Penn State Altoona
- *Aquatic Ecology and Diatom Distribution – S. D. School of Mines
- Big Game Ecology – University of Wyoming
- *Whitebark Pine at Alpine Treeline in GRTE – Virginia Tech
- Butterfly Biodiversity – Utah State University
- Active Tectonics in GRTE – University of Kentucky
- Climate Change and Whitebark Pine in GRTE – Kansas State University
- Teton Geology – Idaho State University
- Art History of GYA – University of Wyoming
- Jackson Lake Fish Survey – Wyoming G. & F. Department
- Water Quality – National Park Service
- Nutrient Cycling and Aquatic Ecology – University of Wyoming
- *High-Resolution Teton Fault Mapping –University of Pittsburgh
- Bushy Tailed Wood Rats – University of New Mexico
- *Aquatic Invertebrate Ecology – University of Wyoming
- *Teton Fault Hazard Analysis – Idaho State University
- Sound Measurements – National Park Service
- Spider Ecology/Biogeography – Craighead Beringia South
- Upper Snake River Hydrology – National Park Service
- Lake Trout Egg Collections – US Fish and Wildlife Service
- Jenny Lake Archeology Survey – Wyoming State Archeologist

Interns and Visiting Scholars Resident at Station (* = funded by UP-NPS/GRTE)
2 Grand Teton National Park interns co-funded by UW and Grand Teton NP and selected competitively for work with Grand Teton National Park staff; 2 guest interns in Ecology/Sustainability and Nature Writing; 1 guest UW faculty member in music composition – 217 user-days

- *Hydrogeology/Glaciers – MS student from University of Colorado-Boulder
- *Museum Curation/History – MS student from Idaho State University
- Ecology/Sustainability – Undergrad, University of the Sunshine Coast Australia
- Nature Writing – MA student from University of Wyoming MFA Writing Program
- Music Composition/Opera – Composition Faculty Member University of Wyoming

Harlow Summer Seminars – UW-NPS Research Station at the AMK Ranch
Weekly Thursday evening seminars from mid-June to mid-August with a $5 donation for a BBQ dinner followed by a seminar – 10 seminar events in 2015 drew an average audience of 120 members of the general public from the Jackson Hole / Greater Yellowstone Area

- Mark Elbroch, Panthera's Teton Cougar Project: Altruism in mountain lions – June 18
- Diana Miller, Wyoming Game and Fish Dept., Jackson: History of fisheries management in the western US with notes on the Hoback River and Jackson Lake – June 25
- Tom Serfass & Kelly Pearce, Frostburg State Univ. & Univ. of Maryland: River otters as flagships for aquatic conservation: The approach doesn't fit the North American model of wildlife conservation – July 2
- Joe Riis, National Geographic, and Arthur Middleton, Yale University: Invisible Boundaries: The Greater Yellowstone elk migration project – July 9
- Hank Harlow, University of Wyoming: Biomimicry, what we can learn from animals living in stressful environments: Lions, dragons, bears and other critters – July 16
- Bob Smith, University of Utah: Immense magma reservoir discovered beneath Yellowstone extending well beyond its caldera – July 23
- Sarah Benson-Amram, University of Wyoming: The evolution of problem-solving abilities in carnivores: Badgers and bears to snow leopards and spotted hyenas – July 30
- Tanja A. Börzel, Freie Universität, Berlin: On leaders and laggards in environmental governance and management: The case of the European Union – August 6
- Mary Centrella, Cornell University: Reading BEE-tween the lines: Honey bees, colony collapse disorder, and the importance of wild bees to agriculture – August 13
- John Stephenson, Grand Teton National Park: Sage-Grouse conservation in Jackson Hole – August 20

Research Project Reports

Geology

A HIGH-RESOLUTION GEOPHYSICAL SURVEY OF JENNY LAKE: USING LAKE SEDIMENTS TO CONSTRUCT A CONTINUOUS RECORD OF TECTONIC ACTIVITY AND EARTHQUAKE-TRIGGERED DISTURBANCES AT GRAND TETON NATIONAL PARK

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MARK B. ABBOTT ✦ UNIVERSITY OF PITTSBURGH ✦ PITTSBURGH, PA

✦ ABSTRACT

The Teton Range, WY contains a legacy of late Cenozoic uplift and periodic Quaternary glaciations. Well-preserved fault scarps along the Teton fault displace glacier deposits from the most recent (Pinedale) glaciation and provide evidence for high fault activity during the past ~15,000 years. Observations of these scarps and previous field investigations indicate that postglacial fault offset occurred through a series of major, scarp-forming earthquakes. However, the postglacial paleoseismic record of the Teton fault remains incomplete. The goal of this project is to use lake sediments, contained in lake basins positioned on the fault, to construct a history of the timing and frequency of past earthquakes at Grand Teton National Park, and assess seismic impacts on sediment erosion (e.g., landslides, debris flows, slope failures) and future hazard potential. Here, we report on multibeam sonar bathymetry and seismic reflection images from Jenny Lake, collected as part of an effort to identify glacial and tectonic landforms and to characterize infill stratigraphy. Our overarching objective is to combine these datasets with lake sediment cores from Jenny Lake and other nearby lakes to construct a continuous, accurately-dated record of past earthquakes and earthquake-generated slope failures in the Tetons.

✦ INTRODUCTION

The spectacular geomorphology of the Teton Mountain Range attracts over 4 million visitors to Grand Teton National Park (GTNP) each year and is attributed to a combination of active uplift along the Teton fault, a major range-bounding, eastward-dipping normal fault that extends for ~70 km along the base of the mountains, and periodic Quaternary glaciations (Figure 1; Love et al. 1992, 2003, Smith et al. 1993, Byrd et al. 1994, Byrd 1995). Total stratigraphic offset across the fault exceeds present topographic relief (~2 km) and is estimated to be 6-9 km since normal faulting initiated 5-13 Ma (Smith et al. 1993). More recent fault activity is evidenced by fault scarps displacing glacier features deposited at the end of the Pinedale glaciation ~15 ka (Figure 1). Surface offsets of these postglacial scarps vary from approximately 3 m to over 30 m, with the largest offsets found in the central part of the range (Smith et al. 1993, Machette et al. 2001, Thackray and Staley 2017). Scarp ages and cumulative offsets have been used to calculate average postglacial slip rates, with estimates ranging from 0.2 to 1.8 mm/a (Smith et al. 1993, Byrd et al. 1994, Machette et al. 2001, Thackray and Staley 2017).

The paleoseismic record of the Teton fault has been pieced together from a few sources but remains incomplete. Interpretations of paleoshorelines in Jackson Lake suggest postglacial faulting occurred in 8-10 discrete rupture events and data from a trench dug at the mouth of Granite Canyon indicate the two most recent events produced >4 m of displacement, and occurred at ~8.0 and ~5.5 ka, respectively (Byrd 1995, Pierce and Good 1992). Such scarp-forming events are considered to require major earthquakes of magnitude Ms = ~7 (Smith et al. 1993). Little else is known about the pattern and timing of fault movement through the late Pleistocene and Holocene time.

However, the available empirical data suggest the majority of postglacial fault offset was accomplished between deglaciation and ~8 ka, and hints at a relationship between the timing of deglaciation and fault slip rate. Modeling simulations show that melting of the Yellowstone and Teton ice masses may have caused a postglacial slip rate increase (Hampel et al. 2007). However, the incomplete paleoseismic record and lack of earthquake data prior to 8 ka preclude the ability to test the model results.

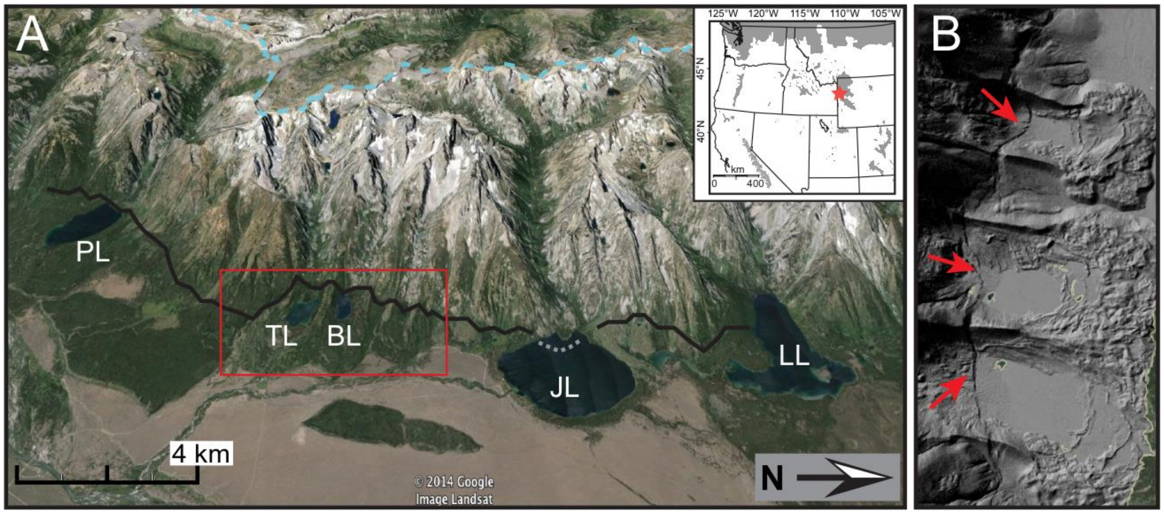

Figure 1. Geologic setting of the study region. (A) Oblique aerial view of eastern flank of the central Teton Range, GTNP. Note the series of glacially carved valleys and impounded piedmont lakes located at their base. The five piedmont lakes targeted in our broader study are identified: Phelps Lake (PL), Taggart Lake (TL), Bradley Lake (BL), Jenny Lake (JL), and Leigh Lake (LL). The position of the range-front Teton fault scarp is highlighted with a black line. Dashed blue line near the top of the frame marks the drainage divide. Inset map highlights the location of GTNP (red star) on map of western U.S. glaciers during Pinedale time (from Porter et al. 1983). A red rectangle delineates area enlarged in panel "B." (B) LiDAR hillshade of three terminal moraine complexes transected by the Teton Fault scarp (identified with red arrows). The large terminal moraines pictured here impound the lake basins and mark the greatest extent of these valley glaciers during the Pinedale glaciation.

While the impressive scenery of GTNP has benefitted from high tectonic activity in the past, future tectonic events pose serious threats to NPS infrastructure, human safety, and resource management (e.g., Smith et al. 1993). A continuous and well-dated paleoseismic record of the Teton fault is crucial for assessing seismic hazards and evaluating the influence of tectonic activity on sedimentary systems. The goal of this project is to provide a quantitative reconstruction of past earthquakes at GTNP (i.e., earthquake timing and frequency), including their impacts on sediment erosion and future hazard potential.

Over the past few years, we have employed a combination of seismic surveys, multibeam sonar bathymetric mapping, and multiple lake sediment cores from Jenny Lake and other nearby lakes, in an effort to study the combined tectonic and climatic history of the range. Our recent findings suggest that past earthquakes at GTNP triggered mass movement events in both lacustrine and subaerial hillslope environments. Sediments deposited in the piedmont lakes positioned along the fault trace (e.g., Jenny Lake) contain a continuous and well-dated archive of these slope failure events in the form of landslides, inflow delta failures, and subaqueous gravity flows (Larsen et al. 2017). These lakes also preserve a record of alpine glacier recession at the end of the Pinedale glaciation ~15 ka (Larsen et al. 2016). In this report, we present emerging findings from geophysical surveys of Jenny Lake that we performed to investigate glacial and tectonic landforms preserved in the lake and to characterize infill stratigraphy.

✦ GEOLOGICAL SETTING

The Teton Mountain Range is a rectangular (~70 km long by ~20 km wide) fault-block mountain range that's flanked on both sides by broad, low-lying basins (Love et al. 2003). The eastern side of the range rises abruptly above the valley floor of Jackson Hole and forms the centerpiece of GTNP. A series of deep glacially carved, U-shaped valleys are cut into the mountain front (Figure 1). Each valley spans >1,000 m of elevation and transects multiple vegetation environments from high alpine tundra down to mixed conifer forests at the valley floor. Many of the valleys contain a chain of lakes composed of multiple small basins, positioned in high elevation glacial cirques, which drain into a large, moraine-dammed piedmont lake at the valley mouth (Figure 1). Lake basins at GTNP formed following regional deglaciation ~15 ka (Licciardi and Pierce 2008, Larsen et al. 2016). Sediment fill in each lake marks the timing of glacier retreat from individual basins (lake inception) and contains a continuous and datable record of subsequent upstream glacier activity and environmental conditions in the catchment. This study focuses on Jenny Lake at the mouth of Cascade Canyon (Figure 2).

Jenny Lake (43.76°N, 110.73°W; 2070 m asl) has an area of ~5 km^2, a maximum depth of ~73 m, and an average depth of ~43 m. Two main inflows to the lake are Cascade Creek, which drains Cascade Canyon, and a stream that emanates from String Lake, a moraine-dammed flowage that receives overflow from Leigh Lake to the north (Figure 2). The primary sediment source to Jenny Lake is via Cascade Creek. Sediment transported by this stream has created a small inflow delta at the mouth of Cascade Canyon along the western lakeshore. Similar to other piedmont lakes at GTNP, Jenny Lake occupies a terminal basin excavated by a major valley glacier during Pinedale times (e.g., Pierce and Good 1992). The relatively narrow terminal moraine complex encircling the lake has multiple closely nested ridges and likely contains outer segments that are buried by outwash (Licciardi and Pierce 2008; Figure 2). The height of the inner moraine crest above the lake surface varies along the lake perimeter from a maximum of ~200 m near the canyon mouth, an average of ~25 m along the eastern shore, and minimum of ~ 4m on the southern margin. Lidar imagery captures the Teton fault trace as it cuts across the moraine deposits and along the lake's western boundary (Figure 2)

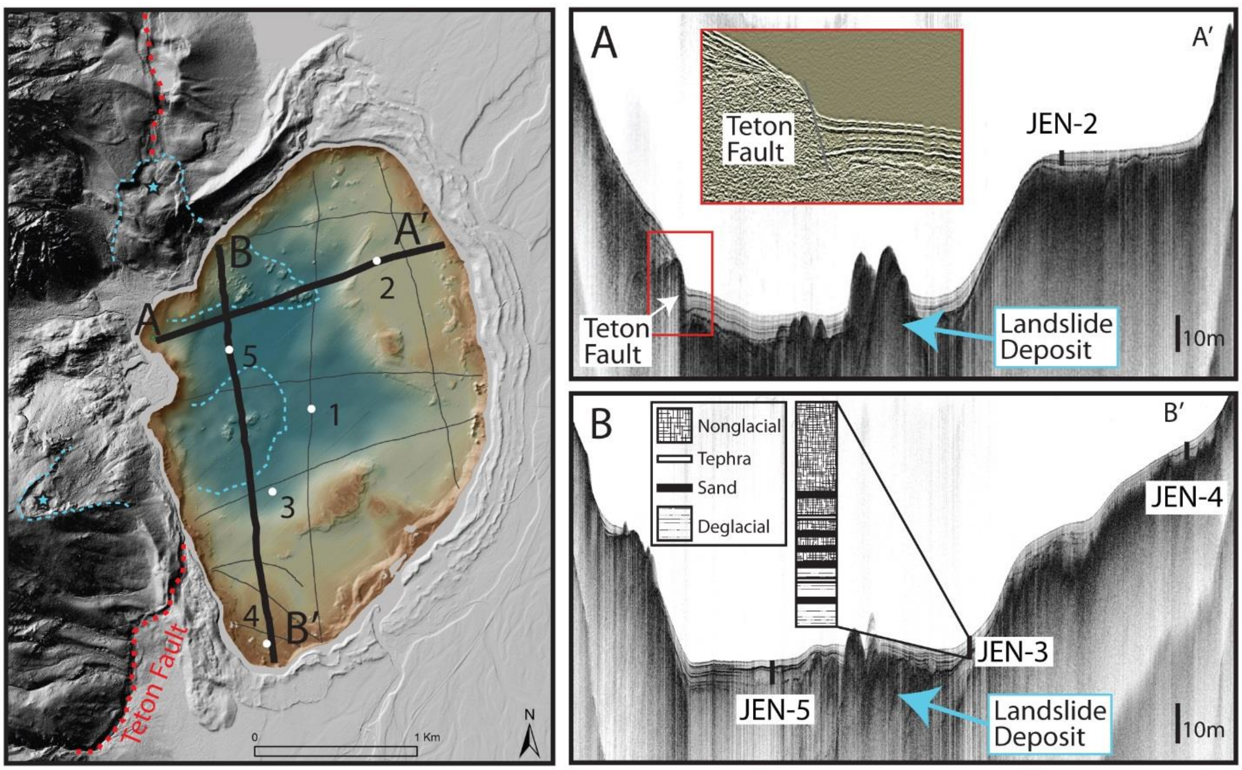

Figure 2. Map of Jenny Lake region and seismic stratigraphy. Left panel: lake multibeam bathymetry and Lidar hillshade map of Cascade Canyon mouth (note: Pinedale moraines impounding lake). Red dashed line highlights location of the Teton fault scarp, which can be traced across the western lakeshore. Blue stars and dashed lines mark the head scarps and runout paths of two major landslides identified in Lidar imagery and observed in lake bathymetry and seismic stratigraphy as block and fan deposits. Locations of sediment cores (numbered white circles) and seismic transects (black lines) are shown. Panels at right: Representative seismic profiles along east-west (A-A') and north-south (B-B') transects of Jenny Lake showing lake floor morphology, sub-bottom stratigraphy, and sediment distribution. Acoustic reflectors indicate regular undisturbed lacustrine sediment fill interrupted by the Teton fault trace and landslide deposits. The two landslide deposits and location of the submerged Teton fault scarp are identified.

✦ METHODS

We performed geophysical surveys at Jenny Lake to map the spatial distribution of lake sediment and lake bottom morphology at high resolution. Bathymetric data were obtained in summer 2015, using a SeaBat 8101 240 kHz multibeam sonar system operated from the research vessel Kingfisher (belonging to the Large Lakes Observatory, University of Minnesota, Duluth). Fieldwork was based out of the UW-NPS AMK research station. Following collection, the data were post-processed and compiled into a raster image file in ArcGIS. We obtained seismic reflection data using an EdgeTech sub-bottom profiler (CHIRP) towed from a boat along transects performed in a gridded manner covering the lake surface area (Figure 2). Each seismic transect was collected in conjunction with a differential GPS device to record spatial coordinates. Individual seismic profiles were processed and analyzed in Kingdom Seismic and Geological Interpretation software. Sediment thickness was estimated using the velocity of sound in freshwater (~1500 m). Over the course of three field seasons between 2013 and 2016, we collected sediment cores from multiple locations in Jenny Lake using percussion-style piston coring systems deployed from the frozen lake surface (e.g., Larsen et al. 2016).

✦ RESULTS

The bathymetry of Jenny Lake is complex and contains multiple sub-basins, but in general, consists of a central deep basin that is partially surrounded by a broad outer shelf (Figure 2). A ~500 m wide trough that emanates from the eastern side of the central basin splits the outer shelf in two. Trough features similar to this can be observed in the bathymetry of other piedmont lakes at GTNP (e.g., Taggart, Leigh) and suggest enhanced glacial erosion and/or meltwater discharge along the middle portion of the Pinedale glacier termini (Figure 2). Numerous small sediment piles can be observed around the shallow perimeter of the lake, most deposited within ~100 m of the moraine. We interpret these features to represent unstable backslope failures of the terminal moraine complex. Two large block and fan deposits are seen in the central basin. Both of these features are positioned below the head-scarps and run-out paths of major landslides visible on the hillsides above the Teton fault trace. We interpret these deposits to have been generated by two large, lake-terminating landslides. The multibeam data also capture the submerged fault trace cutting across the lake inflow delta (Figure 2). In this region the fault trace appears to be split into two or more, closely-spaced scarps.

The sediment fill has a stratified appearance and contains multiple strong seismic reflectors that can be traced around the lake's sub-basins (Figure 2). The strongest reflectors are present in the bottom portion of the sediment fill and are interpreted as dense, glacio-lacustrine deposits. Based on acoustic properties and in conjunction with lake sediment core stratigraphy, we identify three main seismostratigraphic units: 1) a basal till unit, 2) a minerogenic deglacial unit, and 3) an upper low-density, non-glacial unit (Larsen et al. 2016). The succession of these units broadly corresponds to the timing of glacial occupation of the lake, the subsequent deglaciation of Cascade Canyon, and the ensuing interval of non-glacial conditions during the Holocene (Larsen et al. 2016). Seismic profiles reveal high spatial variation in sediment thickness and character (Figure 2). Sediment thickness ranges from <2 m along the outer shelf to >8.0 m in the central deep basin. The two landslide deposits identified in the bathymetry register in the seismic profiles as acoustically opaque mounds that protrude above the lake floor and are partially draped with sediment (Figure 2). Also visible in the seismic imagery is the Teton fault trace, which runs under the western shoreline of Jenny Lake and offsets the lake sediments by about 10 m along the main scarp (Figure 2).

✦ DISCUSSION AND PERSPECTIVES

Multibeam bathymetry and seismic stratigraphy at Jenny Lake reflect a dynamic history of sediment deposition related to tectonic and glacial processes (Larsen et al. 2016). Integrating the geophysical data with stratigraphic information contained in lake sediment cores allows for a more complete understanding of the glacial and tectonic history at this site. All lake cores contain a two-part sequence of laminated glacial sediments overlain by a unit of low-density, non-glacial sediments. The timing of major stratigraphic transitions, dated with radiocarbon and tephrochronology, indicate Jenny Lake became deglaciated just prior to 14 ka and that up-valley glacial recession continued until Cascade Canyon was ice-free by 11.5 ka (Larsen et al. 2016).

Jenny Lake sediment cores also contain evidence for large disturbance events in the form of turbidite deposits. These deposits can be correlated between all core sites but are thicker and more prevalent in cores taken from the central deep basin. A total of nine thick (up to 23 cm thick) turbidite deposits have been identified in a composite core taken from site 1 (Figure 2; Larsen et al. 2017). The stratigraphy of each deposit begins with a sharp basal contact and is characterized by a sequence of sub-angular coarse sand that fines upward to fine silt and clay. We hypothesize that these deposits were generated by past seismic activity. Similar lake sedimentary deposits have been interpreted as earthquake-generated events in other seismically active areas, including in the Cascades (Leithold et al. 2017), Sierra Nevada (Maloney et al. 2013, Smith et al. 2013), Chilean Andes (Bertrand et al. 2008, Moernaut et al. 2017), and Swiss Alps (Kremer et al. 2017). Furthermore, many of the turbidite ages at Jenny Lake corresponds to the age of event deposits identified in cores from nearby Phelps, Taggart, and Bradley Lakes (Figure 1; Larsen et al. 2017), and to the timing of major fault rupture events identified in the Granite Creek trench (Smith et al. 1993).

Our results suggest that earthquake-generated deposits are archived in piedmont lake sediments and can be characterized and accurately dated with bathymetric data, seismic imagery, and lake cores. Based on this study, we have developed an interpretive model that relates earthquakes with lake turbidite deposits (e.g., Kremer et al. 2017). We contend that past ruptures of the Teton fault generated three different types of slope failures at Jenny Lake: landslides, subaqueous gravity flows, and inflow delta failures. In order to unambiguously correlate the slope-failure deposits to past earthquakes, this record must be replicated in other lake basins. Slope failures that occurred simultaneously in multiple lakes along the Teton range front suggest a common trigger and can most plausibly be explained by powerful earthquakes that affected broad sections of the Teton fault. Our ongoing work aims to replicate this study at other piedmont lakes at GTNP.

✦ ACKNOWLEDGEMENTS

We thank the UW-NPS Research Station and staff for financial and logistical support; NPS personnel Kathy Mellander and Sue Consolo-Murphy for facilitating our research; and Devin Hougardy, Nigel Wattrus, Sarah Crump, Dion Obermyer, Chance Roberts, Simon Pendleton, Nick Weidhaas, Joseph Licciardi, and Bryan Valencia for field assistance.

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GEOPHYSICAL AND GEOMORPHOLOGICAL ANALYSIS OF THE TETON FAULT, WYOMING

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✦ SUMMARY

This investigation applied geophysical and geomorphological analyses of the Teton Fault to assess its geometry, history, and influences on landscape evolution. This project builds on results from a preceding geophysical study completed one year ago (Thackray et al. 2014), a recent study of fault scarp morphology (Thackray and Staley, in review), and years of previous studies of the fault by many practitioners.

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 fault scarp cuts into deglacial surfaces in several similar valleys; taking the average scarp height and assuming deglaciation 15,000 yr BP indicates an average postglacial offset rate of 0.87 m/ka (Thackray and Staley, in review). Because the fault is located almost entirely within the Great Teton National Park (GTNP) boundary, in remote and difficult terrain, very few subsurface evaluations of this fault have occurred. As a result, many uncertainties exist in the present fault characterization, including along-strike slip rate, down-dip geometry, and rupture history, among other parameters. Additionally, questions remain about the fault dip at depth.

The geomorphological component of this study focused on refinement of surficial geological mapping and fault scarp height measurements. Geomorphic mapping was accomplished using two existing LiDAR datasets: one collected by EarthScope (2008) and the other more recently by GTNP (2014). Bare-Earth data were processed to produce hillshade and slope angle maps, and DEMs were used to update previous fault-zone geomorphologic mapping and to measure vertical offset across the fault scarp (Thackray and Staley, in review). Samples were collected for cosmogenic radionuclide surface exposure dating on a high lateral moraine north of Taggart Lake, and on the deglacial surface cut by the fault scarp upvalley of Taggart Lake. We also examined soils and sediments in an extensive marsh at the upvalley end of Taggart Lake.

The geophysical component of this investigation included new, non-invasive 2D seismic surveys: P-wave (Vp) refraction and Interferometric Multi-Channel Analysis of Surface Waves (IMASW) (O'Connell and Turner 2011) depth-averaged shear wave velocity (Vs) at Taggart Lake and a site in Granite Creek near the Byrd (1995) trench location. This study also included the reprocessing of data collected at Taggart Lake in the previous study and re-evaluation of the interpreted results (Thackray et al., 2014). The shallow seismic surveys use a non-invasive portable data collection system to image the Teton fault zone, in an effort to provide a basis for estimating vertical offsets of buried faulted bedrock and alluvium.

The findings of this investigation show that surficial topographic scarp heights measured from GTNP (2014) LiDAR and buried velocity horizons imaged in Vp profiles at Taggart Lake and Granite Creek show similar offsets of ~12 – 13 m for post glacial deposits and surfaces. At Taggart Lake the approximate alluvial/bedrock contact was mapped from IMASW surveys, providing a basis for estimating the dip of the Teton fault dip (perhaps no less than 70°) in the upper 200 m. However, a high degree of uncertainty is associated with the top of rock depth picks due to their significant depth relative to the seismic survey length.

✦ STUDY AREA

This study evaluated two sites on the Teton fault within GTNP using shallow seismic survey methods (Figure 1). At the Taggart Lake and Granite Creek sites, 2D Vp refraction tomography and IMASW Vs data were collected across and parallel to the Teton fault scarp, respectively, to evaluate vertical offset and image the fault structure in the shallow subsurface. These sites were selected based upon several selection criteria: 1) on the main trace of the Teton fault, 2) simple fault geometry where all or most slip appears to be accommodated on a single strand, 3) sparse or open vegetation cover, 4) within hiking distance from the nearest trailhead, and 5) expectation of velocity contrasts created by slower alluvium in the hanging wall directly juxtaposing crystalline bedrock of the footwall, improving chances of successful imaging with seismic methods. Additionally, the Granite Creek site was chosen because it is the only location on the entire length of the Teton fault where a paleoseismic fault trench has been excavated (Byrd, 1995).

Taggart Lake

The Taggart Lake study site is located at the mouth of Avalanche Canyon, where a distinct north-striking Teton fault scarp 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 terminal moraines, which formed around the toe of the Pinedale-age alpine glacier that flowed eastward 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 Cosmogenic ages at Jenny Lake (Figure 1) from Licciardi and Pierce (2008) indicate glacial retreat from the range front 15,000 years ago (ages recalculated using current 10Be production rate by J. Licciardi, personal communication, 2015).

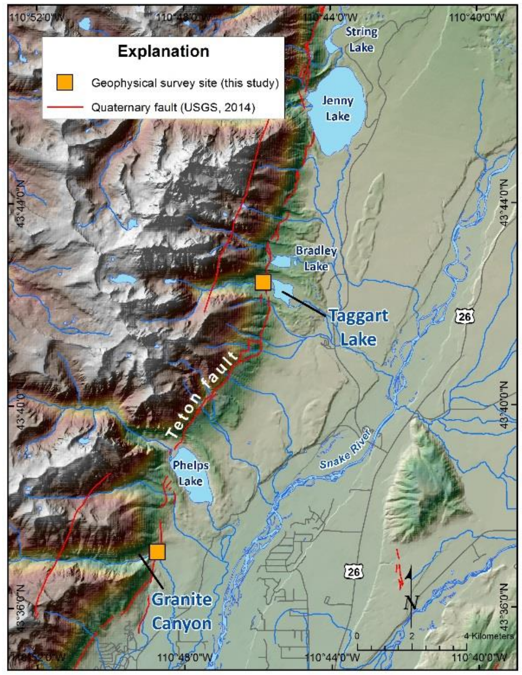

Figure 1. Location map

Figure 2. Oblique view of the Taggart Lake basin from Google Earth. The red arrow shows the approximate location of the Taggart Lake seismic survey, which crosses the Teton fault scarp cutting the deglacial surface, and yellow arrows show the Teton fault scarp on bounding lateral moraines.

Within the vicinity of the Taggart basin the organic soil. The glacial deposits are juxtaposed against layered gneiss and migmatite basement rocks (Love et al. 1992) exposed in the footwall. Teton fault has a northerly strike (~6°) and a distinct east-facing scarp. The fault vertically offsets the highest 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 west-dipping 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.

The high lateral moraine between Taggart and Bradley Lakes is vertically offset along a very distinct 27 m scarp, which indicates a longer record of surface faulting than do the lower scarps in basin sediments or the moraine south of Taggart Lake. The smaller moraine to the south is vertically offset 15.7 m, and the basin floor is vertically offset 12.4 m (Thackray and Staley, in review).

Preliminary cosmogenic radionuclide CRN exposure ages on moraine boulders from both sides of the scarp (Licciardi et al. 2015), indicate that the high lateral moraine predates the terminal moraines at Taggart Lake by several thousand years.

Granite Creek

The Granite Creek study site is located at the mouth of Granite Canyon within a wide basin enclosed by lateral and terminal moraines which formed around the toe of a Pinedale-age alpine glacier (Figures 1 and 4). The distinct east facing scarp of the Teton fault vertically offsets sedimentary deposits and the lateral moraines. Post-glacial slip appears to have been concentrated on a single fault trace that strikes 5° in the southern part of the basin to 0° in the middle and northern parts of the basin. The Teton fault scarp is most prominent 200 m to the north of Granite Creek where the synthetic scarp (13 m) and a smaller antithetic scarp (~1 m) are mapped (Figure 5). In the southern half of the Granite Creek basin the scarp has been either eroded or transformed into a fault-line-scarp due to erosion by Granite Creek, which parallels the scarp for several hundred meters. The only paleoseismic trench exposure of the fault was excavated by Byrd (1995) north of, and adjacent to, Granite Creek (Figure 5).

Inferred sedimentary deposits within the basin include dense glacial sediment (denoted here as till and outwash), Taggart Creek fluvial deposits, colluvium, and organic soil. The glacial deposits are juxtaposed against uplifted Late Archean Rendezvous Metagabbro (Love et al. 1992) exposed in the footwall.

✦ METHODS

We collected seismic data using a DAQ Link-II seismograph with 24 geophone channels spanning 92 m and 10 Hz vertical-component geophones at 4 m spacing. An aluminum strike plate and 12-lb dead-blow hammer were used for active sourcing. This portable system was packed into each site on foot.

At the Taggart and Granite sites, seismic Vp refraction surveys spanning the fault were oriented orthogonal or near-orthogonal to the local fault strike ("dip lines"). IMASW Vs lines intersected the refraction lines and were oriented approximately parallel to local fault strike scarp ("strike lines") (Figure 3 and 5). The Vp refraction dip lines imaged the 2D cross section of the fault and vertically offset geologic units, and the Vs strike lines are intended to constrain fault dip by imaging the more deeply buried bedrock/alluvial contact that characterizes the Teton fault at depth fault.

At the Taggart Lake site, we collected a single IMASW survey (TLVs-03) on the footwall of the topographic scarp formed by the Teton fault. This survey intersected the Taggart Lake refraction survey (TL-01), collected in 2014 (Thackray et al. 2014), near the former channel 1 location (Figure 3). IMASW survey data for lines TLVs-01 and TLVs-02, collected in 2014 (Thackray et al. 2014) were reprocessed for this effort, providing better resolution of the bedrock / alluvium contact at depth.

At the Granite Creek site we collected two overlapping seismic refraction surveys (GC-01 and GC-02) and one IMASW survey (GCVs-01) (Figure 5). The refraction survey lines were oriented ~N90E and extended from the footwall, over the 13 m high Teton fault scarp and smaller (~1 m) antithetic fault scarp, and onto the hanging wall. The center of refraction survey GC-01 was located approximately over the base of the scarp so that half of the survey was located on the footwall (and scarp) and half on the hanging wall. Refraction survey GC-02 was located entirely on the hanging wall. The two refraction surveys had a 6 channel- 20 m overlap. The single IMASW survey (GCVs-01) was oriented approximately parallel to the immediately local fault strike (~0°) and intersected the refraction survey line on the hanging wall approximately 40 m east of the scarp. Granite Creek Vp refraction data (GC-01 and GC-02) were processed using Rayfract software. IMASW Vs data were processed using Fugro Consultant's in-house IMASW processing software (O'Connell and Turner 2011).

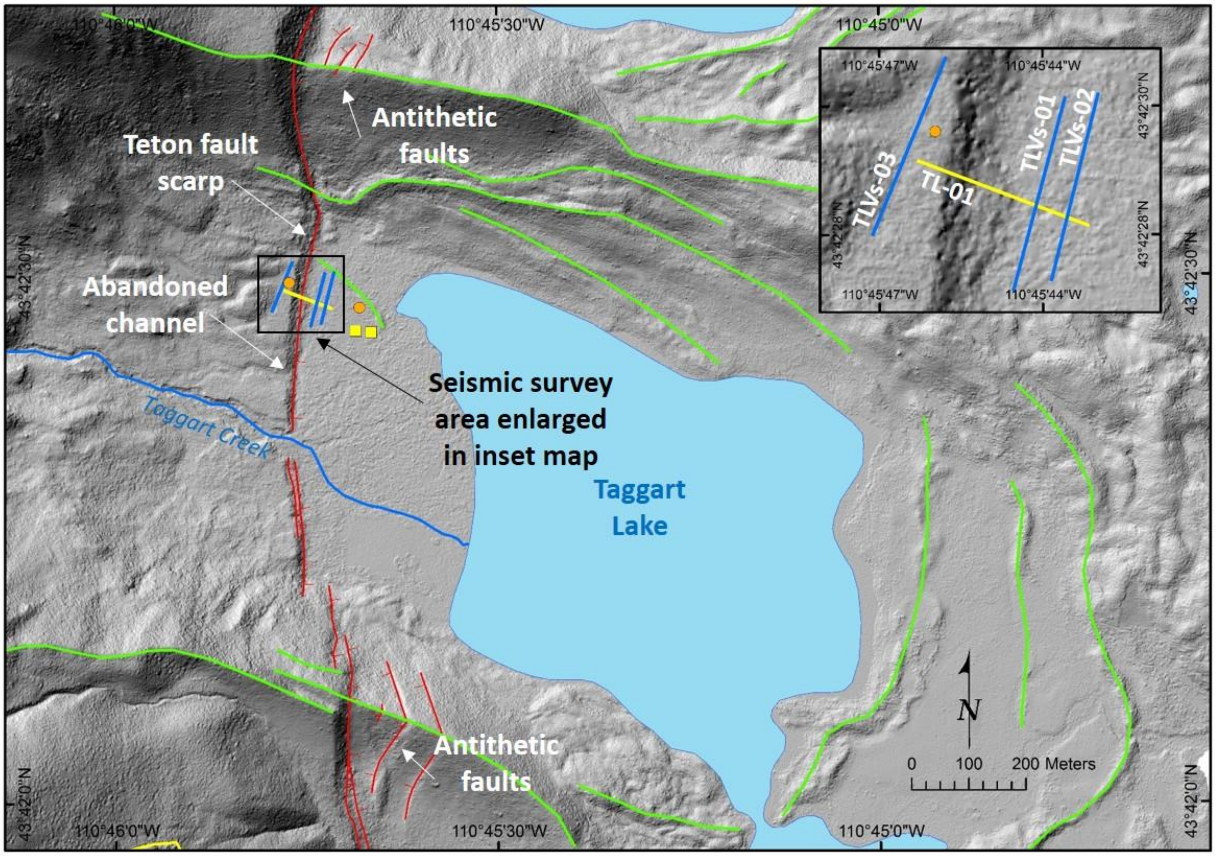

Figure 3. The Taggart Lake study site showing the Teton fault scarp (red lines), moraine crests (green lines), refraction survey (yellow line), IMASW surveys (blue lines), and cosmogenic (orange dot) and radiocarbon (yellow square) sample sites. LiDAR hillshade basemap derived from GTNP (2014) LiDAR.

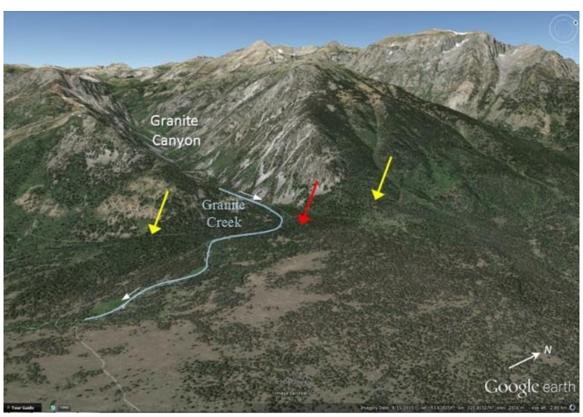

Figure 4. Oblique view of Granite Creek basin from Google Earth. Yellow arrows show the Teton fault scarp on bounding lateral moraine crests. Red arrow shows the approximate location of Granite Creek seismic survey and Byrd (1995) and Byrd et al. (1994) paleoseismic site.

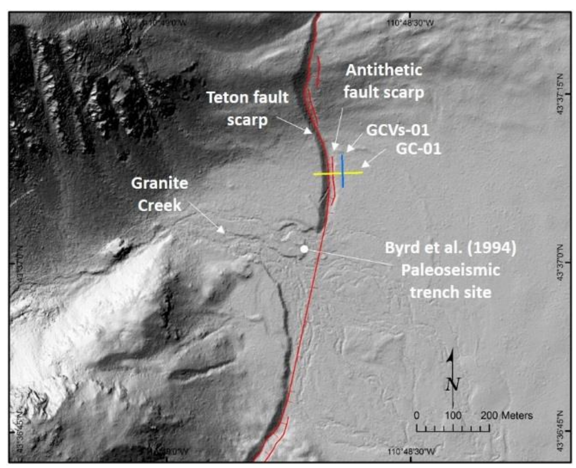

Figure 5. The Granite Creek study site showing the Teton fault scarp (red lines), refraction survey (yellow line), IMASW survey (blue line), and the location of the Byrd (1995) and Byrd et al. (1994) paleoseismic study site are shown. LiDAR hillshade basemap derived from GTNP (2014) LiDAR.

✦ RESULTS

Shallow 2D P-wave refraction profiles and IMASW Vs *vs.* Depth plots from both the Taggart Lake and Granite Creek 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 in the shallow subsurface. The subsurface is not constrained with borehole data or any empirical measurements at these locations, so interpretations are based on geologic and geomorphic context and correlation charts for relating Vp and Vs to material (Table 1.).

In this report we present IMASW Vs-depth plots for IMASW surveys TLVs-01, TLVs-02, TLVs-03, and GCVs-01 (Figure 6). Each plot is presented in 1 of 3 different formats. The reason for the variability in appearance is because different processing scripts were applied to account for unique site conditions between the different surveys, and because the data were plotted at different times throughout a software update phase. Though the appearance may be variable from figure to figure, the data results are consistent. Plots of these data in subsequent presentations will apply a consistent and standardized format.

Type of Material	P wave velocity (Vp)(m/s)	S wave velocity (Vs)(m/s)
Scree, Vegetal soil	300-700	100-300
Dry sands	400-1200	100-500
Wet sands	1500-2000	400-600
Granite	4500-6000	2500-3300
Gneiss	4400-5200	2700-3200

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

Taggart Lake

At Taggart Lake a total of 3 IMASW surveys have been collected (Figure 3). One IMASW survey (TLVs-03) was acquired in 2015 on the Teton fault footwall, and two IMASW surveys (TLVs-01 and TLVs-02) were collected in 2014 on the fault hanging wall (Thackray et al. 2014). As part of this study, the 2014 survey data has been reprocessed and re-interpreted with TLVs-03 to estimate the depth to crystalline bedrock and fault characteristics in the shallow subsurface.

Each of the Vs-depth plots (TLVs-01, TLVs-02, and TLVs-03) (Figure 6) show distinct Vs inflections that are interpreted to be transitions between geologic units and material types (i.e., alluvium, till, crystalline bedrock). At Taggart Lake, we interpret the shallow, slow (Vp <1500 m/s / Vs ≤ 500 m/s) velocity zone to be a mantle of unconsolidated post-glacial alluvial and organic material overlying glacial outwash and till (Vs >500 m/s and < ~2000 m/s, and Vs > ~2000 m/s to be crystalline bedrock.

IMASW surveys TLVs-01 and TLVs-02 (Figure 6) show a pronounced increase in Vs at ~220 m depth (+/- 35 m), which is interpreted to be associated with the bedrock/alluvium contact. The uncertainty associated with the depth of the Vs increase is high (>%20) because the depth more than twice the length of the survey length (92 m). At IMASW survey TLVs-03 (Figure 6) the bedrock alluvial contact is estimated to be at a depth of 70 – 80 m depth.

Granite Creek

At Granite Creek the two overlapping seismic refraction surveys, GC-01 and GC-02, spanned the Teton fault scarp north of the Byrd (1995) trench site and imaged the fault zone and both the hanging wall and footwall to depths of approximately 20-30 m (Figures 5). The refraction profile shows a layered velocity structure that is vertically offset across the Teton fault (Figure 7).

The measured vertical offset of velocity contours (i.e., ~1000 m/s) is measured to be approximately 13 m, which is equivalent to the measured vertical height of the topographic scarp at this location (13 m), inferred by Thackray and Staley (in review) to have developed since deglaciation, ca. 15,000 years ago. The single IMASW survey (GCVs-01) intersected the seismic refraction profile at a point ~40 m east of the base of the scarp. The Vs *vs.* Depth plot for GCVs-01 (Figure 6) shows a low velocity zone (<500 m/s) at depths shallower than 7 m. Between 7 m and ~11m Vs increases to ~800 m/s which is maintained to a depth >40 m, which was our maximum depth resolution at this site.

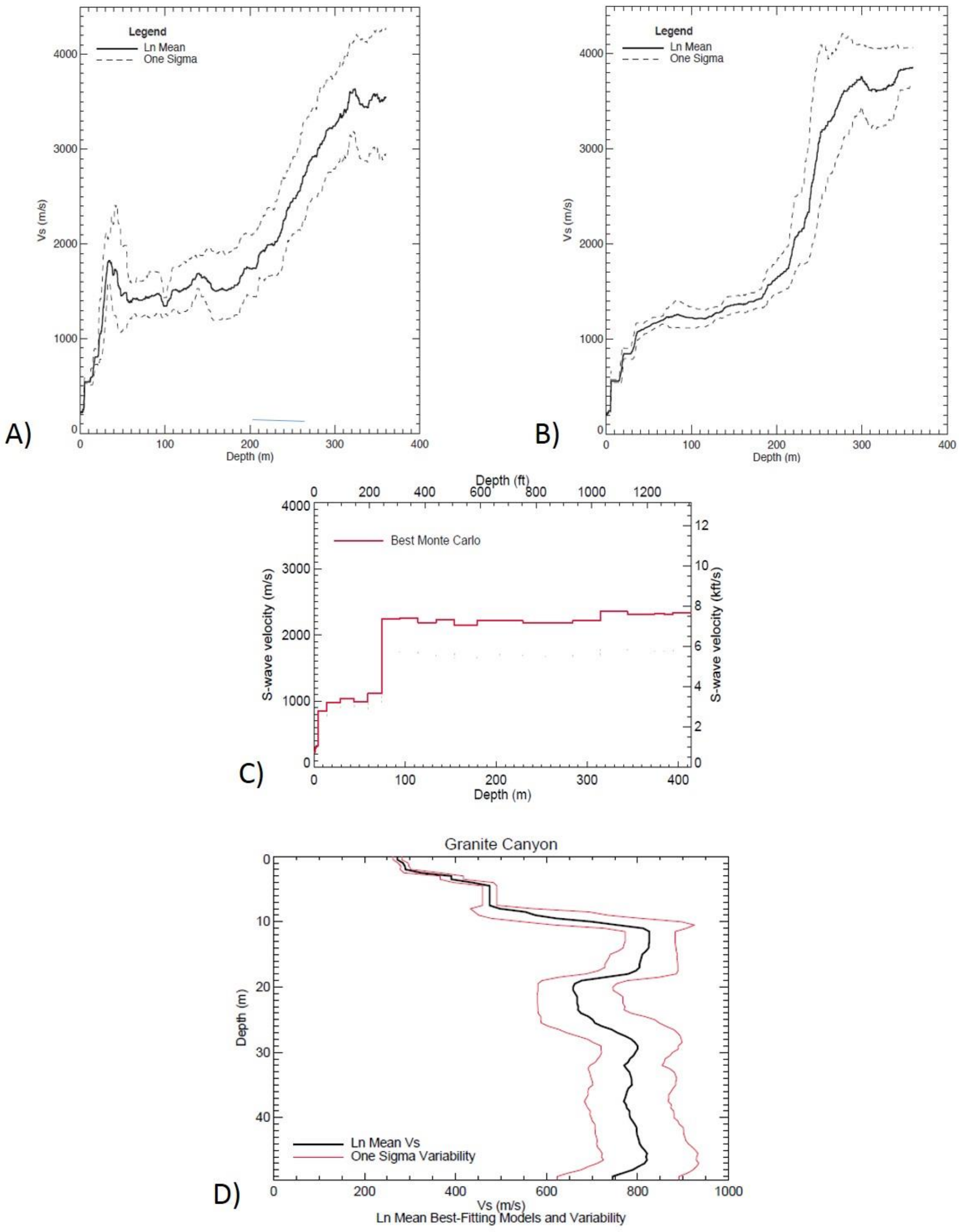

Figure 6. IMASW Depth *vs.* Vs profiles for Taggart Lake IMASW surveys (A) TLVs-01, (B) TLVs-02, and (C) TLVs-03, and Granite Creek IMASW survey (D) GCVs-01. See text for explanation of contrasting profile styles, and note that the axes are reversed in D. See Table 1 for relative velocities in contrasting materials.

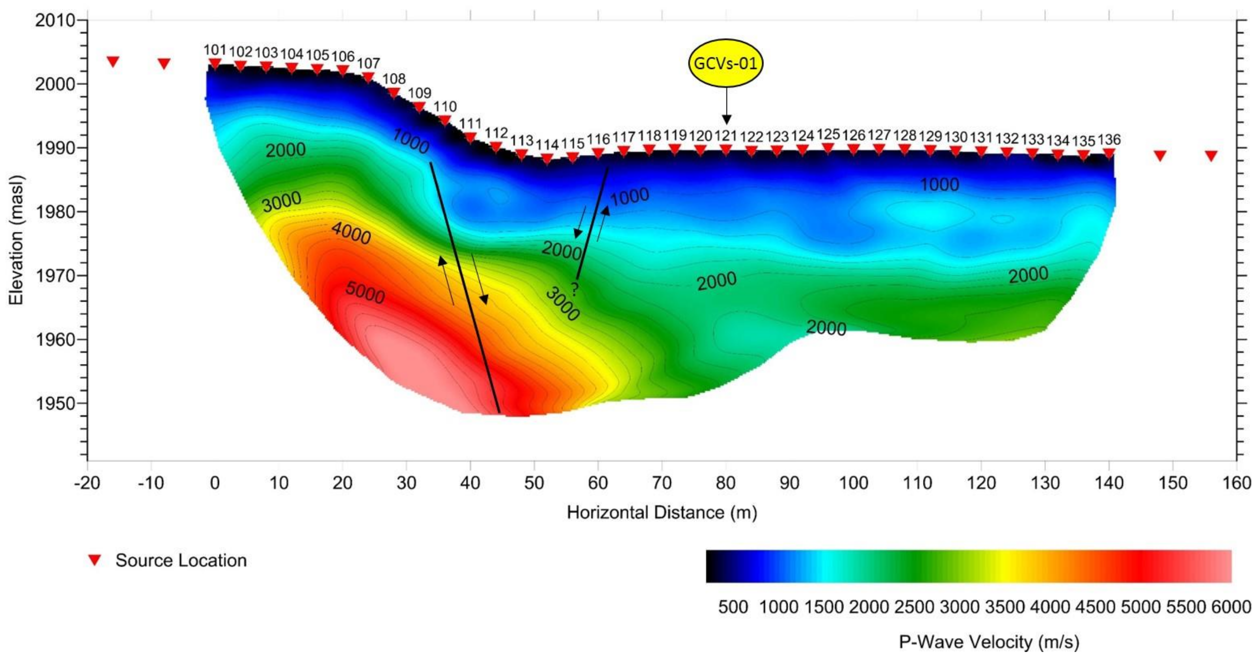

Figure 7. Granite Creek 2D P-wave refraction profile with fault interpretations. The intersection point of IMASW survey GCVs-01 is indicated.

At Granite Creek, we interpret the shallow, slow (Vp <1500 m/s / Vs ≤ 500 m/s) velocity zone to be a mantle of unconsolidated post-glacial alluvium and organic cover overlying glacial outwash and till (Vs > 500 m/s). A Vs indicative of crystalline bedrock (>2000 m/s) was not observed within the resolution of the data at this site.

Figure 8 shows a conceptual structural schematic of the subsurface at the Taggart Lake study site. The Teton fault zone is shown as a wedge to convey uncertainty in location with depth. The wedge is defined by planes that are projected between the location of the Teton fault at the ground surface, estimated from the 2D P-wave tomography and surficial mapping (Thackray et al. 2014), and the 1-sigma uncertainty zones associated with the TLVs-01 and TLVs-02 depth picks. The estimated depth to top of bedrock for TLVs-01 and TLVs-02 suggest the Teton fault dips at least 70°, to a depth of ~220 m. This dip estimate is steeper than the ~63° dip previously estimated in Thackray et al. (2014, Figure 12). This revised estimate is viewed as preliminary and subject to change based on additional information and model refinement.

✦ CONCLUSIONS

Shallow seismic surveys at Taggart Lake and Granite Creek spanned the Teton fault and imaged the fault zone in the subsurface with 2D P-wave refraction surveys and IMASW Vs surveys. These surveys provide information that is useful for evaluating the shallow subsurface fault geometry and for estimating the total vertical faulted offsets since deglaciation. However, this study did not include empirical subsurface data (such as a borehole) and, as such, the geophysical data provide best available estimates.

At Granite Creek, ~12-13 m of vertical offset across the Teton fault is measured from the interpreted buried deglacial surface from 2D P-wave seismic profiles (Figure 6). This estimate is similar to the measured height of the topographic scarp at the same location (13 m), and therefore suggests that the topographic scarp in some locations can provide a reasonable estimate for post-glacial faulted offsets. Our analysis at Taggart Lake in 2014 provided similar findings (Thackray et al. 2014). The subsurface fault offset is estimated at 13 m, which is similar to the 12.4 m vertical scarp height at the site from Thackray and Staley (in review).

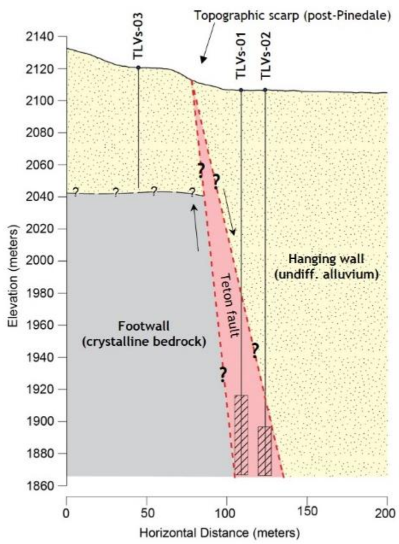

Figure 8. Conceptual structural schematic of the Teton fault at depth in Taggart Lake basin based on IMASW surveys TLVs-01, TLVs-02, and TLVs-03. The Teton fault is shown as a wedge to depict increasing uncertainty of geometry and location with depth. Hachured boxes at base of IMASW survey profile line represent 1-sigma uncertainty zone for estimated depth to top of rock.

The measured depth to crystalline bedrock on the Teton fault footwall at Taggart Lake remains uncertain due to a lack of boreholes or other direct observations. However, IMASW surveys (TLVs-01, TLVs-02, and TLVs-03) provide reasonable estimated for contact depth. TLVs-03 (Figure 6) encountered what we interpret to be the top of crystalline bedrock at a depth of ~70-80 m (i.e., Teton fault footwall) based on an abrupt increase from ~Vs 1000 m/s to ~Vs 2100 m/s (Figure 6). The nature of the interpreted bedrock contact in the footwall survey (TLVs-03) is unknown, but because of its location on the footwall in a previously glaciated valley this contact is interpreted to be erosional. In TLVs-01 and TLVs-02 the bedrock/alluvial contact is interpreted to be faulted (Figure 8) at a depth of ~220 m (+/- 35 m) (Figure 6), and we estimate fault dip of at least 70° to a depth of 220 m.

✦ ACKNOWLEDGEMENTS

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Research Project Reports

Ecology

INTRODUCED AMERICAN BULLFROG DISTRIBUTION AND DIETS IN GRAND TETON NATIONAL PARK

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✦ SUMMARY

Introduced American Bullfrogs (*Lithobates catesbeianus*) have been present in Grand Teton National Park since approximately the 1950s, but little is known about their distribution and potential impacts. In this study, we surveyed the current bullfrog distribution and spatial overlap with sympatric native amphibians in the park, and characterized post-metamorphic bullfrog diets from July – September 2015. Despite surveys in multiple large rivers and floodplain habitats, we only documented bullfrogs in a geothermal pond and 5 km of stream channel immediately downstream of this pond. In these waters, bullfrogs overlapped with native amphibians at the downstream end of their distribution, and we did not document native amphibians in bullfrog stomach contents. Larger bullfrogs (SVL $\geq$ 96 mm) primarily consumed native rodents (especially meadow voles, *Microtus pennsylvanicus*), while smaller bullfrogs frequently consumed native invertebrates and less frequently consumed non-native invertebrates and fish. Taken together, these data indicate that the distribution and implications of the bullfrog invasion in Grand Teton National Park are currently localized to a small area, so these bullfrogs should therefore be vulnerable to eradication.

✦ INTRODUCTION

Introduced American Bullfrogs (*Lithobates catesbeianus*; hereafter, bullfrog) are suspected in the decline of native amphibian populations through predation, depletion of food resources and disease spread (Kiesecker and Semlitsch 2003, Kupferberg 1997, Miaud et al. 2016). Bullfrogs can also have large food web impacts because they are generalist predators. Documented bullfrog prey include invertebrates, reptiles, amphibians, fish, birds, bats, and small mammals (Kiesecker and Semlitsch 2003, Pearl et al. 2004, Wu et al. 2005). Once established, bullfrogs are difficult to eradicate because they can persist at low densities, have high fecundity and negative density dependence, and can disperse through water or overland (Doubledee et al. 2003, Govindarajulu et al. 2005, Adams and Pearl 2007, Peterson et al. 2013).

Bullfrogs are now distributed around much of the US and southern Canada, though their native range is eastern North America (Bury and Whelan 1984). They often occur in temperate and warm permanent water bodies, but their large native and introduced ranges indicate a wide environmental tolerance. Original introductions to western North America occurred more than 100 years ago, when bullfrogs were cultivated for human consumption and escaped from captivity (Jennings and Hayes 1985). More recent introductions can be traced to aquarium dumping, pest (mosquito) control, fishing bait, and hunting (Jennings and Hayes 1985, Boersma et al. 2006, Adams and Pearl 2007). Bullfrogs are now present in western national parks, including Yosemite in California (Drost and Fellers 1996), Big Bend in Texas (Dayton and Skiles 2007), and Grand Teton in Wyoming (Patla and Peterson 2004), which function as important havens for native species. Because invasive species' impacts can be permanent and irreversible (Vander Zander and Olden 2008), they threaten the National Park Service mission to manage park resources as "unimpaired for the enjoyment of future generations".

Here, we report the distribution of bullfrogs, their overlap with one of the native amphibians, and stomach contents of post-metamorphic bullfrogs in Grand Teton National Park. Our goals are to define the spatial extent of the invasion of this non-native species, identify which prey taxa in Grand Teton National Park may be vulnerable to the consumptive effects of bullfrogs as predators, and describe the relative contribution of native and non-native prey to its diet. Knowledge about the distribution and potential effects of bullfrogs is needed to prioritize control efforts for them relative to other looming conservation issues faced by national parks.

Bullfrogs were first documented in the 1950s in Kelly Warm Spring (hereafter, KWS), a geothermal pond near the Park's southeastern border (Figure 1; Patla and Peterson 2004). Bullfrogs are now established in KWS and in Savage Ditch (hereafter, SD), the irrigation canal that drains KWS (Figure 1). Bullfrogs have also been reported in waters on the park's southern boundary (Lake Creek irrigation canal), but these reports have not been confirmed (personal communication, K. Mellander, Grand Teton National Park). Because KWS and SD are hydrologically connected and adjacent to other freshwater habitats (e.g., the Snake River and Gros Ventre River [Figure 1]), there is potential for bullfrog spread into these waters which also provide habitat for the park's four native amphibians: Columbia spotted frog (*Rana luteiventris*), western tiger salamander (*Ambystoma mavortium*), western toad (*Anaxyrus boreas*), and boreal chorus frog (*Pseudacris maculata*) (Ray et al. 2014). Bullfrog overlap with these native amphibians would be of concern since bullfrogs have been implicated as a factor in native amphibian declines throughout the West (Hayes and Jennings 1986, Kiesecker et al. 2001, Pearl et al. 2004).

✦ METHODS

Study area

We conducted this study in valley bottom habitats within the southern section of Grand Teton National Park (Figure 1). This area is atypical bullfrog habitat because it is high elevation (~2000 m) and has long, cold winters with 440 (±129 SD) cm of snow annually (NCDC COOP Station 486428). Summer air temperatures are cool (5 – 27 °C), with occasional drops to below freezing. The Snake River flows north to south through the western portion of this valley, while the Gros Ventre River flows northeast to southwest along the park's southern border.

We focused our diet study in the KWS complex, an approximately 60 × 90 m geothermal pond located on the eastern perimeter of Grand Teton National Park (12N 530948, 483189 UTM; elevation 1989 m). This pond is heavily visited and park-goers have released multiple non-native aquarium species that have successfully established. These include goldfish (*Carrasius auratus*), convict cichlids (*Archocentrus nigrofasciatus*), swordtails (*Xiphophorus hellerii*), guppies (*Poecilia reticulata*), tadpole madtoms (*Noturus gyrinus*) and red-rimmed melania snails (*Melanoides tuberculata*). The KWS complex is less than 1 km overland from the Gros Ventre River, and is hydrologically connected to Ditch Creek, which flows into the Snake River less than 10 km away (Figure 1).

Riparian vegetation along the KWS shoreline consists of willows, grasses, and shrubs with little overhanging canopy cover. A small portion (~15 m) of the perimeter is bare due to human and wildlife trampling of vegetation. From July through September 2015, dense mats of floating algae covered approximately half of the water's surface. During this same season, water temperatures ranged from 20-30° C depending on distance away from the geothermal inputs. Soft-bottomed substrate (e.g., mud and silt) dominated the habitat, though gravel and small cobbles occurred near the geothermal inputs. Maximum pond depth was 1.3 m, but 60% of the pond was less than 0.5 m.

Savage Ditch drains KWS and flows west/northwest along the valley floor and was built to supply irrigation to local hayfields and pastures prior to park designation (Marlow and Anderson 2011). Riparian vegetation bordering the ditch is dominated by sagebrush (*Artemisia tridentata*), with no overhanging canopy cover. From July through September 2015, water temperatures ranged from 17-28º C. Substrate varied from soft-bottomed mud to cobble embedded in silt. Water depths (n = 105 point measurements) ranged from 0.1 – 0.6 m across our surveyed area.

Field sampling

Bullfrog Distribution -- We used daytime visual and dip-net surveys (Thomas et al. 1997) to describe the bullfrog distribution in Grand Teton National Park during three time periods: 14–16 August 2014, 7 July 2015, and 17–22 August 2015. For surveys, we walked along the water's edge, visually scanned the water and shore, and made dip-net sweeps once every three steps to determine the presence of egg, larval, metamorphic, and post-metamorphic bullfrogs and native amphibians between 08:00 and 20:00 hours (Sepulveda et al. 2015a). For August 2015 surveys, we used a dual-observer approach to estimate

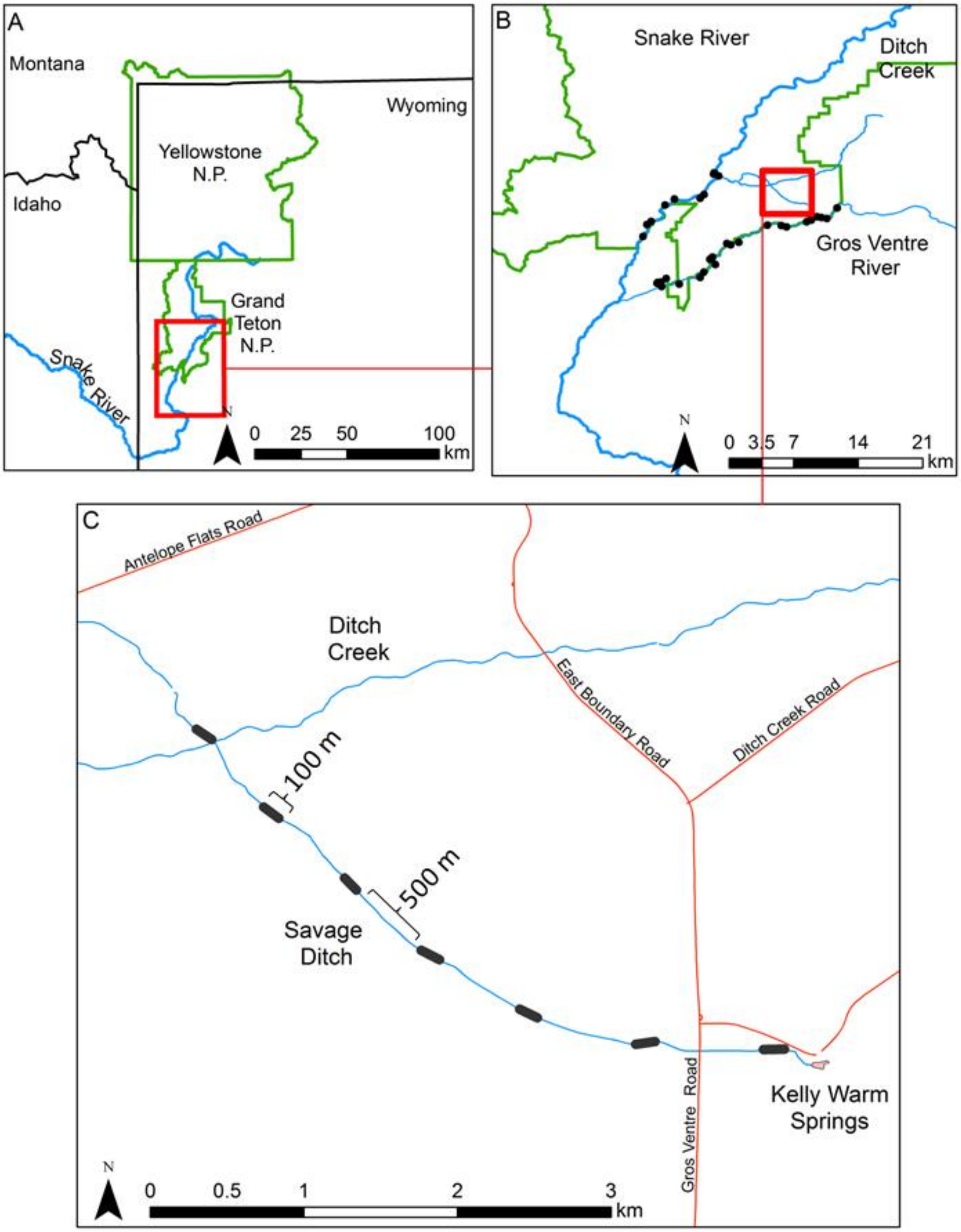

Figure 1. Location of American Bullfrog survey sites in Kelly Warm Spring, Savage Ditch, the Gros Ventre River, and the Snake River in and near Grand Teton National Park, WY (A). Filled circles in panel B are locations of surveys for bullfrogs. Thick black lines in panel C show reach locations and lengths for bullfrog abundance and diet studies in Savage Ditch.

detection probability in a single visit, where two independent surveys were conducted at each site by two trained observers on a single visit (Gould et al. 2012). Safety concerns (e.g., wildlife) necessitated surveying during daylight hours. Diurnal surveys are effective at detecting eggs, tadpoles, and recent metamorphs (e.g., Gould et al. 2012, Sepulveda et al. 2015a), but nocturnal surveys can be more effective for detecting post-metamorphic ranid frogs (Fellers and Kleeman 2006).

During all three time periods, we surveyed (1) the entire perimeter of KWS, (2) the entire length of SD from its source to the Antelope Flats Road, (3) 1 km upstream and downstream of the Ditch Creek confluence with SD, and (4) backwaters of the Gros Ventre River proximate to KWS (Figure 1). In August 2015, we added surveys of randomly selected backwater and side channel habitats of the Gros Ventre River and Snake River (Figure 1). The park border delineated the upstream and downstream boundary for the Gros Ventre River survey. In the Snake River, the upstream boundary was 5 km upstream of the Ditch Creek mouth and the downstream boundary was the park border. We based the Snake River upstream boundary on the assumption that Ditch Creek is the likely movement corridor for bullfrogs. Within this study frame, we used the National Wetlands Inventory layer and aerial imagery to identify lacustrine, palustrine, and riverine wetland habitat types associated with each river (Cowardin et al. 1979, USDI Fish and Wildlife Service 2012). We then used a random tessellation approach to select 25 sites in each river (e.g. Sepulveda et al. 2015a).

Bullfrog Diet -- We observed bullfrogs in KWS and SD in August 2014 and July 2015 surveys, so we collected post-metamorphic bullfrogs (i.e., individuals with four legs and no tail) in these two habitats. To capture bullfrogs for diet analyses, we used a Smith-Root LR-24 backpack electrofisher (250–300 V, pulsed DC; Smith-Root; Vancouver, WA) to shock bullfrogs around the shore of KWS and in seven reaches in SD; reaches were 100 m long and separated by 500 m (Figure 1). We located our SD sampling reaches starting at the most downstream point where we had previously observed bullfrogs (100 m downstream of where SD intersects Ditch Creek; UTM 12 T 528040, 4834000 N). For KWS, we focused electrofishing efforts within 2 m of the shore. For SD reaches, we sampled in an upstream direction and focused electrofishing efforts within 2 m of each bank. Within KWS and each reach, we sampled for post-metamorphic bullfrogs within three discrete time periods: 14-16 July, 20-21 August, and 29 September – 1 October 2015. Temporal sampling allowed us to make inferences about seasonal differences in diet. Due to safety concerns, all electrofishing occurred during daylight hours.

We measured bullfrog snout-vent-length (SVL; mm) with calipers and we recorded their wet weight (g) with a handheld spring scale. We did not attempt to distinguish between juveniles and adults, as this can be difficult without dissection and size alone is not a consistent predictor. In July and August, we used gastric lavage to sample stomach contents from a random subset of up to 15 post-metamorphic bullfrogs in each reach and in KWS. The random subset was selected in proportion to the observed size distribution of all post-metamorphic bullfrogs captured in each reach and KWS. Because the number of stomachs that could be analyzed was constrained by resources, these steps helped to ensure spatial representation of bullfrog diets across a gradient of bullfrog SVLs. For any bullfrogs that died during capture or handling, we excised stomachs to verify that gastric lavage removed all stomach contents. We released bullfrogs near the middle of their respective reaches. In September 2015, we sacrificed all bullfrogs and removed a representative subset of their stomachs. All stomachs and stomach contents were stored in ethanol until analyses by Rhithron Associates (Missoula, Montana), who identified prey items to the lowest possible taxonomic unit and measured blotted wet weights.

Analyses

For August 2014 and July 2015 surveys, we reported bullfrog and native amphibian occurrence as presence only since we did not estimate survey-specific detection probabilities. No bullfrogs were observed during the August 2015 dual-observer surveys so we did not estimate occupancy probabilities.

Based on observed diets, we *a posteriori* binned bullfrogs into three categories for diet analyses: (1) those with only invertebrates in their stomach contents and (2) those that also had aquatic vertebrates and/or (3) terrestrial vertebrates (Table 1). We assumed that these categories helped standardize comparisons by accounting for ontogenetic constraints, such as gape-width limitations (Werner and Gilliam 1984, Werner et al. 1995). We then used two-way analysis of variance (ANOVA) to test if bullfrog SVL (log-transformed) differed by these three ontogenetic categories, by month, and by the interaction of ontogenetic categories and month. All parametric statistical assumptions could not be satisfied because so few bullfrogs consumed aquatic vertebrates each month, so we confirmed our analyses

Table 1. American Bullfrogs whose stomachs contained only invertebrates and those that also contained aquatic vertebrates and terrestrial vertebrates, their corresponding snout-to-vent lengths (SVL), and number sampled during July, August, and September 2015 in the Kelly Warm Spring complex of Grand Teton National Park, Wyoming.

	SVL (mm)		Month			
Diet category	Mean (± 1SE)	Range	Jul	Aug	Sept	*total*
Invertebrate	64 (2)	21 – 140	18	27	29	74
Aq. vertebrate	72 (6)	50 – 96	3	3	2	8
Ter. vertebrate	120 (6)	96 – 153	2	10	2	14

using Wilcoxon nonparametric comparisons. Parametric and nonparametric results were in concordance, so we only report results of the two-way ANOVA tests.

We additionally used the Amundsen modified-Costello method (1996) to assess the contribution of prey to bullfrog diets within each ontogenetic category. Prey were pooled into taxonomic categories for analysis. We pooled invertebrates by order, fish by species, amphibians by family and small mammals by superfamily (Table 2). Heavily digested items that could not be resolved to a prey category were not included in analyses. We calculated the prey-specific abundance (PSA_i) and the percent occurrence ($\%O_i$) for each prey category (i) as follows:

$$PSA_i = 100 \times \frac{\sum S_i}{\sum S_{ti}}$$

$$\%O_i = 100 \times \frac{J_i}{P}$$

where S_i equals the wet mass of prey i in stomachs, S_{ti} equals the total wet mass of prey in predators that contain prey i. Percent occurrence, O_i , equals the number of bullfrogs (J) containing prey i divided by the number of frogs with food in their stomachs (P). To explore patterns of relative prey category importance for each month, we constructed bivariate plots of PSA_i versus $\%O_i$. When plotted in this fashion, graphical techniques can be used to evaluate relative prey dominance and the degree of homogeneity of the diet (Amundsen et al. 1996, Chipps and Garvey 2007).

✦ RESULTS

Bullfrog distribution

In August 2014, we observed all stages of bullfrogs in KWS, including two egg masses. In SD, we observed post-metamorphic bullfrogs up to 1.7 km downstream of KWS and bullfrog larvae up to 5 km downstream. No bullfrogs were observed in surveyed habitats within Ditch Creek or the Gros Ventre River.

In July 2015, we observed all stages of bullfrogs in KWS including one egg mass. In SD, we documented post-metamorphic bullfrogs 3.6 km downstream of KWS and bullfrog larvae 5 km downstream of KWS. We also observed two post-metamorphic bullfrogs in Ditch Creek, ~30 m downstream of the SD crossing. We did not observe bullfrogs in surveyed habitats in the Gros Ventre River. In August 2015, we did not observe any bullfrogs in surveyed habitats in Ditch Creek, the Gros Ventre River, or the Snake River.

The western toad was the only native amphibian species we observed in habitats where bullfrogs occurred. During all survey periods, we documented presence of western toad larvae, metamorphs and post-metamorphs in SD, immediately downstream of the crossing. We also documented presence of toad metamorphs and post-metamorphs in Ditch Creek, immediately downstream of the crossing. We did not observe toads or the other three native amphibian species in other surveyed sites.

Bullfrog diet

We lavaged the stomach contents of 112 bullfrogs across our sampling periods (Table 1). Sixteen bullfrogs had empty stomachs, so we used the remaining 96 individuals for diet analyses. The size distribution of bullfrogs used in diet analyses was comparable to the size distribution of all bullfrogs captured (Figure 2). We dissected stomachs from four bullfrogs in July, three bullfrogs in August and three bullfrogs in September and found gastric lavage successfully removed all visible stomach contents.

Seventy-four of the 96 individuals with discernable prey items in their stomachs only consumed invertebrates, while eight individuals also consumed aquatic vertebrates, and 14 individuals also consumed terrestrial vertebrates (Table 1). Diet composition differed significantly by bullfrog SVL ($F_2 = 38.80$, $P < 0.01$). Bullfrogs that consumed terrestrial vertebrates were significantly larger than bullfrogs in the other two ontogenetic categories, while bullfrogs that consumed aquatic invertebrates were not

Table 2. Prey-specific abundance by weight (PSA_i) and percent occurrence (O_i) of prey in the stomach contents of American Bullfrogs whose stomachs contained only invertebrates (A) and those that also contained aquatic vertebrates (B) and terrestrial vertebrates (C) from the Kelly Warm Spring complex in Grand Teton National Park, Wyoming in July, August and September 2015. Dashed lines indicate values that were less than 1%.

		A						B						C					
		PSA_i			O_i			PSA_i			O_i			PSA_i			O_i		
		Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep
Inverte-brate	Araneae	6	1	3	50	26	24	3	-	-	67	67	-	-	-	-	-	40	-
	Coleoptera	28	4	12	72	30	45	6	-	2	67	33	50	-	-	-	-	-	-
	Dermaptera	4	-	-	28	7	-	-	-	-	-	-	-	-	-	-	-	10	-
	Diptera	7	34	7	39	44	66	-	6	-	-	100	50	-	-	-	-	10	-
	Hemiptera	2	-	-	28	33	10	1	-	-	33	-	100	-	-	-	-	20	-
	Hymenoptera	11	3	2	39	44	38	-	3	-	33	33	50	-	-	-	-	10	-
	Lepidoptera	5	1	3	6	7	17	18	3	-	67	33	100	-	-	-	-	30	-
	Lymnaeidae	2	-	-	22	-	3	-	-	-	-	-	-	-	-	-	-	10	-
	Odonata	16	48	3	11	19	10	-	-	11	-	33	50	-	-	-	-	-	-
	Orthoptera	4	4	-	6	11	-	-	-	-	-	-	-	-	1	-	-	10	-
	Physidae	7	-	17	6	-	7	-	-	-	33	-	-	-	-	-	-	10	-
	Planorbidae	4	1	44	6	7	34	3	-	12	33	-	50	-	-	-	-	10	-
	Succineidae	5	1	-	22	11	-	-	-	-	-	33	-	-	-	-	-	-	-
	Thiaridae	-	3	10	6	19	21	-	-	-	33	-	-	-	-	-	-	-	-
	Thysanoptera	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
	Other	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	10	-
Fish	*N. gyrinus*	-	-	-	-	-	-	-	83	-	-	33	-	-	-	-	-	-	-
	X. hellerii	-	-	-	-	-	-	6	-	-	33	33	-	-	-	-	-	-	-
	Other	-	-	-	-	-	-	64	4	24	67	33	50	-	-	-	-	10	-
Amphibian	Ranidae	-	-	-	-	-	-	-	-	51	-	-	50	-	-	-	-	-	-
Mammal	Muroidea	-	-	-	-	-	-	-	-	-	-	-	-	100	98	100	100	100	100

significantly larger than those that only consumed invertebrates (Tukey HSD; Table 1). These relationships did not vary by month ($F_2 = 1.35$, $P = 0.26$).

For the bullfrogs that only consumed invertebrates, the types of consumed invertebrates varied among individuals and sampling periods (Table 2). In July, bullfrog diets had high within individual variation (i.e., low PSA_i and high O_i; Figure 3). Most individuals consumed a variety of invertebrates, especially adult life stages of beetles (Tenebrionidae), ramshorn snails (Planorbidae), and spiders (Araneae).

In August, bullfrogs demonstrated high between individual variation (i.e., high PSA_i and low O_i; Figure 3). A few individuals had high PSA_i for dragonfly adults (Anisoptera) and hoverfly adults (Syrphidae), but most individuals had low PSA_i for multiple orders of invertebrates. In September, bullfrogs displayed a specialist feeding strategy (i.e., high PSA_i and high O_i; Figure 3) on ramshorn and bladder snails (Physidae).

Few bullfrogs consumed aquatic vertebrates each month (Table 1). In July and August, the six sampled bullfrogs specialized on tadpole madtom fish but invertebrates were rare prey items (i.e., low PSA_i and low O_i; Figure 3). In September, only two sampled bullfrogs consumed aquatic vertebrates. One bullfrog consumed a larval frog in the true frog (Ranidae) family, but this prey item was too heavily digested to further resolve. Given that the only ranids we documented in KWS and SD were bullfrogs, this was likely evidence of cannibalism. The other bullfrog consumed a tadpole madtom fish and dragonfly adult.

Bullfrogs that consumed terrestrial vertebrates consumed little else besides small mammals in the superfamily Muroidea in July, August and September. Nine of the 15 Muroidea documented were identified as meadow voles (*Microtus* *pennsylvanicus*); the remaining six were too heavily digested to further resolve. For each of these months, PSA_i and O_i were ~ 100% for Muroidea (Figure 3). These bullfrogs also consumed fish and invertebrates, but they were rare prey items.

Native taxa were dominant prey (high PSA_i and O_i values) and constituted the majority of prey items documented in bullfrog stomachs in all months. All 96 bullfrog stomachs contained at least one native prey item, while only 14 of these stomachs contained at least one non-native prey item. Red-rimmed melania snails, tadpole madtoms and swordtail fish were the only nonnative prey we documented in bullfrog diets. Only bullfrogs in the invertebrate and aquatic vertebrate categories consumed red-rimmed melania snails, and PSA_i and O_i values for this prey ranged from 0 – 10% and 6 – 33% (Table 2). Since all documented aquatic vertebrate species in bullfrog diets were non-natives, bullfrogs in the aquatic vertebrate ontogenetic category had much higher PSA_i and O_i values for non-native taxa. Only one bullfrog in the terrestrial vertebrate category consumed a non-native fish, so PSA_i and O_i values of nonnatives were low (Table 2).

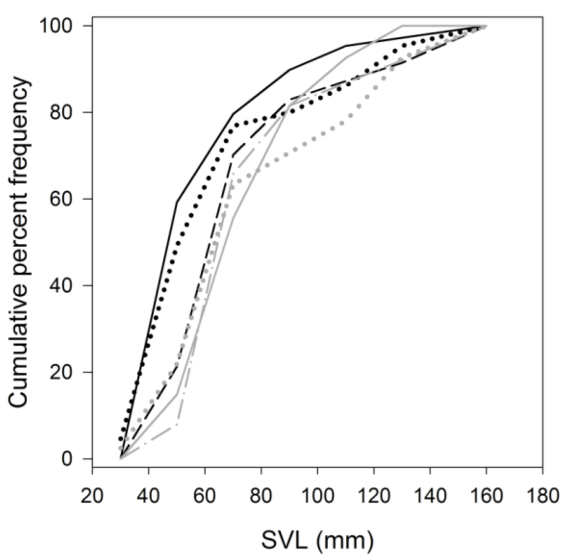

Figure 2. Cumulative percent frequencies of the snout-vent-lengths (SVL; mm) of American Bullfrogs captured in Kelly Warms Spring and Savage Ditch in July (solid lines), August (dotted lines), and September (dashed lines). Black lines describe all captured bullfrogs, while gray lines show the subset used for diet analyses.

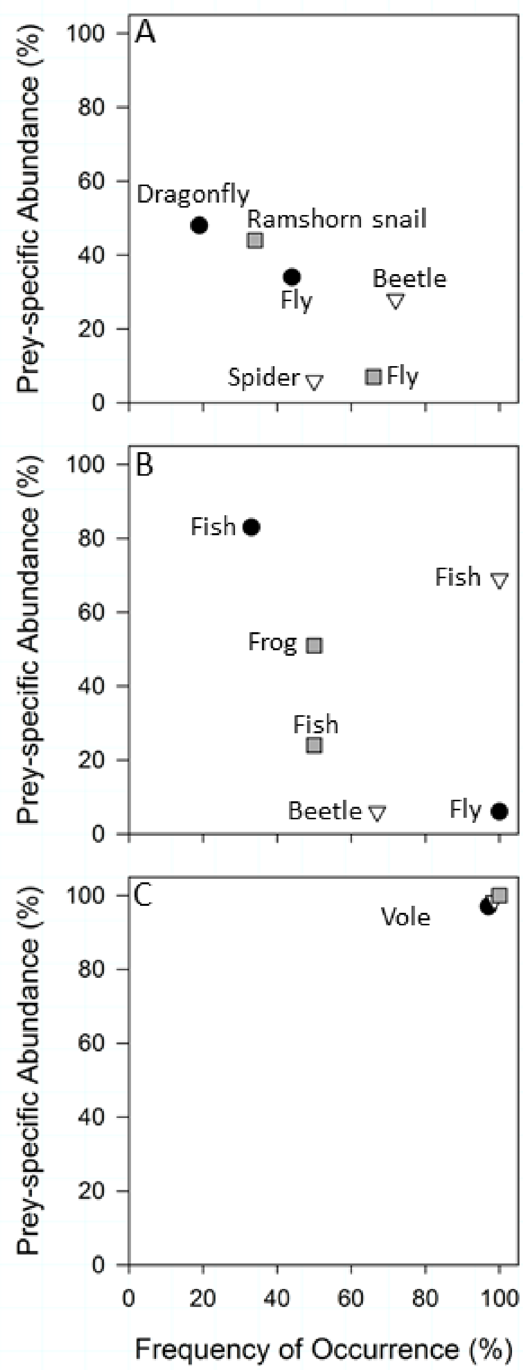

Figure 3. Prey-specific abundance by weight (PSA_i) versus percent occurrence (O_i) for stomach contents of American Bullfrogs that only consumed invertebrates (A) and those that also consumed aquatic vertebrates (B) and terrestrial vertebrates (C) in July (open triangles), August (gray squares), and September (filled circles) 2015. Only the top two taxa that had the largest PSA_i and O_i values are displayed.

✦ DISCUSSION

U.S. national parks form a cornerstone of biodiversity conservation because they provide well-connected landscapes and vital habitats that have relatively low anthropogenic disturbances. However, the introduction and establishment of invasive species can limit the ability of national parks to be safe havens for native species (Koel et al. 2005, Dorcas et al. 2012). In Grand Teton National Park, we documented the distribution and diets of invasive bullfrogs. Despite unconfirmed reports of bullfrogs near the park's southern boundary, we only observed bullfrogs in waters connected to KWS. In this warm spring complex, bullfrogs only overlapped with a native amphibian (western toad) at the downstream extent of the bullfrog distribution and we did not document bullfrog consumption of this native amphibian. Rather, larger bullfrogs (SVL ≥ 96 mm) primarily consumed native rodents, while smaller bullfrogs frequently consumed native invertebrates and less frequently consumed non-native invertebrates and fish. Taken together, these data suggest that the bullfrog distribution appears to be localized at present, so their effects are also likely to be localized but largely concentrated on native taxa. Abundance data on bullfrogs and their prey are necessary for placing bullfrog consumption patterns into context relative to other mortality sources on these prey items and to determine if bullfrog predation is limited to these native taxa.

Our survey results suggest that bullfrog range expansion, and therefore consumptive impacts, are limited in Grand Teton National Park. Bullfrogs were introduced to KWS in the 1950s (Patla and Peterson 2004), but they appear to have only extended their range ~5 km downstream to SD and an adjacent habitat in Ditch Creek in the past 60 years. We documented evidence of bullfrog reproduction (e.g., larvae as small as Gosner stages 23-25) throughout this 5 km section in SD, but not in Ditch Creek. We do not know if the larvae originated in SD (indicating local establishment) or if they dispersed from upstream. Regardless, this limited spread contrasts with the much broader spread of bullfrogs in other invaded waters. For example, bullfrogs in the Yellowstone River in southcentral Montana spread roughly ten times this distance in three years (Sepulveda et al. 2015a) and molecular evidence suggests that this spread was natural and not aided by human secondary translocations (Kamath et al. 2016). In southwest France, bullfrogs have spread to over 2,000 km^2 since their introduction in the 1960s but this spread was likely facilitated by secondary translocations (Ficetola et al. 2007a). The Snake and Gros Ventre Rivers are ~8 km and 1 km, respectively, from KWS– overland distances that bullfrogs in other systems have moved without the aid of human secondary translocations (e.g., 10 km overland in a week in southern Arizona [Suhre 2010] and 1.2 km between June and July in Missouri [Willis et al. 1956]). Despite their proximity, we did not observe bullfrogs in lentic or slower-moving waters associated with the Snake or Gros Ventre rivers. Barriers to bullfrog spread in Grand Teton National Park likely exist since bullfrogs have been present in the KWS complex since the 1950s but have not been documented in neighboring waters.

We suspect habitat suitability is a barrier to bullfrog spread in Snake River habitats. Surveyed sites in August 2015 were spring-influenced and had cold water temperatures < 10° C, which are not conducive to bullfrog rearing or growth (Lillywhite 1970, Viparina and Just 1975). However, summer water temperatures in the Gros Ventre River were much warmer (> 20° C) and comparable to KWS and SD, suggesting that these habitats could have at least seasonal suitability; we have no data on their suitability as overwintering habitat. Post-metamorphic bullfrogs in their native range and in other areas of their introduced range are known to seasonally use habitats, even if they are not conducive to breeding or overwintering (Gahl et al. 2009, Peterson et al. 2013). Thus, factors other than temperature may limit bullfrog spread to these thermally-suitable habitats. Factors that may limit overland dispersal and spread include cold nighttime temperatures and low humidity associated with the high-elevation (~2,000 m) of KWS and SD. Nevertheless, further detection surveys using more sensitive methods, like environmental DNA (e.g., Ficetola et al. 2008), are warranted to confirm bullfrog absence given the proximity of these habitats to KWS, the low capture probabilities documented in SD and KWS (*unpublished data*), and the high and consistent source of bullfrog propagules in KWS and SD.

We found that bullfrog diet contents were related to bullfrog size. The smallest bullfrogs we sampled (SVL 21 – 49 mm) consumed only invertebrates, while larger bullfrogs (SVL 50 – 95 mm) consumed small fish and tadpoles in addition to invertebrates, and the largest bullfrogs (SVL ≥ 96 mm) primarily consumed voles (the largest prey items we documented). These size-based diet patterns are common in bullfrogs (Werner et al. 1995) and likely reflect ontogenetic shifts in gape-width as small bullfrogs were too small to eat fish, medium bullfrogs were large enough to eat fish but too small to eat voles, and large bullfrogs were big enough to eat voles. In addition to anatomical constraints, these size-based diet patterns may also reflect different habitat use by large and small bullfrogs, as large bullfrogs were frequently captured along the water's edge while smaller bullfrogs were captured within KWS or SD. Evidence of ontogenetic shifts in bullfrog diets underscores the importance of incorporating size-structure into implications of bullfrog invasions. Specifically, populations dominated by smaller juveniles will have different impacts than populations dominated by larger adults.

Bullfrogs that consumed terrestrial vertebrates consumed little else besides small rodents in the superfamily Muroidea. In fact, PSA_i and O_i were ~ 100% for all three sampling periods (Figure 3), which indicates that this was an energetically important and common resource that larger individuals specialized on. This contrasts with previous research that showed large prey items (such as mice) to have lower occurrence than small prey items (such as invertebrates) (e.g., Bury and Whelan 1984, Hirai 2004, Jancowski and Orchard 2013, Quiroga et al. 2015). For sit-and-wait predators like large bullfrogs, consumption of prey that are large relative to the predator is predicted to maximize energetic potential. In general, preying upon few, large prey rather than many, small prey minimizes the costs associated with predation, including metabolic expenditure and risk of injury or predation (Cooper et al. 2003, Costa 2009, Werner and Gilliam 1984). Given these first principles and our observation that large bullfrogs in KWS and SD consumed little else besides small rodents, it is likely that small rodents were readily available or that large bullfrogs were highly selective for small rodents because the costs associated with predation are large.

Smaller bullfrogs had a more generalized diet, consisting mostly of invertebrates and occasionally fish and tadpoles. The taxonomic identities of invertebrates shifted across seasons, an expected pattern if bullfrogs tracked seasonal pulses in aquatic and terrestrial prey availability. Aquatic invertebrates were important (high PSA_i or O_i) prey items, especially dragonflies in July and August and native and non-native snails in September. Terrestrial invertebrates, like the adult life-stages of the beetle family Tenebrionidae in July, were energetically important and frequent prey items and other terrestrial invertebrates, like spiders and grasshoppers, were rare prey during each sampling period. Frequent consumption of terrestrial prey by larger bullfrogs contradicts the general patterns of other bullfrog diet studies, where aquatic prey constituted a substantial portion of bullfrog diets (Bury and Whelan 1984, Werner et al. 1995, Wu et al. 2005). Inputs of terrestrial invertebrates into aquatic ecosystems are often associated with closed-canopy riparian zones (e.g., Baxter et al. 2005), however, KWS and SD have minimal canopy cover so a better understanding of how bullfrogs access terrestrial inputs is warranted in this system. Small and large bullfrogs in KWS and SD may be more vulnerable to capture and control efforts if they consume terrestrial prey near the water's edge or on land.

Native prey items were present in every stomach sample we analyzed, while non-native prey occurred in ~ 15% of stomachs. Non-native prey included one putative bullfrog larva, several tadpole madtom and swordtail fishes, and multiple red-rimmed melania snails. Cannibalism is frequent in other introduced, abundant bullfrog populations (Wu et al. 2005, Quiroga et al. 2015), so the single observation of a putative bullfrog larva was unexpected given that we captured at least 225 post-metamorphic bullfrogs and more than 900 larvae during the 2015 sampling season (*unpublished data*). Future studies of native and non-native prey abundance in the KWS/SD complex may help to contextualize these unexpected results.

The bullfrog distribution and consumptive impacts are localized at present to KWS and SD, though changing environmental conditions that increase seasonal and overwintering habitat suitability may allow bullfrogs to expand their range and impacts in this region. Evidence for this scenario is found in the positive relationship between bullfrog occurrence and maximum temperatures observed across their native and nonnative distributions (Ficetola et al. 2007b), rapidly warming air temperatures in this region (Sepulveda et al. 2015b) and our discovery of bullfrogs in habitats along Ditch Creek. However, our lack of bullfrog detections in the Gros Ventre River suggests that factors in addition to temperature and dispersal distance limit bullfrog spread in Grand Teton National Park. Future bullfrog studies in this region should closely track factors in addition to water temperature that are sensitive to climate change and may affect bullfrog spread and establishment in riverine habitats, such as hydroperiods of backwaters, flow magnitude and flow timing (Ray et al. 2016; Al-Chokhachy et al., *in press*).

Managers will need to weigh the impacts of potential bullfrog range expansion against the costs of an eradication effort of the current population. Generally, eradication of invasive species is a difficult endeavor, but can be tractable when an area of infestation is small and contained (Rejmánek and

Pitcairn 2003, Simberloff 2009, Sepulveda et al. 2012). Though the bullfrog population in Grand Teton National Park has been established for ~60 years, our research suggests that this population is currently localized and should therefore be vulnerable to eradication.

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SPATIO-TEMPORAL ECOLOGICAL AND EVOLUTIONARY DYNAMICS IN NATURAL BUTTERFLY POPULATIONS (2015 FIELD SEASON)

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✦ 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 (e.g., 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, in 2012 we began 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, *Lycaeides idas*, is one of five nominal species of *Lycaeides* 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). *Lycaeides idas* hybridizes with a second species, *L. melissa*, in the GYA (Gompert et al. 2010, 2012). *Lycaeides idas* is a holarctic species that is found in Alaska, Canada, and the central and northern Rocky Mountains of the contiguous USA (Scott 1986). *Lycaeides 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's 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 fourth 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. In 2014 we collected *L. idas* and used distance sampling at ten populations. This year, 2015, we visited our ten focal populations for collected *L. idas* from our ten focal populations to sample individuals for future genetic work. We will estimate population sizes most years, but did not in 2015.

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

✦ METHODS

We collected 384 specimens from the ten populations involved in this study between July 10-26, 2015 (Figure 2, Table 1). Four of the populations are within park boundaries (BTB and RNV in GTNP and BNP and HNV in YNP). We are storing these whole adult butterflies at -80º C for later DNA extraction and sequencing.

✦ RESULTS

We collected 29 males and 12 females from BCR, 35 males and 14 females from BNP, 30 males and 20 females from BTB, 24 males and 26 females from GNP, 17 males and 7 females from HNV, 39 males and 11 females from MRF, 22 males and 16 females from PSP, one male and one female from RNV, 22 males and 4 females from SKI, and 42 males and 8 females from USL. We were unable to

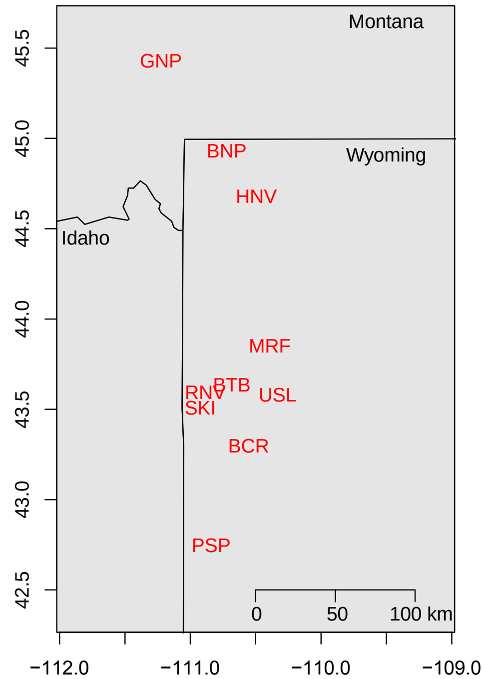

Figure 2. Map of the ten *L. idas* populations in the GYA involved in this long term study.

collect our target 50 individuals from our two higher-elevation populations, HNV (2344 m) and RNV (2894 m); the low snowpack for 2015 shifted the adult butterfly flight season so that it did not overlap with our time in the field.

Here in Table 1 we include our population size estimates from distance sampling in summers 2013-2014 (Buckland et al. 2001, Royle 2004; *distsamp* function in the *unmarked R* package), as well as average host-plant abundance collected during those years. To characterize 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*, which represented 52.6% of the variance in the original dataset. Refer to our 2014 report for further details. 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). The climate variable ranged from -.91 to 5.69 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). 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.

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.

Population	2013 size	2014 size	Ave. host-plant abundance	Climate PC score
Blacktail Butte (BTB)	1838.7	1978.5	0.5	-1.5
Bull Creek (BCR)	2382	1241.7	0.5	-3.8
Bunsen Peak (BNP)	633.9	1273.2	0.9	1.2
Garnet Peak (GNP)	1119.9	1024.5	0.4	3.6
Hayden Valley (HNV)	NA	5291.4	0.3	1.1
Mt. Randolf (MRF)	NA	977.7	0.2	-1.5
Periodic Springs (PSP)	NA	366.6	0.6	-3.9
Rendevous Mountain (RNV)	NA	NA	0.3	5.7
Ski Lake (SKI)	NA	1348.8	0.6	1.6
Upper Slide Lake (USL)	NA	1708.2	0.5	-2.4

✦ DISCUSSION

Because 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 our previous distance sampling surveys and analyses. 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 2016 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 2016. We also will collaborate with both undergraduate and graduate researchers during the 2016 field season.

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TESTING FIELD METHODS TO ASSESS INTERACTIONS BETWEEN NATIVE CADDISFLIES AND THE INVASIVE NEW ZEALAND MUDSNAIL (*POTAMOPYRGUS ANTIPODARUM*)

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✦ ABSTRACT

In Polecat Creek, WY, located in the Greater Yellowstone Ecosystem, the invasive New Zealand mudsnail (*Potamopyrgus antipodarum*) has been found to reach densities exceeding 500,000 individuals/m^2. At this extremely high density, *P. antipodarum* has been observed to consume most of the gross primary production and have a negative impact on native macroinvertebrates such as the *Hydropsyche* caddisfly. The current population of *P. antipodarum* in Polecat Creek has declined suggesting the population "boomed and busted"; the population was booming in 2000-2001, but in 2011 the population had decreased substantially suggesting a "bust" period for *P. antipodarum.* Native *Hydropsyche* caddisflies have increased dramatically in biomass during the 10-year span of data, which may indicate that some native macroinvertebrates have increased in biomass due to release of suppression by *P. antipodarum*. Consequently, during my research this summer I assessed several possible methods to test suppression of *Hydropsyche* by *P. antipodarum*. I devised a method to collect *Hydropsyche* and determined whether *Hydropsyche* can survive in experimental chambers for use in a future field experiment. I built wooden tiles to colonize *Hydropsyche* out of 4x4x2 inch wood blocks with 1/2 inch grooves along the length of the tile. Colonization was successful with approximately two *Hydropsyche* collected per tile in a 24-hour period. Based on low survival of *Hydropsyche* within experimental chambers, the use of different experimental chambers will be necessary. Specifically, chambers that are open on the upstream side should be used to better allow a fast flow of water, which is a requirement for *Hydropsyche* to collect food.

✦ INTRODUCTION

Non-native species that cause ecological or economic harm are commonly referred to as invasive species (Lockwood et al. 2007). The invasive New Zealand mud snail (*Potamopyrgus antipodarum*) is indigenous to New Zealand and is currently considered an invasive species in Australia, Europe, and North America (Zaranko et al. 1997). Although in its native range *P. antipodarum* reproduces both asexually by parthenogenesis and sexually, in its invaded range it reproduces only parthenogenically (Alonso and Castro-Diez 2008). This means that one female snail can colonize a new stream without a mate and that all snails are clones; embryos develop into identical female offspring without fertilization.

P. antipodarum first invaded streams and rivers in the Greater Yellowstone Ecosystem (GYE) of Wyoming in 1994 and has since reached extremely high population densities in some invaded streams and rivers (Kerans et al. 2005, Hall et al. 2006). In my study stream, Polecat Creek WY, densities exceeding 500,000 individuals/m^2 have been documented (Hall et al. 2006). Because of its abundance in Polecat Creek, *P. antipodarum* can control fluxes of carbon and nitrogen (Hall et al. 2003), dominate the flux of nitrogen from primary producers (Hall et al. 2003), consume 75% of the gross primary production, and represent 97% of invertebrate biomass (Hall et al. 2003, 2006). *P. antipodarum* are primarily grazers and consume periphyton, macrophytes, and detritus (Haynes and Taylor 1984, James et al. 2000).

P. antipodarum may also alter the Polecat Creek ecosystem by negatively affecting native macroinvertebrate species. For example, the high biomass of *P. antipodarum* found in Polecat Creek nearly ceased growth of a native snail (Thon et al. in prep). In field experiments conducted in Polecat Creek, *P. antipodarum* growth also outpaced growth of a different native snail when the two species co-occurred (Riley et al. 2008). Other native taxa may also be negatively affected by *P. antipodarum*: mayflies in the genus *Ephemerella* overlap with *P. antipodarum* in their preferred diet (Krist and Charles 2012) and a colonization experiment in the Madison River of Yellowstone National Park showed that the number of native macroinvertebrates colonizing experimental tiles decreased with increasing *P. antipodarum* abundance (Kerans et al. 2005). Taken together, these negative effects of *P. antipodarum* on individual taxa, along with their consumption of up to 75% of gross primary production (Hall et al. 2003), suggest the possibility of widespread resource competition between *P. antipodarum* and native macroinvertebrates.

The abundance of *P. antipodarum* in Polecat Creek has significantly decreased since 2001 (Thon et al. in prep.). This severe decline may represent a population that has “boomed and busted”: a population that reached high abundance (boom) followed by a sharp decline in abundance (bust). Moore et al. (2012) documented a boom and bust of *P. antipodarum* in the Upper Owens River, California. Moore and colleagues (2012) collected data over a 10-year period from the beginning of a *P. antipodarum* invasion and through the population bust. Immediately following the invasion of *P. antipodarum*, native grazing invertebrates decreased in abundance by 80% and then doubled in abundance after *P. antipodarum* abundance declined (Moore et al. 2012). Because *P. antipodarum* affects community structure (Moore et al. 2012) and ecosystem processes (Hall et al. 2003), its decline in Polecat Creek will also likely cause changes in the macroinvertebrate community. In support of this prediction, Thon et al. (in prep.) found that the decrease in *P. antipodarum* biomass from 2001-2009 coincided with an increase in biomass of a native snail species (*Fossaria sp.*) in Polecat Creek.

By comparing 2000-2001 and 2011 data, I have identified several native invertebrate taxa that were likely suppressed by *P. antipodarum* during the boom period (their abundance has increased greatly since the bust of *P. antipodarum).* Of those taxa, *Hydropsyche* caddisflies showed one of the greatest increases in abundance. In preparation for performing field experiments to elucidate the mechanisms by which *P. antipodarum* suppresses *Hydropsyche* caddisflies, I tested one method of collecting *Hydropsyche* and determined whether these caddisflies can survive inside experimental chambers.

✦ METHODS

***Hydropsyche* collection**

Hydropsyche caddisfly larvae spin silk nets, which they use to collect and gather food. To take advantage of this behavior, I constructed colonization tiles from 4x4x2 inch wooden blocks. I used a circular power saw to cut 1/2 x 1 inch grooves down the length of the topside of the tile (Figure 1). I attached collection tiles to bricks to anchor them to the stream substrate (Figure 2). I left 12 tiles in Polecat Creek for 24 hours to assess whether *Hydropsyche* caddisflies would colonize the tiles.

Figure 1. Two *Hydropsyche* collection tiles attached to a brick.

Figure 2. Six *Hydropsyche* collection tiles placed in Polecat Creek.

***Hydropsyche* survival**

In a future experiment, I plan to house *Hydropsyche* caddisflies and the invasive *P. antipodarum* together in experimental chambers. For the experimental chambers, I will use modified, square plastic sandwich containers (156.3 cm^2) with mesh (600-µm) windows on the top and sides to keep invertebrates in the chamber and allow fresh, oxygenated water to flow through the chamber (Figure 3). To determine the efficacy of these chambers, I

Figure 3. Modified sandwich container used as an experimental chamber.

wanted to know if *Hydropsyche* could survive in them for a duration of 5-7 days.

I placed 12 collection tiles, containing 1-3 colonized *Hydropsyche* caddisflies (29 larvae total), into experimental chambers and anchored them to bricks (Figure 4). I recorded the number and position of caddisfly larvae on the tiles before closing the chamber. I left the chambers in Polecat Creek and recorded the number of caddisfly larvae present within the chambers after seven days.

In a separate experiment, I placed six chambers in Polecat Creek as described above (13 larvae total). I also placed five colonized tiles in the creek without housing them inside chambers to determine if the chambers affected survival of larvae (12 larvae total). After five days, I recorded the number of larvae present on tiles of both treatments, ignoring new colonizations on tiles outside of chambers.

Figure 4. Eight *Hydropsyche* collection tiles within anchored experimental chambers.

✦ Results

Hydropsyche collection

Hydropsyche collection was successful. After 24 hours in Polecat Creek, a total of 29 *Hydropsyche* larvae colonized the 12 collection tiles. All tiles were colonized by larvae with a minimum of one and a maximum of three larvae per tile (Figure 5).

Figure 5. *Hydropsyche* collection tile with three colonized caddisflies.

Hydropsyche survival

For the first experiment, after seven days in Polecat Creek, a total of 7 of 29 *Hydropsyche* larvae were present within the 12 experimental chambers (21.4%). In the second experiment, after five days in the creek, 4 of 13 larvae were present in the six chambers (30.8%). Five tiles not contained in chambers contained 11 of 12 larvae after five days in the creek (91.7%).

✦ Discussion

The *Hydropsyche* collection tiles performed above expectation. In 24 hours I collected 29 *Hydropsyche* larvae. Importantly, the tiles were colonized *only* by the target taxa, making separation of *Hydropsyche* from other taxa unnecessary.

Survival of *Hydropsyche* larvae within the experimental chambers was low (21-30%). These percentages represent larvae present, however, and may not have resulted from death, but departure of larvae from the chambers. The mesh size on the chamber windows was large enough for larvae to escape and larvae may have migrated out of the chambers due to undesirable conditions. Because *Hydropsyche* larvae require a fast flow of water in order to collect food in their nets, reduced flow from the chamber mesh may have caused larvae to migrate out of the chamber in search of better flow conditions.

In contrast, tiles that remained outside of chambers contained ~90% of the original larvae present. These results indicate that the experimental chambers used in future experiments must be modified. Accordingly, I will remove the mesh from the upstream side of the chambers to allow faster flow of water through the chamber. Escape from the open side of the chamber is unlikely since a large portion of larvae remained on tiles even when left in open water.

✦ ACKNOWLEDGEMENTS

I would like to thank director Harold Bergman and all the staff at the UW-NPS research station for providing tools and supplies for the construction of *Hydropsyche* collection tiles used during this research. I thank my field assistant, Meghan Bochanski and Wyoming EPSCoR for funding her summer research. I also thank my adviser, Amy Krist, and her colleague, Teresa Tibbets, for their valuable advice when designing my experiments.

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River reach delineations and beaver movement in Grand Teton National Park

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✦ Introduction

This project had two components, with the first component providing a background for the second component. Water resources in Grand Teton National Park (GTNP) are both unregulated and regulated by human management. The Jackson Lake Dam and the ponds scattered across the park influence the flow of water. In the process of managing the water it is important to have knowledge of the different components of the streams through which the water flows. One component of this project was to examine the different segments of the major rivers in GTNP and identify the river forms that are displayed by the different reaches of the Snake River above and below Jackson Lake, Buffalo Fork and Pacific Creek. The river form can be segregated into three main categories; the single channel, the meandering channel and the braided channel (Knighton 1984). The different river forms are part of the overall structural composition of the river and can be used to delineate the segments or reaches of the river. The river continuum concept presented by Vannote et al. (1980) provides a theoretical background upon which to construct the river reach system. In 2007, Nelson (2007) completed a reach system project while investigating the fluvial geomorphology of the Snake River below Jackson Lake Dam (Figure 1.). His 20 river reaches provided a zonation of the river that incorporated a range of geomorphic features. This same type of system can be used throughout the GTNP so that researchers have a common spatial unit designation when referencing portions of the Snake River and its tributaries. Ackers (1988) in his work on alluvial channel hydraulics identified three dimensions of meanders that should be considered; width, depth and slope. He further agreed with Hey (1978) that there are nine factors that define river geometry and that these should be considered as well: average bank full velocity, hydraulic mean depth, maximum bank full depth, slope, wave length of bed forms, their mean height, bank full wetted perimeter, channel sinuousity and arc length of meanders. Nelson's work (Nelson 2007) added another parameter by including a braiding index into the representation of river reach designations. In a more recent work, the Livers and Wohl (2014) study confirmed Nelson's approach by comparing reach characteristics between glacial and fluvial process domains using similar reach designation characteristics to determine reach differences.

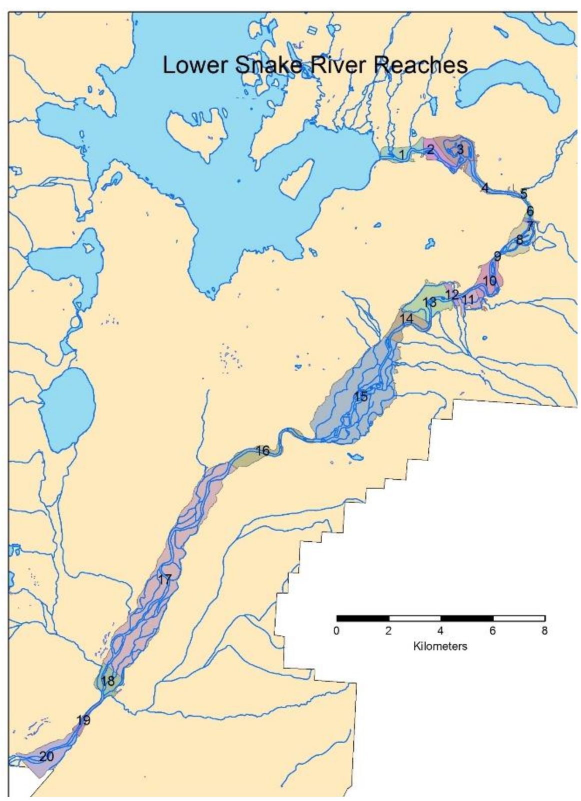

Figure 1. Lower Snake River reaches (Nelson 2007).

Determining reach units for analytic purposes provides an important mechanism by which researchers from a variety of disciplines can address river characteristics in a uniform way. Naiman et al. (1987) examined the longitudinal patterns of ecosystem processes and community structure of the Moisie River, Canada. The significance of this work was that the fluvial geomorphic reaches of the river provided a means by which vegetation ecologists and both micro- and macro-invertebrate specialists could uniformly distinguish differences and similarities along the full length of the river referencing the same reach units. Markovic et al. (2012) utilized the same types of concepts in their study of fish ecology along river studies in New York and Germany incorporating GIS techniques and modeling to analyze fish distributions along reach segments. Again, the utility of forming a reach segment based on physical characteristics of the river provides a solid base upon which other researchers can reference.

The second component of this research project was to continue work on the spatial ecology of beavers in Grand Teton National Park (GTNP). The beaver population of GTNP is divided between beaver colonies located along the major tributaries and those that are aligned with specific ponds. In the 2014 beaver census (Gribb and Harlow 2014), the number of beaver colonies adjacent to a major stream tributary was over 2:1 relative to those found in ponds. Figure 2 illustrates the dispersion of beaver caches identified during the October 2014 aerial census. In an attempt to understand the spatial behavior of beavers, this study attempted to concentrate on river beaver movement. Most beaver movement studies examine beavers adjacent to ponds (McClintic et al. 2014, Bloomquist et al. 2012, McNew and Woolf 2005, and Fryxell and Doucet 1991). Beaver ponds and their smaller streams inhibit the area of foraging. However, as the GTNP data suggests, there are more colonies adjacent to rivers in the GTNP and there is little knowledge of the spatial ecology of these river beavers. In a recent article on beaver movement, McClintic et al. (2014) state that beavers are active in their search for food, to acquire resources, breeding purposes, and to escape predation. Beavers are central place foragers and their trips from the lodge or den generally relate to food gathering; however, the distance traveled is based on their age and maternal status: frequent short trips for provisioning their off-spring with longer trips for self-feeding or sub-adults exploring for new habitats. This component of the project would have focused on beaver movement along the four major rivers: the Snake River above Jackson Lake, the Snake River below Jackson Lake, the Buffalo Fork and Pacific Creek. In the 1975-77 study by Collins (1976), he only examined the territory of each colony and speculated on a density of 1 colony per 1.3km along the Snake River below Jackson Lake Dam. He did not investigate the actual range of movement of beavers along the river. Baker and Hill (2003) found that beavers construct or utilize multiple lodges or bank dens throughout their home range, thus their movements could extend beyond the colony territories as delineated by Collins.

Unfortunately, the University of Wyoming Institutional Animal Care and Use Committee process was not completed until mid-September, 2015. This situation did not provide the researchers with enough time to locate, trap and attach GPS units to beavers to collect sufficient location data to determine beaver movements during the summer months. It was imperative to the research that movement data was collected through the summer, fall and winter months because of the feeding behavior differences during the seasons. While this component of the project was not completed, it is rescheduled into our future efforts.

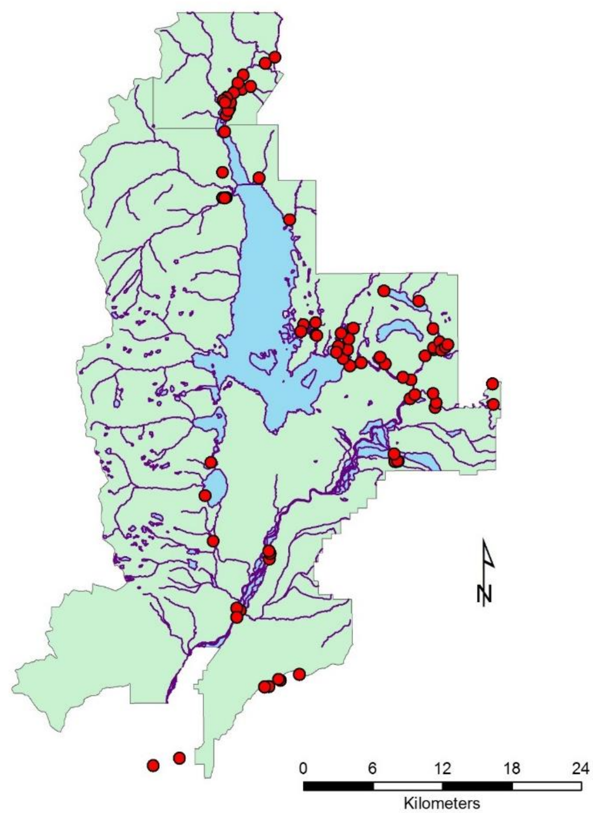

Figure 2. Beaver cache locations, aerial survey, October, 2014.

This ongoing project addresses the problem of determining the concentration of beaver colonies based on river reach characteristics and a geomorphic interpretation of beaver habitat based on river form. It is hypothesized that beaver colonies will have a higher concentration in areas that are braided, offering more opportunity to access water and associated vegetation communities as preferred beaver habitat. The river reach segment system was continued along the three rivers not completed by Nelson (2007): Upper Snake River above Jackson Lake, Buffalo Fork, and Pacific Creek. The river reaches delineation process involved a combination of satellite imagery (LiDAR), hydrology and field measurement. The LiDAR imagery data was obtained in 2014, with an estimated elevation accuracy of 25cm (Hodgson et.al 2005). Studies on hydro-geomorphology demonstrate that LiDAR data is a useful tool to discern river structure (Liermann et al. 2012, Bertoldi et al. 2011, and Hauer et al. 2009).

A total of 157 river field transects were collected to both act as ground truth for LiDAR measurements and to collect measurements of river hydraulic characteristics. Vegetation along the river banks introduces some error in the LiDAR measurements (Hutton and Brazier 2012), but this was not corrected. Stromberg et al. (2007) determined that accurate surface topography and vegetation are required to "…understand the complex interactions between riparian vegetation, water availability and channel morphology" (Hutton and Brazier 2012).

✦ METHODS AND ANALYSES

In verifying the river reaches delineated by Nelson (2007) two approaches have been taken. First, compiling spatial data for GIS analysis using soils (Figures 3-5; SCS 1982) vegetation (Figures 6-8; GTNP 2005), DEM, and river hydrology and comparing each reach for distinct characteristics. The second approach was to collect specific fluvial geomorphic factors at random locations along the Lower Snake River below Jackson Lake Dam (Figure 9). The samples were based on river confluences and braiding characteristics. The factors measured at each location provided a basic understanding of river structure and vegetation characteristics: bankfull elevation, width, bank height, bank vegetation types, vegetation height, and braiding index. A combination of aerial photography and LiDAR data were used to determine critical geometrical structures in the river system including bars, islands, and the overall floodplain (Hauer et al. 2009). These same river

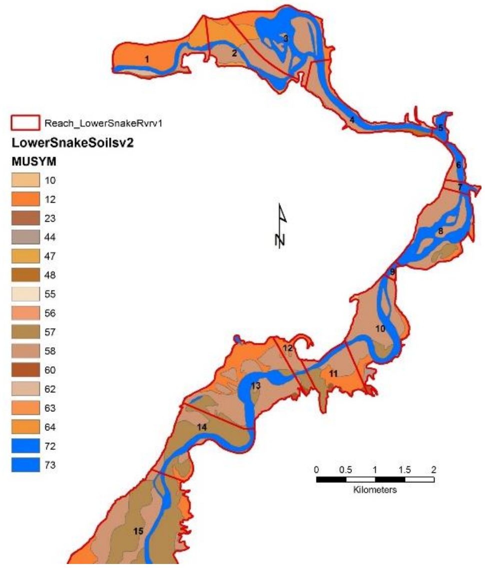

Figure 3. Lower Snake River soils, North Section (SRC 1982). See Appendix A for soil codes in figure.

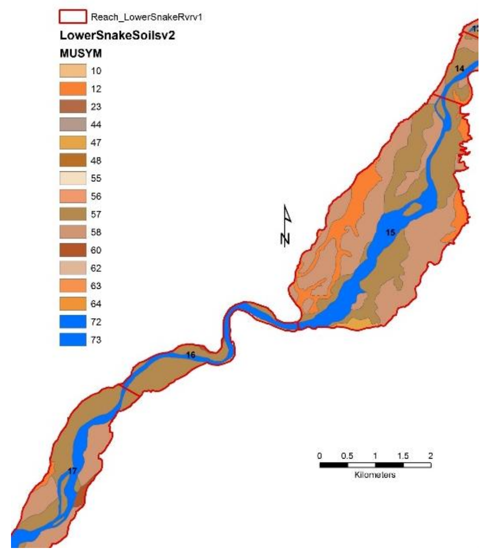

Figure 4. Lower Snake River soils, Middle Section (SRC 1982). See Appendix A for soil codes in figure.

structure and vegetation variables were collected at sample sites along the Upper Snake River, Buffalo Fork, and Pacific Creek. As mentioned previously, 157 transects were completed on the four main rivers in Grand Teton National Park. This portion of the study, however, examined only the characteristics of the Lower Snake River incorporating the 43 transects along the 43km of the Lower Snake River. All of the data was then integrated into ArcGIS (ESRI v.10.2) and preliminary statistical analysis performed in EXCEL (v10. 1).

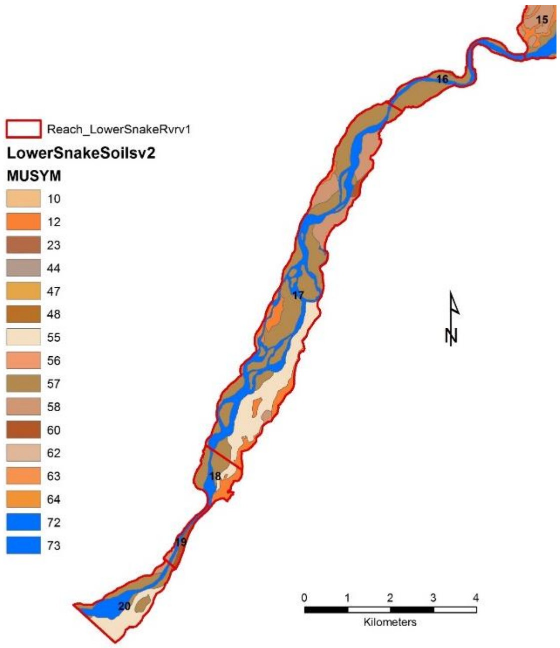

Figure 5. Lower Snake River soils, South Section (SRC 1982). See Appendix A for soil codes in figure.

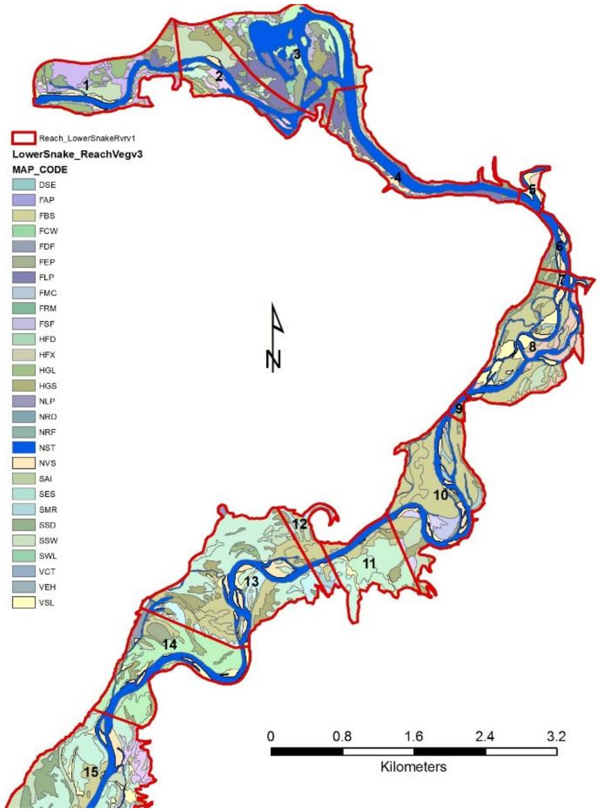

Figure 6. Lower Snake River vegetation, North Section (GTNP 2005).). See Appendix A for vegetation codes in figure.

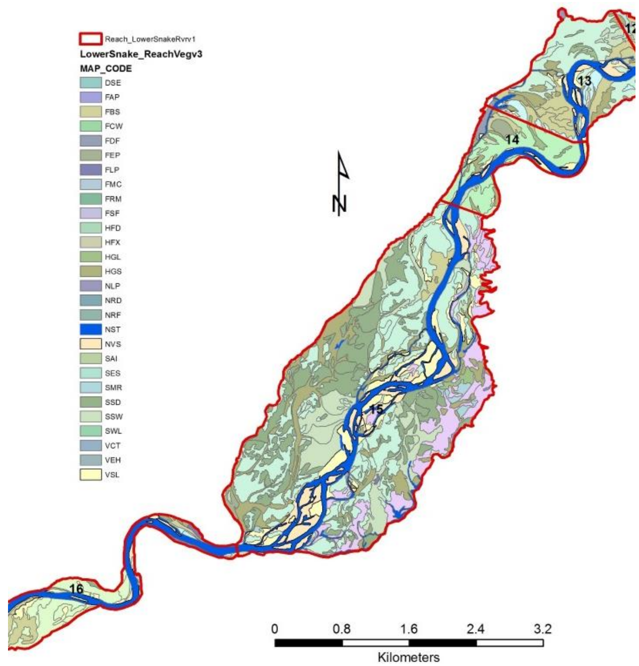

Figure 7. Lower Snake River vegetation, Middle Section (GTNP 2005). See Appendix A for vegetation codes in figure.

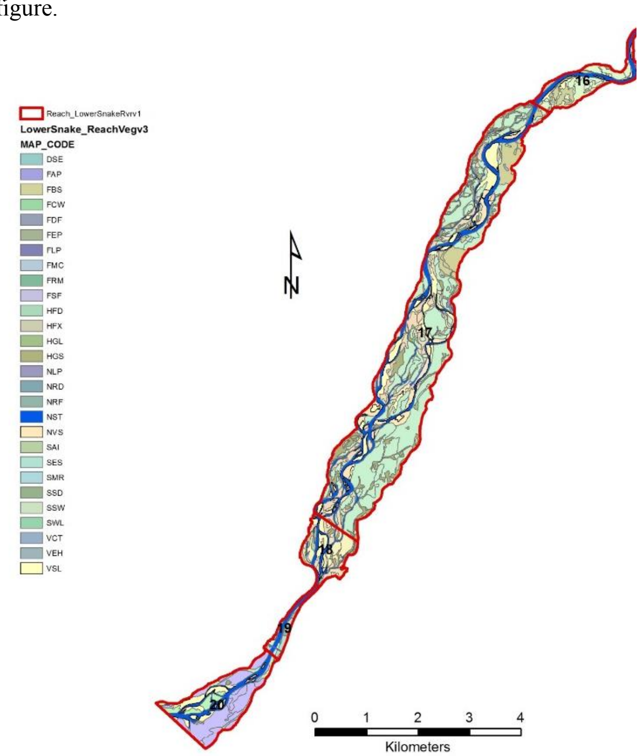

Figure 8. Lower Snake River vegetation, South Section (GTNP 2005). See Appendix A for vegetation codes in figure.

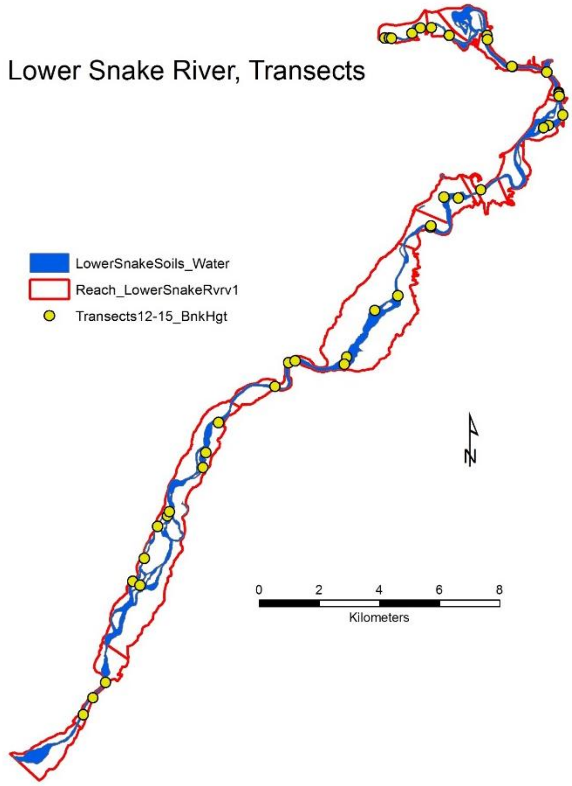

Figure 9. Lower Snake River transects.

Three main characteristics of the Nelson reach delineations were used to verify his reach boundaries: floodplain width, river form, and braiding index. The other major characteristics concerning river depth and width would have been difficult to verify because of the movement and changes in the Snake River since his 2007 study. Using simple overlay techniques superimposing the Nelson reach boundaries to the LiDAR imagery and NAP aerial photography sample points were designated to determine the accuracy of the Nelson boundaries for the Lower Snake River. In the 125 points selected, the Nelson boundary was within 5m in 97% of the locations. It was believed that this falls within the U.S.G.S. mapping standards, and thus his delineations could be used as geomorphic reaches along the Lower Snake River.

A total of 18 variables were used to examine the relationship between river reaches and concentrations of beavers (Figure 10) along the lower Snake River (Appendix B). Table 1 lists the correlations between variables and active beaver lodges with correlations of r=0.5 or above (p=0.05) (Appendix B). Some of the most logical relationships exist between soils and physical features on the ground. For instance, the more sand in the soil, there is more likelihood to find sandbars (0.964); similarly, the higher the braiding index, the higher the number of sandbars along the river (0.632). Sand soils are also strong factors in vegetation, with a positive relationship between sand and *Populus spp.* (0.988), and *Salix spp.* (0.720) was considered strongly correlated as well. The distribution of number of beavers (ReachTot) by reach has a strangely configured distribution: it is mildly strong with *Populus spp.* (0.506) and even stronger with *Salix spp.* (0.752) and somewhat strong with sandbars (0.617) and soils with GT3in cobbles (0.567). Surprisingly, beavers generally try not to build bank dens in sands and cobbles, so in this case, they are building bank lodges. The relationships change when we convert from total number of beavers to beaver density per sq. km. in each reach. Reaches #15 (19) and #17 (10) have the most beavers, however, when you convert to a density value they do not have the highest density of beavers; reaches #5 and #6 at the confluences of Pacific Creek and Buffalo Fork have that distinction with 18.73 and 13.68, respectively. In addition, it was found that there was a negative relationship between the density of beavers per sq. km. and the percent of a reach in *Populus spp.* (-0.579). This can be explained by the fact that though cottonwoods and aspens are a favorite tree, as the tree density increases there is less area for willows (*Salix spp.*), which is a more stable component to their diet.

Table 1. Summary of correlations between stream variables and active beaver lodges with correlations of r=0.5 or above (p=0.05). See Appendix B for variable definitions and Appendix C for the full correlation matrix.

	BraidIndx	Salix	RvrSandBars	Sand	SandPc	ReachTot	BvrDenSqKm
Sandbars	0.519			0.964		0.617	
RvrSandbar	0.632			0.600			
Populus		0.788	0.716	0.988		0.506	
PopulusPC				0.581	0.831		-0.579
Salix				0.720		0.752	
GT3in						0.567	
GT3inPC							0.513
BvrDenSqKm					-0.562		

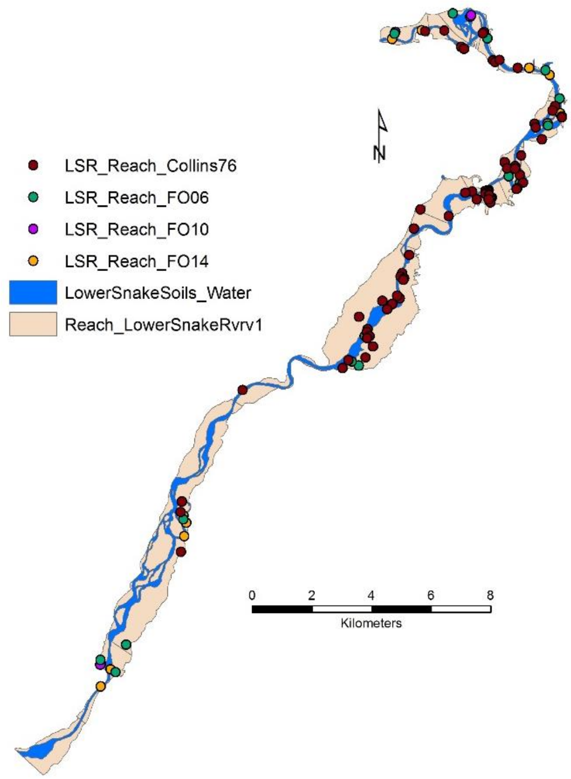

Figure 10. Lower Snake River, Beaver Locations, 1976-2014.

In reviewing the correlation matrix of all variables (Appendix C), there are some relationships that need to be examined. One of our working hypotheses is that there would be a higher concentration of beavers in reaches with a higher braiding index. Indeed, there is a mild correlation between braiding index (BraidIndex) and number of beaver colonies in a reach (ReachTot) (0.365), however, in comparison to beavers per river kilometer (BvrDenKm), there is a weak negative correlation (-0.088) and the same is true for the number of beavers per sq. km. per reach (BvrDenSqKm) (-0.115). These correlations could be a function of the larger reaches having more braids and more beavers in total, but when calculated per river km. or sq.km., it holds that a slightly negative correlation exists because there is less of a probability to build a bank den or lodge. This condition exists because sands are a dominant soil with braids. Another characteristic of importance is that the percent *Populus spp.* (PopulusPC) is negative for both the density of beavers along the river length (BvrDenKm) (-0.382) and beaver's per sq. km (BvrDenSqKm) (-0.579), again this relates back to the fact that beavers have a preference for willows (*Salix spp.*) for food rather than cottonwoods and aspen (*Populus spp.*). Just the opposite occurs in the relationship between beaver density along the river (BvrDenKm) (0.479) and beaver density per square km. (BvrDenSqKm) (0.184) as well as the percent of each reach in *Salix spp.* (SalixPC) which are both positive, however, the latter is much weaker because of the influence of the larger reaches with less density of beavers per sq. km.

In summary, the basic relationships between the main reach physical characteristics provide a strong background for understanding Nelson's reach configurations. Nelson's reaches are premised on river form: single channel, meandering channel and braided channel. The reach soils that are predominately sand have the most sandbars and area in sandbars. Similarly, the amount of area of each reach with *Populus spp.* and *Salix spp.* is mildly related to the length of river segments that have the most sandbars. Also, the braiding index has a strong relationship with the length of river segments that is sandbars. The one variable that represented the river form, sinuosity index (SinIndex), did not display any strong or even mild relationships with any of the other reach physical properties.

Overall, the relationship between beaver totals (ReachTot) and beaver densities (BvrDenKm and BvrDenSqKm) and the physical characteristics of the reaches appear to be weak or, in only a few factors, somewhat mild. There is a weak relationship between beaver totals (ReachTot) within a reach and the braiding index (BraidIndex). Beaver totals per reach also have a mild relationship with *Populus spp., Salix spp.* and sandbars, as well as areas in which *Populus spp.* and *Salix spp.* are found. However, if converting to the number of beavers to a density per sq. km. (BvrDenSqKm), there is a mild negative correlation with the percent of a reach in *Populus spp.* Interestingly, as the beaver density per sq. km. increases, the percent of the reach with soils that have large cobbles (greater than 3") (GT3inPC) also increases. Though beavers do not prefer cobbled river banks for bank dens, they will use the bank for a bank lodge. It appears that active beaver lodge/den areas aligned with areas of *Populus spp.* and *Salix spp.* as long as there is easy access by water.

✦ CONCLUSIONS

There are three main conclusions that can be drawn from this study. First, the Nelson reaches do follow the river form pattern and the physical characteristics of each reach, as they relate soils, vegetation, and braiding. Second, the total number of beavers or their density is only weakly related to the physical form of the river, while the stronger correlations are with the vegetation. Without the appropriate density of *Populus spp.* for building materials and a supplementary source of food, in concert with *Salix spp.* as a main food item, the beavers would not be within that reach. This is evident by the reaches that are single channel or a meandering channel. However, variables that were not included in this summary analysis were the possibility that the reach included a confluence with another major river (Pacific Creek or Buffalo Fork) or a smaller tributary (Cottonwood Creek, Spread Creek or Ditch Creek). These could be sources of additional beavers that are introduced into the Lower Snake River from these waterways into that reach. Further, Nelson et al. (2013) stated that the dynamic characteristics of the Snake River below Jackson Lake dam have a more "…temporal and longitudinal complexity" than previously considered. They later state that river channel changes are greatly influenced by streamflow and flood events. This can be easily illustrated by the change in flow patterns on the Lower Snake River yearly and over time. Finally, this study demonstrates the need for more in-depth analysis of beaver movement between reaches or into back channels. Beavers are very mobile during the spring runoff and during the summer; it is only in the late fall, after the first freeze, that beavers establish their cache for the winter. Thus, more information on the six month period (May-October) would provide a better understanding of their spatial dynamics during the period of most river activity.

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Appendix A. Category labels for maps showing soils (Figures 3-5) and vegetation (Figures 4-6).

Soils

10	Crow Creek silt loam 10-20% slope
12	Cryaquolls-Cryofibrists Complex
23	Leavitt-Youga Complex 0-3% slope
44	Slocum-Silas loams
47	Taglake-Sebud Association
48	Taglake-Sebud Association Steep
55	Tetonville gravelly loam
56	Tetonville Complex
57	Tetonville-Riverwash Complex
58	Tetonville-Wilsonville fine sandy loam
60	Tineman gravelly loam
62	Tineman-Bearmouth gravely loam 0-3% slope
63	Tineman-Bearmouth gravely loam 3-40% slope
64	Tineman Association
72/73	Water

Vegetation

DSE	Artemisia arbuscular Dwarf Shrubland
FAP	Populus tremuloides Forest
FBS	Picea pungens Riparian Forest
FCW	Populus angustifolia-P.balsamifera Riparian Forest
FDF	Pseudotsuga menziesii Forest
FEP	Mixed Evergreen-Populus spp. Forest
FLP	Pinus contorta Forest
FMC	Mixed Conier Forest
FRM	Mixed Conifer-Populus spp. Ribarian Forest
FSF	Abies lasiocarpa-Pinus englemannii Forest
HFD	Montane Mesic Forb Herbaceous Vegetation
HFX	Montane Xeric Forb Herbaceous Vegetation
HGL	Mixed Grassland Herbaceous Vegetation
HGS	Flooded Wet Meadow Herbaceous Vegetation
NLP	Natural and Artificial Lakes and Ponds
NRD	Transportation Communication, and Utilities
NRF	Mixed Urban or Built-up Land
NST	Streams
NVS	Sandy Areas other than Beaches
SAI	Alnus incana Shrubland
SES	Artemisia spp. – Purshia tridentate Mixed Shrubland
SMR	Mixed Tall Deciduous Shrubland
SSD	Artemisia spp. Dry Shrubland
SSW	Artemisia spp./Daisphora floribunda Mesic Shrubland
SWL	Salix spp. Shrubland
VCT	Cliff and Talus Sparse Vegetation
VEH	Exposed Hillside Sparse Vegetation
VSL	Exposed Lake Shoreline-Stream Deposit Sparse Vegetation.

Appendix B. List of variables used in correlation analyses between river reach variables and concentrations of beavers along the lower Snake River. See Appendix C for the full correlation matrix and see Table 1 for a summary of correlations between variables and active beaver lodges with correlations of r=0.5 or above (p=0.05).

BraidIndex	The number of stream braids per km.
Slope	The slope of each river reach measured by river elevation
SinIndex	Sinuosity index
Populus	The number of sq. meters in each reach with Populus spp.
Salix	The number of sq. meters in each reach with Salix spp.
Sandbars	The number of sq. meters in each reach that is a sand bar
PopulusPC	Percentage of each reach in Populus spp.
SalixPC	Percentage of each reach in Salix spp.
SandbarPC	Percentage of each reach in sand bars
RvrSandbar	The sq. meters of sand bar per km. of river length
GT3in	The percent of soil fragments that is greater than 3 inches in diameter, cobble
GT3inPC	The percent of soil sample that is greater than 3 inches in diameter
Sand	The number of sq. meters in each reach with Soils with at least 50% sand
SandPC	The percentage of each reach with soils with at least 50% sand
ReachTot	The total number of active beaver lodges from surveys by Collins 1976, And aerial surveys from 2006, 2010 and 2014
ReachPC	Percentage of beaver lodges in each reach from the total of 98 active lodges
BvrDenKm	Beaver lodges per km of stream distance
BvrDenSqKm	Beaver lodge density per sq.km of reach

Appendix C. Correlation matrix showing relationship between river reach variables and concentrations of beavers along the lower Snake River. See Appendix B for a listing of variable codes. Also see Table 1 for a summary of correlations between variables and active beaver lodges with correlations of r=0.5 or above (*p=0.05*).

	BraidIndex	*Slope*	*SinIndex*	*Populus*	*Salix*	*Sandbars*	*PopulusPC*	*SalixPC*	*SandbarPC*	*RvrSandbar*	*GT3in*	*GT3inPC*	*Sand*	*SandPC*	*ReachTot*	*ReachPC*	*BvrDenKm*	*BvrDenSqKm*
BraidIndex	1.000																	
Slope	0.571	1.000																
SinIndex	-0.196	-0.149	1.000															
Populus	0.441	0.467	-0.094	1.000														
Salix	0.463	0.478	0.034	0.739	1.000													
Sandbars	0.519	0.459	-0.112	0.983	0.788	1.000												
PopulusPC	0.177	0.565	-0.153	0.595	0.266	0.491	1.000											
SalixPC	0.070	0.146	0.055	-0.164	0.416	-0.120	-0.201	1.000										
SandbarPC	0.476	0.247	-0.286	0.272	0.078	0.309	0.224	-0.225	1.000									
RvrSandbar	0.632	0.477	-0.260	0.656	0.562	0.716	0.416	-0.043	0.757	1.000								
GT3in	-0.066	-0.058	-0.135	0.277	0.313	0.328	-0.023	-0.157	-0.115	0.198	1.000							
GT3inPC	-0.301	-0.473	-0.139	-0.193	-0.271	-0.184	-0.318	-0.276	0.189	-0.079	0.456	1.000						
Sand	0.430	0.462	0.027	0.988	0.720	0.964	0.581	-0.161	0.234	0.600	0.220	-0.205	1.000					
SandPC	0.020	0.467	0.261	0.424	0.123	0.316	0.831	-0.193	-0.027	0.151	-0.096	-0.308	0.483	1.000				
ReachTot	0.365	0.202	0.118	0.506	0.752	0.617	-0.012	0.305	0.053	0.488	0.567	-0.080	0.486	-0.045	1.000			
ReachPC	0.365	0.202	0.118	0.506	0.752	0.617	-0.012	0.305	0.053	0.488	0.567	-0.080	0.486	-0.045	1.000	1.000		
BvrDenKm	-0.088	-0.357	-0.102	-0.258	-0.077	-0.189	-0.382	0.479	0.194	0.158	-0.104	0.125	-0.279	-0.372	0.169	0.169	1.000	
BvrDenSqKm	-0.115	-0.478	-0.053	-0.417	-0.308	-0.350	-0.579	0.184	0.404	0.018	-0.086	0.513	-0.423	-0.562	0.002	0.002	0.736	1.000

SPIDERS REVISITED: RETRACING THE STEPS OF HERBERT AND LORNA LEVI'S HISTORIC INVERTEBRATE SURVEYS OF THE JACKSON HOLE REGION OF WYOMING

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✦ ABSTRACT

In 1950, Herbert and Lorna Levi collected invertebrates in Yellowstone and Grand Teton National Parks and other localities in the region. Sixty-five years later and looking towards the centennial of the National Park Service, a preliminary reassessment of the biodiversity of spiders was conducted in a subset of localities that were collected by the Levis. Specimens have been collected and are in the process of being identified. Comparison of this new collection with the historical records is currently underway. As the arts have played a crucial role in the history of national parks, we are exploring how to partner art and science to share the beauty and wonder of spiders based on our fieldwork in celebration of the upcoming National Park Service centennial.

✦ INTRODUCTION

The purpose of this study is to conduct a preliminary reassessment of the biodiversity of spiders in select locations in Grand Teton National Park and the surrounding area and to compare our assessment to historical records. It is part of a larger project to explore using spiders as a way of thinking about interconnectedness, innovation and stewardship.

Herbert Walter and Lorna Rose Levi

Herbert Walter Levi (3 January 1921 – 3 November 2014) was one of the "grand arachnologists of the 20th century" (Maddison 2014) and is known for his contributions to spider taxonomy, especially orb-weaving spiders. While in Wisconsin, Levi said he attended every lecture he could by Aldo Leopold, considered by some to be the father of wildlife ecology and the United States wilderness system, in order to learn everything he could and apply it to invertebrates (Levi, pers. com.). Levi later became the Alexander Agassiz Professor of Zoology and the Curator of Invertebrate Zoology at Harvard's Museum of Comparative Zoology. As an alpha taxonomist Levi described more than 1,250 species of spiders new to science during his career. He left a long lineage of students including curators of invertebrates at institutions like the American Museum of Natural History and the Smithsonian, and he made spiders accessible to people through his drawings and work at a time when macro field photography and the imaging techniques we have now were not so readily available. Along with his wife Lorna (who was a co-investigator on much of his research), the Levis dedicated their lives to arachnology, conservation, education and stewardship, and they shared their fascination with spiders with broad audiences through their classic book: "Spiders and Their Kin" (Frances Levi, personal communication; Levi et al. 1968).

In 1950, the Levis travelled from Wisconsin to Wyoming to conduct some of the first surveys of terrestrial invertebrates in the area. The Levis were stationed at the Jackson Hole Wildlife Park from July 15 to August 15, 1950 (Figure 1). The purpose of their study was to "obtain specimens of several groups of invertebrates of the Jackson Hole region for purposes of study of their taxonomy, ecology, life history and distribution" (Levi and Levi 1951a). The Levis travelled to various field sites to collect and attended lectures by other researchers including a talk that summer by Olaus Murie (Levi and Levi, pers. com.).


Figure 1. Lorna and Herbert Levi and a pronghorn antelope in the GYE, 1950 (photo courtesy Frances Levi).

Spiders and invertebrate conservation

Invertebrates make up more than 95 percent of animal species – they are some of the "little things that run the world" according to E. O. Wilson (Wilson 1987). Despite their being the most abundant creatures on our planet (Smithsonian Institution 2014), there are fewer and fewer places where people can learn about invertebrates. Last year the National Zoo permanently closed its Invertebrates Exhibit. As NPR's Christopher Joyce reported over ten years ago, these animals have been a tough sell for conservation efforts because they "are not furry" and "they don't eat out of your hand…but their disappearance would fundamentally change our planet" (Joyce 2004).

Of the invertebrates, there are 45,756 accepted species of spiders according to the World Spider Catalog (2015), compared to the eight species of bears living in the world (Servheen et al. 2009) – only two of which make their home in the Greater Yellowstone Ecosystem (GYE) (Gunther et al. 2002). Spiders have been found in every terrestrial ecosystem (except in Antarctica) as well as in some aquatic ones. Spiders play an important role in the food web as both predator and prey. As predator, they help control the insect and pest populations that could otherwise devour the plants that are food sources for many animals such as the herds of bison important to the American West, and as prey they are a food source for birds, wasps, frogs and other animals. All spiders can spin silk, although not all spiders make webs. Most spiders produce venom that they use to assist with prey capture. Spiders capture their prey using a variety of strategies usually involving some combination of venom and silk. Spiders are considered the most abundant predator on land today (Selden and Penny 2010).

Spiders and innovation

Spiders' incredible diversity is rich territory for bio-inspired design. Spiders (specifically their venom and silk) are a focal point for many areas of research: from medical and pharmaceutical applications (Blüm and Scheibel 2012); to biotechnology (Blum et al. 2014, Chaim et al. 2011, Senff-Ribeiro et al. 2008); to agricultural pesticide research (Nakasu et al. 2014). Former University of Wyoming Professor Randy Lewis, currently the Director of the Synthetic Bioproduct Center at Utah State University, has made significant contributions with his research of spider silk proteins toward synthetic spider silk production (Utah Statesman 2011, Dong et al. 1991). Jackie Palmer, one of Levi's students, also played an important role in advancing knowledge of spider silk through her research on silk production in "primitive" mygalomorph spiders (Palmer 1985, 1990, Shear et al. 1989). Through their scientific contributions, along with the research of many others who have looked to spiders for inspiration over several centuries, they advanced knowledge on how to synthesize a fiber whose ratio of strength to density exceeds that of steel and is more flexible than Kevlar (Oyen 2013) – something spiders have been doing for over 400 million years on a liquefied diet of dead bugs (Brunetta and Craig 2010). This has led to recent innovations such as the North Face's Moon Parka that is "the world's first successful use of synthetic spider silk materials on an actual manufacturing line" (North Face 2015).

Spiders and the Greater Yellowstone Ecosystem

Despite their ecological importance and remarkable diversity, research on spiders in Grand Teton National Park has advanced little since the 1950s when Levi and Levi conducted their surveys in the then Jackson Hole Wildlife Park and surrounding areas (Donald Lowrie and Willis Gertsch studied spiders from the western Wyoming region during the early 1950s as well) (Levi and Levi 1951b, Lowrie and Gertsch 1955, Lowrie 1968). As of December 2015, the IRMA National Park Service database lists forty-three "Spider/Scorpion" records in Yellowstone, and only one, a mite, in Grand Teton National Park (National Park Service 2015a). This number is not commensurate with their abundance nor their importance.

Art and conservation

Art has played an important role in protecting the natural environment. Paintings by Thomas Moran and photographs by William Henry Jackson captured the imagination of the young nation and are credited with helping to convince Congress to establish Yellowstone as the first National Park in 1872 (Cantrell 2014). The depiction of some animals through artwork has raised awareness, shifted public attitudes and inspired actions. Audubon's accomplishments as a bird artist sparked awareness and inspired the formation of the Audubon Society in the 1800s, an organization that remains committed to science-based bird conservation and continues to use his images in their conservation efforts (Audubon Society 2015). Photographs were crucial for building public support and moving lawmakers to designate lands for conservation – the photographs by N. S. Leek of the wasting elk were instrumental in moving the public and Congress to found the National Elk Refuge in 1912 (Morriss 2012).

Exploring and nurturing our connection with nature through art continues today in various forms: from the Ucross Pollination Experiment that paired prominent artists and scientists from the University of Wyoming to create original works (University of Wyoming 2014); to Jackson Hole Public Arts commissions for celebrating endangered species in the GYE (Daly 2013); to the multi-disciplinary performance Hi-Fi Sci Art: Preserving Our Planet with Dinosaur Annex at the MIT Museum (Massachusetts Institute of Technology 2015); to the exhibits and dialogue sparked by the National Museum of Wildlife Art and its public programming that "enrich and inspire appreciation and knowledge of humanity's relationship with nature" (National Museum of Wildlife Art 2015); to Arts for the Parks, where artists create works inspired by the parks and a portion of the proceeds goes back to supporting the parks (Grand Teton Association 2015).

While successful in communicating the grandeur of the region, some of the early iconic images of the American West (such as Moran's paintings from the Hayden Geological Survey of 1871) did not represent the reality of native peoples inhabiting the land. Moran's daughter said of her father's experience, "To him it was all grandeur, beauty, color and light – nothing of man at all, but nature, virgin, unspoiled and lovely" (Wilkins 1998). Native peoples are still marginalized and frequently under-represented in the story of our national parks. Many of the lands in the northern Rocky Mountain west referred to as "untouched wilderness" were actually lands important to tribes such as the Blackfoot, Shoshone, Bannock, Gros Ventre and others. Evidence of indigenous peoples in the area of Grand Teton National Park dates back at least 11,000 years (National Park Service 2015b, Crockett 1999).

Spiders and stories

From early cave drawings that depicted spiders, to the oral tradition of Anansi spider stories of the Ashanti/Asante people of West Africa, to the Greek's stories of Arachne, to Hollywood's live action spiderman stories, spiders have touched human imagination and inspired stories among peoples around the globe and across time (Hillyard 1994, Michalski 2010). Spiders are important in many Native American cultures, ranging from Na'ashjéii Asdzáá, Spider Woman, who lives atop Spider Rock in Canyon de Chelly and taught the Diné weaving (Locke 2001), to traditional instructional stories of Iktomi, the trickster spider of the Sioux (Zitkala-Sa 1985). Contemporary native artists pull from traditional imagery to create striking, thought-provoking works important for our times.

✦ STUDY AREA

We revisited a subset of the Levi's field localities in Grand Teton National Park from the Levi and Levi (1951a) study and collected invertebrate specimens focusing on the arachnofauna.

✦ METHODS

We retraced part of Herbert and Lorna Levi's invertebrate field collections in the Jackson Hole region in 1950. Permission was obtained from the Levi family to use original materials from this fieldwork and from the Craighead family to use their original vegetative survey maps from 1950 to guide our work. Our team was joined by the Levi's daughter, Frances, who assisted us in sampling a subset of the original field sites that were studied by her parents. Derek Craighead assisted with spider collection as well. Animals were observed in the field, photo-documented in situ when possible or in the lab, then collected.

Project methods have been approved by the respective permitting authorities and modified accordingly. This research is conducted under research permit# GRTE-2015-SCI-0065 obtained from the Grand Teton National Park in the summer of 2015. Collection techniques included sweep netting, hand collecting, litter sifting, and beating. Field teams conducted sampling both diurnally and nocturnally (usually two collectors during diurnal collecting; usually teams of three collectors for nocturnal collecting). Pitfall traps were not used during this past field season and will only be used in future work on a case-by-case basis per agreement with the National Park Service. Spiders were preserved in 20 mL scintillation vials containing 95% ethanol solution.

✦ Preliminary Results

Over the course of our fieldwork in July and August, we observed, collected, and photo-documented (Figure 2) representative species of spiders (Arachnida: Araneae) from selected sites that were originally surveyed by Levi and Levi (Figure 3). The historic Levi collection can be accessed at MCZ base: http://www.mczbase.mcz.harvard.edu and may be used as a comparative basis and future research. We are working with the National Park Service (NPS) curator to create a database and collection for our study in compliance with NPS curatorial protocols.

A preliminary contribution at the junction of the arts and science is the poem “Populus tremuloides: We Are One” written by S. J. Kariko that highlights our interconnectedness and is inspired by events from this summer’s field season. It was selected to be read at Wonder Of The World, a benefit for the environment on the eve of the international climate talks in Paris in November 2015.

Figure 2. Female crab spider *Misumena vatia,* (Thomisidae) collected in 2015 (Photo S. J. Kariko)

Figure 3. Male *Misumens vatia,* (Thomisidae) collected in 1950 in Moran, WY by Herbert and Lorna Levi. © President and Fellows of Harvard, Museum of Comparative Zoology

✦ Discussion and Future Work

Spiders also give us the metaphor of the web – a way to think about our own interconnectedness and interdependence in both the natural and global world. Engaging visitors through art and science can spark imaginations, inspire discussion, and foster conditions for creative collaborations that can help us develop innovative solutions to meet today’s challenges. To this end, our team is exploring how to create an invitation for visitors to learn about some of the little creatures in Grand Teton National Park during next summer’s centennial celebration through sharing the beauty and wonder of spiders. We envision that art, including contemporary Native works, with its ability to communicate as the "universal language" will be an important vehicle to reach a diverse audience. In celebration of the centennial and to the Levi’s legacy, we aim to create work that combines not only the legacy of Herb’s arachnological research but also the conservation, storytelling and stewardship that were so important to both of them.

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THE STATE-DEPENDENT RESOURCE ALLOCATION HYPOTHESIS: IMPLICATIONS FOR THE FORAGING ECOLOGY AND LIFE HISTORY OF MIGRATORY UNGULATES IN THE GYE

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✦ INTRODUCTION

Understanding the behavioral and physiological responses of animals to environmental stressors is vital to our comprehension of their ecology and life history. The life-history strategy of ungulates is for females to prioritize survival over reproductive effort to maximize life-long fitness (Stearns 1992, Eberhardt 2002, Bårdsen et al. 2008). Consequently, an individual's reproductive decisions are expected to be dependent on nutritional state (Bårdsen et al. 2008). Researchers have long assumed that individuals reduce their metabolism and energy expenditure to conserve nutritional reserves (i.e., fat and protein) during winter because winter has been demonstrated to be a period of energetic loss for temperate ungulates. Recent research, however, has shown that mule deer (*Odocoileus hemionus*) in a poor nutritional state are capable of increasing their nutritional reserves over winter (Monteith et al. 2013), and hormone analysis of moose (*Alces alces*; Jesmer et al. *in review*) indicates that animals with low nutritional reserves have high energy expenditure and energy intake. Therefore, regulation of nutritional state through plasticity in foraging behavior may allow animals to cope with resource shortages. We refer to this notion, wherein animals alter their energy intake and expenditure via foraging behavior as the **State-Dependent Resource Allocation Hypothesis** (Figure 1). In 2014 we proposed to apply state-of-the-art nutritional, isotopic, and hormone analyses to test the State-Dependent Resource Allocation Hypothesis (SRAH) in migratory mule deer within the Greater Yellowstone Ecosystem.

Stable isotope analyses facilitate the study of foraging behavior by quantifying the relative proportions of metabolic fuels derived from exogenous (forage) and endogenous (internal tissue) sources. The carbon isotope signatures ($\delta^{13}C$) of certain non-essential amino acids differ depending on whether its carbon is derived from endogenous (in this case fat tissue) or exogenous sources (Newsome et al. 2011, Whiteman et al. 2015). Additionally, nitrogen isotope signatures ($\delta^{15}N$) are useful for studies of foraging behavior because $\delta^{15}N$ values vary considerably between ungulate tissue and dietary items, permitting the quantification of endogenous (in this case muscle protein) and exogenous sources of protein (Taillon et al. 2013). For mule deer that may be exhibiting state-dependent foraging strategies, synthesizing amino acids from endogenous sources would result in low quantity of $\delta^{13}C$ in a protein rich substrate (e.g., red blood cells), whereas amino acids synthesized from exogenous sources results in greater amounts of $\delta^{13}C$ (DeNiro and Epstein 1977). Conversely, mule deer relying more heavily on endogenous protein sources have higher quantities of $\delta^{15}N$ in red blood cells when compared to individuals deriving protein primarily from forage. Additionally, thyroid hormones, such as triiodothyronine (T3), may be useful in the study of state-dependent foraging because T3 plays an important role in regulating metabolism, where higher circulating T3 reflects a higher metabolic rate (Zheng et al. 2014). Finally, by affixing collars to mule deer with onboard global positioning systems, foraging activity can be quantify based on a variety of movement parameters (Gurarie et al. 2016). Thus, the combination of stable isotope, hormone, and movement analyses provides a powerful framework for studying state-dependent foraging.

To elucidate the influence of foraging decisions on nutritional state, reproduction, and survival, we began testing two primary predictions of the SRAH:

Foraging and catabolism prediction

Mule deer in poor nutritional condition will have higher energy intake (T3) and increased foraging activity (movement), resulting in red blood cells containing more C and N derived from forage than from somatic tissues (catabolism). Mule deer in good nutritional condition will have lower energy intake and reduced foraging activity, resulting in red blood cells containing more C and N derived from somatic tissues than from forage.

Life history prediction

Mule deer will regulate their nutritional reserves in a manner that will optimize life-long fitness (i.e., survival and reproduction). To increase their probability of survival and future reproduction, individuals that have a surplus of nutritional reserves will reduce metabolism to conserve energy and forage less to minimize their exposure to sources of potential mortality. Individuals in a nutritional deficit will have high metabolic rates to support foraging activities and the synthesis of nutritional reserves needed for survival and future reproduction.

✦ METHODS

Nutritional state

During 2013-2016, approximately 95 female mule deer were captured twice annually: once when they arrive onto winter range in December, and once just before they begin spring migration in March. All methods were approved by the University of Wyoming Animal Care and Use committee and the Wyoming Game and Fish Department. Ultrasonography and body condition scoring were used in tandem to calculate total nutritional reserves in the form of both fat and protein per the methodologies of Monteith et al. (2013). December values of fat and protein reserves provided an accurate measure of nutritional state at the beginning of winter. March values of fat and protein reserves allowed us to calculate the over winter change in both reserves. The amount of fat and protein an individual has in December will determine the nutritional state of the individual at the beginning of winter and guide our predictions of the relationships between foraging and activity profiles.

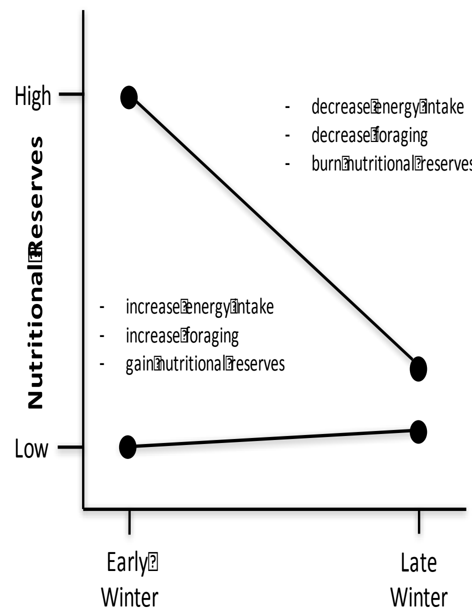

Figure 1. Conceptual figure illustrating the observed trends in nutritional gains and losses (circles and lines) over winter (Monteith et al. 2013). Predictions of the State-Dependent Resource Allocation Hypothesis (hashed bullets) are outlined for individuals with relatively high and low nutritional reserves.

Sampling design

The distribution of body fat losses from fall 2014 through spring 2015 ranged from -6 percentage points (fat loss) to positive 1 percentage point (fat gain). Therefore, during fall 2015 captures we collected red blood cells, feces, and biopsied muscle and fat (somatic tissue) from the rump of deer after applying a local anesthetic, from 4 individuals within each 1 percentage point bins (8 total bins, n=32).

Movement

Each captured mule deer was fit with a global positioning system (GPS) collar that recorded the location of the individual once every hour. The spatial location data was used to quantify the proportion of time each individual spent in a behavioral state, i.e., foraging, bedding, and moving between foraging and bedding sites. We are using a Bayesian state-space model that uses step lengths (the distance between successive locations), turning angles, and movement of the neck (tilt meter inside the collar; more tilts when foraging than when bedded) to assign each location as belonging to one of the three behavioral states (Ditmer et al. *unpublished*, Morales et al. 2004, Gurarie et al. 2016).

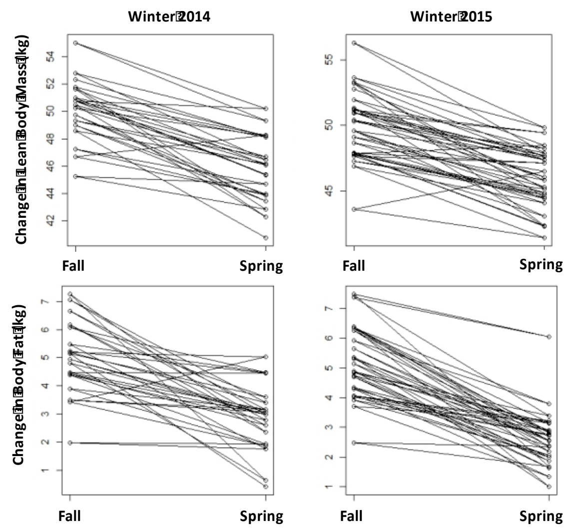

Figure 2. Schematic demonstrating that individuals who entered winter with few fat and protein reserves tended to lose fewer reserves overwinter. Some individuals gained fat or protein overwinter. Open circles represent individual nutritional reserves in fall (December) and spring (March), and black lines illustrated the degree to which nutritional reserves were lost or gained overwinter.

Stable isotopes and hormones

Red blood cells reflect the sources of $\delta^{13}C$ and $\delta^{15}N$ during the 4-8-week period prior to sample collection, and are therefore appropriate for our research. We collected red blood cells during both December and March captures. While isotopic values of fat and muscle tissue provide an isotopic signature of body reserves, plant fibers found in the fecal sample provide an isotopic signature of forage. Red blood cells, fat tissue, muscle tissue, and plant fibers found in feces were sent to the University of New Mexico, Center for Stable Isotopes for analysis of $\delta^{13}C$ and $\delta^{15}N$. Additional whole fecal samples were collected at time of capture and will be sent to the University of Washington, Conservation Biology Lab for T3 analysis.

Life history

We annually monitored nutrition, reproduction and survival in all study animals. Survival of female mule deer was monitored using GPS collar-based mortality sensors. These sensors emit a faster pulse rate once the collar has not moved for five hours. Hence, we performed mortality surveys every two weeks as we search for individuals while conducting time budget observations. During March capture we assessed fetal rates (presence and number of fetuses) using trans-abdominal ultrasonography (Monteith et al. 2014).

✦ RESULTS

We have only completed exploratory lab and statistical analyses at this time because funding for this study came in two installments (½ in 2014, and ½ in 2016). Changes in lean body mass (protein reserves) and body fat overwinter were dependent on the amount of these reserves individuals possessed in the fall when they returned to winter range from their summer ranges. Although most mule deer lost reserves overwinter, individuals that entered winter with few fat and protein reserves tended to lose fewer reserves overwinter. Interestingly, some individuals gained fat or protein overwinter (Figure 2). These results demonstrate that physiological or behavioral plasticity allows mule deer to overcome the nutritional limitations presented by winter in temperate climates—an important first step in our study.

Despite previous reports of statistically significant correlations between bulk $\delta^{13}C$ or $\delta^{15}N$ and body fat or lean mass in lab rodents and other small vertebrates, linear regression revealed no pattern between $\delta^{13}C$ or $\delta^{15}N$ and body fat or lean mass in mule deer (all $P>0.2$). This result, however, did not surprise us. The large and diverse microbial community found in the rumen of large herbivores, such as ungulates, is capable of synthesizing many types of amino acids (the building blocks of somatic tissues) that monogastric animals, such as lab rodents, cannot (Church 1988, Puniya et al. 2015). Bulk isotope analysis (used here) quantifies $\delta^{13}C$ and $\delta^{15}N$ for the entire (red blood cell) sample and thus all amino acids. Some amino acids can be synthesized by the body (somatic cell) and some must be acquired in the diet, thus understanding the contribution of C and N from the somatic reserves versus diet may be necessary to elucidate patterns of state-dependent foraging.

✦ CONTINUED WORK

We are currently investigating which amino acids can be synthesized endogenously (from microbes or catabolism of somatic tissues; non-essential amino acids) by ruminants and which amino acids can only be acquired from forage (essential amino acids). Once this investigation is complete we will use compound-specific amino acid analyses to quantify $\delta^{13}C$ and $\delta^{15}N$ in the non-essential amino acids of red blood cells (i.e., amino acids that are synthesized within somatic cells), such that we can develop overwinter catabolism and foraging profiles for each mule deer. Once isotopic methodologies and analyses are complete we will begin linking foraging (energy intake [T3] and movement) and catabolism profiles (stable isotopes) to life history characteristics (i.e., reproduction and survival), thereby providing a test of the SRAH.

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SMALL MAMMAL MOVEMENTS AND FIRE HISTORY: TESTING THE LONG-TERM EFFECTS OF THE 1988 HUCKLEBERRY MOUNTAIN FIRE

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✦ ABSTRACT

Fires are an important ecological force shaping biological communities in western North America. Fires change landscapes in ways which influence the relative abundance and activities of the organisms occurring in those habitats. Preliminary results from previous work suggest the stage of fire succession may influence individual movements on the landscape. As part of a long-term study of the 1988 Yellowstone fires along the John D. Rockefeller, Jr. Memorial Parkway, we set out to examine these patterns in more detail to (1) test whether the two dominant small mammal species were moving different distances based upon the stage of succession in a particular habitat, and (2) determine the role of habitat complexity, resource types, and species abundance in driving these patterns. Using movement distances from capture-recapture data and fluorescent powder tracking of individuals we compared movement distances and habitat usage between mid-succession and late-succession trapping grids for red-backed voles (*Myodes gapperi*) and deer mice (*Peromyscus maniculatus*). The results suggest deer mice, some of the first colonizers to burned habitat, are moving farther than red-backed voles, and move farther in burned habitats than in unburned habitats. Red-backed voles exhibit slightly, but not significantly, longer movements in burned habitats. Powder tracking results suggest habitat complexity, in particular the quantity of coarse woody debris, may partially explain the differences in movement patterns by burn history. These results are important for understanding the long-lasting impacts of fire history on population and community patterns.

✦ INTRODUCTION

Fire disturbance continues to be an important force shaping communities in the Intermountain West. Fire disturbances thin out old-growth forests, redistribute nutrients, increase landscape variability in plant communities, and shape vegetation structure (reviewed in Wallace 2004). Despite the widely recognized importance of fire in these ecosystems (see review in Romme et al. 2011) few studies have followed long-term responses (>10 years) in small mammal communities, or have evaluated how fire history shapes how individuals interact on the landscape. Given the varied history of fires across the Yellowstone region, evaluating the role fire may be playing in shaping animal movements and community connectivity is important to understanding ecosystem health. Previous UW/NPS work by Stanton et al. (1990, 1991), Spildie (1994), Seville et al. (1997), Stanton et al. (1998), Burt et al. (2009, 2010), and Lanier et al. (2014) at Huckleberry Mountain, Wyoming has built a baseline for understanding how small mammal communities and habitat structure have changed over a 26-year post-fire interval. These small mammal and vegetation surveys, begun after the extensive 1988 fire season, have provided biologists with the unique opportunity to study the short and long-term effects of a natural disturbance on community dynamics and the relationships between successional stages of the vegetative community and the corresponding faunal community structure. As predicted by Taylor (1973), small mammal species diversity was highest 25 years after fires; however, diversity in unburned plots has increased over the same time period, species evenness and abundance continues to differ between burned and unburned plots, and the increases in diversity do not yet show a clear leveling out. Further unknown is how these changes in abundance and habitat during post-fire succession impact mammal movements, and long-term ecological responses in small mammal communities.

Most fire-succession studies on small mammals (rodents and shrews) have focused on the early stages (0–10 years), providing important evidence on initial community structure (e.g., Fisher and Wilkinson 2005). Early on, the *initiation stage* (0–10 years post-burn; Lee 2002) often include changes in relative abundance within the community rather than outright species replacement. The deer mouse (*Peromyscus maniculatus*), a generalist, typically responds positively in the years following fire and is often the most numerically dominant species. This was true for our study sites, with initially large populations of deer mice, which were 3 times as abundant in the burned habitats than in the unburned habitats (Stanton et al. 1991). The southern red-backed vole (*Myodes gapperi*), another numerically dominant species in the GYE, tends to be an old-growth specialist, but can sometimes recolonize rapidly (see Fisher and Wilkinson 2005). Red-backed voles were present but at low relative abundance (approximately 25% that of deer mice) within the communities on our study sites over the initial 3 years after the burn (Stanton et al. 1991). Given grasses are common in the years immediately following a fire, the presence of grassland species such as jumping mice (*Zapus* spp.) and voles (*Phenacomys intermedius* and *Microtus* spp.) is often initially increased. These grassland specialists were initially detected on our study sites within the first 10 years after the burn, but comprise a smaller proportion of the total small mammal community (Seville et al. 1997). Less is known regarding the responses of insectivores, particularly shrews, in the initiation stage; however, the more xeric conditions predominating post-fire are likely less hospitable to shrews. Initial data from our sites bear this pattern out. For example, Spildie (1994) reported 90% ($N = 40$) of shrews captured in pitfall or live-traps at the Huckleberry Mountain study sites were mainly captured in control grids (84%), and no masked shrews (*Sorex cinereus*) were trapped in burned habitats.

Given the challenges associated with long-term studies, few studies have focused on small mammal responses during the *establishment stage* (11–25 years post-burn; Lee 2002) in North American ecosystems. In boreal forests, the same species are often present, but relative abundances continue to differ. Roy et al. (1995) showed red backed voles were common, but still less abundant than in old growth stands. Other species, such as meadow voles and jumping mice were uncommon or absent, presumably from habitat changes and limited food resources. Deer mice, though still common, were at a lower relative abundance than in earlier years. Data from our sites support the gradual shift in dominance from red-backed voles to deer mice, with more than twice as many red-backed voles as deer mice captured on the burn sites, despite the fact deer mice were more often captured on burned habitats than on adjacent old growth habitats, 26 years post-burn (Lanier et al. 2014). However, jumping mice and other species of voles maintained or increased in relative abundance during this time period, compared to the first 10 years post-fire (Lanier et al. 2014). Similar to the initiation stage, even less is known regarding the response of insectivores to fire disturbances. Since mammalian insectivores feed on invertebrates, correlative responses to habitat change are less predictable as is the case with granivores and folivores (Kirkland et al. 1997). Nonetheless, as ground cover increases in quantity (leaf litter, etc.) and shifts to a more mesic microhabitat, shrews would be predicted to increase in abundance. During the establishment stage on our sites shrews increased in abundance, comprising 17% of total captures on the burned grids (Lanier et al. 2014).

The larger montane shrew (*S. monticolus*) and the smaller masked shrew (*S. cinereus*) were both captured on previously burned habitats, as well as in the adjacent old-growth grids (Lanier et al. 2014).

In addition to shifting community structure, fires (and the resulting vegetation and biogeochemical changes) may impact small mammal movements. Small mammal movements and home-range sizes have long been known to reflect multiple factors, such as the availability of resources in space and time (Stapp 1997), pressures from population density (Fretwell and Lucas 1970), and structural complexity (Zollner and Crane 2003). For example, optimum foraging theory (Sinervo 1997) suggests animals will tend to have smaller home ranges and move less when food resources are abundant. High population density will likewise tend to reduce home range size of a species (Fretwell and Lucas 1970). In contrast, high structural complexity (such as presence of many shrubby species and large amounts of coarse woody debris [CWD]) has been shown to increase movement of small mammals (eastern chipmunks), possibly due to reduced predation risk (Zollner and Crane 2003). Analysis of previous re-capture data (Lanier et al. 2014) suggests differential movements in burned than unburned habitats, which may relate to either abundance differences or the presence of more CWD or differential food resources based on burn history.

We used capture-recapture data and powder tracking to examine (1) whether movements in the 2 dominant species (deer mice and red-backed voles) differ by burn history, and (2) if those greater movements are related to either structural complexity (i.e., presence of CWD), population density, or particular resource types (e.g., herbs, grasses, shrubs) within each habitat.

✦ METHODS

Study sites

Initially established by Stanton et al. (1990) these study sites have been the subject of repeated studies at regular intervals by Stanton et al. (1991), Spildie (1994), Seville et al. (1997), Stanton et al. (1998), Burt et al. (2009, 2010), and Lanier et al. (2014). Although the initial study design involved more survey grids, efforts over the last 20 years have focused primarily on 4 study grids, 2 located in areas burned in the Huckleberry Mountain Fire in 1988 and 2 located in adjacent old-growth habitats (hereafter referred to as burned and control, respectively). Although the control grids are not true controls in the experimental sense, we have opted to retain this term for consistency with previous work. One burned and one control grid is located on the wetter east-facing aspect: east-facing burn (EFB) and east-facing control (EFC) grids. One burned and one control grid are located on the drier west-facing aspect: west-facing burn (WFB) and west-facing control (WFB). Each grid comprises 100 trap stations, located on a 1-ha plot, with each trap station spaced 10 m apart. Every trap station has a Sherman live trap, for small mammals, and a subset of those trap stations (25/grid) also included a pitfall trap for small mammals and invertebrate communities.

Community survey techniques

Small mammal surveys consisted of a 4-night trapping period during the months of June, July, and August 2015, following previously established protocols for trap effort (i.e., number of traps/grid, trap nights, and location). Each Sherman trap was baited with rolled oats and peanut butter, opened between 1530 and 1730, and checked between 0500 and 0830 the following day. Traps were closed during the day, as per previous work, to limit trap mortalities. Each trap also contained cotton batting for insulation. Captured animals were uniquely ear-tagged (in one ear) for later identification and injected with a subdermal passive integrated transponder (PIT) tag between the shoulder blades to permit longer-term identification of individuals. Each individual was classified by species, sex, age class (juvenile or adult), and reproductive condition; weighed to the nearest gram; and released where caught. Animals and traps were handled in accordance with current IACUC guidelines for handling small rodents (#20170517ZR0071-01). As animals were processed (weighed, measured, and tagged) for this study any fecal samples produced were collected in 2 mL microcentrifuge tubes and later preserved in a 2.5% w/v aqueous potassium dichromate solution for study of potential protozoan parasite infection (Williams et al. 2010). All traps were cleaned with a viricide at the conclusion of each 4-day trap session. In addition to live traps, a small pitfall trap with propylene glycol was placed at ground level at every 4th trap station (25 pitfalls/grid) to capture voucher specimens, primarily targeting shrews, which are underrepresented in Sherman traps, and the corresponding invertebrate communities.

Tracking movements and microhabitat use

In addition to trapping to establish community composition and abundance, we conducted several directed tests of small mammal movements. First, we used a subset of capture-recapture data to estimate movements for recaptured deer mice and red-backed voles, estimating the within-grid movements of an individual. While recapture data provide some information on the movement among traps, they may not accurately capture the exact distance and microhabitat usage of individuals. Therefore, we compared those movement estimates with information from fluorescent powder tracking. Fluorescent tracking, using fluorescent powder and UV light to reveal and track animal movements, can be used to determine movement of small animals up to 900 m (Lemen and Freeman 1985). It can also provide information on habitat use, such as what plants are climbed, movements relative to CWD, food consumed, and even where a species burrows (Lemen and Freeman 1985). Trapping effort for powder tracking included 20 additional traps place parallel to the west-facing control and west-facing burn grids for 3 nights in August (the only month with a sufficient number of dry days to trap). Traps were baited with peanut butter and oats, set around 1730, and checked and closed after sundown (2100–0000). Target mammals were captured and processed, as described above, and coated in fluorescent powder taking care to avoid getting powder on the face of the animal. Animals were released at the point of capture, and we returned the following night to track their movements using a UV light. For each individual, we measured total distance traveled, distance traveled using CWD as a percentage of total path distance, and percentage total distance corresponding differing vegetation types (i.e., shrub, grass, CWD, bare ground).

Vegetative structure

Vegetation characteristics were recorded at a stratified subset of trap stations using 25 different microhabitat measurements following the methods of Deuser and Shugart (1978) and Daubenmire (1959). These included microhabitat characteristics capturing vertical habitat around the trap site: distance to nearest tree and tree size (diameter at breast height, dbh), distance to nearest sapling and size (in dbh), distance to nearest seedling, distance to nearest shrub, and canopy cover. We also recorded ground cover around the trap using a Daubenmire frame, estimating percentage of herbaceous plants, woody plants, grasses, leaf litter, downed logs, and area disturbed by the pitfall trap, each to the nearest 25% (i.e., 0%, 1–25%, 26–50%, 51–75%, 76–100%). At each chosen station distance to the trap, length, diameter, height from the ground, and decay class of coarse woody debris (i.e., downed logs >7.5 cm in diameter) was quantified for a 5-meter distance in the four cardinal directions following procedures developed by Brown (1974) and Harmon and Sexton (1996). Microhabitat sampling occurred in July (ground cover and canopy cover measurements, as well as some CWD and distance measurements) and August (CWD and distance measurements only), when herbaceous/grassy vegetation was at maximum height and flowering or fruiting was occurring.

Analyses

To assess the distances moved by individuals, we evaluated maximum movement distance and average movement based upon traps where an individual was caught, using the 10 m by 10 m trapping grid design to estimate distance traveled. Maximum movement distance was taken as greatest total distance between any of the traps in which an individual was caught. Average movement distance was the average of trap-to-trap movements of an individual, taken sequentially as an individual moved around the grid. When an animal was only caught in 2 traps the average and maximum distances were the same. A series of multimodel comparisons (Burnham and Anderson 2002) were run using the R package MuMIn to examine relative ability of uni- and multivariate models to evaluate distance traveled in the capture/recapture dataset relative to age, sex, grid, aspect, and/or burn history. All single and multiple combinations of variables were compared, with the exception of models including grid and history or grid and slope, which were excluded. For the powder tracking data, we examined percentage of path traveled as the response and individual ID, relationship to log, and vegetation type, and fire history as possible explanatory variables. Multimodel comparisons were run on these data to quantify the relative influence of explanatory variables in path distance using the R package glmulti (Cacagno 2013).

We estimated population abundance as the number of unique captures per species. Diversity within sites was estimated using the Shannon-Wiener Index ($H' = -\sum p_i \log p_i$), using only genus for shrews and microtine voles (*Microtus* spp.) due to difficulty of identifying these species while living. Summary results from microhabitat sampling variables were compared between grids to gauge the amount of difference in vegetative structure and to look for purported relationship between changes in habitat structure and small mammal movements. Significant differences by burn history were examined using a non-parametric Kruskal-Wallis rank-sum test in R.

✦ Results

Out of 4,800 total trap nights, we captured 1,876 small mammals, of which 919 were unique individuals, representing a minimum of 10 species. Overall, red-backed voles were most abundant and were more than three times as abundant on control grids relative to adjacent burned grids (N_{burned} = 109, $N_{control}$ = 346; Figure 1). However, deer mice were more abundant on burned grids than on control grids and equaled or exceeded abundance of red-backed voles on burned grids (N_{burned} = 126, $N_{control}$ = 38; Figure 1). Shrews (*Sorex* spp.), mainly *Sorex monticolus* and *S. cinereus* based on voucher specimens, were captured on all four grids, and shrew abundance was higher on burned grids than on control grids (N_{burned} = 130, $N_{control}$ = 107). Voles (*Phenacomys intermedius* and *Microtus* spp.) were only captured on two of the four grids (EFC and WFB), and were slightly more abundant on burned grids (N_{WFB} = 13, N_{EFC} = 10). Overall, both burned grids had higher Shannon-Wiener diversities (H'_{EFB} = 1.20, H'_{WFB} = 1.51) than control grids (H'_{EFC} = 1.02, H'_{WFC} = 0.94), related in part to the presence of pocket gophers (*Thomomys talpoides*) and greater species evenness in these sites.

Preliminary results of capture-recapture movement metrics suggest both red-backed voles and deer mice moved more than 1.5 times farther in burn grids (average distance moved: $\bar{X}_{DM,burn}$ = 37.5 m vs $\bar{X}_{DM,control}$ = 23.5 m and $\bar{X}_{RBV,burn}$ = 24.6 m vs. $\bar{X}_{RBV,control}$ = 16.0 m; Figure 2). However, only differences in movement distances for deer mice were statistically significant by burn history. Because average movement distances and greatest movement distances ($\bar{X}_{DM,burn}$ = 45.3 m vs $\bar{X}_{DM,control}$ = 25.6 m and $\bar{X}_{RBV,burn}$ = 34.3 m vs. $\bar{X}_{RBV,control}$ = 23.0 m) were similar with respect to our findings, the average distances will be focused on for other comparisons. Multimodel comparisons suggest these movement differences in deer mice are best explained by burn history (burned vs. unburned), with the top 2 models also including age (Table 1), as individuals initially trapped as juveniles moved slightly farther than adults. In contrast, the best explanatory models for red-backed voles included capture grid, as opposed to burn history (Table 2), sex and age appear in the second- and third-best models. Overall, deer mice ($\bar{X}_{DM}$ = 34.3 m) moved significantly farther than red-backed voles ($\bar{X}_{RBV}$ = 17.8 m; Figure 3).

Due to an exceptionally rainy summer in 2015 we were only able to conduct powder tracking for 120 trap nights. Out of those trapping sessions we

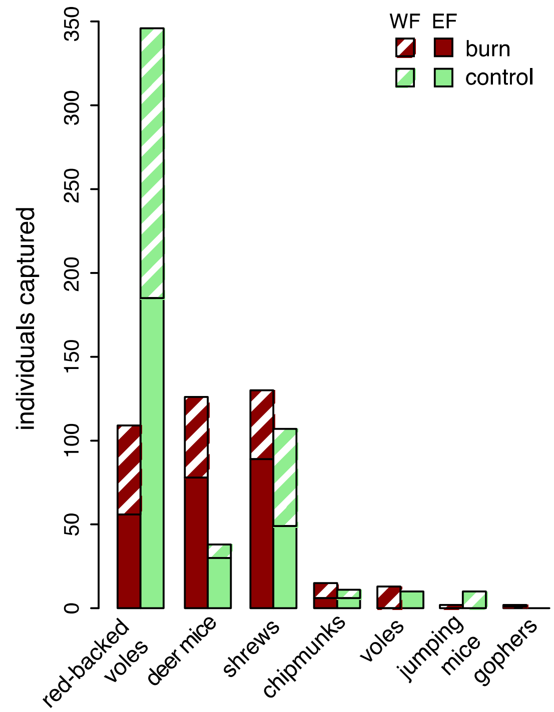

Figure 1. Red-backed voles, deer mice, and shrews (*Sorex* spp.) dominated small mammal captures, with more red-backed voles in control grids and more deer mice and shrews in burned grids. Other species of voles, both *Phenacomys intermedius* and *Microtus* ssp. are combined under ‘voles’. West-facing (WF) captures shown with stripes and east-facing (EF) captures shown with solid colors.

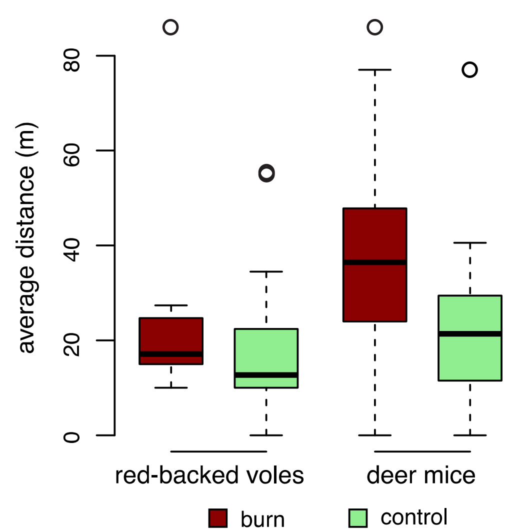

Figure 2. Average movement distances of red-backed voles are greater in burned grids (24.6 m) than in control grids (16.0 m), but this difference is not statistically significant (p = 0.1). However, deer mice move significantly farther in burned grids (37.5 m) than in control grids (23.5 m; p = 0.02).

Table 1. The top 5 models based on a multimodel comparison for average movement distances in red-backed voles. Variables included in each top model are shown with a '+'.

Intercept	Sex	Age	Grid	History	Aspect	df	logLik	AICc	delta	weight
43.20			+			5	-196.778	405.0	0.00	0.248
41.27	+		+			6	-195.763	405.5	0.58	0.186
45.20		+	+			6	-195.979	406.0	1.01	0.150
43.23	+	+	+			7	-195.089	406.9	1.96	0.093
24.64				+		3	-200.566	407.7	2.72	0.064

Table 2. The top 5 models based on a multimodel comparison for average movement distances in deer mice. Variables included in each top model are shown with a '+'.

Intercept	Sex	Age	Grid	History	Aspect	df	logLik	AICc	delta	weight
33.39		+		+		4	-433.204	874.9	0.00	0.289
29.12	+	+		+		5	-432.408	875.5	0.64	0.210
36.15				+		3	-435.033	876.3	1.48	0.138
27.71	+	+		+	+	6	-432.001	877.0	2.10	0.101
32.24	+			+		4	-434.369	877.2	2.33	0.090

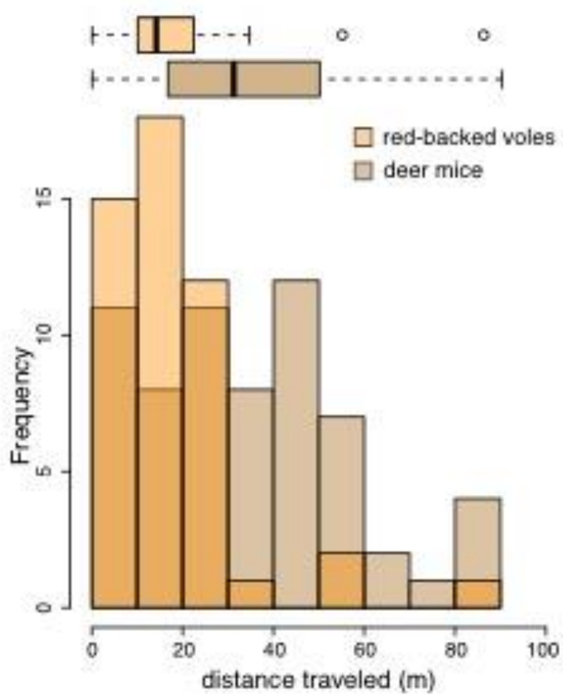

Figure 3. On average, deer mice moved nearly twice as far as red-backed voles (34.26 m vs. 17.79 m, respectively; $p < 0.001$).

captured and powdered 9 red-backed voles and 2 deer mice. Overall, trails were followed for an average of 2,026 cm. In red-backed voles, 72.5% of total trackable trails followed downed logs (CWD), with animals most frequently running on top of logs (as opposed to below or beside logs). Red-backed voles in burned habitats spent a greater proportion of their total path on or near logs than voles in control habitats ($\bar{X}_{RBV,burn}$ = 82.7% vs. $\bar{X}_{RBV,control}$ = 67.3%; Figure 4). Much of the red-backed vole movement was through shrubby areas, primarily grouse whortleberry (*Vaccinium scoparium*), comprising 25% of total trackable trails, with paths in control habitats moving more frequently through shrubs (Figure 4). However, burned traps also have a greater number of logs ($\bar{X}_{burn}$ = 14.04 vs $\bar{X}_{control}$ = 10.14 within 5 m of a trap) and shrubs comprise a greater proportion of ground cover around control sites (Figure 5). Contrary to recapture data, powder tracking results suggest red-backed voles were moving slightly, but not significantly farther in control habitats; however, this is based on a small sample size (N_{burn} = 3; $N_{control}$ = 6). While burn history was an important variable, as was presence and use of logs for travel, distance traveled (as a proportion of path length) was best explained by individual-level variation in red-backed voles. Although only 2 deer mice were captured, both in burned grids, an average

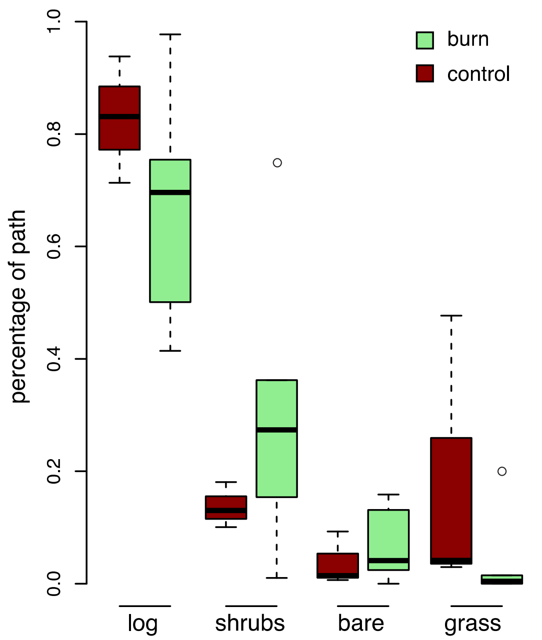

Figure 4. As a percentage of total path, red-backed voles ($N_{burn} = 3$; $N_{control} = 6$) mainly followed downed logs (CWD), with shrubs being the second-most traveled habitat. Red-backed voles spent more path distance in grassy habitats on burned grids than on adjacent control habitats.

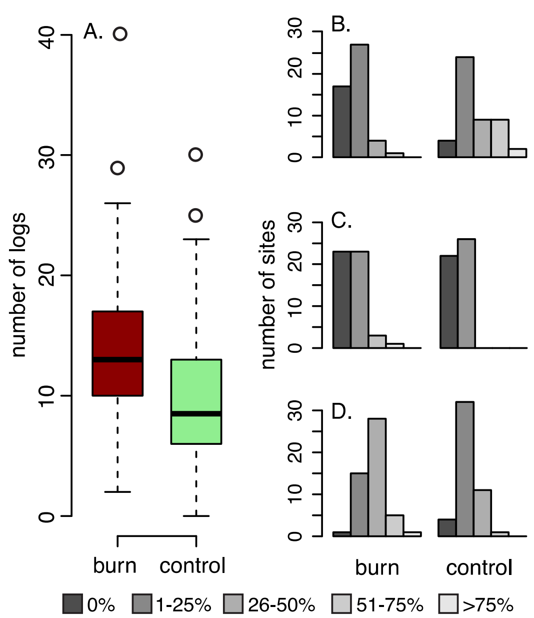

Figure 5. (A) The burned grids had significantly more coarse woody debris (CWD; i.e., logs exceeding 7.5 cm diameter) around each trap than control grid sites (14.04 vs. 10.14 logs respectively; $p = 0.001$). Ground cover on control sites consisted of generally (B) more shrubs, (C) less bare ground, and (D) slightly less grass than burn sites.

of 83% of their trails followed downed logs (CWD), with the animal often moving on top of the log, and 19% included shrubby habitats, mostly grouse whortleberry.

✦ Discussion

Preliminary results indicate deer mice, and possibly red-backed voles, are moving farther in burned habitats, a pattern which may be related to greater numbers of downed trees in those areas (i.e., CWD; Figure 5). Powder tracking revealed both species were frequently using CWD for movements, often moving on top of logs, regardless of burn history of the habitat they were in. Taken together, this suggests the habitat complexity hypothesis (Zollner and Crane 2003) may be the best explanation for the home range size and movement distances among habitats. It is worth noting these results do not exclude the abundance hypothesis. While movements are greater on burn grids, habitats where deer mice are more abundant and red-backed voles have lower abundance, small mammals were more abundant overall on control grids (Figure 1). Both species are also frequently moving through shrubs (grouse whortleberry), a pattern which supports previous work proposing presence of shrubs is a good predictor for red-backed vole captures (Lanier et al. 2014). Previous work has suggested these species are not competitively excluding one another, and habitat differences are the result of species-specific preferences (Wolff and Deuser 1986). Because both species appear to be using these habitat features in relative proportion to their presence (i.e., there are no obvious differences in relative path percentage that differs substantially from the proportion of those habitats within each grid), these habitat features may be important throughout the Greater Yellowstone Ecosystem (GYE).

These findings have implications for the role of intermediate levels of fire succession in mediating movements across the landscape in the GYE. If species are traversing greater distances in areas with greater density of downed trees, there may be stronger gene flow and more disease transmission as post-fire succession proceeds in intermountain forests. Deer mice (*Peromyscus* spp.), in particular, are vectors of numerous zoonotic pathogens with implications for human health, including hantavirus (Hjelle et al. 1995), Lyme disease (Rand et al. 1993), viral encephalitis (Deardorff et al. 2013), and plague (Walsh and Haseeb 2015). Understanding the impacts of landscape structure on these movements and transmission patterns is important for epidemiological models of viral infection in deer mice (Langlois et al. 2001). The greater distances moved by deer mice may also partially explain why they are some of the first colonists during post-fire succession (Stanton et al. 1991).

More broadly, our findings contribute to the knowledge of long-term responses to fire in the intermountain west. Despite becoming more similar to the adjacent old-growth grids, i.e., the control grids, habitats burned in 1988 continued to support greater diversity and more evenness of small mammal species. Relative to previous years we seemingly observed a leveling out of species richness, with similar diversity to captures in 2014 (Lanier et al. 2014). This appears to fit the pattern predicted by Taylor (1973), who suggested small mammal richness should plateau around 25-years post-burn. While proportions of red-backed voles have increased on burn sites, they were less abundant in burned habitats than deer mice (Figure 1). Shrews continued to increase on all grids, and were more abundant in burned habitats than deer mice. Overall, small mammal abundance increased nearly 150% from the previous year (Lanier et al. 2014); however, this pattern was almost entirely driven by increases in red-backed voles, deer mice, and shrews. Interestingly, although these changes may reflect more regional trends in population shifts (small mammals were more abundant in other areas of Wyoming in 2015; M. Ben-David, pers. comm.), these increases were limited to specific grids or habitats on our sites. Red-backed voles only increased greatly on control grids; deer mice increased on two burned and one control grid, and shrews increased greatly on only one of the burned grids. Rare species, such as pocket gophers (*Thomomys intermedius*) and jumping mice (*Zapus princeps*), continued to be captured in low numbers, similar to previous years (Lanier et al. 2014). Long-term studies, such as this, are important for revealing the ways in which fire-driving habitat mosaics are influencing and will continue to influence population and community dynamics.

✦ Acknowledgements

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CAN INVASIVE SNAILS REDUCE PARASITISM IN NATIVE SNAILS? AN EVALUATION OF THE DILUTION EFFECT HYPOTHESIS

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✦ INTRODUCTION

The dilution effect hypothesis states that any non-target host species can act as a decoy or resistant host to disease or parasite transmission stages, thereby reducing the negative effects of the diseases or parasites on the coevolved host (Prenter et al. 2004, Johnson and Thieltges 2010). Invasive species are often resistant to parasites in the new ecosystem because native parasites have not evolved to be able to successfully infect them (Prenter et al. 2004). In laboratory experiments, Kopp and Jokela (2007) found the presence of the invasive snail, *Lymnaea stagnalis*, acted as a resistant host for trematode infection resulting in reduced infection rates in the native snail. Similarly, the presence of the invasive American slipper limpet, *Crepidula foricata*, and invasive Pacific oysters, *Crassostrea gigas*, reduced trematode infection load on native mussels, *Mytilus edulis*, in both single species and mixed species (both invasive species present) treatments (Thieltges et al. 2009). However, both of these experiments were conducted in mesocosms with simplified biotic interactions (Kopp and Jokela 2007, Thieltges et al. 2009).

We know of no field experiments that have tested the dilution effect under complex, natural conditions. Therefore, we conducted field experiments to determine whether native species benefit from reduced rates of trematode parasitism when *P. antipodarum* are present. This work is important because *P. antipodarum* have been shown to have variable effects on native species (e.g., Schreiber et al. 2002, Riley et al. 2008, Brenneis et al. 2010). If *P. antipodarum* provide some benefit to native snails through a dilution effect, potential negative effects on native snails could be partially ameliorated.

✦ METHODS

We conducted field experiments in 2014 and 2015 to determine whether the presence of *P. antipodarum* reduces trematode infections in native snails. Each experiment had three experimental treatments: native snails only (control), native snails with the ambient biomass of invasive *P. antipodarum* snails, and native snails with double the ambient biomass of invasive snails. We assessed ambient biomass of *P. antipodarum* in Polecat Creek for each year by collecting four quantitative samples (stovepipe sampler) and using the mean biomass of all samples as the ambient biomass of *P. antipodarum* for that year.

In 2014, we placed native snails (Family Physidae or *Pyrgulopsis idahoensis*) and the treatment level of *P. antipodarum* into experimental chambers (modified square plastic sandwich containers (156.3 cm^2) with mesh windows on the top and each side). The screen keeps snails in the chamber and allows fresh, oxygenated, water and the infective stage of trematodes into the chambers. The experiment with physid snails was conducted using floating platforms to keep the experimental chambers at the water-air interface since physids are pulmonate snails and require air for respiration. We attached the chambers housing *P. idahoensis* and treatments of *P. antipodarum* to bricks to anchor the chambers to the streambed. As a food source for the snails, we covered the bottom of each chamber with algae-covered pebbles from the stream. In 2014, eight replicates were created for each treatment in the two experiments.

We conducted the same experiment in the summer of 2015 in the same area of Polecat Creek, but reduced the period that the snails were exposed to trematode infection to 12 days instead of four weeks. Due to the high mortality of physid snails in the 2014 experiment, we used *Fossaria* sp. instead of physids. *Fossaria* sp. are also pulmonate snails and consequently were placed in experimental chambers in floating platforms in the 2015 experiment. In 2015, eight replicates were created for each treatment with the native *Fossaria* sp. while only seven replicates were possible for the experiment using *P. idahoensis*.

During both years, each experimental chamber was monitored twice a week to: 1) assess snail mortality, 2) clean screens of silt/debris and 3) replace algae covered pebbles. To reduce background infections in experimental snails, we shed all snails to determine infection status and only use uninfected snails in the experiments. At the end of each experimental period, we transported native snails to University of Wyoming where these snails were housed for sixteen weeks to allow adequate time for development of trematode infections. After sixteen weeks, we dissected all snails to determine trematode infection status.

Due to infiltration of cages by *P. antipodarum* resulting in non-discrete independent variables (treatments) and proportional dependent variables, we conducted logistic regressions between each dependent variable and *P. antipodarum* density for the 2014 experiments (Dalgaard 2002). Once final data collection has occurred for the 2015 data, we will analyze the data using logistic regressions to determine if density of *P. antipodarum* reduced trematode prevalence or trematode diversity in each native snail species.

✦ RESULTS

For the 2014 experiments, we found no effect of the density of *P. antipodarum* on infection rates of the native snail, *P. idahoensis* ($z = 0.847$, $p = 0.397$; Figure 1A). Trematode diversity and *P. antipodarum* density had a near significant relationship ($z = -1.899$, $p = 0.058$) for the *P. idahoensis* experiment with trematode diversity decreasing with increased density of *P. antipodarum* (Figure 1B). Neither infection rate ($z = -0.729$, $p = 0.466$) nor trematode diversity ($z = -0.621$, $p = 0.534$) had a significant relationship with *P. antipodarum* density in physid snails (Figure 2).

✦ DISCUSSION

Overall, the experiment in 2014 had no significant results between infection rates and *P. antipodarum* density. We believe the high infection rates for all treatments with the native species *P. idahoensis* (Figure 1A) were due to the high infection

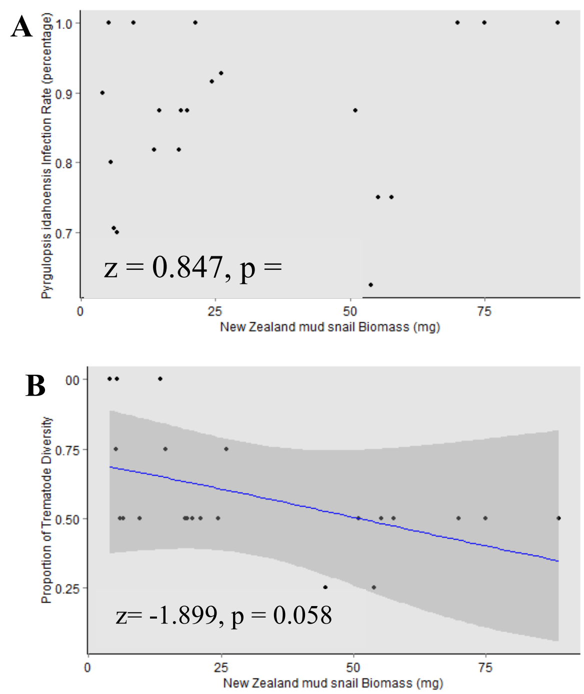

Figure 1. Relationship between New Zealand mud snail, *P. antipodarum*, biomass and Trematode prevalence (A) and Trematode diversity (B) in the native snail, *Pyrgulopsis idahoensis*.

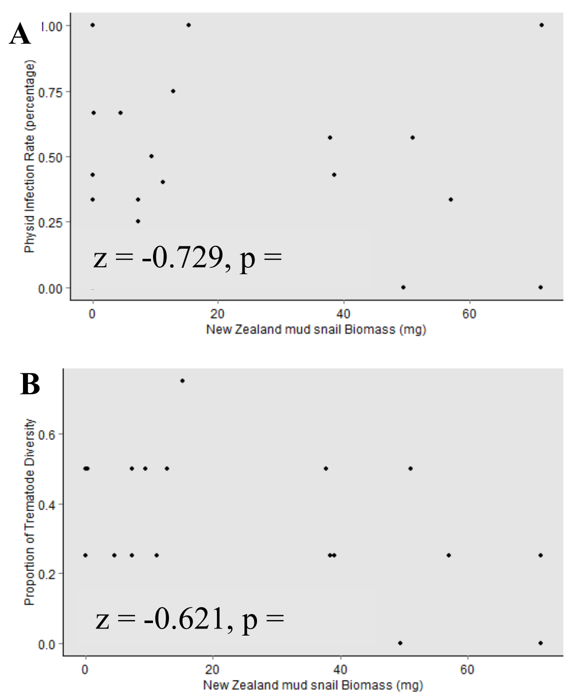

Figure 2. Relationship between New Zealand mud snail, *P. antipodarum*, biomass and Trematode prevalence (A) and Trematode diversity (B) in native physid snails.

rates in the area of the stream so that nearly every *P. idahoensis* was infected, regardless of experimental treatment. The high mortality (57.1%) in the stream of the native physid snails created many treatment replicates with less than 4 individuals which may have skewed the infection prevalence metrics to overestimate infection of physids. Consequently, the 2014 experiment did not accurately test the hypotheses of the dilution effect.

We are optimistic that once the data are analyzed for the 2015 experiments, a more accurate assessment of the dilution effect hypothesis will be possible.

✦ ACKNOWLEDGMENTS

We thank Daniel Greenwood and Kara Wise for field assistance. All research was conducted under the permission of the Wyoming Game and Fish Department (Chapter 33 Permit #718) and Grand Teton National Park (Research permit #GRTE-2014-SCI-0039).

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SUMMARY OF AN ONGOING POPULATION STUDY OF *PARNASSIUS CLODIUS* BUTTERFLIES

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✦ INTRODUCTION

Climate change presents unique challenges to high-altitude, high-latitude flying insects such as butterflies, bees, and flies. Models predict that climate change will cause general range shifts toward the poles and high elevations (Parmesan and Yohe 2003, Root et al. 2003) and empirical studies confirm that these range shifts are occurring (Parmesan et al. 1999, Kerr et al. 2015). As the earth warms, animals already living at high elevations and/or high latitudes may have nowhere to go. Furthermore, the body temperature of insects is dependent on ambient temperatures, and therefore many aspects of their ecology and general biology (development, growth, survival, dispersal, mating) may be stressed by or incompatible with a changing climate. Finally, animal flight at altitude involves substantial aerodynamic and physiological challenges, and significant reductions in air density and oxygen constrain flight at higher elevations (Dillon and Dudley 2015). Moving up in elevation therefore may not be an option for some high-altitude fliers.

The Greater Yellowstone Ecosystem (GYE) has served as a model worldwide for the preservation of a large-scale, relatively intact ecosystem. However even in the GYE there are numerous taxonomic groups for which biodiversity patterns are poorly understood. Invertebrates are particularly challenging because they can be difficult (and sometimes impossible) to identify in the field. Parnassius butterflies link the GYE to national parks and reserve areas worldwide. They have a Palearctic/ Nearctic distribution and are a high elevation and high latitude species, generally inhabiting unforested areas above latitudinal or elevational treeline. Both Parnassius butterflies and their habitats are exhibiting responses to climate change (Nakonieczny et al. 2007). In Europe *P. apollo* and *P. mnemosyne* are listed on the IUCN Red List as vulnerable species, while in Canada the range of *P. smintheus* is shrinking due to treeline encroachment (Roland and Matter 2007).

Our research group has been studying *Parnassius clodius* (Figure 1) in the GYE since 1992 and we have been collecting population data within the Pilgrim Creek region of Grand Teton National Park since 1998 (Auckland et al. 2004). Our recent surveys within Grand Teton National Park identified 32 locations where the species could be found. However, none of these supported large populations: 11 had medium-sized populations (~25 butterflies observed/survey) and 21 had small-sized populations (~3 butterflies observed/survey) (Szcodronski 2014). Furthermore, our previous research showed that during drought, butterflies associated with particular habitats in the GYE show declining trends (Debinski et al. 2013).

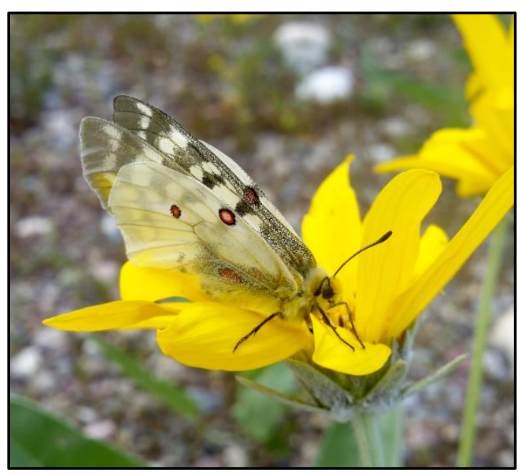

Figure 1. *Parnassius clodius* butterfly.

It is unclear whether the current population configuration in Grand Teton National Park is a stable one. Forest encroachment and shrinking meadow habitat related to climate change could threaten the viability of the *P. clodius* population. Recent studies of sister-species *P. smintheus* have been conducted in alpine meadows along the Rocky Mountain range of Alberta, Canada. Roland et al. (2000) found that treeline changes reduced the average meadow size by 78% from 1952 to 1993, interfering with habitat connectivity and reducing the number of *P. smintheus* moving between meadows by 41%. Butterflies in the Alberta system do not disperse among meadows if there is more than 1 km of forest separating the populations (Roland and Matter 2007).

Montane meadow butterflies such as Parnassius that are constrained to isolated, shrinking habitats and that avoid forest edges are highly vulnerable to genetic isolation, and could be under an increased extinction threat (Keyghobadi et al. 1999, Roland et al. 2000, Keyghobadi et al. 2005, Roland and Matter 2007, Dirnbock et al. 2011). Between 1975 and 1999, *P. apollo* went extinct in 10% of its range, and is in decline in 43% of its range. Populations are known to be stable in only 18% of its territory. Major factors causing the decline of the species include extreme weather variability, shrinking population sizes leading to reduced genetic diversity, and shrinking habitat due to forest encroachment (Nakonieczny et al. 2007).

This study, begun in 2009, was established to provide more information about the population dynamics of one of the largest populations of *Parnassius clodius* in Grand Teton National Park. We collected data using mark-recapture techniques to assess population parameters such as emergence date, population size, and sex ratio. Here we compile information obtained from population studies and observations of *P. clodius* from 2009 through 2015.

✦ METHODS

Study organisms

Parnassius clodius are moderately large (5 to 7 cm wingspan), predominantly white butterflies found in western Canada and the western United States. Highest densities of *P. clodius* are typically found in dry, gravelly sagebrush meadows (Auckland et al. 2004). *P. clodius* males emerge several days before the females in June-July and adults fly for 3-4 weeks. Adult females oviposit on vegetation near the host plant species, *Dicentra uniflora*, a spring ephemeral that grows near the edges of snowmelt. *P. clodius* larvae feed on the host plant throughout the spring until pupation.

Study sites

We conducted our mark-recapture-release (MRR) surveys in a dry sagebrush meadow with a relatively homogeneous topography at an elevation of ~2100 meters in Grand Teton National Park, WY. The meadow is approximately 2 km x 0.5 km in size (Auckland et al. 2004) and located along Pilgrim Creek Road, just south of the University of Wyoming-National Park Service Research Station. The Pilgrim Creek population is one of the larger populations of *P. clodius* within the Greater Yellowstone Ecosystem (Szcodronski 2014).

Mark-recapture-release (MRR) study

We investigated adult population parameters during the flight period in 2015. We initiated MRR studies immediately after adult emergence and terminated surveys when less than 10 butterflies were seen summed across all of the plots, signaling population decline. Daily surveys were limited to the hours between 10:00 and 17:00, when the temperature was above 21° C, wind was less than 16km/h, and the sun was not obscured by clouds.

Using MRR technique, two investigators walked within 50 x 50 meter plots (located approximately 200 meters apart) for 20 minutes and captured any *P. clodius* individual within the boundary of the plot using a butterfly net. Individuals were then placed in glassine envelopes and held by the investigator in a small box attached to a belt until the end of the survey. We marked all captured individuals with unique numbers on the ventral side of each hindwing using a felt-tip permanent marker. We identified males and females based on external morphological differences. Female mating status was determined by the presence or absence of sphragus (a waxy structure deposited by the male during mating that prevents future matings). Wing wear (an indicator of age) and behavior at the time of capture were also recorded.

✦ RESULTS

Field work

Parnassius clodius butterflies emerged at the Pilgrim Creek site on June 7, 2015. We began field surveys on June 9th, and continued surveys through July 4th. Over the course of the flight season we conducted a total of 76 surveys and marked a total of

621 butterflies in 664 capture events. Captures and recaptures are listed in Table 1.

Table 1. *Parnassius clodius* butterflies captured in 76 surveys during the 2015 flight season

Number of captures	1	2	3
Males	357	29	3
Females	225	6	1
Total	582	35	4

Data analysis

Population size and capture probability from raw MRR data can be estimated using methods developed by Craig (1953) and refined by Matter and Roland (2004).

✦ DISCUSSION

Six years of mark-recapture-release studies on the Pilgrim Creek population of *Parnassius clodius* butterflies indicate that the size of this population is highly variable. Future work should examine environmental conditions that might be responsible for the fluctuations in the population sizes. This population is also demonstrating a trend toward earlier emergence and longer flight periods. Possible asynchrony between the flight season and the flowering season of its primary nectar sources (e.g., *Eriogonum umbellatum*) should be the topic of future analyses. Increased asynchrony may lead to a higher percentage of unmated females stranded at the end of the flight season (Calabrese et al. 2008). Increasing asynchrony in this population may make it more likely to suffer from the Allee effect, in which population growth rate decreases at low population densities. Finally, an investigation into the phenology of the larval stage of the butterfly could provide insights into causal mechanisms driving earlier adult emergence dates.

✦ ACKNOWLEDGEMENTS

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RIVER OTTER DISTRIBUTION AND FOOD HABITS IN GRAND TETON NATIONAL PARK AS PART OF AN ONGOING PROJECT IN THE GYE

ASSESSING THE POTENTIAL OF THE RIVER OTTER (*LONTRA CANADENSIS*) TO PROMOTE AQUATIC CONSERVATION IN THE GREATER YELLOWSTONE ECOSYSTEM: A UNIQUE APPROACH FOR DEVELOPING A LONG-TERM AQUATIC FLAGSHIP

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✦ ABSTRACT

Grand Teton National Park is part of the known range of the North American river otter, however not much is known about this semi-aquatic mammal within the park. The results presented here are part of a larger project to investigate the potential of the river otter (*Lontra canadensis*) to serve as an aquatic flagship (species that engender public support and action) for the Greater Yellowstone Ecosystem. River otters, known for their charismatic behavior have the potential to serve as an aquatic flagship species to promote conservation of aquatic ecosystems. The primary objective of this portion of the study was to identify river otter latrines on portions of the Snake River, between Flagg Ranch and Jackson Lake, and between Jackson Lake Dam and Pacific Creek, collect river otter scats to determine diet of the river otter, and employ remote cameras to determine activity patterns of the river otters. Between 20 June and 1 July 2015, 26 river otter latrines were identified during shoreline surveys, 186 river otter scats were collected, and cameras were deployed at 6 latrines between 7 July and 24 August 2015. River otter scats have been cleaned and prepared for analysis, but have not all been processed to date. Camera traps recorded 222 images, of which 7% (n = 14) were of carnivores, 70% (n = 155) were of non-carnivore mammals, and 9% (n = 22) were of birds. River otters were detected at 1 of the 6 latrines, a total of 5 independent times during the study.

✦ INTRODUCTION

The North American river otter (*Lontra canadensis)* is a semi-aquatic mammal that was historically distributed throughout the conterminous United States and Alaska, but faced severe declines throughout many parts of its range from overharvest, disturbance to riparian habitats (e.g., deforestation) and various forms of water pollution (Hall 1981, Melquist and Dronkert 1987, Kruuk 2006). Through natural expansion of remnant populations and reintroduction projects in 22 states, the river otter now occupies at least portions of its historic range in each state (Bricker et al. 2015). In Wyoming, the river otter was extirpated from most of the state, except the Greater Yellowstone Ecosystem (GYE), but is currently known to occupy the western two-thirds of the state, with a stable-expanding population (Keinath 2003, Wyoming Game and Fish Department 2010, Bricker et al. 2015). In the GYE, part of the known range of the river otter includes Grand Teton National Park (GRTE).

This proposed research is an extension of a project which began in GRTE during the summer of 2014: Assessing the potential of the river otter (Lontra canadensis) to promote aquatic conservation in the Greater Yellowstone Ecosystem: A unique approach for developing a long-term aquatic flagship (Pearce and Serfass 2014). We have developed a conceptual framework to guide our ongoing evaluation of the following aspects of the species to determine its prospective value as an aquatic flagship species: 1) public support, 2) viewability, 3) public education and involvement, and 4) protocols for long-term monitoring.

During summer 2014, we began initial evaluation (step 1 of the above framework) of the potential for the river otter to serve as a flagship species for the GYE by conducting social science surveys with visitors to GRTE who were participating in guided-raft trips on the Snake River, and Oxbow Bend, a popular turn-out for viewing aquatic wildlife, including river otters. We conducted additional surveys in the Trout Lake parking lot in Yellowstone National Park (YELL) during the summer of 2015 to determine visitor attitudes towards the environment in general, and specifically the river otter and its habitat, and assess if different direct exposure types to the river otter (i.e., observing the river otter in wild, in captivity, or both), or indirect exposure to marketing materials about the species influences behavioral intentions to conserve the river otter and its habitat (Pearce and Serfass 2016).

The primary objective of this part of the study was to evaluate step 2 of the framework—visibility. Specifically, our objectives for this portion of the project were to: 1) identify river otter latrines along portions of the Snake River between Flagg Ranch and Jackson Lake and between Jackson Lake Dam and Pacific Creek and Flagg Ranch (Figure 1), and 2) collect scats at latrines for later diet analysis of river otters in GRTE and determine size of prey.

✦ METHODS

Data collection

Between 20 June and 1 July 2015, 26 river otter latrines were identified during shoreline surveys along portions of the Snake River, north of Jackson Lake, and between Jackson Lake Dam and Pacific Creek (Figures 1 and 2). Latrines were classified as active based on the presence of fresh otter scat deposits. Fresh river otter scats were collected from latrines, stored in a plastic bag, labeled, and frozen until analysis. In preparation for analysis, scats were washed by soaking overnight in soapy water, then rinsed through a sieve to eliminate organic material and other debris. After drying, food particles were separated to facilitate identification of scales, exoskeletons and other undigested prey remains.

Six of the river otter latrines were selected as sites for placement of camera traps (Figure 3). Cuddeback Attack© cameras were secured to a tree using straps or attached with straps to metal stakes (150 x 5.08 x 5.08 cm), if a tree was unavailable. Camera trapping occurred from 7 July to 21 August 2015 for a total of 216 camera trap-days (defined as the sum of days [24-hr period] each camera was operational). Camera traps were checked every 7 days to replace SD cards, batteries (if necessary), and perform any other needed maintenance. Camera traps at latrines were programmed to take 1 image after a trigger with a 30-second delay. All camera traps were set at low sensitivity to extend battery life. Date and time were automatically recorded by cameras on to each image, and all images were sorted and organized based on Sanderson and Harris (2013).

Data analysis

Remains were identified to the species or family using Daniels (1996) scale identification key and reference collection of scales and other bony structures. Prey items were recorded by frequency of occurrence, determined by tabulating the number of scats the prey occurred in and dividing by the total number of scats.

All images were summarized by species and location, and classified images as temporally independent if a lapse of >60 min occurred between 2 images of the same species at a site.

✦ PRELIMINARY RESULTS

Twenty-six river otter latrines were identified (Figure 2). A total of 186 scats were collected during regular visits to latrines. Scats have been cleaned in preparation for analysis. To date, 3 fish families have been identified in the scats, including Catostomidae, Salmonidae, and Cyprinidae, but not all scats have been processed.

Camera trapping occurred between 7 July and 24 August 2015 for a total of 216 camera trap-days. Camera traps recorded 222 images, of which 7% (n = 14) were of carnivores, 70% (n = 155) were of non-carnivore mammals, and 9% (n = 22) were of birds. We could not determine species in 14% (n = 31) of the photographs due to poor lighting, angle or if species was too far or close to camera. Species captured on photographs included 4 carnivore species (river otter, red fox [*Vulpes vulpes*], coyote [*Canis latrans*], and black bear [*Ursus americanus*]), 2 cervidaes (elk [*Cervus canadensis*], mule deer [*Odocoileus hermionus*]), 1 accipitridae (bald eagle [*Haliaeetus leucocephalus*]), 2 species of anseriformes (Canada goose [*Branta canadensis*] and common merganser [*Mergus merganser*], one gruiformes (sandhill crane [*Grus* canadensis]), one pelicaniformes (great blue heron [*Ardea Herodias*]), and one passeriformes (Common raven [*Corvus corax*]).

River otters were detected at 1 of the 6 latrines a total of 5 independent times during the study. The group size ranged from 1-8 otters visiting the site at one time. On average, 3.8 (±2.78SD) river otters were detected at a time at the latrine. River otters exhibited primarily diurnal behavior at the latrine site. They were detected at the latrine sites at 5 different times, 01:23, 06:01, 08:12, 09:12, and 23:42.

✦ MANAGEMENT IMPLICATIONS

Based on our preliminary results, river otters in Grand Teton National Park appear to exhibit unique behaviors unlike river otters in other riverine systems. Specifically, the river otters we detected formed large groups, and were active during daylight hours. These results are consistent with another study on river otter behavior that was conducted in GRTE by Hall (1986). These results indicate that river otters may be viewable to visitors of GRTE, an essential characteristic of a successful flagship species.

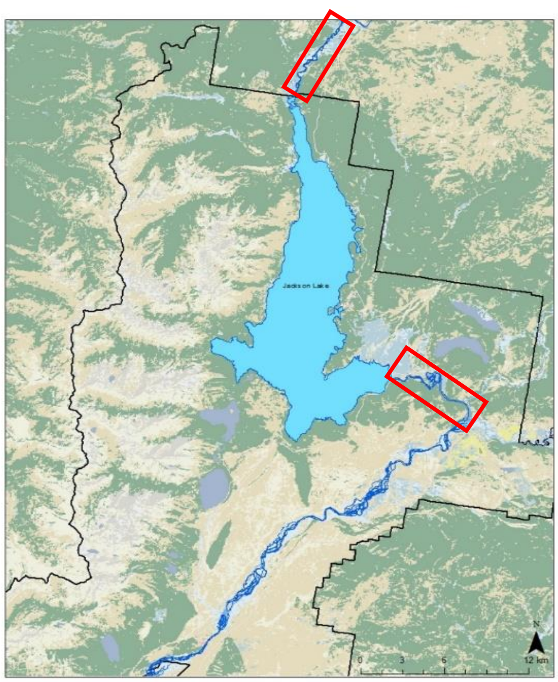

Figure 1. Surveys for river otter latrines were conducted along portions of the Snake River, Grand Teton National Park between Flagg Ranch and Jackson Lake, and between Jackson Lake Dam and Pacific Creek from 20 June and 1 July 2015.

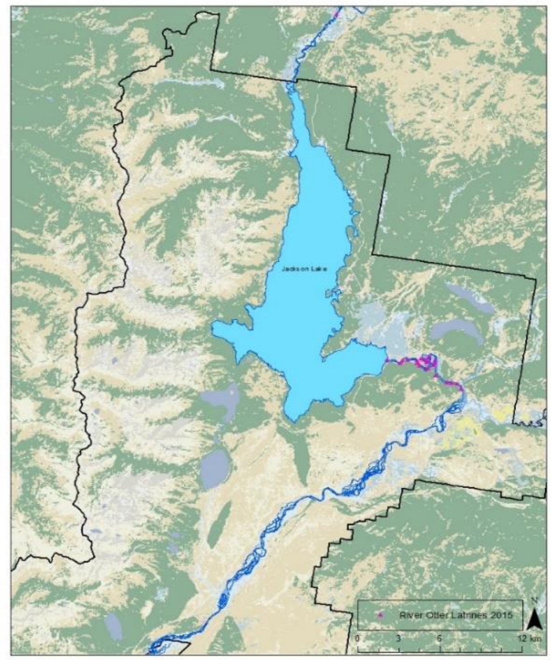

Figure 2. Twenty-six river otter latrines were identified along portions of the Snake River, Grand Teton National Park, between Flagg Ranch and Jackson Lake, and between Jackson Lake Dam and Pacific Creek from 20 June and 1 July 2015.

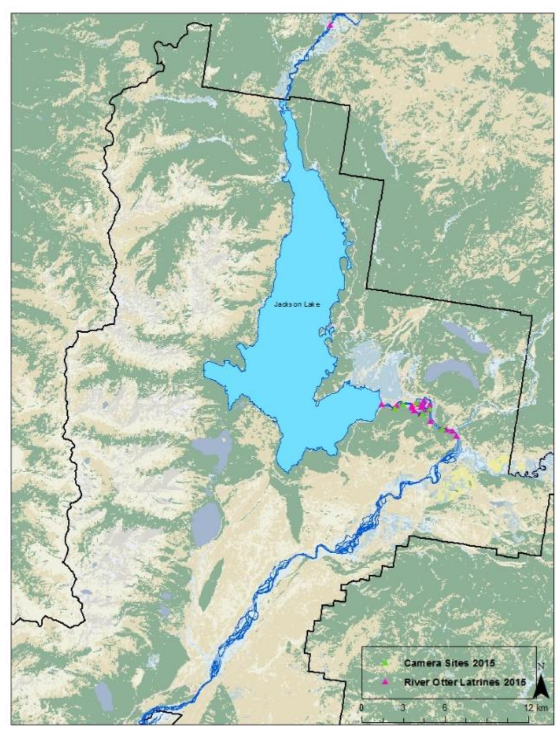

Figure 3. Six latrines were selected for camera-trapping which occurred from 7 July to 21 August 2015 for a total of 216 camera trap-days. River otters were detected at 1 of the 6 latrines during the study.

✦ ACKNOWLEDGEMENTS

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ASSESSING FUNCTIONAL ROLE AND COMMUNITY DYNAMICS OF WHITEBARK PINE AT ALPINE TREELINE, GRAND TETON NATIONAL PARK

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✦ ABSTRACT

Whitebark pine (*Pinus albicaulis*) is a keystone and foundation tree species in high elevation ecosystems of the Rocky Mountains. At alpine treelines along the eastern Rocky Mountain Front and in the Greater Yellowstone Ecosystem, whitebark pine often initiates tree islands through facilitation, thereby shaping vegetation pattern. This role will likely diminish if whitebark pine succumbs to white pine blister rust infection, climate change stress, and mountain pine beetle infestations. Here, we established baseline measurements of whitebark pine's importance and blister infection rates at two alpine treelines in Grand Teton National Park. Our specific objectives were to: 1) examine the potential relationship between whitebark pine establishment and krummholz tree island formation at the upper alpine treeline ecotone in GTNP; 2) characterize blister rust infection rate and intensity at two treeline study areas and in whitebark pine growing both solitarily and within tree islands; and 3) characterize the biophysical environments a) where whitebark pine is/is not a majority tree island initiator, and b) with varying blister rust infection rates in treeline whitebark pine. In July 2015, we field-sampled treeline composition and blister rust infection in all krummholz whitebark pine in a total of 40 study plots. Preliminary results reveal: 1) that whitebark pine is a substantial component of treeline ecosystems, but is not a significant majority tree island initiator, and 2) blister rust infection levels for both study areas combined is 15.65%. Blister rust and mountain pine beetle interactions were not evident at the two study areas. This work provides important baseline measurements for understanding how community structure and composition may be altered given infestation by pathogens and pests in GTNP, especially in light of changing climate regimes.

✦ INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is a keystone species of upper subalpine and treeline forests throughout its range in the western mountains of the United States and Canada (Tomback et al. 2001, Ellison et al. 2005, Tomback and Achuff 2010). In subalpine forests, whitebark pine trees foster forest biodiversity in numerous ways, including provision of an important wildlife food source, and by fostering community development (e.g., Tomback et al. 2001). Along the eastern Rocky Mountain Front in the Northern Rocky Mountains and in the Greater Yellowstone Ecosystem (GYE), whitebark pine sometimes initiates tree islands through facilitation, thereby shaping vegetation patterns (Haebeck 1969, Resler and Tomback 2008, Smith-McKenna et al. 2011). These roles will likely diminish if whitebark pine succumbs to disturbance factors such as blister rust infection, climate change stress (Tomback and Resler 2007) and mountain pine beetle infestations (e.g., Bockino and Tinker 2012).

At many North American alpine treeline ecotones (ATEs) throughout the range of whitebark pine, vegetation pattern is characterized by the presence of tree islands, or clusters of trees surrounded by herbaceous vegetation. Change in vegetation patterns at the ATE is often expected to manifest itself as an upward migration of vegetation belts that include conifer invasion and eventual exclusion of alpine tundra (e.g., Hall and Fagre 2003 for Glacier National Park, Schrag et al. 2008 for the GYE). Landscape responses of treelines, however, have been varied worldwide with measureable advance reported in approximately half (Harsch et al. 2009). Treelines of the Rocky Mountains of North America have, in particular, exhibited variable responses with some research reporting conifer infilling and densification

(Butler et al. 1994, Klasner and Fagre 2002), but no measureable advance at the study resolutions. Given the pine's role in community development at alpine treeline, and disturbance factors that threaten this role, Rocky Mountain ATEs where whitebark pine is present are ideal locations to study interacting factors affecting treeline dynamics.

In Grand Teton National Park (GTNP), studies assessing alpine treelines are few. One exception is Schrag et al. (2008) who simulated hypothetical future climate scenarios and monitored the response of whitebark pine and its conifer associates. Results indicated that conifer distributions may be altered by increased temperature and dominant pine forests may be replaced by fir and spruce forests. Surveys have been made of whitebark pine health and infection rates in subalpine stands (e.g., Bockino et al. 2013); however the importance of whitebark pine specifically for treeline ecosystem dynamics within GTNP has not been assessed.

A study that establishes important baseline measurements for alpine treelines is warranted for this key protected region, especially in light of interactions between disturbance, climate and vegetation dynamics. Thus, in order to fill this gap, we assessed alpine treelines where whitebark pine is present in GTNP. Our specific objectives were: 1) to obtain exploratory field observations to examine the potential relationship between whitebark pine establishment and krummholz tree island formation at the upper ATE in GTNP; 2) to characterize blister rust infection rate and intensity at two treeline study areas and in whitebark pine growing both solitarily and within tree islands at the upper ATE; and 3) to characterize the biophysical environments a) where whitebark pine is/is not a majority tree island initiator, and b) with varying blister rust infection rates in treeline whitebark pine.

Whitebark pine and tree island development

Whitebark pine is restricted to high elevations with a few conifer associates, including (but not limited to) subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and lodgepole pine (*Pinus contorta*). The pine has a spatially heterogeneous distribution in mountainous topography, which subjects it to a wide range of environmental conditions that impact its local distributions, densities and associates (Tomback and Achuff 2010).

At some ATEs in North America, an important functional role of whitebark pine is tree island initiation — a role that likely results both from the sheltered seed caching sites selected by Clark's nutcrackers (*Nucifraga columbiana*, Family Corvidae) and the hardiness of the seedlings (McCaughey and Tomback 2001). Whereas the seeds of whitebark pine's forest associates are mostly wind-dispersed (McCaughey and Tomback 2001), whitebark pine seedlings grow primarily from seeds that are stored, but not retrieved by the Clark's nutcracker (Hutchins and Lanner 1982, Tomback 1982). Nutcrackers typically harvest whitebark pine seeds from the subalpine forest and transport them to treeline for seed caching (Tomback 1986, Baud 1993) near "landmarks," which are often sheltered sites in the lee of trees, rocks, logs, and stumps (Tomback 1978; Figure 1). These sheltered sites contribute to whitebark pine survival because of enhanced snow burial, protection from blowing ice, reduced sky exposure, and greater soil moisture after snowmelt (Germino et al. 2002, Smith et al. 2003, Resler et al. 2005). Germination of other conifers follows snowmelt in microsites leeward of tree islands and in the lee of microtopography (Resler et al. 2005). The presence of whitebark pine may further mitigate shelter sites, for example, by reducing sky exposure or moderating temperature and soil moisture.

Figure 1. Whitebark pine growing in lee of boulder, ATE, Paintbrush Divide, Grand Teton National Park.

Furthermore, newly geminated whitebark pine seedlings are relatively robust (Arno and Hoff 1990, McCaughey and Tomback 2001); established trees also show greater general vigor than other treeline conifers (Blakeslee 2012). Combined, these factors enable pioneer colonization under harsh conditions, and pave the way for less hardy species to establish in their lee, promoting tree island development (Resler and Tomback 2008).

Despite the relative consistency in conifer associations across treelines across its range, whitebark pine's role in tree island development varies geographically. Previous studies by Resler and Tomback (2008), Resler and Fonstad (2009), and Smith et al. (2011) showed that whitebark pine initiates tree islands more than any other conifer area along the eastern Rocky Mountain Front of Montana. Callaway (1998) also found that whitebark pine served as an important nurse tree for subalpine fir on exposed sites in the upper subalpine in the northern U.S. Rocky Mountains. However, where climate conditions are more moderate, subalpine fir was found to be more important than whitebark pine in community development (Resler et al. 2005) — a pattern also noted by Tomback et al. (2014) in moist, Canadian sites. Under the assumption that the relative importance of facilitation at a location relates to species-specific tolerances to abiotic stress (Bertness and Callaway 1994), Resler et al. (2014) characterized the relationship between the role of whitebark pine in tree island facilitation and several biophysical variables. They found that temperature was the most important predictor of whitebark pine as a majority tree island initiator, with colder temperatures correlating to higher initiation by the pine as opposed to other treeline conifers.

Coupled effects of climate change and blister rust at alpine treeline

At a global scale, treeline position is primarily controlled by temperature. However, at local scales, treeline is controlled by multiple mechanisms, such as propagule/seed availability, microclimate, microtopography, and community structure; combined, these factors confound its relationship with temperature (Malanson et al. 2007). Furthermore, geographic location and latitude influences treeline pattern (Young and León 2007), and ultimately, response to changing climate.

Until recently, predictions of vegetation shifts at ATEs have not factored in species-specific responses to environmental change, much less the influence of pathogens. The latter is likely because few pathogens have consequences on as large an ecological scale as does blister rust, caused by the introduced fungal pathogen *Cronartium ribicola.*

Tomback and Resler (2007) presented a conceptual model of the potential outcomes of interactions among invasive pathogens, climate change, and whitebark pine whereby they proposed blister rust threatens the existence of whitebark pine in the ATE in two primary ways (Figure 2). First, as trees in the subalpine forest zone succumb to blister rust, they lose their ability to produce seeds (e.g., Hoff et al. 2001, McKinney and Tomback 2007), so fewer seeds are available for nutcrackers to disperse to the alpine treeline ecotone (Tomback 1986). Second, blister rust is killing established trees in the ecotone (Resler and Tomback 2008) before they facilitate the recruitment of other conifers. With the diminished presence of whitebark pine, the dynamics of treeline establishment could be disrupted, and treelines would result in altered community structure. With fewer whitebark pine at treeline, tree island formation may be delayed or precluded (Tomback and Resler 2007). This process has recently been simulated using agent-based modeling (Smith-McKenna et al. 2014). Loss of whitebark pine may limit the response of treeline to warming temperatures, leading to the perception that treeline is not moving up or moving more slowly than suitable temperature zones would suggest (Tomback and Resler 2007). Potential implications include a loss of treeline biodiversity as species composition changes or very sparse to no treeline community development under the harshest conditions. The GYE is near the southernmost limit of whitebark pine's distribution. Romme and Turner (1991) examined the effects of three general climate change scenarios on whitebark pine and other forest species in the GYE and found that for all scenarios, whitebark pine moves higher in elevation and thus occupies less area. The damage and mortality in whitebark pine from blister rust may counter tendencies towards northward or upwards movements if tree island initiation is reduced in frequency. Thus, the effects of blister rust may be at landscape scale, impacting vegetation development and even countering global warming predictions.

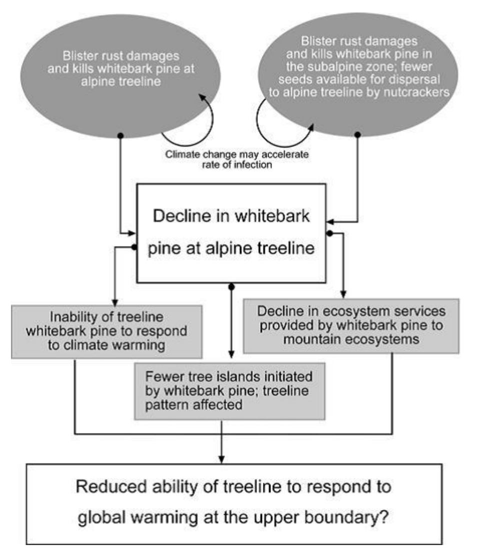

Figure 2. Conceptual model showing interactions among blister rust/climate change and functional role of whitebark pine at alpine treeline. (Source: Tomback and Resler 2007).

✦ STUDY AREA AND METHODS

Based on consultation with GTNP Park staff, two general treeline study areas were selected: Paintbrush Divide/Holly Lake and Hurricane Pass/Avalanche Basin. Study area characteristics are shown in Table 1. The Hurricane Pass/Avalanche Basin site is proximal to the Schoolroom Glacier (Figure 3; area ~ 0.0081 km^2), which lies at approximately 3200 m (10,400 ft), and is currently receding. Through modeling, our previous work (e.g., Smith et al. 2011, Smith-McKenna et al. 2014) revealed that proximity to glaciers and streams may impact blister rust infection rates, since they are a likely moisture and humidity source.

Table 1. Characteristics of study areas

	Holly Lake/Paintbrush Divide	Avalanche Basin/Hurricane Pass
Plot Size, No.	227 m^2, N=20	227 m^2, N=20
Elevation Range	3051-3261 m	3038-3204 m
Lat/Long	43°47'34" N, 110°47'54" W	43°43'41" N, 110°51'02" W
Aspect	NE, SE, SW, NW	NE, SE, NW
Tree Composition	*Pinus albicaulis*	*Pinus albicaulis*
	Abies lasiocarpa	*Abies lasiocarpa*
	Picea Engelmannii	*Picea Engelmannii*
		Pseudotsuga menziesii

Figure 3. Schoolroom Glacier, GTNP. Photo by Brian Bond, taken from Hurricane Pass looking toward Avalanche Basin.

Thirty year climate normals for May-September 1981-2010 (PRISM) revealed that growing season temperatures are generally higher and precipitation is generally lower at the Paintbrush Divide/Holly Lake site (Figure 4).

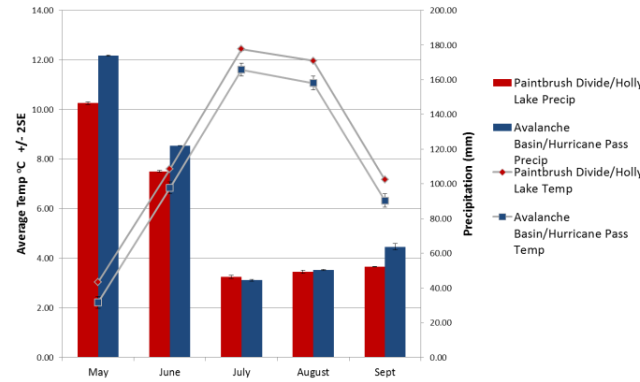

Figure 4. Growing season climate characteristics of study sites (PRISM, 30 year climate normals, 1981-2010).

Field methods

In July 2015, we field-sampled treeline composition and blister rust infection rates of all krummholz whitebark pine in a total of 40 study plots at the two study areas. Fieldwork in support of Objectives 1-3 focused on the upper elevations of the alpine treeline ecotone, where trees are environmentally stunted, flagged and frequently grow as krummholz. Vegetation sampling inside GTNP was conducted under a NPS permit.

We sampled the composition of upper ATE communities using 20 circular (r = 8.5 m, area ~ 227 m^2) sampling plots at each of the two study areas. Prior to entering the field we used ArcGIS and aerial photographs to stratify sampling areas by slope aspect; within each strata, we randomly selected 50 points positioned at least 50 m apart (to reduce potential spatial autocorrelation) at each site to serve as potential study plot centroids. Coordinates of each random point were uploaded into a Trimble GeoXT handheld GPS with submeter accuracy. In the field, we navigated to a total of 20 points per study area, and designated the coordinates as the plot centroid. Plot size was determined based on our previous sampling strategies of whitebark pine ATE communities (e.g., Smith-McKenna et al. 2013). Since tree-pathogen interactions are likely to differ strongly with meso-climate as influenced by slope, aspect, and elevation, our goal was to sample over a large range of whitebark pine at the ecotone.

We recorded elevation and aspect of each plot. Within each plot we identified the number and composition of all tree islands and solitary trees, (regardless of age or size) that fell completely or partially within the sampling plot. We measured the longest and shortest dimension of each conifer patch to provide a rough estimate of tree island size. To determine the importance of whitebark pine in tree island composition and development, we recorded the number of whitebark pine trees per tree island and noted the starting and leeward conifer(s), and characterized shelter type (if applicable) (i.e., rock, topographic depression, vegetation, or other) following Resler et al. (2005). Finally, for the purpose of describing growth form, we categorized each whitebark pine as krummholz (low growing, often matted, wind-sculpted trees), flagged (trees with asymmetrical foliage indicating wind-damage and ice abrasion) or upright (fully erect). Number of dead trees per plot were also recorded.

To determine blister rust infection in whitebark pine, identification of blister rust infection followed methods by Hoff (1992). To estimate infection rates, we recorded the number of inactive cankers (old cankers that sporulated, with swollen and cracked bark on dead branch or stem), and active cankers (fresh or old aecial sacs; Figure 5) found on each whitebark pine. Since Mountain Pine Beetle (MPB; *Dendroctonus ponderosae*) is also present in GTNP, and important interactions occur with MPB and white pine blister rust (Bockino and Tinker 2012), we scanned each whitebark pine tree for evidence of MPB, such as the presence of pitch tubes, j-shaped galleries, entrance and emergence holes, and the presence of beetles (e.g., Bockino et al. 2013).

Figure 5. Sporulating (active) white pine blister rust canker on whitebark pine.

Statistical analysis

Data was tested for normality; non-parametric tests were chosen when the assumptions for normality were not met. To determine if a conifer species is found significantly more as an initial tree island colonizer than other species (Objective 1), we used a G goodness-of-fit test (McDonald 2009). Tree island composition was summarized with descriptive statistics. Blister rust infection rates (Objective 2) were summarized at the plot and study area level. To compare the incidence of blister rust among sites and between solitary trees and tree islands, we used the nonparametric Mann Whitney *U* test (McDonald 2009).

To explore relationships between the biophysical environments of the study areas blister rust infection rates in treeline whitebark pine (Objective 3), we derived a suite of biophysical variables that have been shown to correlate with blister rust infection at alpine treeline (Smith et al. 2011, Smith-McKenna et al. 2013). These biophysical variables included: solar radiation, elevation, surface curvature, flow accumulation, aspect, slope angle, precipitation, and temperature. Surface curvature, solar radiation, slope, flow accumulation and aspect were derived from 1/3 arc-second (approximately 10 m) digital elevation models, available from the United States Geological Survey. Climate data (30 year normals) were obtained from Precipitation-Elevation Regressions on Independent Slopes Models (i.e., PRISM data). Determining the relationships between the selected biophysical variables is an ongoing analysis; we anticipate its completion by July 2016. However, we have performed preliminary analyses using Spearman's rank correlations.

✦ PRELIMINARY RESULTS

Functional role of whitebark pine at alpine treeline

The first objective of our study was to examine the potential relationship between whitebark pine establishment and krummholz tree island formation at the upper ATE in GTNP. In addition to tree island components, whitebark pine trees growing solitarily (i.e., not as a part of tree islands) are of interest here because they are considered: 1) to represent potential for tree island development, and 2) because research has shown the blister rust infection rates are often lower in solitary treeline whitebark pine (e.g., Resler and Tomback 2008).

At Hurricane Pass/Avalanche Basin, there were 136 total whitebark pine, 73 of which were in tree islands, and 63 of which were growing solitarily. There were a total of 138 solitary trees of all represented species (Figure 6), among all the plots (min, median and max number of solitary trees per plot = 0/ha, 242.31/ha and 793.02/ha, respectively). Min, median and max number of tree islands/plot was 0/ha, 66.09/ha and 352.45/ha (n = 45).

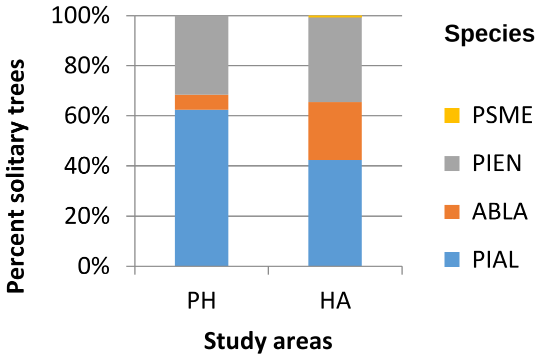

Figure 6. Percent composition of the solitary conifer tree community for each study area. Study areas are abbreviated as follows: PH = Paintbrush Divide/Holly Lake, HA = Hurricane Pass/Avalanche Basin. Species are abbreviated as follows: PSME = *Pseudotsuga menziesii*, PIEN = *Picea engelmannii*, ABLA = *Abies lasiocarpa*, PIAL = *Pinus albicaulis*.

At Paintbrush Divide/Holly Lake, there were 283 total whitebark pine; 107 were in tree islands, and 176 were growing solitarily. There were a total of 282 solitary trees of all represented species (Figure 6), among all the plots (min, median and max number of solitary trees per plot = 0/ha, 550.71/ha and 1497.92/ha, respectively). Min, median and max number of tree islands/plot was 0/ha, 88.11/ha and 308.40/ha (n = 45). Species representation within tree islands by study area is shown in Figure 7.

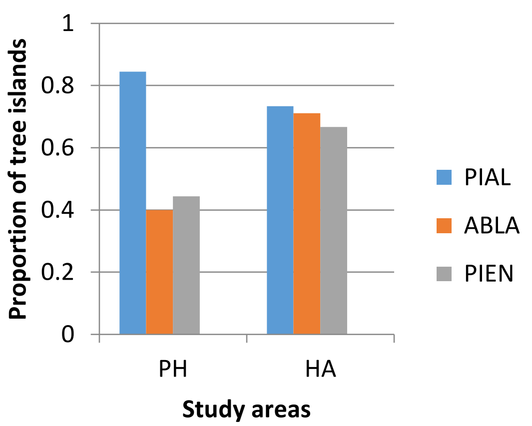

Figure 7. The proportion of tree islands within a study area with one or more individuals of each species. Study areas are abbreviated as follows: PH = Paintbrush Divide/Holly Lake, HA = Hurricane Pass/Avalanche Basin.

We used G goodness of fit tests to assess whether whitebark pine initiated tree islands significantly more than other common treeline species (subalpine fir and Engelmann spruce). At Hurricane Pass/Avalanche Basin, the G-test revealed that there were no significant differences between observed and expected proportions (P = 0.72) among species that initiated tree islands. However, at Paintbrush Divide/Holly Lake, Engelmann spruce (n = 30) initiated tree islands significantly more than both whitebark pine (n = 7) and subalpine fir (n = 8, G = 20.86, P < 0.001). Tree initiation by species is shown in Figure 8.

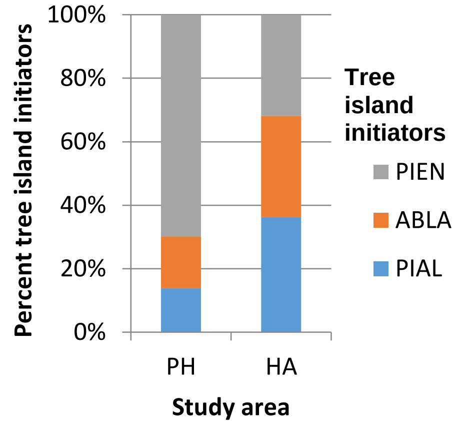

Figure 8. Relative proportional abundance of whitebark pine as a tree island initiator within each study area. Study areas are abbreviated as follows: PH = Paintbrush Divide/Holly Lake, HA = Hurricane Pass/Avalanche Basin. Species abbreviations listed in Figure 6.

Blister rust infection

Blister rust was present in krummholz whitebark pine at both study areas. Of all whitebark pine trees measured, 14.7% (n = 20) were infected with blister rust (as evidenced by the presence of at least one active or inactive canker) at Hurricane Pass/Avalanche Basin. At Paintbrush Divide/Holly Lake 16.6% were infected (n = 47). Although we looked for evidence of MPB in our study plots, we only found two (n = 2) krummholz trees with entrance/emergence holes, and these trees were uninfected by blister rust.

At Paintbrush Divide/Holly Lake, we counted seven total dead whitebark pine; one of these trees had obvious signs of blister rust infection. Five (n = 5) dead whitebark pine trees were measured at Hurricane Pass/Avalanche Basin, two of which had obvious signs of blister rust infection.

A Mann-Whitney U test was conducted to determine if there was a difference in total cankers between the study areas. The test revealed no significant differences (Z = -0.26, P = 0.79) in total cankers (active and inactive) between Paintbrush Divide/Holly Lake (n = 195; $\bar{x}$ = 0.69; min = 0; max = 13) and Hurricane Pass/Avalanche Basin (n = 84; $\bar{x}$ = 0.65; min = 0; max = 15).

The spatial distribution of blister rust infection (rate and intensity) was mapped for each of the 20 study plots at Hurricane Pass/Avalanche Basin (Figure 9) and Paintbrush Divide/Holly Lake (Figure 10).

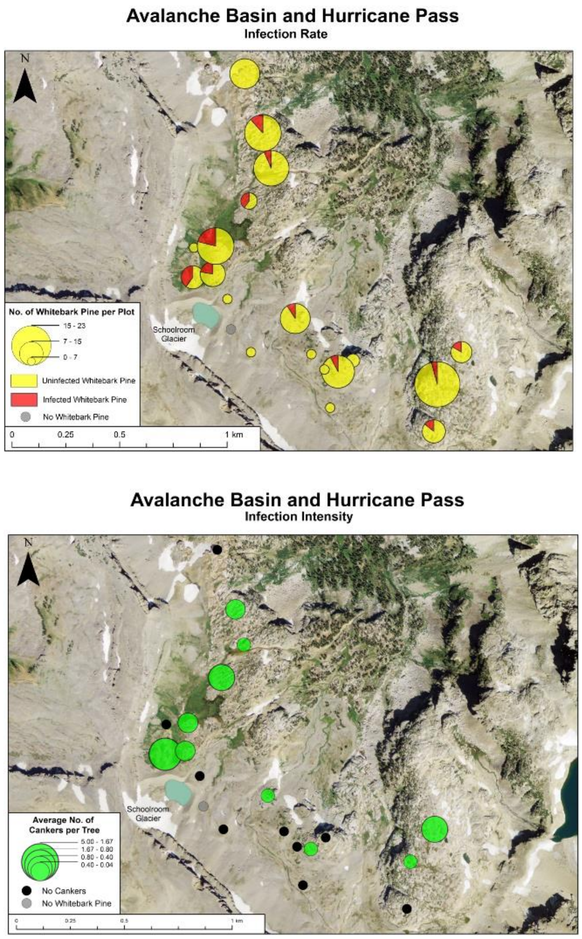

Figure 9. Percent of whitebark pine infected as compared to total whitebark pine per plot (top). Infection intensity mapped as average number of cankers per tree (bottom).

Cool late summer temperatures and high humidity levels are conditions conducive to the spread of blister rust infection (McDonald and Hoff 2001). Through modeling, our previous work (Smith et al. 2011, Smith-McKenna et al. 2014) revealed that proximity to glaciers and streams may impact blister rust infection rates, since they are a likely moisture and humidity source. Although our results are preliminary and warrant further study, proximity to the Schoolroom Glacier, along with higher growing season precipitation rates at Hurricane Pass/Avalanche Basin (Figure 4) do not seem to contribute to higher infection rates or intensities, when compared to Paintbrush Divide/Holly Lake — a site characterized by lower precipitation and substantial distance from the glacier or similar potential moisture source.

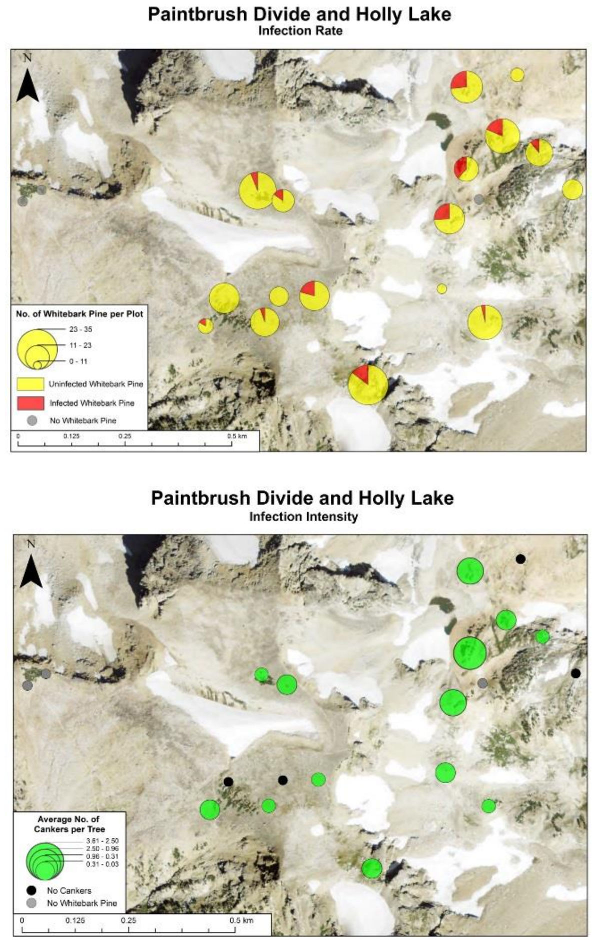

Figure 10. Percent of whitebark pine infected as compared to total whitebark pine per plot (top). Infection intensity mapped as average number of cankers per tree (bottom).

Finally, we assessed whether growth form (trees growing as solitary trees or within tree islands) affected blister rust infection levels. At Hurricane Pass/Avalanche Basin, there were 19 active and inactive cankers in solitary whitebark pine trees, and 65 in tree island whitebark pine. No significant differences ($P > 0.05$) were found between number of cankers/tree in solitary and tree island whitebark pine (Figure 11).

At Paintbrush Divide/Holly Lake, there were 24 active and inactive cankers in solitary whitebark pine trees, and 171 found in tree island whitebark pine. There were significantly more cankers/tree in tree islands than in whitebark pine growing solitarily ($Z = 6.13$, $P < 0.001$, Mann Whitney U test; Figure 11).

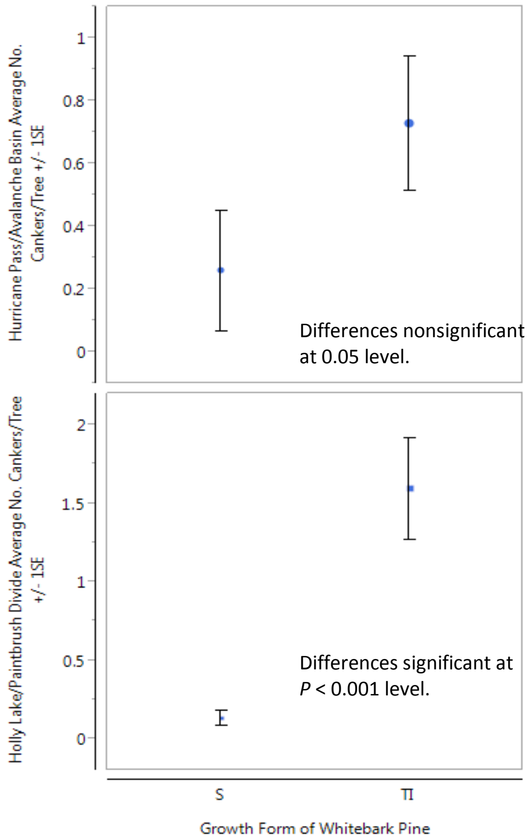

Figure 11. Blister rust infection intensity (no. cankers/whitebark pine) in the GTNP, in tree islands (TI) and in solitary trees (S).

Previous studies have highlighted the importance of microsite pattern in blister rust infection rates. For example, in Resler and Tomback (2008), Smith (2011) and Smith-McKenna (2013), we have found significantly more cankers per tree in tree islands than in solitary trees, suggesting that vegetation pattern and its generation of distinct microclimate (i.e., Pyatt 2013) may be a primary influence on blister rust infection rates in treeline whitebark pine.

Biophysical characteristics

The third objective of this study was to characterize the biophysical environments a) where whitebark pine is/is not a majority tree island initiator, and b) with varying blister rust infection rates in treeline whitebark pine. As discussed in above in ‘Methods’, derivation of GIS variables for the biophysical analyses has been completed, but statistical analysis of the relationship between these biophysical variables and blister rust infection is in progress. Anticipated completion is March 2016. Preliminary statistical analyses revealed a significant correlation between positive surface curvature (convexity) and no.cankers/tree Spearman’s $\rho = 0.41$, $P < 0.01$).

✦ IMPLICATIONS AND OUTCOMES

We have yet to understand the full consequences of ecological interactions altered by pathogens and pests in Rocky Mountain alpine treelines; this is especially true in communities where keystone species, such as whitebark pine, are present. This work contributes to our baseline knowledge on treeline communities and their dynamics in GTNP. Primary outcomes of this work include: 1) a unique, georeferenced field dataset of treeline communities in Grand Teton National Park that will provide important baseline information; 2) an estimate of blister rust infection rates and mortality in ATE whitebark pine communities; and 3) an assessment of biophysical characteristics associated with tree island development and blister rust, specifically at alpine treeline. The latter will help address the importance of whitebark pine in the continued development of tree islands under current climate scenarios and how this role may vary geographically. Preliminary results of this work related to blister rust incidence and glacier proximity were presented at a regional geography conference in November 2015 (SEDAAG 2015).

Furthermore, a manuscript has been submitted that contextualizes some of the results of this work within the larger framework of our knowledge on whitebark pine ATEs throughout the pine’s range in the Rocky Mountains, and an additional manuscript is in preparation. With information obtained in this study we can further refine models to help Park staff assess how an introduced pathogen, by reducing the ability of its host tree to facilitate the establishment of other tree species, will affect tree species ranges and the landscape-level ecotone response to climate change in GTNP and beyond.

✦ ACKNOWLEDGEMENTS

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CHARACTERIZING BIODIVERSITY OF ALPINE STREAMS IN GRAND TETON NATIONAL PARK, WYOMING

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✦ ABSTRACT

The highest rate of climate change is occurring in alpine areas above permanent treeline. The Teton Mountains in northwestern Wyoming are one of these ecosystem and little work has been done on alpine streams in the area. We sampled 6 streams in the Teton Mountains in 2015 at both upper and lower sites. We measured environmental variables (e.g., glacierality index, basic water quality, and temperature), aquatic invertebrate assemblages and microbial diversity. The water sources for sampled streams were glacier-fed, snowmelt and icy-seep. Aquatic invertebrate density (116-11,523 ind/m^2) and biomass (31-21,704 mg/m^2) varied greatly among streams. Snowmelt streams had the highest biomass of invertebrates, but the density and richness did not differ among stream types. Micrbial diversity in groundwater-fed springs harbored higher diversity than glacier-fed streams. The discovery of an icy-seep stream type lead us to sample rock glacier in the Teton Mountains during 2016. We hope to continue to sample alpine streams in the Teton Mountains to understand how climate change will alter streams of different types.

✦ INTRODUCTION

The highest rates of climate change are occurring above the permanent treeline in alpine and arctic ecosystems (Bradley et al. 2006). In the Rocky Mountains, warming is proceeding at two to three times the rate of the global average (Hansen et al. 2005, Pederson et al. 2010), resulting in extensive loss of glaciers and snowpack at higher-elevations (Hall and Fagre 2003). Environmental changes to mountain streams expected with climate change include a general shift upward of biological communities (Finn et al. 2010, Sheldon 2012, Giersch et al. 2015, Hotaling et al. in press), ultimately taking a significant toll on freshwater biodiversity. This loss of biodiversity will especially be seen in high-gradient alpine streams, as the diverse assemblage of species that can only live in a narrow temperature range are especially vulnerable to warming and snow loss (Brown et al. 2007, Hotaling et al. in press). Streams with physically steep gradients are accompanied by similarly steep gradients of species turnover, a pattern well-documented for aquatic macroinvertebrates (Allan 1975, Finn and Poff 2005, Sheldon and Warren 2009, Finn et al. 2013). Although alpine streams undergo extended periods of cold temperatures throughout the year, increased solar radiation during the late summer and the lack of canopy cover results in rapid warming of the water downstream of glaciers and snowfields, further isolating coldwater dependent species to short sections near the source (Ward 1994). Additionally, these streams tend to be geographically isolated from one another by either distance among mountain ranges or by dispersal barriers caused by extreme topography (Finn et al. 2006, Clarke et al. 2008), limiting gene flow. Along with increasing temperatures, additional effects may include increasing stream conductivity and water temperature. Macroinvertebrate diversity at the mountain range scale is predicted to decrease due to summit traps (i.e., highest-altitude species and communities having nowhere higher to disperse as the environmental gradient shifts upward), as well as loss of specific types of aquatic habitat, particularly the unique conditions associated with meltwater from once-permanent sources like glaciers, snowfields, or subterranean ice (Brown et al. 2007, Milner et al. 2009, Jacobsen et al. 2012, Finn et al. 2013, 2014, Hotaling et al. in press).

A number of recent studies, primarily in European alpine streams, have attempted to predict the degree to which regional aquatic macroinvertebrate biodiversity will be impacted by climate change, especially following decreasing or complete loss of glacial meltwater hydrology (Hotaling et al. in press). These studies have used space-for-time observational approaches (i.e., monitoring stream reaches with varying current degrees of meltwater influence; Brown et al. 2007, Finn et al. 2013) and/or modeling (Bálint et al. 2011, Khamis et al. 2014). These studies came to the general conclusion that loss of alpine meltwater sources will result in decreased regional biodiversity and that alpine stream fauna will be increasingly dominated by the species, communities, and genetics of streams fed primarily by groundwater (which are expected to remain after permanent meltwater sources are gone). In other words, the decreasing environmental heterogeneity that will accompany disappearing meltwater sources will likely result in the loss of biodiversity at the mountain-range scale.

Closer to home, the alpine invertebrates in streams of the Rocky Mountains are receiving increased attention. Previously unknown, endemic species have been described (e.g., *Lednia tetonica*, Teton Range; Baumann and Call 2012), uphill range contractions have been documented (e.g., *Zapada glacier* in Glacier National Park; Giersch et al. 2015), putatively undescribed alpine species are being discovered (Finn and Poff 2008, Giersch et al. 2016), and the ecology of previously described alpine-endemic species is being evaluated (e.g., Finn and Poff 2005, 2008, Muhlfeld et al. 2011, Giersch et al. 2015, 2016); however, no work has been done in the alpine streams of Grand Teton National Park (GRTE). Studies investigating population genetic structuring of Rocky Mountain alpine-endemic species have revealed strong structure across relatively short geographic distances (Finn et al. 2006, Finn and Adler 2006, Giersch et al. 2015), suggesting that local populations are evolving in isolation, a pattern expected to be exacerbated as climate change proceeds and habitat is further reduced. The potential reduction of biodiversity in response to anthropogenic climate change should be considered in terms of both morphological and genetic diversity loss. For instance, Bálint et al. (2011) showed that under future warming scenarios, the net loss of cryptic genetic diversity will greatly exceed loss of species diversity. Aside from obvious conservation implications associated with a reduction in genetic diversity among extant populations, this loss of genetic diversity may also hinder the adaptive potential of populations in response to rapidly changing environments (Hoffman and Sgrö 2011).

Rocky Mountain and European studies both concluded that continued climate change will result in the loss of permanent meltwater sources (e.g., glaciers and snowfields) and upstream shifts of environmental gradients. These changes are predicted to lead to the loss of endemic species in the highest reaches of alpine streams and to decrease regional biodiversity of stream biota. Interestingly, very little is known of the alpine stream assemblages of GRTE. GRTE has unique characteristics relevant to its alpine streams. First, GRTE is a young range composed of granite and sedimentary bedrocks. Therefore, spring-fed streams may be rare, especially at higher altitudes in the granite areas (L. Tronstad, personal observation). This potential lack of stable, spring-fed streams suggest that a loss of permanent meltwater sources could result in alpine streams shifting from permanent to intermittent. Such a shift from permanent to intermittent streamflow would have a strong impact on invertebrate communities, as many aquatic insects in alpine streams lack the life history characteristics necessary to survive drying (Finn and Poff 2005, Poff et al. 2010). A second important characteristic of GRTE is its geographic setting in the Middle Rockies which are understudied. This region is important biogeographically given hypotheses of the Rocky Mountain spine as a narrow dispersal corridor for alpine taxa connected all the way from Beringia (Siberia/Alaska) to the Southern Rockies of Colorado (Finn and Adler 2006).

Here, we report on preliminary results of our efforts to sample aquatic biodiversity of the highest-altitude streams of GRTE in 2015. Our proposed objectives were three-fold. 1.) Most fundamentally, we aimed to characterize the alpine communities of aquatic invertebrates occupying the Teton Range of GRTE. Compared to other national parks in the Rocky Mountains containing a high density of alpine streams (e.g., Rocky Mountain and Glacier National Parks), very little is known of alpine stream invertebrates in GRTE. 2.) We also implemented a sample stategy specifically designed to characterize variation in aquatic invertebrate assemblages and environmental variables between glacier-fed and non-glacier-fed alpine streams in GRTE. This objective included both macroinvertebrate community sampling and measuring environmental variables known to vary between glacier-fed and non-glacier-fed alpine streams. With these data, we will be able to understand the degree to which glacier meltwater drives a unique community structure and contributes to regional biodiversity. Results will provide insight into how we might expect biodiversity patterns to shift as permanent meltwater sources disappear. 3.) We proposed to assess basic patterns of intraspecific genetic diversity among drainage basins in resident GRTE alpine-stream invertebrates. Intraspecific genetic diversity comprises an important component of regional biodiversity and the results of this objective will provide insight into whether environmental drivers affect species diversity and population-genetic diversity in alpine streams (as has been observed elsewhere) as well as the degree of connectivity linking populations of these alpine-endemic species both within GRTE, and between Glacier National Park and other portions of the Rocky Mountain Range.

Beyond these originally proposed objectives, we also took the opportunity to collect and analyze microbial samples from the same GRTE study sites. The goal of this fourth objective was to assess the degree to which biodiversity at this additional taxonomic scale varied across the same habitats discussed in the context of macroinvertebrate and genetic diversity above.

✦ METHODS

Study sites

In August 2015, we sampled three pairs of alpine stream reaches, initially paired according to hypothesized dominant hydrological source of streamflow. Pairs chosen prior to 2015 fieldwork included one representative “icemelt” stream from either surface glacier or subterranean ice and one stream of predominantly seasonal snowmelt source, with no surface glacier present in the drainage basin. In each of the six streams representing the three pairs, we established one upstream and one downstream sample site, such that the total number of sites sampled was N=12 (Figure 1).

Included in the three pairs of streams are each of the sites for which we had previous records (published or unpublished) of either *L. tetonica* or *Z. glacier*. Generally, site pairs straddle a drainage divide, such that geology is as similar as possible within pairs. Pairings were as follows:

- Petersen Glacier stream (Figure 2A) and North Fork Teton Creek (Figure 2B). The Petersen Glacier stream drains to the east and feeds Mica Lake, and North Fork Teton Creek is fed primarily by snowmelt and drains to the west.
- Middle Teton glacier stream (Figure 2C) and South Fork Cascade Creek (Figure 2D). This pairing covered the east and west sides of the Middle Teton and included a putatively snowmelt-fed stream (S. Cascade Creek) where *L. tetonica* and *Z. glacier* had previously been documented in small tributaries to the drainage.
- South Fork Teton Creek (Alaska Basin; Figure 2E) and Wind Cave stream (Darby Creek drainage) (photos Figure 2F). While this pairing does not include a true glacial source, the stream originating from Wind Cave is fed by permanent, subterranean ice and is the only published locality for *L. tetonica*. S. Fork Teton Creek is a ‘classic’ snowmelt alpine stream that has yielded samples of either *Z. glacier* or a potentially undescribed *Zapada* species (see Giersch et al. 2016).

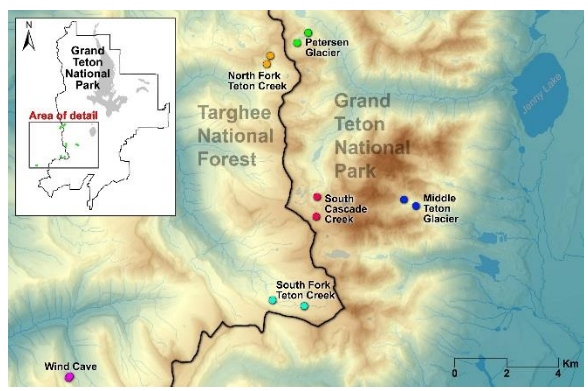

Figure 1. Locations of 12 sample sites, including upper and lower reaches on each of six streams.

Macroinvertebrate sampling

We collected quantitative benthic invertebrate data from each sample site using a Surber sampler (area 0.09 m², 243 µm mesh size). Number of replicate Surber samples ranged from 5 to 10 at each site and depended on stream size and density of macroinvertebrates. Invertebrates were sorted from the debris, and identified, counted and measured under a dissecting microscope using Merritt et al. (2008) and Thorp and Covich (2010). We measured the length of the first 20 individuals of each taxon and calculated biomass using length-mass regresions (Benke et al. 1999). The data were standardized as the number of individuals and biomass per m^2. Samples were elutriated in the field to reduce the amount of inorganic substrate and stored in Whirl-Pak bags with 90% ethanol. In the laboratory, invertebrate samples were divided into large (>2 mm) and small fractions (between 250 µm and 2 mm), and the small fraction was subsampled using a record player subsampler when necessary (Waters 1969). Specimens are currently preserved in the lab (L. Tronstad) in 90% ethanol in preparation for genetic data collection.

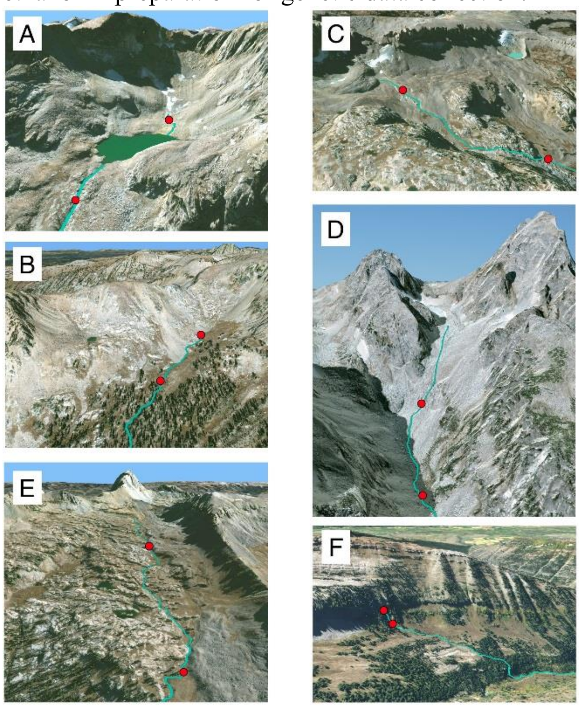

Figure 2. Images of the six 2016 sample basins and locations of N=12 stream sample sites (red dots) from satellite imagery draped over elevation data in ArcGIS. A) Petersen Glacier stream (with Mica Lake); B) N. Fork Teton Creek; C) S Fork Cascade Creek (Schoolroom Glacier in upper right of panel); D) Middle Teton stream; E) S Fork Teton Creek in Alaska Basin; F) Wind Cave stream in Darby Canyon.

Environmental data collection

We deployed temperature dataloggers (HOBO) at each of the 12 sample sites in August 2015 and allowed them to run for approximately one year, returning to collect them in August 2016. Data were recorded at one-hour intervals for the full year. We also measured a suite of environmental variables commonly used to characterize the degree of glacier meltwater influence (Ilg and Castella 2006, Finn et al. 2013). These included four key variables: water temperature patterns (data from loggers described above), electrical conductivity (measured with a YSI Professional Plus Multiprobe), physical habitat stability (with a modified version of the Pfankuch Index for streambed stability, which has been demonstrated to work well in mountain streams, Peckarsky et al. 2014), and suspended sediments (filtered from water samples in the field, then dried and weighed in the lab). We also made spot estimates of stream discharge (m^3/sec) for each sample site during mid-day hours (ca. 10:00-16:00) on each visit, using a Global Water Flow Probe. We used a YSI Sonde to record dissolved oxygen concentration, oxidation-reduction potential, water temperature and pH.

Microbial data collection and analyses

In the field, we collected microbial samples for the upper sample sites on each of the six focal streams (Figure 1). At each site, we sampled streamwater, biofilm from benthic substrate, and when applicable, source snow or ice. All samples were filtered in the field using 0.2 µm sterile filters. Ice was melted before filtering. Biofilm samples were collected by scrubbing rocks with sterile tools, rinsing them with sterile water, and filtering the rinse water. For most localities, three replicates were collected and these were subsampled/combined during DNA extraction.

DNA was extracted and the V4 region of the 16S rRNA was amplified using a modified Direct-to-PCR approach (Flores 2012). Unique combinations of Illumina barcodes were incorporated into each sample during PCR. Amplicons were sequenced using Illumina MiSeq sequencing with 250 bp paired-end chemistry. Forward and reverse reads were merged using FLASH (Magoc 2011). Reads were then quality filtered using FastX-Toolkit (Hannon 2010). 83% of a read had to have a quality score (Q) of 24 or higher to be included in downstream analyses. QIIME (Caporaso et al. 2010) was used for all additional data filtering (e.g., removal of putative chimeras) and analyses. Operational Taxonomic Units (OTUs) were assigned using ≥ 97% similarity. Given the challenges of removing all microbial contaminants during the molecular component of the process, we elected to sequence a PCR negative. After OTU calling, we removed dominant negative OTUs from all samples. Two of these were members of the human-associated genera *Propionibacterium* and *Streptococcus*. After filtering, all samples (N=36) were rarified to the lowest common number of sequence reads: 37,469. As an initial step in analyzing the microbial data, we compared Shannon diversity across samples and microhabitats, compared alpha diversity between samples, and quantified the make-up of individual microbial communities at the Family level. We also made initial comparisons to a data set with nearly identical experimental design, collected in Glacier National Park, MT in 2015.

Data analysis

Our paired sample design, which included one currently glaciated (or containing subterranean ice in the case of the Wind Cave stream) and one ice-free basin on either side of a drainage divide, allows a robust statistical approach to assess whether significant differences in environmental and/or biological characteristics exist between directly ice-fed streams and streams fed by other alpine sources. We used a multivariate framework (PCA, within the PC-ORD software, McCune and Mefford 2006) to characterize each stream according to the suite of variables indicating degree of meltwater influence. We are in the process of characterizing biodiversity at both the community level (macoinvertebrates and microbes) and the intraspecific population-genetic level for the rare/endemic macroinvertebrate species. Population-genetic patterns of biodiversity will be determined according to haplotype distribution at the mitochondrial COI locus within and among populations, data generated according to standard methods (e.g., Finn et al. 2013, Giersch et al. 2015). Spatial biodiversity patterns at both community and population levels are being estimated as *alpha* (per sample site), *gamma* (whole region, i.e., all sites combined), and *beta* (variation from one local site to the next) diversity with common statistics for partitioning regional-scale biodiversity (e.g., Finn et al. 2011, 2013, Kubo et al. 2013). By applying the same biodiversity statistics at both community and population-genetic levels of organization, we will be able to assess the degree to which environmental differences in Teton high-alpine streams influence species and genetic diversity in a parallel manner. We will also be able to compare the genetic results from the commonly measured COI sequence data to other alpine species (e.g., *Lednia tumana* in Glacier National Park) and around the world.

✦ PRELIMINARY RESULTS

Environmental differences among streams

We preliminarily classified streams according to four variables associated with degree of glacier meltwater influence: streambed and channel stability, conductivity, suspended sediments in the water column, and spot daytime water temperature. (Note that while we retrieved all temperature dataloggers in August 2016 we have not completed data analysis.) The Pfankuch Index (streambed stability; lower values = higher stability) ranged across the upper sites of our six streams from 15 (N Fork Teton Creek snowmelt stream) to 42 (at both the Petersen Glacier and Middle Teton Glacier streams). Higher specific conductivity is expected in streams fed by groundwater and lower specific conductivity is expected in streams with little groundwater influence. For the six study sites, specific conductivity ranged from 3.7 µS/cm (Petersen Glacier stream) to 176.8 µS/cm (Wind Cave stream). Suspended sediments in the water column ranged from undetectable in the Wind Cave stream to 34.5 mg/L in the Petersen Glacier stream. Spot summer daytime water temperature ranged from 0.3°C in the Petersen Glacier stream to 11.8°C in S. Fork Teton Creek (Alaska Basin).

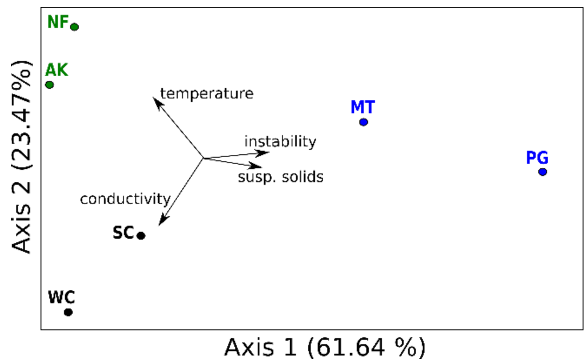

Figure 3. Results of principal components analysis (PCA) showing the environmental heterogeneity among the uppermost reaches of the six alpine streams sampled in 2015. Sites in blue (MT = Middle Teton glacier stream, PG = Petersen Glacier stream) group together and represent streams fed predominantly by surface runoff from glaciers. Sites in green (NF = North Fork Teton Creek, AK = South Fork Teton Creek in Alaska Basin) group together and are likely fed predominantly by seasonal snowmelt runoff. The two sites marked in black include the Wind Cave stream (WC), fed by subterranean ice, and the S Cascade stream (SC) that we originally thought was a seasonal snowmelt-dominated stream but the environmental characteristics suggest the possibility of an alternative, subterranean ice-like hydrological source.

The PCA combining these four key variables (Figure 3) suggests three primary stream types. Sites in blue are fed by surficial runoff from glaciers and are characterized by high streambed instability, high suspended solids in the water column, and low conductivity. Sites in green are fed by seasonal snowmelt and are characterized by higher water temperatures, higher streambed stability, and low suspended solids. Sites in black are seemingly grouped according to low water temperature, high conductivity (indicating groundwater influence), high streambed stability, and low suspended sediments (high water clarity). We expected the Wind Cave stream in this unique group; however, we expected the S Cascade Creek site to group with the sites marked in green representing seasonal snowmelt-fed streams. Rather, it appears likely that this stream is fed primarily by subterranean ice, perhaps from a rock glacier. Analysis of the long-term temperature data will help resolve this issue, as well as recent efforts to identify rock glaciers in the Teton Range (see Fegel et al. 2016) but the implication is that rock glaciers, which are common in the high Tetons, could be a vital hydrological source for a unique alpine stream type in GRTE (Figure 4).

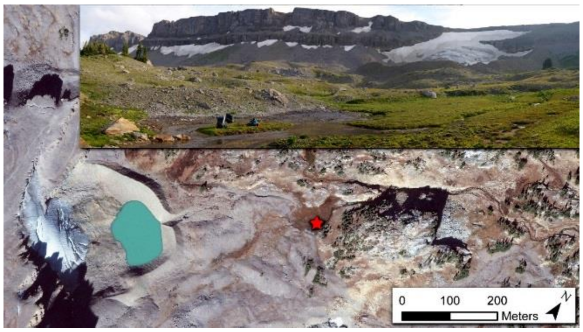

Figure 4. A photo and satellite image of what we have termed an 'icy seep' stream type (black dots in PCA, Figure 3) in GRTE below Schoolroom Glacier. The red star is a location where *Lednia tetonica* was collected in 2015 (but was not one of the focal six sample streams for the current project).

Macroinvertebrate diversity

We collected macroinvertebrate community data from 12 sites in the GRTE (Figure 1). *L. tetonica* was present in four of the six basins, including the location of it's original description, Wind Cave (Baumann and Call 2012), an undescribed tributary to S. Fork Cascade Creek near Schoolroom Glacier (Figure 4), S. Fork Teton Creek in Alaska Basin, and the lower sample site on the Petersen Glacier stream. We collected *Zapada* species from all six basins (S. Fork Cascade Creek, S. Fork Teton Creek in the Alaska Basin, Wind Cave, a Teton Meadows tributary to the Middle Teton Glacier stream, the lower sample site on the Petersen Glacier stream, and N. Fork Teton Creek). We have tentatively identified the specimens from the Tetons as *Z. glacier,* but more thorough genetic analysis is needed. If the stoneflies in the Teton Range are *Z. glacier*, we would show that this species is more widely distributed than previously thought.

We have analyzed invertebrate samples from 8 sites in the Tetons (Table 1). Invertebrates had the highest densities in the stream below Middle Teton Glacier and the upper site of S. Fork Cascade Creek and biomass was highest in the S. Fork Teton Creek in Alaska Basin. S. Fork Teton Creek in the Alaska Basin also had the highest diversity of invertebrates. The density (ANOVA; $P = 0.84$) and richness ($P = 0.14$) of invertebrates did not vary by stream water source (i.e., glacier, snowmelt or ice), but the biomass of invertebrates varied by water source ($P = 0.003$). Snowmelt sites had higher biomass than the other types of streams and snowmelt sites had higher richness than streams below glaciers.

Table 1. Density, biomass and richness (R) of invertebrates in alpine streams in the Teton Mountains.

Stream	**Site**	**Density (ind/m^2)**	**Biomass (mg/m^2)**	**R**
Petersen Glacier	Lower	294	658	13
	Upper	116	31	6
Middle Teton	Lower	11,523	2507	7
	Upper	10,694	753	8
South Cascade	Lower	11,198	8050	17
	Upper	1545	767	7
Teton Creek AK Basin	Lower	4165	21,704	27
	Upper	2041	14,901	14

Microbial diversity

After quality filtering and removal of putative contaminants and singleton OTUs, we identifed 2.87M reads for 36 libraries (min. = 37,798; max. = 314,040). Streamwater was consistently the most diverse microhabitat sampled, with source ice or snow intermediate, and biofilms having the lowest diversity (Figure 5). Source appears to heavily influence microbial community diversity with groundwater-fed springs harboring greater diversity than glacier-fed streams. Interestingly, ice-fed biofilms were some of the least diverse biofilms sampled, yet associated streamwater was among the highest (Figure 5). When viewed in PCoA space, biofilm and streamwater samples are widespread, meaning there is greater variation among their assemblages. Ice (from the surface of both glaciers and snowfields) samples formed a much tighter grouping (Figure 6). Proteobacteria were significant portions of almost all sampled communities. Bacteriodetes was most abundant in ice and Cyanobacteria dominated many biofilm communities. Streamwater was consistently the most diverse microhabitat in terms of total phyla observed (Figure 7). In the Swiss Alps, Wilhelm et al. (2013) focused on microbial biodiversity of glacier-fed streams only. Our PCoA results are similar with ice forming a tight, distinct cluster and biofilms/streamwater having broader profiles. However, from a total diversity perspective, Wilhelm et al. (2013) identified an increase from ice to streamwater to biofilms, whereas in our study, we see much lower diversity in glacier-fed biofilms but similar values for ice and streamwater.

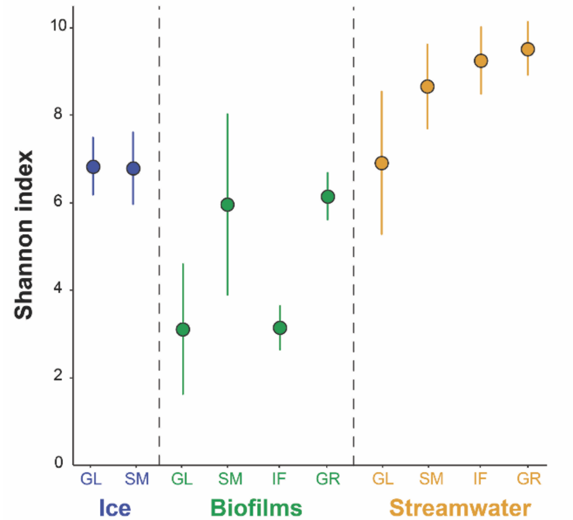

Figure 5. Shannon's diversity index for each microhabitat (ice, biofilm, streamwater) and source. Higher values indicate greater taxonomic diversity. Dark lines represent standard error. Source abbreviations: Glacial fed = GL, Ice-fed streams = IF, Snowmelt fed = SM, Groundwater-fed streams = GR. This figure includes complementary data from Glacier National Park, Montana.

✦ Conclusions

Our results clearly show that three key "stream types" exist in the Teton Range: snowmelt, glacier-fed, and an "icy seep". The unexpected third type is likely fed by the melting of subterranean ice and acts as an intermediate between snowmelt and glacier-fed streams. The existence of this third stream type represents an area of strong interest both in the Teton Range and alpine stream biology (Hotaling et al. in press) as the subterranean ice type could be more resistant to the effects of climate change (Hotaling et al. in press). Though the ice source of these habitats appears to result in temperature profiles similar to those of glacial streams, the limited sediment load, low turbulence, and stable flows may result in different community composition altogether. In GRTE, this is especially important given the presence of rare, endemic species in these icy seeps.

Our efforts have also expanded the known distributions of two rare stoneflies – *L. tumana* and *Z. glacier* – imperiled by climate-induced loss of glaciers and snowfields. (Giersch et al. 2016). *L. tumana* was previously only known from a single site just west of GRTE, Wind Cave, and our surveys identified three additional streams, two of which are within GRTE. For *Z. glacier*, preliminary results from COI barcoding of *Zapada* nymphs has revealed an additional population from the inlet to Delta Lake, and further sampling will likely yield more locations of this species as well as shed additional light on the possibility of cryptic *Zapada* species present within GRTE and across the American West. Of particular interest is a monophyletic clade, termed 'WY-NM' by Giersch et al. (2016) that appears to be an underscribed *Zapada* species ranging from GRTE to northern New Mexico.

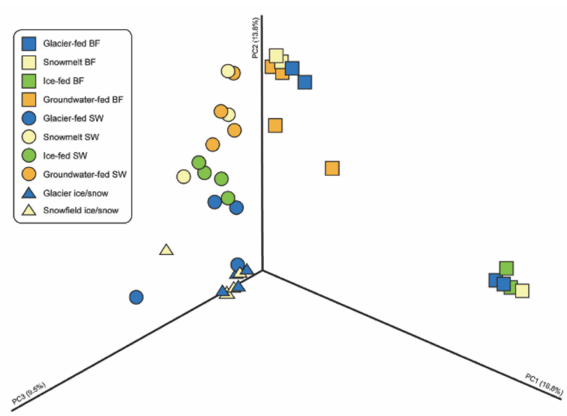

Figure 6. 3D Principal coordinates analysis (PCoA) of the 36 samples included in this study. Dissimilarity values are Bray-Curtis. Samples are grouped by source (color) and microhabitat (shape). Microhabitat abbreviations: Springwater = SW and Biofilm = BF. This figure includes complementary data from Glacier National Park, Montana.

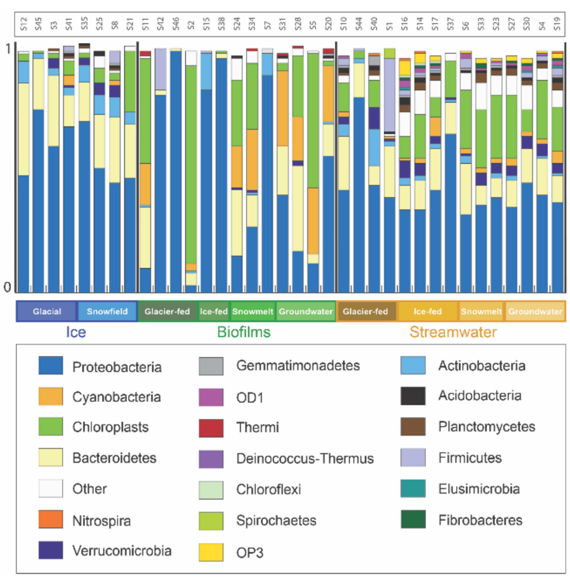

Figure 7. Dominant phyla (those found at greater than 1% frequency) for each sample grouped by source (colored text) and microhabitat (colored boxes). Reported values for Cyanobacteria are with Chloroplasts separated out. All samples do not equal one as many trace phyla were not included. This figure includes complementary data from Glacier National Park, Montana.

The streams we sampled in the Tetons varied from extremely low to high densities. The density of invertebrates collected in a stream below a glacier in the Austrian Alps (2798 ind/m^2; Füreder et al. 2001) was lower than Middle Teton and higher than Petersen Glacier. Additionally, they estimated that the density of invertebrates in a nearby spring-fed stream was higher (5357 ind/m^2). We measured much variation in our samples, including between glacier-fed sites. Further analysis of the invertebrate assemblages with environmental data will further explain the variation we observed in our data.

For microbial taxa, it is clear that a diverse, active community of microscopic organisms are at work in alpine streams of the Teton Range. Initial comparisons to Glacier National Park reveal little effect of mountain range on microbial diversity. Rather, microhabitat (i.e., ice/snow, streamwater or biofilm) appears to be a significant influence of community composition, a pattern also observed by Wilhelm et al. (2013).

✦ FUTURE WORK

Given our identification of a potentially novel alpine stream type from our 2015 efforts, a major goal of the 2016 field season was to sample additional sites with a specific focus on rock glaciers. We hope to use these data to select alpine stream monitoring sites in the Teton Range. Alpine streams are predicted to be strongly impacted by climate change and we are not aware of any other efforts monitoring stream assemblages in the area. For both the 2015 and 2016 samples, an ongoing goal is to generate COI sequence data for *L. tetonica*, *Z. glacier*, and any other alpine-obligate taxa that emerge from our macroinvertebrate analyses. The goals of this genetic data collection are two-fold: 1) to compare population-genetic diversity across (and within) study sites, and 2) to aid in addressing our overarching hypotheses regarding how biodiversity varies with glacier influence across taxonomic scales.

Our primary future goal is to compare results across levels of taxomic resolution (i.e., micro- and macroscopic species and macroscopic genetic diversity) to better understand the influence of alpine glaciers and other habitat characteristics on biodiversity. While individual examples of glaciers acting as important drivers of biodiversity have been made elsewhere, incorporating these three data sets for the same mountain range and streams will provide powerful evidence for or against this hypothesis. Moreover, efforts to collect complementary data are ongoing for Glacier National Park, and we intend to continue broadening the geographic scope of this project (and comparisons) to other mountain ranges in North America (e.g., North Cascades, Olympic, Sierra Nevada).

Lastly, given the conservation discussion surrounding *Z. glacier*, and specifically, the possibility of distinct *Z. glacier* species inhabiting each mountain range where it occurs, a project incorporating genomic data to robustly assess *Z. glacier* species boundaries is ongoing.

✦ ACKNOWLEDGEMENTS

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RESEARCH PROJECT REPORTS

CULTURAL RESOURCES

IN SITU PERFORMANCE ASSESSMENT AND EVALUATION OF HYDROPHOBIC AND ULTRAVIOLET PROTECTIVE TREATMENTS FOR HISTORIC LOG STRUCTURES

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✦ ABSTRACT

Beginning in the summer of 2015, research was conducted on protective wood coatings and accelerated weathering testing methods for architectural log and timber. A rack for supplementary natural weathering testing of hydrophobic and ultraviolet protective surface treatments for logs was also erected as a subsequent phase at Grand Teton National Park. This laboratory and field research is part of an ongoing project to develop an appropriate treatment for historic log structures in the region that will preserve their original fabric while maintaining the intended historic appearance of the buildings, i.e., unpainted. The weathering rack will be in place for upwards of five years to verify the lab-based results from Phase I[1] and to determine the long-term durability of the chosen treatments on already aged materials in situ. This report addresses the methods and materials for preparation of the weathering rack and samples as well as the methods being used to monitor their progress and initial results. Readings will be taken yearly to monitor the effects of weathering on each treatment.

✦ INTRODUCTION

This project is part of an ongoing study on the durability of selected traditional and modern sustainable hydrophobic and ultraviolet (UV) resistant penetrating treatments for historic log structures in the Greater Yellowstone Area, such as those found at the Bar BC Dude Ranch in Grand Teton National Park (Figure 1). These treatments are being evaluated using selected criteria including physico-chemical performance under accelerated and natural weathering conditions, ecological sustainability, and impact on aesthetic and heritage character.

Phase I accelerated weathering tests were performed at The Architectural Conservation Laboratory (ACL) at the University of Pennsylvania in cooperation with the National Park Service and the Western Center for Historic Preservation (WCHP). Phase II supplementary natural weathering was begun during the summer of 2015 to verify lab results and develop an environmentally benign treatment protocol for local log structures that will attempt to protect the historic log buildings from UV and water-related deterioration while maintaining the current aged appearance of the wood without environmental or public safety hazards.

Figure 1. The Main Cabin of the Bar BC Dude Ranch with the Teton Mountain Range. Photograph by the author.

[1] Full results of Phase I accelerated weathering testing can be found in the master's thesis, Performance Assessment and Evaluation of Hydrophobic and Ultraviolet Protective Treatments for Historic Log Structures by Courtney Magill (Magill 2015).

Context

While Grand Teton and Yellowstone National Parks have traditionally been known for their natural resources, new management policies recognize the need to preserve and protect the Parks' rich collection of historic buildings and features. A plethora of historic log structures originating from the first wave of settlement during westward expansion and later in the Great Camp Movement survive in both parks ranging in size and complexity from small guest cabins on dude ranches to the Old Faithful Inn, a pinnacle monument in western rustic log construction. These buildings form a rich cultural landscape for the public to explore.

Climate

Grand Teton National Park is in climate zone 7B (Figure 2), a semi-arid mountain climate with mild summers and long, very cold winters; spring and autumn seasons are very brief. According to National Weather Service data compiled from 1958 to 2010 in Moose, Wyoming, located just a few miles south of the Bar BC, average temperatures range from 0.9 ˚F in January to 80.5 ˚F in July, with an extreme low of -63 ˚F in the winter and an extreme high of 97 ˚F in the summer. Daily ranges in these extreme seasons on average span from 1 ˚F to 26 ˚F in the winter and 41 ˚F to 80 ˚F in the summer. The average precipitation for the area is 21.32 inches and the average snowfall is 172.6 inches.

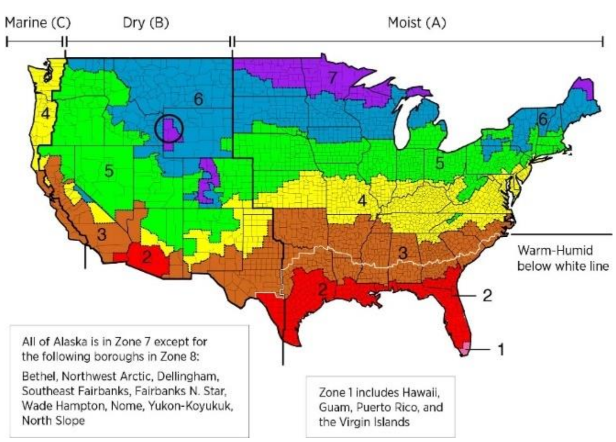

Figure 2. IECC Climate Zone Map with Grand Teton National Park and surrounding area encircled (U.S. Department of Energy 2012).

This data suggests that the climate is very dry with a low relative humidity throughout most of the year and most annual precipitation occurs during winter months. Heavy snow loads from November to April can create problems both with overloading unstable historic structures as well as establishing a prolonged supply of water through daily cycles of freezing and thawing on the lower portions of these structures for months at a time. Summer months can include afternoon thunderstorms that move swiftly up the valley from the southeast, exposing structures to heavy rain and sometimes hail for short periods of time. This rain in an otherwise low-humidity environment results in quick drying of the surface material after such showers, so the wood is additionally stressed by shorter cycles of absorption and desorption which frequently results in checking. These checks occur naturally in wood when stresses occur along the grains created by the fibers of cellulose and are usually not a source for alarm in themselves; however, upward facing checks warrant concern for their ability to gather and hold dirt, debris, and water, creating environments conducive to fungal and insect decay. According to a condition assessment survey of the site conducted by the University of Pennsylvania's Architectural Conservation Laboratory in 2011 (Collins et al. 2011), cabins oriented with their larger elevations facing north and south displayed much worse conditions due to prevailing winds and sun exposure, especially on the southern elevation (Cantu 2012). This demonstrates that the degradation of lignin by UV radiation and the subsequent removal of surface cellulose and other wood material by abrasives carried in the wind or water is one of the major degradation mechanisms of the site. Additionally, some of the structures surveyed show evidence of the deeper penetration of ultraviolet radiation, and thus greater degradation into the end grain than across the grain.[2]

Wood degradation and treatments

Many historic log structures in the American West are exposed to a large amount of UV radiation due to their base elevation. In addition to problems delineated from contact with water, the wood itself is damaged by UV light through degradation of lignin, the component of wood that holds cellulose fibers together (Figure 3). Exposed wooden members are often affected in a matter of days. Small depth of penetration restricts damage to surface area; however, when combined with shrinkage and swelling of water

[2] A study through the Forest Products Laboratory shows that ultraviolet light can more readily penetrate the open pores of the transverse sections of wood exposed in end grain than the tangential section exposed along the length of the tree (Chang et al. 1982).

sorption or abrasion from weathering, surface material delaminates, exposing untreated surfaces for further delignification (Ridout 2000). Additionally, coatings that do not protect against radiation also face polymer degradation from the release of free radicals in the wood caused by substrate surface breakdown, causing them to be rendered ineffective.

Figure 3. Extant Logs found at the Bar BC Dude Ranch displaying a range of coloration due to lignin loss. Photograph by Christine Leggio for the Bar BC Condition Assessment and Report, 2011 by the Architectural Conservation Laboratory.

Alongside durability of treatments for sites that cannot be maintained often, increasing emphasis is being placed on environmentally sustainable solutions for wood coatings. Many past treatments for wood have included large amounts of volatile organic compounds (VOC's), but increasing ecological regulations have driven companies to develop less toxic alternatives. In an effort to collaborate with NPS on utilizing environmentally safe products, low VOC content was a major criterion for treatment selection in this experiment. While Wyoming has no state limits, federal limits may change in the future causing higher VOC products to become illegal and no longer available.

Additionally, treatments should protect against high moisture gradients within the wood substrate to prevent decay. At moisture contents above the fiber saturation point, various agents of decay such as insects, fungi, and water-soluble impurities can begin to degrade the material. The speed of attack of organisms depends on various combinations of moisture content, temperature, relative humidity, and different extractives present in the wood. Most of these decay agents cannot tolerate moisture levels below 18%, some as low as 8% (Ridout 2000). Thus, prevention of moisture content higher than this level can be an effective way to limit wood decay.

Cultures that have traditionally used wood as a building material have developed various techniques for its protection from rot and decay that occurs above the fiber saturation point. The evolution and success of these treatments depends on the environmental conditions of the area as well as the available resources, but most treatments for wood involve regular maintenance and reapplication to ultimately be successful.[3] Wood will last longer if it is regularly treated with finishes that add water repellency and reduce cracking and weathering while inhibiting fungal growth. One such treatment, linseed oil, was commonly used, and still is, for its hydrophobic properties and deep penetration into wood surfaces for protection from water and rot. Even a thin layer can reduce wood movement and cracking by preventing rapid surface absorption and avoiding steep surface moisture gradients. This treatment was utilized historically at the Bar BC according to an account given by Nathaniel Burt, one of the founder's sons (Graham and Associates 1993).[4]

More commercial products were developed by the growing chemical industries, especially after World War II. The desire for exposed wood surfaces continues today, and the wood decking industry especially drives the widespread market for longer-lasting, low-maintenance, UV-resistant stains and coatings. The research conducted for Phase I evaluated a range of commercial products as well as traditional formulations, giving preference to product properties that better met the needs of the site. Many of these commercial products are proprietary with limited access to composition due to trade secrecy clauses, however some key information such as class of coating, solvent type, percent solids by weight, and hazardous materials were available along with other logistical information in technical data and material safety data sheets.

[3] The frequency of reapplication of coatings depends on the product and the conditions of the site. Some film-forming coatings like paints require that the old material is removed before application of a new layer while other treatments, such as pine tar resin, benefit from layering new coatings on top of older treatments.

[4] In an interview Burt does not distinguish what kind of oil was used to treat the cabins. The oil used for the waterproofing and protection of the logs was most likely linseed oil or a similar natural drying oil.

Treatments chosen for Phase I, Accelerated Weathering

Due to the high UV radiation in the Rocky Mountain region, ultraviolet protection for the wood is a significant concern; additionally, due to the decay mechanisms caused by high moisture content, water repellence was also prioritized. Also, because the traditional protective coatings for such regional log structures in the past were clear or only lightly colored, selected products had to be as such with very little visual impact on the aesthetic appearance of the wood. Moreover, low VOC content was considered due to increasingly strict laws on volatile organic compounds. The five modern treatments chosen largely met these criteria. Because an oil finish had been historically applied to the logs on site at the Bar BC Dude Ranch and likely on other buildings in the area, boiled linseed oil was chosen as a traditional finish as well as another historically used treatment for water repellency: paraffin wax melted and dissolved in mineral spirits. Seven treatments in all were chosen for accelerated weathering testing:

1. Armstrong's Wood Stain™ (Natural) (oil-based)
2. DEFY Extreme Exterior Clear Wood Stain™ (water-based)
3. Messmer's UV Plus™ (Natural) (oil-based)
4. TWP® 1500 Series (Natural) (oil-based)
5. Flood CWF UV®5 (Clear) (acrylic emulsion)
6. Allbäck Boiled Linseed Oil™
7. Paraffin Wax in Mineral Spirits

✦ METHODS AND MATERIALS

Summary of Phase I, Accelerated Weathering

Accelerated weathering testing was conducted for 800 total hours in the spring of 2015 using a QUV Weatherometer at the ACL (Figure 4), which simulates weathering by subjecting samples to cycles of UV-B light, heat, condensation, and sprayed water. While artificial weathering occurs in more intense, concentrated cycles than those in nature, results can be a good indicator of longer-term performance of the treatments. In this preliminary testing, treatments were tested on samples of sapwood of Idaho-sourced lodgepole pine (*Pinus contorta latifola*), a common building material in the Greater Yellowstone Region, obtained from Wilmore Lumber Ltd., a supplier in the area. Samples were monitored every 100 hours for weight, surface, and color changes to observe surface degradation alongside extensive evaluations pre- and post-weathering using weight, color, and water repellency changes as well as analysis using Fourier Transform Infrared Spectroscopy (FTIR) to detect lignin loss. As can be seen in Table 1, showing results of Phase I tests, each product displayed strengths and weaknesses after weathering. Treatments such as Armstrong's Wood Stain and DEFY Extreme appeared to perform quite well while other treatments such as the paraffin and minerals spirits mixture or Flood CWF UV5 largely failed. As a result, the two latter treatments were excluded from Phase II natural weathering testing.[5]

Figure 4. The QUV Weatherometer used for accelerated weathering in the Architectural Conservation Laboratory at the University of Pennsylvania. Photograph by the author.

Phase II, Natural Weathering Rack

A natural weathering rack based on those found at industrial weathering sites across the United States (McGreer 2001) was designed and constructed on site at the NPS pit area across from the Jackson Airport. This location allows for full exposure to the sun from the south, limits environmental impact of the weathering bracket on surrounding flora, restricts human interaction with the samples that could potentially cause damage, and allows access to the site even during the heavy snow of winter months. The rack was placed at the edge of the pit area near the gravel mounds. The system is open-backed to allow for air circulation and set at a 45˚ angle facing due south for the greatest exposure to solar radiation.

[5] These treatments were eliminated because they did not meet the criteria of an optimal coating for the site. These criteria include long-term durability, water repellence, UV protection, low impact on aesthetic character, and ecological sustainability.

Eight 8-foot lengths of aluminum strut channel were fastened to 5-foot lengths of strut with zinc-plated steel brackets and high-strength steel cap screws to create a rectangular bracket. This design allows for six rows of samples to be bolted in place on the struts. This rectangular bracket was then inclined by bolting it to 3-foot lengths of strut at both ends and in the center; these were in turn connected and braced to another 8-foot length of strut for stabilization of the setup. Sandbags were laid on the base struts to anchor the bracket in place (Figure 5).

Figure 5. Erected weathering bracket viewed at an angle (above) and from the side (below). Photos by the author.

Samples were randomly dispersed across the face of the setup by independent work associates to eliminate bias and distribute each type of sample across the frame. The pieces were bolted to the struts with steel cap screws and zinc-plated strut-channel nuts in six rows containing either seven or eight samples. The whole assembly was weighted down with seven sandbags.

Treatments chosen for Phase II, Natural Weathering

As previously noted, not all the products used in the accelerated weathering lab tests were selected for the Phase II natural weathering tests. Those products that performed well in the lab testing are being tested alongside a formulation derived from a treatment designed by the Forest Products Laboratory that combines both linseed oil and paraffin wax in mineral spirits. In all, six products are currently being tested alongside a control:

1. Armstrong's Wood Stain™ (Natural) (oil-based)
2. DEFY Extreme Exterior Clear Wood Stain™ (water-based)
3. Messmer's UV Plus™ (Natural) (oil-based)
4. TWP® 1500 Series (Natural) (oil-based)
5. Allbäck Boiled Linseed Oil™
6. Allbäck Boiled Linseed Oil™ – Paraffin Wax – Mineral Spirits formulation

Sample preparation

Log samples for each treatment were prepared according to standard D7787-D7787M – 13 Standard Practice for Selecting Wood Substrates for Weathering Evaluations of Architectural Coatings (ASTM 2011). To observe how these coatings behave on weathered material as well as new wood, sample panels were cut from both newly felled and older logs (Figure 6). Weathered panels were cut from logs salvaged from naturally fallen lodgepole pine sourced on the property of the White Grass Dude Ranch. New panels were created from newly cut, but seasoned, logs of lodgepole pine also from material at White Grass. These logs were sourced by the Western Center for Historic Preservation for use on onsite repairs and replacements. Both new and old log samples were stripped of any remaining bark using a draw knife. The panels were cut tangentially from the outer edges of the chosen logs to give a curved, convex surface to better imitate architectural logs in situ.

Figure 6. Samples were prepared by cutting off tangential sections of both new and weathered logs onsite at the White Grass Dude Ranch. Photograph by the author.

Sample panels were chosen from the pool of cut material to limit the number of knots, cracks, resinous streaks, blue stains, and fungal infections. Each panel is approximately 10 inches long x 8 inches wide x 2 inches thick at its thickest point. Panels were characterized before treatment application to evaluate how much of each treatment was absorbed and to observe any visual changes to the wood substrate caused by the coating application.

Treatments were applied to the panels (Figure 7) according to each manufacturer's instructions. They were applied to the face of the panel with brushes, but not on the end grain or the back to imitate treatment application of stains in the field on architectural logs. Once the treatments properly dried, the end grain of the panels was sealed by dipping each end in satin-finish polyurethane and allowing it to cure.

Each treatment is represented by a cohort of seven test panels: four weathered samples and three new wood samples. Additionally, five controls of untreated wood were included, three weathered and one new sample, totaling forty-six panels on the weathering rack.

Figure 7. Application of stains to cohorts of samples. Photograph by the author.

The panels were bolted to the struts of the natural weathering rack horizontally to mimic the orientation of logs in structures. Small stamped aluminum tags were fastened to the backs of each panel using small tacks to act as long-term labels.

Analytical methods

A variety of methods were utilized to evaluate the samples before treatments and weathering to serve as comparisons for later evaluations in the performance of each treatment over time. These methods include photography, quantitative color measurements, surface inspection, water repellency measurements, and weight measurements. The full range of evaluations will take place yearly to compare to initial measurements taken in August of 2015. At the time of this report, the samples have been evaluated at one year and two years. Initial results of testing will be broadly discussed below.

Color change

Absorption of ultraviolet radiation and the subsequent degradation of lignin in the wood substrate is the primary cause of color change in the weathering of wood. Lodgepole pine tends to darken with the accumulation of lignin degradation products, and, as these product wash away, the wood becomes lighter and more silvered due to the concentration of mostly cellulose fibers at the surface. Perception of color can vary enormously depending on a variety of factors such as the viewer, light source, and surface texture, so two methods are being utilized to monitor these color changes due to weathering as well as the change in the material after treatment application: color-corrected photographs were taken of the samples and quantitative measurements of color were taken with a Konica Minolta Spectrophotometer CM-2500d (Figure 8).

Figure 8. Color measurements of the wood surface taken using a Konica Minolta Spectrophotometer CM-2500d. Photograph by the author.

All samples, both new and old, significantly lightened over the two-year test period and most approached a similar grey and weathered appearance to that of the control panels. The most striking treatment shifts over the two years occurred on the panels treated with TWP (Figure 9). While these panels had a red hue to begin with, the finish became quite orange after one year and irregularly spotted and streaked with grey and orange patches by year two, especially on the new wood panels. The Messmer's product also appeared mottled upon inspection at two years, on the new wood for the most part, but was less striking visually because the treatment appeared more brown. The mottled appearance of TWP and Messmer's indicates that both treatments were likely not absorbed as well by the new wood panels and created more film-like coatings.

Figure 9. Progression of new wood sample N-TWP-2 showing before weathering (top), at one year (middle) and at two years (bottom). Photographs by the author.

The DEFY-treated panels are significantly lighter than the other panels, especially the new wood panels. After one year, these new wood panels were mostly white with light brown streaks, but after two years have more closely approached the grey color of the controls (Figure 10).

Figure 10. DEFY new wood sample N-DEF-3 at one year (above) and two years (below). Photographs by the author.

The linseed oil and mixture treatments had similar effects on the coloring and appearance of their panels (Figure 11). On the new wood panels, each treatment enhanced the grain of the early and late wood after one year, likely due to differential penetration of the product in these areas; however, during the second year the wood surfaces also began to approach the same coloring as the controls, both for new and old wood (Figure 12).

Figure 11. New wood linseed oil panel, N-LIN-3, at one year (above) and two years (below). Photographs by author.

Armstrong panels of both new and old wood were fairly dark brown upon application. After two years samples have lightened significantly and retained a light brown hue with less irregular streaking than seen in other products.

Surface morphology

Many panels, both treated and untreated, experienced macroscopic changes as well such as checking, cracking, and warping in certain cases; these changes were easily noticeable in photographs over time.

Figure 12. Weathered control panel, W-CON-2, progression from before weathering (above) to two years (below). Photographs by the author.

Microscopic changes occurred as well in the form of microchecking and roughening of the surface. Surfaces of each sample were inspected at 70x magnification with a Celestron 5 MP Handheld Digital Microscope Pro to visualize the change in the morphology of the surface of the samples after weathering for an extended period (Figure 13). As the material weathered, many of the finishes began to wear away and loose cellulose fibers separated from the wood substrate, making the surface much rougher. This change is much more visible in the new wood samples, as they previously showed very little deterioration damage before exposure.

All samples accrued microchecks and loose cellulose fibers over the two-year period. All the oil-based treatments appear to have prevented some major damage for the first year, but were ineffective after a period. The DEFY product, being water-based, had little to no conditioning effect on the wood surface and showed checking patterns like that of the control throughout testing.

Figure 13. Surfaces of new wood panel, N-MES-1, treated with Messmer's UV Plus before weathering (top), at one year (middle), and at two years (bottom) (70x magnification). Photographs by the author.

Water repellency

Water repellency of the samples is being evaluated using contact angle measurements. The method for taking such measurements is outlined in ASTM D7334-08 Standard Practice for Surface

Wettability of Coatings, Substrates and Pigments by Advancing Contact Angle Measurement (ASTM 2013) as well as in papers by Woodward (1999) and Lamour et al. (2010). The experiment uses the measurement of the angle of contact when a drop of liquid is applied to a coated surface – water in this experiment. This angle is the interior angle that a drop makes between the substrate and a tangent drawn at the intersection between the drop and the substrate. By measuring the advancing contact angle, the angle immediately after the drop is deposited on the surface, the hydrophobicity of the coating and wood surface can be determined; for water, an angle less than 45˚ indicates a hydrophilic surface, greater than 90˚ indicates a hydrophobic surface, and anywhere between 45-90˚ is intermediate.

A transfer pipette was used to deposit drops of water, termed sessile drops, onto the top (tangential) surface of samples and a camera set up with a mounted concave lens and backlighting was used to record the drop immediately after it was placed on the surface.

These photos were then processed using the plug-in Contact Angle in the open-source software ImageJ to calculate contact angles. Contact angles generated from photos will help to determine the hydrophobicity of the coatings on the wood surface and how weathering may affect the water resistance of the coatings over time.

Many of the weathered wood samples appeared to have retained hydrophobicity longer than the new wood samples, likely because the weathered wood more readily absorbed and retained a significantly greater amount of the treatments.

Samples before weathering, even the new control panel, exhibited fairly high levels of hydrophobicity. However, most lost their water repellency over time with outdoor exposure. At the one-year evaluation, DEFY samples were no longer water repellent, but all the oil-based treatments showed intermediate to strong hydrophobic properties on the surface. The mixture of linseed oil, paraffin wax, and mineral spirits displayed especially good retention of hydrophobicity at one year.

However, at the two-year evaluation, only two products still exhibited intermediate hydrophobicity on all their test panels: Armstrong and TWP (Figure 14). Other panels absorbed the water droplet faster than could be recorded.

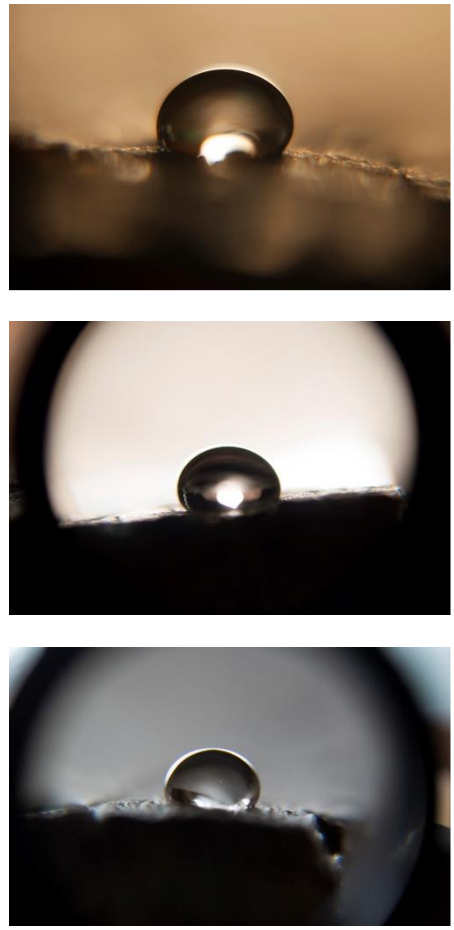

Figure 14. Drops of water deposited on weathered TWP-treated panel, W-TWP-3, before weathering (top), at one year (middle), and at two years (bottom). Photographs by the author.

Weight

With ultraviolet degradation of the lignin and potentially of the treatments, the degraded lignin and cellulose on the surface of the samples become susceptible to removal by abrasion mechanisms such as driving rain or wind laden with abrasive particles. To measure the amount of degradation, samples were weighed to the nearest one-hundredth of a gram with an analytical balance before being weathered and at each evaluation period. Moisture content of each panel was also measured at the time of weighing to inform the influence of water content on measurements.

Over the first year of weathering, the weathered wood control panels lost an average mass of 57 g. While the other treatments on weathered panels lost approximately 50 g, the weathered linseed oil treated panels lost only 38 g on average indicating a greater retention of treatment and wood material.

The new wood control lost approximately 45 g of mass in the first year. All the new treated samples lost a similar amount of mass within 3 grams of the control, perhaps indicating only a small number of treatments deeply penetrated the new wood samples during application and were lost or largely ineffective over the first year.[6]

✦ Results and Discussion

Preliminary results from the Phase II tests are summarized in Table 2. Many of the treatments fared well for the first year, but declined in their protective ability and visual quality over the second year. Considering the extreme southern exposure of the samples and the manufacturers' recommendations to re-treat every few years, this breakdown is logical. Thus, in evaluation of treatments for potential use, it is essential to note that even though manufacturers' guidelines were followed for application, the panels were only treated once and left unmaintained in the field. If maintained and treated annually or biennially, different results would likely be found.

The traditional finishes (linseed oil and the mixture) may have penetrated deeply and repelled water for the first year, but by the end of the second year appear to have largely weathered out of the wood surface and lost conditioning and hydrophobic properties. Additionally, while their overall appearance generally matched that of the controls during the experiment, neither treatment was designed to prevent UV radiation.

The DEFY product is an interesting development in the field of nanoparticles for UV resistant treatments; however, due to the water-based formula, the treatment appears to have neither penetrated deeply enough in the wood material nor fixed the nanoparticles upon the surface to offer long-term protection in this environment without re-treating often.

Although the TWP product was one of the only products to retain a high level of hydrophobicity over the two-year period of testing thus far, the orange mottled appearance of both new and previously weathered samples would not be ideal for the intended historic appearance of the log structures over time. Similarly, the mottled red-brown appearance of the Messmer's product over the two years is not ideal. This product also did not retain hydrophobicity as well as other treatments of similar coloring.

Armstrong's product retained intermediate hydrophobicity over the two years. While its UV protection derives from metal oxides in the stain and in turn colors the panels a browner tone than the controls, these panels lighten over time and Armstrong was found to be one of the better performing treatments for both new and old wood test panels.

To receive legitimate results from the natural weathering process, samples must undergo an extended period of exposure over multiple years. Natural weathering in the field is a much slower process than artificial weathering in the lab, but it is necessary to be able to follow the real-time degradation of the wood samples and their coatings through numerous weather cycles in the target environment. Samples have been evaluated twice so far and will remain in their positions on the rack for further testing and documentation in the coming years.

Figure 15. Weathering rack with samples at time of installation in August 2015 (top), at one year (middle), and at two years (bottom). Photographs by the author.

[6] During the second year of measurements, the panels were coated with snow during the site visit (Figure 15). Attempts were made to dry them out before measurement, but the moisture levels were higher than previous evaluation and the panels weighed more than the previous year. Therefore, the data was not viable for analysis.

Table 1. Comparison of treatments used in Phase I, accelerated weathering testing in terms of testing properties. Treatments were rated on a 1-10 scale with a score of 1 indicating very poor performance and 10 indicating excellent performance.

	Physical Degradation of Surface (Microscopic Inspection)	Treatment Absorbed (Weight Change)	Material Lost During Weathering (Weight Change)	Color Change - Final Result to Control (Spectroph-otometer)	Lignin Degradation at Surface (FTIR)	Water Repellence (Contact Angle Measurement)	Treatment Retention (FTIR)	Overall Performance (Average)
Control	2	n/a	5	n/a	1	2	n/a	n/a
Linseed Oil	8	9	4	6	2	9	7	6.42
Paraffin and Mineral Spirits	2	1	5	8	1	2	1	2.86
DEFY Extreme	5	8	7	9	5	7	7	6.85
Armstrong's Wood Stain (Natural)	7	10	9	9	4	8	9	8
TWP 1500 Series (Natural)	8	5	4	6	3	10	8	6.14
Flood CWF UV-5 (Clear)	4	3	6	2	2	5	4	3.71
Messmer's UV Plus (Natural)	6	7	5	4	5	8	9	6.28

Table 2. Comparison of treatments used in Phase II, natural weathering testing in terms of testing properties after two years of testing. Treatments were rated on a 1-10 scale with a score of 1 indicating very poor performance and 10 indicating excellent performance.

	Physical Degradation of Surface (Microscopic Inspection)	Material Lost During Weathering (Weight Change)	Overall Appearance and Color Change - Final Result to Control (Spectrophotometer)	Water Repellence (Contact Angle Measurement)	Overall Performance (Average)
Control	2	5	n/a	1	n/a
Armstrong's Wood Stain (Natural)	4	6	7	8	6.25
DEFY Extreme	2	5	8	2	4.25
Linseed Oil	3	7	8	4	5.5
Messmer's UV Plus (Natural)	4	6	4	5	4.75
Mixture of Linseed Oil, Paraffin Wax, and Mineral Spirits	3	4	8	6	5.25
TWP 1500 Series (Natural)	4	6	1	9	5

✦ ACKNOWLEDGEMENTS

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THE 2015 TABLE MOUNTAIN ICE PATCH PROJECT: GRAND TETON NATIONAL PARK, TETON COUNTY, WY

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✦ ABSTRACT

Ice patches are permanent snow and ice fields that survive through the summer months but are not massive enough to become glaciers. Prehistorically, people used ice patches for hunting, and organic hunting-related artifacts have been recovered from them. As a result of global warming, the ice patches are melting and exposing artifacts and other material that were preserved under the ice for millennia. Once exposed, the organic artifacts deteriorate. Recovery of these artifacts before they are lost is critical to understanding the paleoecology of and the prehistoric people who used the Teton high elevations (Lee 2009, 2015). In 2015, I surveyed ice patches on Table Mountain pursuant to Section 110 of the National Historic Preservation Act. The work was conducted under OWSA permits 15-GRTE-01 and GRTE-2015-SCI-0040 and was partially funded by the UW-NPS Research Station. One historic archaeological site (48TE1983) was documented and four paleobiological specimens were collected.

✦ ENVIRONMENTAL SETTING

Table Mountain is located on the western boundary of Grand Teton National Park (the park) in the Teton Range. It consists of remnant limestone, shale, and sandstone that was originally deposited in large shallow seas during the Paleozoic Period before the Teton Range rose. Most of the sedimentary rocks have eroded exposing the granite, gneiss, and schist beneath, but Table Mountain remains (Craighead 2006, Love et al. 1992, Love and Reed 1968). The project area is located above tree line between 10,720 and 11,100 ft. above sea level in an alpine vegetation zone (Knight et al. 2014). The Table Mountain ice patches consist of three smaller noncontiguous patches on the eastern and northern sides of the mountain. Dr. Craig Lee (2014) designated the two larger of these AB11_A and AB12_C (Figure 1). The "AB" stands for the Alaska Basin, and the rankings "A" and "C" indicate their generally high potential for archaeological or paleobiological material (Lee 2014).

Figure 1. Table Mountain ice patches looking west (Photo by M. Peterson, 8/25/2015).

✦ BACKGROUND RESEARCH

A review of regional ice patch literature revealed that chipped stone artifacts (Lee 2012), modified wooden objects (Sgouros and Stirn 2015, Lee 2014), arrow/dart shaft fragments (Reckin 2013, Lee 2010, 2012), bows (Kelly, personal communication 2015), leather/bark artifacts (Reckin 2013, Lee 2012), basketry and cordage (Lee, personal communication 2016, Reckin 2013), digging or walking sticks (Lee 2012), burned wood (Reckin 2013, Lee 2012), trees (Lee 2012), and culturally modified and unmodified sheep, bison, elk, and deer bone (Reckin 2013, Lee 2012) have been recovered from ice patches in the Middle Rocky Mountains.

Further, on July 27, 1872, famous pioneer photographer William Henry Jackson along with Charles Campbell, Philo Beveridge, Alexander Sibley, and possibly John Colter took off on horseback with two pack mules to explore Teton Canyon and summit Table Mountain (Blair 2005, Daugherty 1999). Jackson's goal was to take the first photographs of the Grand Teton from its western side (Jackson 1994). His photography equipment consisted of a canvas dark tent, 11 x 14 inch and 8 x 10 inch cameras, developing plates, chemicals for developing, and wooden containers for washing the plates (Figure 2, Upper). With his equipment loaded on the mules, they crossed the ice patch on the eastern side of Table Mountain to reach the perfect spot for the photos. Jackson spent one day photographing the Tetons. He saw a bighorn sheep watching him from Table Mountain (Figure 2, Lower), and he also noted many sheep, bears, elk, deer, and moose while around Table Mountain (Jackson 1994, Blair 2005).

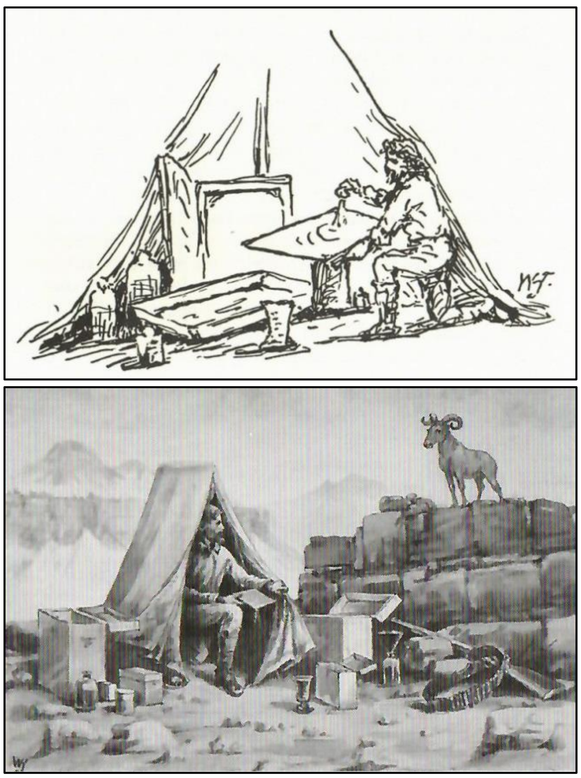

Figure 2. Sketch of Jackson's dark tent on Table Mountain (Upper) (Jackson 1994:206) and Jackson ca 1929 representation of the bighorn sheep (Lower) (Blair 2005:82).

✦ METHODS

This project involved the pedestrian inventory of the ice patches around Table Mountain on August 9 and 25, 2015. All margins of the ice patches were examined, including the fore-fields, runoff channels, and surfaces of the lower-sloped areas. Overview photos were taken from far enough away to allow the extent of the ice to be compared annually (Lee 2015). One historic wallet, two bison bones, and three sticks were collected. Archival-quality Coroplast fluted plastic board and rolled cotton bandages were used to stabilize the collected bones and sticks and transport them from the field (Lee 2015) (Figure 3). The wallet was sealed in an archival quality plastic bag and kept in a cooler until taken to the University of Wyoming Archaeological Repository for conservation (Figure 4).

Figure 3. Collecting/transporting organic artifacts (Photo by C. Castle, 8/9/2015).

Figure 4. Close-up of the wallet at the time of discovery looking south (Upper) and packaged for transport looking west (Lower) (Photos by M. Peterson and C. Castle, 8/9/2015).

The University of Wyoming Archaeological Repository contacted Spicer Art Conservation, LLC (Spicer) to process the wallet and save it and as many of its contents as possible. Spicer examined the wallet on August 18, 2015 (Figure 5, Upper). She performed conservation treatment from August 20 to November 25, 2015. Following conservation, she rehoused the contents of the wallet in a custom-made acid free box and returned them to OWSA (Conservation Treatment Report 2015) (Figure 5, Lower).

Figure 5. The wallet prior to and after treatment (Photos by Spicer, 8/20/2015 and 11/16/2015).

I processed a token found in the wallet by soaking it in increasingly acidic liquids until enough corrosion was removed. It was first soaked in mildly acidic olive oil for about two weeks and periodically scrubbed using a soft bristle brush. The olive oil did not remove enough corrosion, so it was soaked in Diet Pepsi (~pH 3) for about one week and periodically scrubbed using a soft bristle brush. The Diet Pepsi removed some corrosion but not enough for identification, so it was soaked in distilled white vinegar (~pH 2.4) for approximately one week and periodically scrubbed using a soft bristle brush. The vinegar removed enough corrosion from the token for identification.

Dr. Kathryn Puseman of Paleoscapes Archaeobotanical Services Team (PAST), LLC identified the wood specimens. She measured each stick then removed a piece of each for identification. The fragments were broken to expose fresh, cross, tangential, and radial sections and examined under a Bausch and Lomb Stereozoom microscope at a magnification of 70x and under a Nikon Optiphot 66 microscope at magnifications of 100-600x. She recorded images with an AmScope 10MP microscope digital camera and identified the wood with standard wood identification manuals, internet web sites, and a modern comparative collection (Puseman 2016).

Beta Analytic and the University of Arizona AMS Laboratory completed accelerator mass spectrometry dates on the collected wood and bone samples, respectively, using standard AMS procedures for wood and bone (Beta Analytic Inc. 2016, University of Arizona AMS Laboratory 2016).

✦ RESULTS

One historic site, 48TE1983, was located. In addition, two unmodified sticks and two bison bones were collected for identification and/or radiocarbon dating.

Site 48TE1983

Site 48TE1983 is a historic site located on the northern and eastern sides of Table Mountain (Figure 6). The site has been extremely impacted by modern recreation, dense trash, collection/vandalism, and erosion. It consists mostly of 1940s to 1960s historic debris associated with the recreational use of Table Mountain. Artifacts include a historic wallet from the mid to late 1940s (collected), one carved Boy Scout troop stick in three segments (collected), other carved walking sticks and worked sticks (two collected), food cans, one lard pail, 1960s Shasta soda cans, other tin cans, one clear glass 1958 Canada Dry bottle, condensed milk cans, puncture/church key opened beverage cans, short tin cans, clear glass fragments, one coffee can, meat tins, one Hershey's tin, one clear glass 1953 Big Chief beverage bottle, unidentifiable tin can and metal fragments, milled lumber, and one moccasin of unknown antiquity. Dense modern trash is intermixed with the historic debris.

Figure 6. Site 48TE1983 looking south (Upper) and southeast (Lower) (Photos by M. Peterson, 8/9/2015).

The wallet's cotton stitching had completely deteriorated, but the leather was in good shape. The cover was tooled and painted leather with a horse and rider in the center, a boot on one side, and a cactus on the other (Figure 5, Upper). Also, portions of an address book, photographs, and documents were partially preserved and four coins and one metal token were recovered. The conserved paper contents of the wallet indicate it was owned by Gordon Stokes, a young man from Rigby, Idaho. His name was visible on a certificate naming him a Star Scout on March 21, 1947 and on a piece of a letter from Dr. Aldon Tall dated January 9, 1946 (Figure 7). The date of 1947 is the latest date identified and is likely the year that it was lost. He was born on February 11, 1933, in Ogden, Utah, and as of April 1940, he lived in Rigby, Idaho with one sister two years younger and one brother five years younger. He may still have lived in Rigby when he lost his wallet given that he was in Rigby Boy Scout Troop 29 in 1947 and had some barely legible addresses in the address book that were in Rigby. He would have been around 14 years old when he lost his wallet, which is consistent with its contents and style. He died on August 20, 2012, in Provo, Utah and is buried in a cemetery there. He served in the US Navy and taught in the Computer Science department at BYU for 30 years. He was married and had nine children. The wallet contained

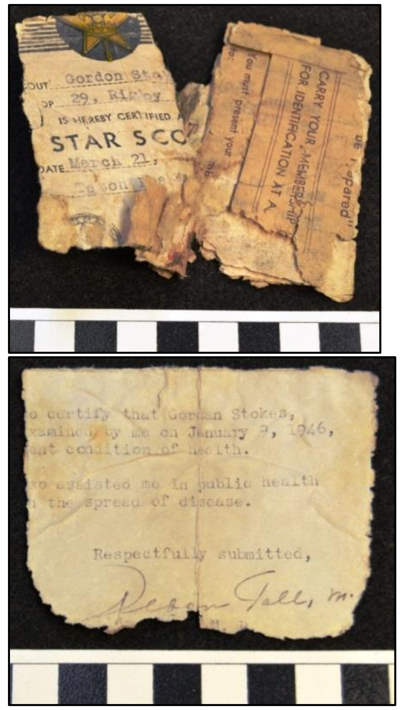

Figure 7. Pieces of the Star Scout Certificate (Upper) and letter from Dr. Tall (Lower) (Photos by M. Peterson, 1/19/2017).

photographs, many of which are well-preserved (http://interactive.ancestry.com; http://www.findagrave.com).

The coins were the best preserved contents in the wallet. They include one 1924 Peace silver dollar, two quarters (1943 and 1944), and one 1944 wheat penny (Figure 8, Upper). In addition, one metal token was recovered. It is a brass pocket guardian angel token about the size of a quarter (Figure 8, Lower). Charities have given out these tokens since the mid-1940s in exchange for donations (http://www.stampboards.com/viewtopic.php?f=27&t=26845; http://www.crs.org/?gclid=CJj0jtHG29ECFY-1wAodKRgIbA). They are religious good luck coins that are carried for fortune, and the practice dates back to as early as 1792 (https://www.reference.com/hobbies-games/guardian-angel-coins-1d9f93b9315cf6da).

The Treasure Mountain Boy Scout Camp is located in Teton Canyon near the Table Mountain trailhead. It started in 1936 and continues today (https://www.facebook.com/TreasureMountainBSA/about/). Since the young man was a Boy Scout in 1947, it is likely he was a Treasure Mountain camper in the summer of 1947 and lost his wallet on the Table Mountain hike.

Figure 8. The Peace Silver Dollar, 1943 and 1944 Quarters, and 1944 Wheat Penny (Upper) and the Guardian Angel Token: Collected token (Lower Left); pristine token (Lower Center; http://www.terapeak.com/worthguardian-pocket-angel-1-token-coin-goldtone-wings-clouds-goldtone-rim-vintage/371554486545/); and pristine token superimposed on the collected token (Lower Right) (Photos by M. Peterson, 1/18-19/2017).

Further, three worked sticks were collected from the melting ice patch. One is a carved Boy Scout walking stick in three segments. The segments refit to form a 151-cm long walking stick with an average diameter of 2 cm and "TROOP 4" or "TROOP 11" carved near its midsection (Figure 9). Given that it was found near the historic wallet and the Treasure Mountain Boy Scout Camp has been operating since 1936, it is possible that this stick is also historic (>50 years old).

Figure 9. The carved Boy Scout walking stick. The bottom segment is the top, the middle segment is the midsection, and the top segment is the bottom (Upper photo). The bottom photo shows the refit ends where it reads "Troop 4" or "Troop 11" (Photos by M. Peterson, 1/19/2017).

The other two collected worked sticks were found melting from the ice patch near the Boy Scout walking stick. The functions of both are unknown. One stick is carved to a blunt point on one end and measures 15.7 cm long with a diameter of 1.3 cm (Figure 10, Upper). Dr. Puseman identified the stick as *Pinus* sp. (pine) (Puseman 2016). Beta Analytic returned a calibrated radiocarbon date of AD 1685-1730, AD 1810-1925, and post AD 1950 (Beta-441531). The last collected stick is 127 cm long with a diameter from 13 to 17 mm. Both ends are sharpened, but the thicker end is more tapered and may have been burned. The narrower end of the stick has a notch carved in it 6 cm from the end (Figure 10, Lower). Dr. Puseman identified the stick as *Pinus* sp. (pine) (Puseman 2016). Beta Analytic returned a calibrated radiocarbon date of AD 1680-1735, AD 1755-1760, AD 1800-1935, and post AD 1950 (Beta-441532).

Both sticks' dates cross the calibration curve in multiple areas, making pinpointing their actual ages difficult; but, they are likely historic. They might relate to the 1872 Hayden Expedition when Jackson was photographing the Grand Teton, or they are more sticks associated with the Boy Scouts who have frequently made this trek since 1936, or with other historic recreational use of the area. Also, they might relate to Late Prehistoric/Protohistoric Native American use of the mountains from AD 1680-1760, or they could relate to the early fur trade.

Figure 10. The worked stick showing the carved point on the right end (Upper) and the long notched stick (Lower) (Photos by M. Peterson, 1/19/2017).

Paleobiological specimens

Two unmodified sticks were collected from the ice patch (~10,975 fasl) on August 9, 2015 (Figure 11). Dr. Puseman identified both sticks as *Pseudotsuga menziesii* (Douglas-fir) (Puseman 2016). Neither of these sticks has been dated. Currently, 58% of Grand Teton National Park is non-forested, and modern tree line is around 9,500 ft. Approximately 4% of the forested land is Douglas fir woodland (Knight et al. 2014). Douglas-fir is present in Grand Teton National Park as a dominant forest species between around 5,500 to just over 7,000 ft., and it has only been documented up to 9,000 ft. (Knight et al. 2014). Douglas fir grows best on soil derived from sedimentary rocks, and it can grow at higher elevations in such a substrate (Knight et al. 2014, Evert 2010, Powell and Hansen 2007, Romme and Turner 1991, Despain 1990, Patten 1963). It prefers drier and warmer environments, and it can act as a good indicator of climate change (Gugger and Sugita 2010).

Figure 11. Collected stick 1 (Upper) and stick 2 (Lower) (Photos by M. Peterson, 1/19/2017).

Paleoclimatic studies indicate that during the early to middle Holocene (~9,000-5,000 years ago), the park experienced a period of maximum warmth. Tree line was at a higher elevation and there was a higher ratio of Douglas fir to pine (Whitlock 1993, Whitlock and Bartlein 1993, Gugger and Sugita 2010, Romme and Turner 1991). Cool, wet conditions returned in the late Holocene, and Douglas fir numbers declined and its elevation lowered (Whitlock 1993). The Douglas fir samples I collected indicate that it may have grown up to ~10,975 ft. above sea level at some time in the past. Table Mountain is comprised of remnant sedimentary rocks, which produce an optimal substrate for growing Douglas fir, and if it was warm and dry enough, maybe it grew this high. Or, given that the sticks would represent Douglas fir at almost 2,000 ft. higher than where it has been documented in the park, the sticks may be manuports. They need to be dated to determine which scenario is most likely and to add another age for the ice patch.

Also, I collected two bison bones as paleobiological specimens to determine when bison were at this high of an elevation in the Tetons, as bison are not currently found at these elevations (~10,800 ft. above sea level) (Figure 12). I identified one bone as a bison thoracic vertebra and the other bone as a bison rib. The University of Arizona AMS Laboratory dated the vertebra to 1,021-1,218 cal. years BP and the rib to 1,027-1,183 cal. years BP (University of Arizona AMS Laboratory 2016). The dates overlap and likely represent remains from the same animal or animals that died at the same time.

Figure 12. Collected bison vertebra (Upper) and rib (Lower) (Photos by M. Peterson, 2/22/2016).

Now, less than 1,000 bison live in the park, but they are not commonly found in the Teton high country (https://www.nps.gov/). It was originally believed that mountain economies focused on artiodactyls other than bison and that bison in the mountains were limited (Cannon et al. 2015). Little is understood of the range extent of pre-contact bison in the Tetons, and the evidence we have of these bison comes from archaeological sites that have been excavated in the valleys (Cannon et al. 2015). Continued investigations in the Tetons show that bison were more prevalent in the faunal community than originally thought, and bison range extended higher into the mountains than previously documented (Cannon et al. 2015, Peterson 2017). At Table Mountain, we have documented bison bone at around 10,800 ft. that date to 1,021-1,218 cal. years BP. Bison may have targeted ice patches in the high country to escape heat and insects and because they were relatively easy to access and did not use the high country when lowland temperatures did not necessitate it or too much high country summer snow inhibited travel (Reckin 2013, see also Lee 2012, Lee et al. 2014, Ion and Kershaw 1989, Ryd 2010). Climatic studies identified three periods of glacial advance during the Holocene: the Little Ice Age (~450-100 cal. years BP); a short period from 1,200-1,050 cal. years BP; and a longer period from 2,900-2,100 cal. years BP (Reckin 2013). The Table Mountain bison bones' dates overlap with the 1,200-1,050 BP stadial and show that at least during that stadial, bison used the high country even when conditions may not have been favorable. A larger sample of dated bison bone is needed to draw broader conclusions on bison ice patch usage.

✦ DISCUSSION

Site 48TE1983 could provide significant information about the early historic exploration of the Tetons and recreational use of Table Mountain. It is associated with the first photographs of the Grand Teton, and artifacts associated with that expedition may be present. Also, it might be significant to the Boy Scouts of America and the historical use of Treasure Mountain Boy Scout Camp. Further, two of the sticks potentially date to the Late Prehistoric/Protohistoric periods and could provide significant information on Native American use of the high Tetons. With ~900 year old bison bone and sticks that might date to the Late Prehistoric/Protohistoric, it could be a prehistoric site, too. It could yield more animal bone that might indicate which species were exploited in the higher elevations, or it could yield perishable artifacts associated with prehistoric hunting and gathering. Ice patch artifacts could help answer questions, such as: What role ice patches played in prehistoric hunter-gatherer subsistence and settlement systems (Vanderhoek et al. 2012, Andrews et al. 2012); What the designs of and materials used in prehistoric weapons were (Andrews et al. 2012, Alix et al. 2012); How alpine people organized their technologies to take advantage of the resources available (Alix et al. 2012); When technological transitions occurred and how hunting changed over time (Hare et al. 2012, Voosen 2013); How prehistoric people adapted to the alpine environment (Andrews et al. 2012); When ice patches were used and what floral, faunal, and mineral resources were exploited (Vanderhoek et al. 2012, Callanan 2012, Dixon et al. 2005, Lee 2009, 2010, 2011, 2012).

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RESEARCH PROJECT REPORTS

HUMAN DIMENSIONS OF RESOURCE MANAGEMENT

INFLUENCE OF THE RIVER OTTER (*LONTRA CANADENSIS*) ON THE FORMATION OF PRO-CONSERVATION INTENTIONS IN THE GREATER YELLOWSTONE ECOSYSTEM

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✦ ABSTRACT

The potential to increase participation in support and fundraising, as well as affect pro-conservation intentions and behaviors makes the flagship approach valuable to conservation. Flagships are charismatic species that engender public interest and promote broader ecological and economic values of conservation. Advocates for wildlife tourism suggest that viewing flagships can increase tourists' awareness and participation in conservation behaviors such as philanthropy, volunteering and activism. However, empirical support for behavioral outcomes associated with flagship exposure is lacking. Exposure to a flagship can vary, such as exposure to marketing materials (i.e., websites, guide books, environmental organizations) or direct viewing experience (i.e., wild, captive). The specific goal of this study was to: (a) determine if direct exposure to the river otter, or marketing material about the species and/or (b) a person's level of environmental concern influences behavioral intentions to conserve the river otter and its habitat. On-site self-administered questionnaires (*n* =523) were conducted at 6 locations throughout the Greater Yellowstone Ecosystem (GYE) from 5 June 2015 to 24 August 2015. The results of this study suggests that exposure to the river otter heightens concern and can lead to the formation of specific environmental intentions such as keeping local waterways unpolluted and planting trees along local waterways.

✦ INTRODUCTION

Governmental and private conservation organizations often use flagship species (ambassadorial species that act as rallying points to stimulate conservation awareness and action [Dietz et al. 1999]) to achieve conservation goals. The ability of flagship species to raise awareness, increase knowledge and trigger behavioral changes makes this approach valuable to conservation campaigns, especially during this time of large-scale environmental concerns (Smith and Sutton 2008, Skibins and Powell 2013). Advocates for wildlife tourism suggest that viewing flagships can increase tourists' awareness and participation in conservation behaviors such as philanthropy, volunteering and activism (Smith and Sutton 2008). However, empirical support for behavioral outcomes associated with flagship exposure is lacking.

The river otter (*Lontra canadensis*), a top aquatic predator, has many physical, behavioral and ecological attributes indicative of a flagship species. For example, the river otter has been popularized through media portrayals as being charismatic, cute, and playful. Such portrayals engender public support, interest and awareness of the river otter, which contribute to enhanced recognition that the species has an obligate dependence on healthy aquatic environments.

A variety of aquatic systems exist in the Greater Yellowstone Ecosystem (GYE), which provide undisturbed habitat to the river otter and other charismatic wildlife. GYE, a popular wildlife tourism destination, encompasses both Yellowstone (YELL) and Grand Teton National Park (GRTE), and is an ideal location to evaluate the ability of the river otter to act as a flagships species by assessing the willingness of visitors to engage in aquatic conservation behaviors such as planting trees along local waterways, spending time to keep rivers and streams unpolluted, or making a financial contribution to river otter habitat conservation.

The results presented here are part of a larger project to investigate the potential of the river otter (*Lontra canadensis*) to serve as an aquatic flagship for the Greater Yellowstone Ecosystem. The primary objective of this study was to determine visitor attitudes towards the environment and the river otter, and assess if different direct exposure types to the river otter (i.e., observing the river otter in wild or in captivity), or indirect exposure to marketing materials about the species influences behavioral intentions to conserve the river otter and its habitat.

✦ METHODS

Data collection

On-site self-administered questionnaires were conducted at 6 locations throughout the GYE, including Trout Lake in YELL, 2 fishing access locations on the Madison River, 2 fishing access locations on the Yellowstone River, and 1 fishing access location on the Snake River (Figure 1). The goal of the questionnaire was to survey both general visitors and visitors who were engaged in fishing activities (i.e., anglers). Researchers administered surveys to visitors (n = 523) from 5 June 2015 to 24 August 2015 visitors. An intercept sampling method was used for survey-data collection and efforts were made to ask every visitor (over the age of 18) encountered to take the survey (Davis et al. 2012). The questionnaire was designed to assess 1) socio-demographic factors such as age, education, residency, and income, 2) level of concern for the river otter, its habitat, and the environment in general, 3) willingness to participate in pro-conservation behaviors, and 4) exposure to the river otter and its habitat. Five hundred and twenty-three surveys were completed, with a response rate of 81%.

Visitor intentions to conserve the river otter and/or its habitat, specific and general environmental concern variables were collected by asking them to rank their level of agreement with various statements on a 5-point Likert scale, ranging from "1, strongly disagree," to "3, neutral," to "5, strongly agree." These statements were designed to address a variety of actions people could take to protect the river otter and its environment, and general and specific environmental concerns. Some of the survey statements were based on a previous study on flagships by Smith and Sutton (2008).

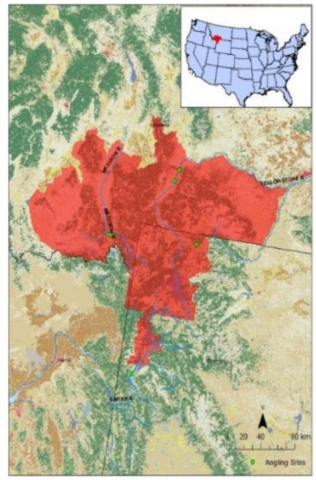

Figure 1. On-site self-administered questionnaires were conducted from 5 June 2015 to 24 August 2015 at 6 locations in the Greater Yellowstone Ecosystem, United States.

Data analysis

Descriptive statistics were used to summarize socio-demographic characteristics, and other closed-ended survey questions. A series of logistic regression analyses were used to test the effects of exposure and environmental concern variables on the probability of having intentions to conserve the river otter and its habitat (Figure 2). Prior to analysis, the ordinal measures of general and specific environmental concern and intentions were transformed into dichotomous variables—a score of 3 or less was recorded to represent "no intention" and a score of 4 or 5 were recorded to represent "intention" or "environmentally concerned."

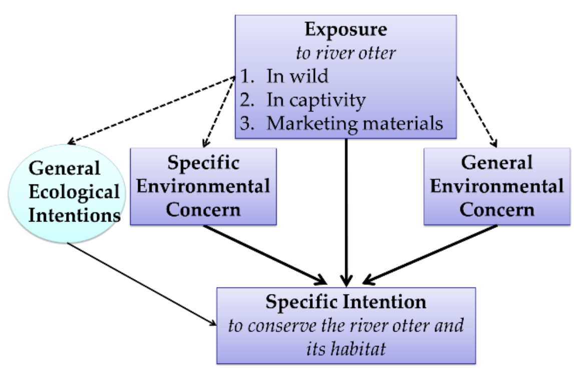

Figure 2. Pathway of analysis for determining the relationship between exposure, environmental concern, and intention. Bold solid arrows represent the primary path; dotted arrows are the secondary path, and the solid thin arrows indicate control for general ecological intentions. (Based on a conceptual framework by Smith and Sutton [2008]).

✦ PRELIMINARY RESULTS

Most visitors held an Associate's degree or higher (*n* = 406) and the average age of participants was 46 (± 0.70 SE) (Table 1). Most people (*n* = 311, 68%) of respondents were classified as having intentions to engage in ecological behaviors, and 53% (*n* = 217) were classified as having intentions to conserve the river otter and its habitat. Seventy-two percent of participants (*n* = 378) indicated they had previously viewed a river otter in the wild or in captivity (Figure 3). Some visitors (*n* = 175, 33%) were previously exposed to river otter marketing materials (i.e., a guidebook, NPS brochure or website, National Wildlife Federation website, Yellowstone Association website/visitor center) that described some natural history of the river otter and its associated habitat (Figure 3).

General environmental concern, and general ecological intentions were determined to influence intentions to conserve the river otter and its habitat (Table 2). Only 1 of the exposure effects tested was significant. The odds of an individual being specifically concerned about the river otter and its habitat increased 1.87 times with exposure to marketing materials about the river otter.

Table 1. Socio-demographic characteristics of visitors surveyed (*n* = 517) from 5 June 2015 to 24 August 2015 at 6 locations throughout the Greater Yellowstone Ecosystem.

Characteristic	Frequency	Percent
Gender		
Male	300	58
Female	217	42
Education		
Some High School or less	3	<1
High School Diploma	34	7
Some College	61	12
Associates or Bachelor	190	37
Some Graduate	43	9
Graduate Degree	173	34
Income		
≤24,999	28	6
25,000 ≤ 74,999	131	26
75,000 ≤ 124,999	114	23
125,000 ≤ 174,999	59	12
≥175,000	55	10
Prefer not to answer	117	23
Location of survey		
Madison River	69	13
Snake River	19	3
Trout Lake	396	76
Yellowstone River	39	8

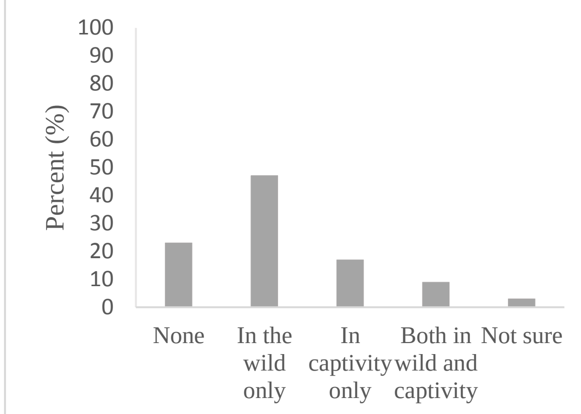

Figure 3. Percent of respondents to the question "Please indicate your previous exposure to the river otter" in our 2015 survey of visitors (*n* = 517) to the Greater Yellowstone Ecosystem. Surveys were conducted from 5 June 2015 to 24 August 2015 at 6 locations throughout the Greater Yellowstone Ecosystem.

✦ MANAGEMENT IMPLICATIONS

This study provides empirical support that exposure to the flagship heightens concern and can lead to the formation of specific conservation intentions.

Specific environmental concerns regarding the river otter and exposure to marketing materials were significant predictors in willingness to engage in pro-conservation behaviors. These findings are consistent with other studies investigating the effects of educational tools focusing on flagship species (e.g., Smith and Sutton 2008). Future research should consider the specific effect of each marketing type to identify the most effective tool in influencing heightened concern for the behavioral intention target.

Direct exposure to the river otter was not a predictive variable in pro-conservation intentions, which counter previous studies which indicated exposure to wildlife increases concern (Skibins and Powell 2013). However, quality of the exposure experience (e.g., time spent watching the species, distance to species) is likely a factor in influencing connection with a species, which was not directly measured in this study, but could be the focus of future research.

Regardless of exposure type, visitors are more likely to spend time to keep local waterways unpolluted and plant trees along local waterways if they knew their contributions would help river otter populations (Figure 4). These results provide empirical evidence that the river otter has the potential to serve as an aquatic flagship for the Greater Yellowstone Ecosystem.

Table 2. Results of logistic regression analysis, testing for significant effects of exposure types and environmental concern variables on intentions to conserve the river otter and its habitat. Surveys were conducted from 5 June 2015 to 24 August 2015 at 6 locations throughout the Greater Yellowstone Ecosystem.

Parameter	*df*	β	SE	*p*-value	OR (95% CI)
General ecological intentions	1	0.93	0.321	0.004	2.53 (1.34-4.74)
Otter in wild	1	0.08	0.315	0.802	1.08 (.583-2.00)
Otter in captivity	1	0.19	0.322	0.546	1.22 (0.646-2.29)
Otter in wild and captivity	1	0.12	0.51	0.812	1.23 (.497-2.23)
Marketing material	1	0.63	0.304	0.02	1.87 (1.03-3.40)
Specific environmental concern	1	1.28	0.329	<0.0005	3.62 (1.89-6.9)
General environmental concern	1	0.79	0.342	0.02	2.20 (1.13-4.31)

n= 306; Model $\chi2$= 85.92; df=8; p=<0.0005; Overall concordance= 23.2%

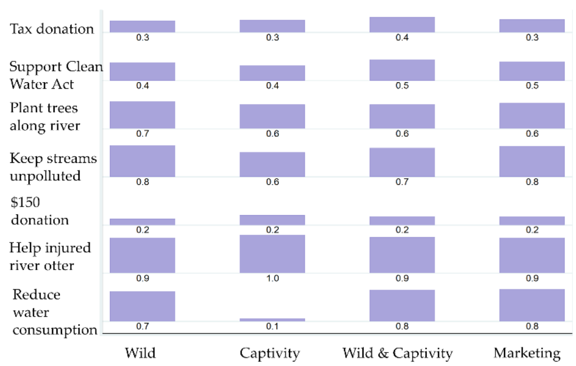

Figure 4. Odd's ratio examining the effects of different types of exposure to river otters (i.e., viewing river otters in wild, in captivity, both in wild and captivity or via marketing materials) on general and specific ecological intentions. Surveys were conducted with visitors (n = 517) from 5 June 2015 to 24 August 2015 at 6 locations in the Greater Yellowstone Ecosystem, United States.

✦ ACKNOWLEDGEMENTS

Support for this study was provided by Frostburg State University. This research would not have been possible without the great assistance of Marie Tosa who helped conduct all the surveys. We would also like to thank Sarah Dewey from GTRE and Stacey Gunther from YELL for permit and logistical assistance, the UW-NPS Research Station for letting us use the kayaks during field research. Our sincere thanks go out to Harold Bergman and Gordo Richman for logistical assistance and great conversations.

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EXPLORING VERTICAL WILDERNESS IN THE ACOUSTIC ENVIRONMENT

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✦ ABSTRACT

Hearing sounds of nature is an important motivation for visitors to National Parks, such as Grand Teton National Park (GRTE; Newman et al. 2015). Furthermore, managers are required to provide park visitors with an enjoyable soundscape experience. In 2006, Pilcher and Newman conducted a study on visitor perceptions of soundscapes in highly trafficked locations in GRTE, the Jenny Lake boat dock and Inspiration Point. While this study used similar methods, it aimed to better understand the influence of soundscapes to a unique visitor group -- climbers on the Grand Teton. This iconic climbing destination is located in an area that is potentially susceptible to anthropogenic or human caused noise interruptions because of its proximity to an airport and heavily used highways. In the summer of 2015 researchers from Penn State University used a combination of qualitative interviews and listening exercises with climbers to identify sounds that were being heard during their climbing experience and their emotions related to those sounds. These data provide managers with information about sounds that could be prioritized when managing for an optimal soundscape experience.

✦ INTRODUCTION

Noise, or the unwanted sound commonly associated with vehicle traffic, construction and airplanes, is on the rise in national parks (Lynch et al. 2011). In a place where human caused environmental impacts are kept to a minimum, natural sound is becoming overshadowed by human induced noise. According to the U.S. National Park Service (NPS 2006), "noise levels in park transportation corridors today are at 1,000 times the natural level." National parks and wilderness areas are places where one could expect to find silence or escape from noisy urban environments.

Figure 1. Researcher collecting data at the Meadows Site.

In fact, enjoying sounds of nature, silence and escaping noise are often the most common motivations for visitors to parks and protected areas (Driver et al. 1991). With increased visitation to these areas, the amount of unwanted sounds from traffic, airplanes, helicopters, and people, has also increased, thus becoming a topic of concern. The NPS Soundscape Management Policy 4.9 states "the service will take action to prevent or minimize all noise that, through frequency, magnitude, or duration, adversely affects the natural soundscape or other park resources or values…" (NPS 2006). National park managers are taking steps to understand acceptable levels of noise and to mitigate noise so that natural sounds are not compromised. The purpose of this study was to investigate the types of sounds heard by climbers during their experience on the Grand Teton in GRTE and their perceptions of sounds.

The summit of the Grand Teton is one of North America's most desirable mountaineering destinations. This 13,770 foot peak has a rich climbing history and attracts both advanced and novice climbers craving a more magnificent view of the Teton Range. Since the mountain was first summited in 1898, climbing on the Grand Teton has grown in popularity. There are two climbing concessions that operate guided trips to the summit year round. Because this area has faced growing use, it is challenging to provide quality visitor experiences that depend on high-caliber resource and social conditions.

The Garnet Canyon trail is frequently used by climbers approaching the Grand Teton and is subject to aircraft and traffic noise given its proximity to the Jackson Hole Airport and two major highways. Additionally, this area of the park is within a recommended wilderness area and is managed by the National Park Service (NPS) as wilderness. Federal wilderness areas are expected to provide "outstanding opportunities for solitude or a primitive and unconfined type of recreation" (National Wilderness Preservation Act 1964, Section 2c). This location is unique in that there is a combination of high climbing use and human caused noise within proposed wilderness --- impacts that may counteract a desired wilderness experience.

Earlier studies have identified the impacts of anthropogenic or manmade sounds to visitors to National Parks (Kariel 1990, Marin et al. 2011, Pilcher et al. 2009, Taff et al. 2015). Rock climbers are a unique community of recreationists and to date no study has examined the influence of sounds on climbers. Taff et al. (2015) interviewed mountaineers on Mount McKinley in Denali National Park to inform managers on their perceptions of social and resource conditions in this designated wilderness area. The research determined mountaineers place an emphasis on sound. Tarrant et al. (1995) evaluated the effects of overflights on visitors to wilderness areas in Wyoming. This study used a dose exposure survey technique to gain an understanding of how visitor characteristics influence evaluations of overflights. Researchers concluded that respondents had strong negative attitudes towards hearing overflights and were slightly more affected by hearing overflights than seeing them. Levels of solitude and tranquility were also decreased by sounds of overflights.

The Grand Teton is in a location that is potentially susceptible to anthropogenic sound given its proximity to the airport and highways. This is an ideal place to examine the influence of sounds, both natural and anthropogenic, to rock climbers. This project aims to provide managers with baseline information about the sound impacts in Garnet Canyon and the Grand Teton.

✦ STUDY AREA

This study was conducted with climbers who had used the Garnet Canyon trail to access the Grand Teton. This area was chosen because of its proximity to the Jackson Hole Airport, as well as major roads within the park. With help from NPS staff, two separate sites were chosen for a listening exercise and associated survey.

The 3 Mile Junction site is located in an area closer to anthropogenic sound sources. At this site, it was possible to view roads within the park and the Jackson Hole Airport. The Meadows site was further into the backcountry and the Garnet Canyon (See Figure 2). The 3 Mile Junction site is roughly 3 miles from the trailhead and the Meadows site is roughly 5.2 miles from the trailhead. Two different sites were chosen so that the researchers could analyze perceptions of sound from a site presumed to be more natural (the Meadows) and a site presumed to be less natural (the 3-Mile Junction).

✦ METHODS

In order to effectively develop indicators and related thresholds for acceptable amounts of noise heard and to understand the feelings associated with sounds heard by climbers, two separate methods were used: 1) qualitative interviews with climbers who have recently attempted or successfully summited Grand Teton, and 2) an in situ listening exercise and accompanying survey. This study used qualitative interviews to better understand the types of sounds climbers were hearing throughout their experience on the Grand Teton. The listening exercises and surveys provide managers with information about sounds heard at the two specific sites that were chosen, while the qualitative interviews provide information about sounds heard at other locations throughout the approach and climb on the Grand Teton.

Phase one: Climber qualitative interviews

Thirty-three climbers were interviewed through 18 semi-structured (n=18) qualitative interviews. They were conducted with climbers after their climb on the Grand Teton from 7/3/15 to 7/12/15

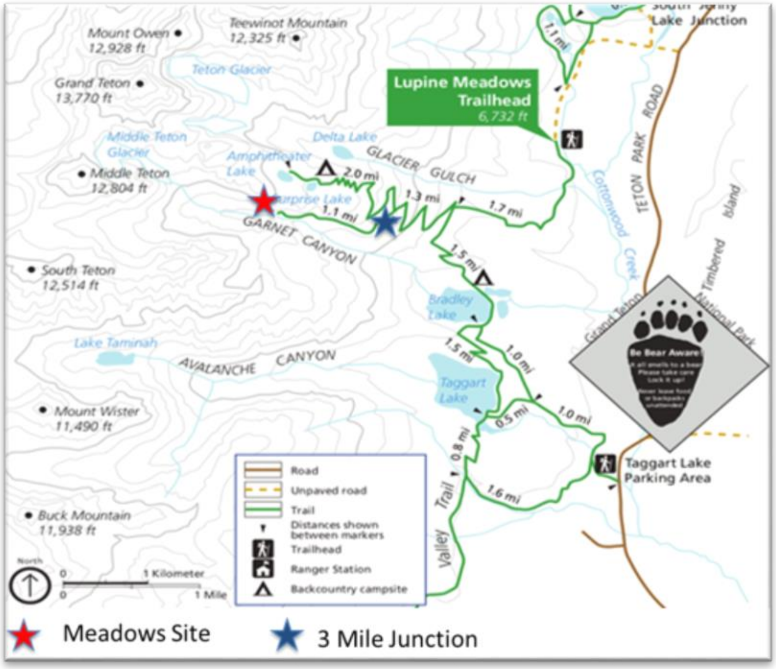

Figure 2. Study area map

with a 90% response rate. All respondents were interviewed within 24 hours of returning from their climb on Grand Teton. Interviews ranged from 7 minutes to 22 minutes. All interviews were conducted within GRTE, at two locations, the Lupine Meadows Trailhead parking lot or the American Alpine Club Climbers' Ranch.

Figure 3. Researcher Lauren Abbott at the Lupine Meadows Trailhead.

Interview questions were developed based on a similar study that had been conducted with mountaineers on Mount McKinley in Denali National Park and Preserve (Taff et al. 2015). Interviews were recorded and transcribed verbatim. The purpose of the interviews was to identify sounds heard by climbers and determine their interpretations of sounds, therefore the data were treated as exploratory. Rather than seeking to define theoretical implications, interview questions were analyzed by inductively reviewing transcripts and determining reoccurring themes (Bogdan and Biklen 1998). The interview began by asking climbers questions about their motivations for climbing the Grand Teton and other experiences during their trip. The focus of the study was to understand the sounds climbers recalled hearing during their climbing experience.

Phase two: Listening exercise and survey

This study used methods commonly applied to other studies that examine the effects of human caused noise on visitors to protected areas (Kariel 1990, Marin et al. 2011, Pilcher et al. 2009, Taff et al. 2015). Respondents were asked to participate in the exercise during their descent from the Grand Teton at one of two different locations: near the Meadows site or the 3-Mile Junction. They were instructed by the researchers to close their eyes and listen to the sounds around them for two minutes, then use the iPad survey to indicate what sounds were heard and to rate whether the sounds were pleasing or annoying and the acceptability of the sounds heard. For example, a respondent may hear other people talking and rate it as annoying, but also rate it as highly acceptable given the location.

Sampling at the two locations took place between July 13 and August 10, 2015, a time period of high climbing use on the Grand Teton. There was an 89% response rate with at total $n = 234$. Sampling at 3 Mile Junction took place from July 13 to August 10, 2015, with a total $n = 122$. Sampling at the Meadows took place from July 19 to August 9, 2015 with a total $n = 112$.


Figure 4. A climber completing the listening exercise at the Meadows Site.

✦ RESULTS

Phase one: Climber qualitative interviews

The climbers interviewed ranged in age from 23 to 60, and all but one party were from the United States. We interviewed one climbing party from Canada. Climbers ranged in self-described experience from beginner to professional, and in years of climbing experience with one climber having 3 days of experience and others having 40 plus years. Eleven climbers had climbed the Grand Teton for the first time and 7 were return climbers. The majority of parties climbed on the Owen Spalding route, one party climbed the Black Ice Couloir and the East Ridge. Other parties climbed on the Upper Exum Ridge and Direct Petzoldt Ridge. The following semi-structured interview results describe information about the sounds climbers recall hearing during their climbing experience.

First we asked what kind of sounds they heard during their trip. Eight of the parties interviewed mentioned hearing aircraft. Three of the parties that heard aircraft mentioned that it sounded like thunder. The following are examples of the responses we received:

<u>Int 2:</u> *Other than wilderness sounds, there were a lot of birds, did hear a couple of planes, saw a helicopter, flew by the saddle at some point. That was most of it. You could hear some people's electronic devices at some point, as well, which was kind of annoying.* (Interviewer) What kind of electronic devices? (Climber 1) *Oh, like their cellphone, or something else.* (Interviewer) Like a cellphone ringing? (Climber 1)*Yeah, some people would bring their cellphones up to the saddle. Evidently, a lot of people had fairly good reception up there. I think that defeats kind of the whole purpose of going up into the mountains, so, yeah.*
<u>Int.9:</u> (Climber 2*) Airplanes. It was startling. I was like oh I guess the airports really close.* (Climber 1) *Yeah and it can sound like thunder or rock fall, the initial loud noise is a real concern because I spend so much time on the mountains. I get startled. Yeah the jets. And part of the Marian was collapsing. That made us jump but it was probably just a big boulder shifting.*
<u>Int. 12:</u> (Climber 1) *Rock fall, hail, cracking my helmet, high winds blowing through.* (Climber 2) *Marmots chirping.* (Climber 1) *Thunder and lightning, certainly the sound of running water, the beauty of a creek or a small river running is very pleasant. I guess the other sound is just the sound your feet make, especially in a snowfield, just listening to the sounds your feet make.*

Next we asked what sounds they enjoyed hearing. The following are examples of common responses:

<u>Int. 5:</u> *I like the drowning sound of the falls a little bit. It's far enough, sometimes it can be, uh, it can break up communication, but it was just a faint noise so it was kind of nice, peaceful.*
<u>Int. 8:</u> *I always enjoy hearing, uh, gear placements in rock, like it's just an enjoyable sound, so in the couple technical pitches we did, um, just hearing carabiners click and ropes, you know, running through carabiners and, you know, all the climbing sounds.*
<u>Int. 18:</u> (Climber 1) *Aw I like all the sounds up there, I like the sounds of the avalanches and the rocks falling it's just something primal about it.* (Climber 2) *I like the water* (Climber 1) *You an avalanche coming down and *inaudible * it's like a present for climbers. More rock falling.*

Subsequently, we asked respondents what sounds they enjoyed hearing the least. The following are examples of common responses:

<u>Int. 3:</u> *The sound I enjoy hearing the least is the dude screaming 'rock!' as he kicked that thing off, but like on days off it's nice to not hear other people and just go climb. You know? You don't have to hear questions*

like, 'oh, what routes are you guys doing? Oh, was it cool?' you know? Shit like that gets old. I guess you can leave that for work.
Int. 6: *Rock fall is a scary one. That's probably mine*
Int. 10: (Climber 1) *The airplanes.* (Climber 2) *Yeah I mean they didn't bother me that much I was more nervous that it was thunder coming. That's what I enjoyed the least but we were well down by then.*
Int. 13: *The wind is sickening, like I got tired of that sound. Um, but usually a breeze sounds amazing, I usually love that sound. There are local businesses that fly small planes [inaudible from wind] I get a little weirded out about that too.*

Finally, we asked respondents if they specifically heard motorized or other human caused sounds while on or near the summit of the Grand Teton. The following are some examples of the responses we received:

Int. 2: *Not at the summit, but up mid-route we could definitely hear planes flying over a couple of times.*
Int. 7: *No. I didn't hear anything up there.*
Int. 8: (Climber 1) *I don't remember that, I mean, maybe there* (Climber 2) *We heard other climbers.*
(Climber 1) *Yeah, we definitely heard other climbers, but no aircraft or anything like that that I can remember.*
Int. 10: (Climber 2) *We heard the helicopter when we were at the summit. Or was it lower down, I'm not sure* .(Climber 1) *I don't remember.*

Not all parties interviewed reached the summit, therefore their question was broader. They were asked if they recalled hearing motorized or human caused sounds during their trip. The following are examples of some of the responses:

Int. 4: (Climber 1) *I don't remember any helicopters. Airplanes? No. I mean, I have. Not today. Yeah, with the airport. Some helicopters last time we were up here when me and Joe were coming off the summit there was a rescue going on and there was a helicopter just circling us looking for someone, but not today. I don't think so.* (Interviewer) Okay. (Climber 1) *Oh, except, you know what? The, um, so I think the Exum Mountain Guides have 2 tents up there, so you can hear them flapping in the wind.* (Interviewer) Oh, the tents flapping? (Climber 1) *Yeah, when you walk past them, it's just a chaotic tent going at it. So, yeah, there's that up there.*
Int. 17: *Actually yeah, I heard maybe a jet going over because of the airport being so close. But that was it and it was only once.*

Phase two: Listening exercise and survey

Of the 243 climbers that participated in the listening exercise between July 13 and August 10, 2015, 79% of the sample were male and 21% were female and the average age was 33 years old. Twenty-three percent were guided climbers, 72% were climbing with private parties and 5% identified themselves as climbing guides. Sixty-four percent rated themselves as intermediate or advanced climbers, and 70% of climbers were on overnight trips.

During this portion of the study to identify potential soundscape indicators, respondents were asked whether they would be willing to participate in a listening study. Willing participants listened to the sounds around them for two minutes, and then completed an IPad survey. The results of this sample are presented below. Table 1 provides the five most frequently heard natural sounds at 3 Mile Junction. Wind and bird song were heard most frequently, as 88% of respondents indicated hearing these sounds. Acceptability of sounds were based on a 9-point scale (-4 = Very Unacceptable; 0 = Neutral; 4 = Very Acceptable) and personal interpretation of sounds were based on a 9-point scale (-4 = Very Annoying; 0 = Neutral; 4 = Very Pleasing). The sound of wind was, on average, perceived as acceptable (*M*=2.8) and very pleasing (*M*=3.0). Bird song was perceived as very acceptable (*M*=3.2) and very pleasing (*M*=3.3). Wind rustling in the trees was the second most frequently heard sound. Eighty-five percent of respondents indicated that they heard wind rustling in the trees, on average these respondents found the sound to be acceptable (*M*=2.8) and very pleasing (*M*=3.2). Eighty-four percent of respondents at 3 Mile Junction heard insects, and mean acceptability dropped considerably compared to the sounds of wind or bird song. These respondents indicated that insect sounds were still acceptable (*M*=2.2), but annoying (*M*=-0.3). Finally, water was heard by 62% of respondents, and considered acceptable (*M*=1.8) and very pleasing (*M*=3.4).

Table 2 provides the five most frequently heard anthropogenic sounds at the 3 Mile Junction site. Walking sounds were heard most frequently, as 78% of respondents indicated hearing this sound. Walking sounds was, on average, perceived as acceptable (*M*=2.5) and slightly pleasing or almost neutral (*M*=0.8). Voices were heard by 76% of respondents and were perceived as slightly acceptable (*M*=1.7) and slightly pleasing or almost neutral (*M*=0.4). Sixty-three percent of respondents indicated that they heard vehicles (other than motorcycles). The sounds of

Table 1. 3-Mile Junction climber evaluation of the five most frequently heard natural sounds

Sound Heard		*n*	Percent Heard	Mean[1] Acceptability	SD Acceptability	Mean[2] Personal Interpretation	SD Personal Interpretation
1.	Wind	107	88	2.8	1.7	3.0	1.7
2.	Bird song	107	88	3.2	1.2	3.3	1.2
3.	Wind rustling in the trees	104	85	2.8	1.7	3.2	1.1
4.	Insects	102	84	2.2	2.2	0.3	2.8
5.	Water, streams, rivers, etc.	75	62	1.8	2.1	3.4	1.1

[1]Acceptability based on 9-point scale (-4 = Very Unacceptable; 0 = Neutral; 4 = Very Acceptable)
[2]Personal interpretation based on 9-point scale (-4 = Very Annoying; 0 = Neutral; 4 = Very Pleasing)

Table 2. 3-Mile Junction climber evaluation of the five most frequently heard anthropogenic sounds

Sound Heard		*n*	Percent Heard	Mean[1] Acceptability	SD Acceptability	Mean[2] Personal Interpretation	SD Personal Interpretation
1.	Walking	95	78	2.5	1.9	0.8	1.9
2.	Voices	93	76	1.7	2.3	0.4	1.9
3.	Vehicles	77	63	-0.3	2.6	-1.3	2.5
4.	Climbing Gear	68	56	2.0	2.0	0.9	1.8
5.	Jet Aircraft	64	53	-0.2	2.6	-1.3	2.4

[1]Acceptability based on 9-point scale (-4 = Very Unacceptable – 4 = Very Acceptable)
[2]Personal interpretation based on 9-point scale (-4 = Very Annoying – 4 = Very Pleasing)

vehicles were, on average, considered neutral in terms of acceptability (*M*=-0.3) and slightly annoying (*M*=-1.3). The sounds associated with climbing gear were perceived as acceptable (*M*=2.2) and almost neutral concerning whether those sounds were annoying or pleasing (*M*=0.9). Fifty-three percent of respondents indicated hearing jet aircraft, on average these sounds were just barely unacceptable (*M*=-0.2), but annoying (*M*=-1.3).

Table 3 provides the five most frequently heard natural sounds at the Meadow site. The sounds of water, streams, rivers, etc., were heard most frequently, as 98% of respondents indicated hearing this sound. These sounds, on average, were perceived as very acceptable (M=3.6), and very pleasing (M=3.4). Wind was the second most frequently heard sound. Ninety-six percent of respondents indicated that they heard wind and, on average, these respondents found the sound to be acceptable (*M*=2.8) and pleasing (*M*=2.6). Eighty-one percent of respondents at the Meadows site heard wind rustling in the trees and indicated that these sounds were acceptable (*M*=2.6) and pleasing (*M*=2.8). Birdsong was heard by 66% of respondents, and considered acceptable (*M*=2.7) and very pleasing (*M*=3.2). Finally, mammals were heard by 38% of respondents, and they indicated that the sounds were acceptable (*M*=1.9) and pleasing (*M*=2.4).

Table 4 provides the five most frequently heard anthropogenic sounds at the Meadows site. Voices were heard most, by 77% of respondents. These sounds were slightly acceptable (*M*=1.3), but slightly annoying as well (*M*=-0.03). Walking sounds, which were heard by 74% of respondents, were perceived as acceptable (*M*=2.3), but slightly pleasing (*M*=0.6). Fifty-two percent of respondents indicated that they heard climbing gear, and, on average, considered these sounds to be acceptable (*M*=1.7) and slightly pleasing (*M*=0.8). Jet aircraft were heard by 30% of respondents. These sounds were found to be slightly unacceptable (*M*=-1.0) and slightly annoying (*M*=-1.5). Twenty-seven percent of respondents indicated hearing propeller aircraft, and, on average, these sounds were just slightly unacceptable (*M*=-0.9) and annoying (*M*=-1.4).

Table 3. The Meadow Site climber evaluation of the five most frequently heard natural sounds

Sound Heard		*n*	Percent Heard	Mean[1] Acceptability	SD Acceptability	Mean[2] Personal Interpretation	SD Personal Interpretation
1.	Water	110	98	3.6	1.8	3.4	1.1
2.	Wind	107	96	2.8	1.7	2.6	1.6
3.	Wind rustling in the trees	91	81	2.6	1.9	2.8	1.6
4.	Birdsong	74	66	2.7	2.0	3.2	1.2
5.	Mammals	42	38	1.9	2.3	2.4	1.8

[1]Acceptability based on 9-point scale (-4 = Very Unacceptable; 0 = Neutral; 4 = Very Acceptable)
[2]Personal interpretation based on 9-point scale (-4 = Very Annoying; 0 = Neutral; 4 = Very Pleasing)

Table 4. The Meadow Site climber evaluation of the five most frequently heard anthropogenic sounds

Sound Heard		*n*	Percent Heard	Mean[1] Acceptability	SD Acceptability	Mean[2] Personal Interpretation	SD Personal Interpretation
1.	Voices	86	77	1.3	2.1	-0.3	1.9
2.	Walking	83	74	2.3	1.8	0.6	2.0
3.	Climbing Gear	58	52	1.7	1.9	0.8	2.3
4.	Jet Aircraft	33	30	-1.0	2.0	-1.5	1.7
5.	Propeller Aircraft	30	27	-0.9	2.2	-1.4	1.8

[1]Acceptability based on 9-point scale (-4 = Very Unacceptable – 4 = Very Acceptable)
[2]Personal interpretation based on 9-point scale (-4 = Very Annoying – 4 = Very Pleasing)

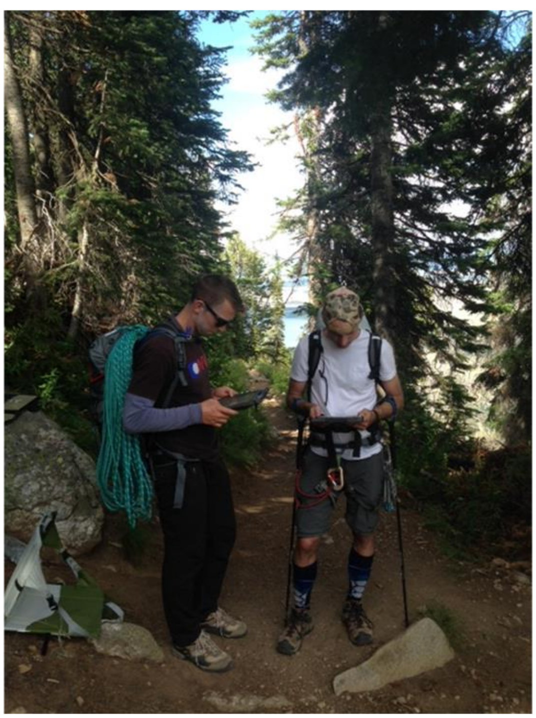

Figure 4. Climbers completing the listening survey at the 3-Mile Junction Site.

Tables 5 and 6 provide combined results from the 3 Mile Junction and the Meadows sites. Table 5 provides the five most frequently heard natural sounds. Wind was heard by 91% of climbers and was rated at acceptable (*M*=2.8) and pleasing (*M*=2.8). Eighty three percent of climbers heard wind rustling in the trees. This sound was rated as acceptable (*M*=2.7) and very pleasing (*M*=3.0). Water, streams, or rivers were heard by 79% of climbers and was rated as acceptable (*M*=2.9) and very pleasing (*M*=3.4). Birdsong was heard by 77% of respondents and was rated as very acceptable (*M*=3.0) and very pleasing (*M*=3.2). Finally, insects were heard by 62% of climbers and was rated as acceptable (*M*=2.0) and interpreted as neither pleasing nor annoying (*M*=0.7).

Table 6 provides the five most commonly hear anthropogenic sounds. Voices were heard most frequently with 76% of climbers reporting they were slightly acceptable (M=1.4) and interpreted as very slightly pleasing (M=0.9). Walking sounds were also heard most frequently with 76% of climbers reporting them as acceptable (M=2.4) and interpreted as neutral (M=0.7). The third most frequently heard sound was climbing gear. Fifty four percent of climbers heard this sound and reported it as acceptable (M=1.9) and

Table 5. Overall climber evaluation of the five most frequently heard natural sounds

Sound Heard	*n*	Percent Heard	Mean[1] Acceptability	SD Acceptability	Mean[2] Personal Interpretation	SD Personal Interpretation
1. Wind	214	91	2.8	1.7	2.8	1.7
2. Wind rustling in the trees	195	83	2.7	1.8	3.0	1.4
3. Water, streams, rivers, etc.	185	79	2.9	1.7	3.4	1.1
4. Birdsong	181	77	3.0	1.6	3.2	1.2
5. Insects	104	62	2.0	2.3	0.7	2.6

[1]Acceptability based on 9-point scale (-4 = Very Unacceptable; 0 = Neutral; 4 = Very Acceptable)
[2]Personal Interpretation based on 9-point scale (-4 = Very Annoying; 0 = Neutral; 4 = Very Pleasing)

Table 6. Overall climber evaluation of the five most frequently heard anthropogenic sounds

Sound Heard	*n*	Percent Heard	Mean[1] Acceptability	SD Acceptability	Mean[2] Personal Interpretation	SD Personal Interpretation
1. Voices	179	76	1.4	2.2	0.9	1.9
2. Walking	178	76	2.4	1.8	0.7	1.9
3. Climbing Gear	126	54	1.9	2.0	0.9	2.0
4. Jet Aircraft	97	41	-0.5	2.4	-1.3	2.1
5. Vehicles	95	40	-0.5	2.5	-1.5	2.3

[1]Acceptability based on 9-point scale (-4 = Very Unacceptable – 4 = Very Acceptable)
[2]Personal Interpretation based on 9-point scale (-4 = Very Annoying – 4 = Very Pleasing

interpreted it as neutral or slightly pleasing (M=0.9). Jet aircraft, the fourth most frequently heard sound, was heard by 41% of climbers and was rated as neutral or almost slightly unacceptable (M=-0.5). Jet aircraft was interpreted as annoying (M=-1.3). Finally, vehicles were heard by 40% of climbers and was reported as neutral or almost slightly unacceptable (M=-0.5) and interpreted as annoying (M=-1.5).

✦ Management Implications

This study was successful in identifying baseline data regarding the sounds heard by climbers during their experience on the Grand Teton, as well as their perceptions of sounds. The qualitative interviews provided the following information:

- Eight of the 18 interviews mentioned hearing aircraft when asked generally about sounds they remember hearing during their climb.
- Waterfalls, gear placement and avalanche are examples of sounds climbers enjoyed hearing the most.
- Rock fall, airplanes and wind are examples of sounds climbers enjoyed hearing the least.

The listening exercise identified sounds heard by climbers and their evaluation of sounds (See Tables 5 and 6). Results from the listening exercise (n=234) indicated:

- Jet aircraft was the fourth most frequently heard anthropogenic sound. Forty one percent of climbers rated the sound as slightly unacceptable and annoying.
- Vehicle sounds were the fifth most frequently heard anthropogenic sound, with 40% of climbers rating it as slightly unacceptable and annoying.

These sounds signify a priority for managers to address, given the substantial number of climbers who reported hearing these sounds and their negative evaluation. A majority of climbers heard wind (91%), wind rustling the trees (83%), water (79%), birdsong (77%), voices (76%), and walking (76%). The natural sounds were rated as acceptable and pleasing, while voices and walking were rated as acceptable but were interpreted as neither pleasing nor annoying. These results identify climbers' positive evaluation of natural sounds.

The purpose of this study was to provide managers with information about the sounds climbers are hearing during their experience on the Grand Teton. These data can aid in informing a future visitor survey. The future survey would aim to identify a threshold that indicates when anthropogenic sounds, such as jet aircraft and vehicle sounds, become unacceptable in a way that negatively impacts visitor experience.

✦ ACKNOWLEDGEMENTS

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INTERNSHIP REPORT

<u>Summary of all 2015 interns and visiting scholars resident at the UW-NPS Research Station</u>
2 Grand Teton National Park interns co-funded* by UW and Grand Teton NP and selected competitively for work with Grand Teton National Park staff; 2 guest interns in Ecology/Sustainability and Nature Writing; 1 guest UW faculty member in music composition – 217 user-days

- *Hydrogeology/Glaciers – MS student from University of Colorado-Boulder
- *Museum Curation/History – MS student from Idaho State University
- Ecology/Sustainability – Undergrad, University of the Sunshine Coast Australia
- Nature Writing – MA student from University of Wyoming MFA Writing Program
- Music Composition/Opera – Composition Faculty Member Univ. of Wyoming

Glacier Monitoring Internship Report: Grand Teton National Park, 2015

Emily Baker
University of Colorado-Boulder ✦ Boulder, CO

✦ Background

The small glaciers of Grand Teton National Park (GTNP) are iconic landmarks, enhancing the experience of millions of visitors to the park each year. They are valuable far beyond their beauty, and play a critical role in the park's unique high-elevation ecosystems.

Glaciers act as water towers of the mountain ecosystem, storing winter precipitation as ice which can be utilized slowly over the summer months, as it slowly melts to become runoff. Glacial melt controls stream temperatures, enhances late-season streamflow volumes, and is a critical input for many high-elevation plant and animal communities. Additionally, change in glacier volume serves as a multi-year record of climate, and gives a stark illustration of how climate is changing. A series of high-snow winters and cloudy, cool summer years cause glaciers to grow, while low-snow winters and clear, hot summer years cause glaciers to shrink. Changes in glacial extent and volume are good indicators of multi-year climate trends.

Recent studies of glacial extents in GTNP show significant and rapid retreat of glaciers in all areas. On-the-ground estimates of glacier volume, yearly volume changes and glacial motion are not yet studied; this research aims to fill this gap. Here, we detail the development of a simple mass-balance (overall ice melt or accumulation) monitoring protocol for reference glaciers in GTNP, using readily available equipment currently owned by GNTP, which can be performed in-house, with existing NPS expertise and equipment.

✦ MEASUREMENT OBJECTIVES

- **Glacier Size**
    - What is the volume of the glacier?
    - What is the surface area of glacier?
- **Change in Volume**
    - How much did the glacier grow or melt, since last measured?
    - Why: summer temperatures, date of snow melt-off, or incoming sun (cloudiness)?
- **Movement**
    - Is the glacier moving? If not, it is no longer technically a glacier, but stagnant ice.
    - How far did it move?
    - What time of year did it flow fastest?

✦ TOOLS

Thermistors (air temperature sensors)

Pyranometer (solar radiation / sunlight energy sensor)

Repeat photo monitoring points

Time lapse cameras (daily photos)

Mapping grade GPS: Geo X7

Energy Balance Melt Modeling

$$M = \begin{cases} [TF + SRF(1-\alpha)G]T & \frac{T>Tt}{T<Tt} \\ 0 & \end{cases}$$

Vs.

Sun **Air Temperature**

✦ METHODS

Glacier areal extent

Glacier area can be mapped in three ways: using remotely sensed aerial imagery (i.e., satellite, or airplane), using orthorectified ground-based photography (i.e., repeat photo monitoring points), or directly mapping glacier margins with a GPS unit. Recent research has used available historical aerial photography (Reynolds 2012, Tootle 2010) but reported difficulties distinguishing ice from snow, and remained unable to correlate change in glacier area with available climate forcings (PRISM). Our deployment of high-elevation, glacier-adjacent temperature sensors and pyranometer will allow for partitioning of observed melt into that caused by higher air temperatures vs. incoming shortwave solar radiation, and additionally allow for re-analysis of PRISM data, with the potential of using enhanced PRISM to review and improve this earlier work on historical glacial area change.

Change in glacier area can be analyzed as frequently as data are available: either whenever late-season (early September) aerial imagery is flown; yearly, based upon field photo-monitoring points; or yearly, based upon field-surveyed GPS glacial margins.

Glacier volume and volume change

Surface elevations on reference glaciers will be taken with a GPS survey on an annual basis, or multi-year basis, as GIS and Climbing Ranger staff time allows. A high density of points collected on the glacier surface allows for computation of a complete, interpolated glacier surface elevation. Comparison of this surface from year-to-year allows for calculation of change in volume.

Absolute volume of the glacier can be determined with use of a Ground Penetrating Radar unit, which maps the depth to bedrock underneath the ice. Cooperation with partners at the University of Colorado is pending to use a GPR unit in the Fall 2015 survey of Middle Teton Glacier, and thus map the bedrock and measure true glacier volume. Bedrock needs to be mapped only once with a GPR; subsequent years with different ice surfaces will still have the same underlying bedrock surface. Ideally, a GPR survey would be completed at each glacier of interest, for knowledge of true remaining ice volume. However, estimates of ice volume change are not affected by knowing absolute size of the glacier. Rather, knowledge of absolute volume allows for better estimates of glacial longevity (i.e., how long it will likely survive, under current or projected climate conditions). Melt rates and ice volume are the two key variables needed to estimate how long a glacier will survive.

Glacier movement

A glacier is defined by its motion; a glacier which is no longer flowing is technically a body of stagnant ice (also known as perennial snow and ice), and no longer a glacier. Recent studies on GTNP glaciers have focused on aerial extent, and not motion. We do not currently know how fast the glaciers are flowing, or even if flow is occurring at all. This is especially true of rock-covered glaciers (Petersen) and portions of glaciers which are rock covered (lower lobe of the Middle Teton Glacier), where crevasses (also an indicator of recent motion) cannot be observed. Motion will be quantified using time lapse photography. Moultrie brand time-lapse cameras have been deployed at glaciers of interest, during the summer of 2015, at stable locations, allowing for continuous monitoring of the glacier from a static point. The cameras are programmed to take three daily photos, which should yield at least one per day where clouds do not obscure the field of view. Compiling daily images gives a time-lapse video of glacier motion and melting over the course of the summer – including dates when snow melts from the surface of the glacier, and ice (as opposed to seasonal snow) begins melting. Measurement of two fixed points in image background, and distance from camera, will allow calculation of flow rates, using basic trigonometry.

Additionally, glacier movement will be measured directly using markers placed on the ice surface. Rocks wrapped with surveyor's tape were placed on the surface of the Middle Teton Glacier on July 2, 2015, and their location measured with the mapping grade GPS unit. Measuring the location of these fixed points on the glacier's surface will allow calculation of annual flow at 3 fixed points along its surface, and provide a check on the accuracy of photo-derived estimates of motion. Depending on the frequency of surface marker re-visitation, sub-annual measurement of flow rate can be calculated, approximate timing of maximum flow rate can be determined, and potentially correlated with climate variables (solar radiation and air temperature). High flow rates are known to coincide with times where more melt is present at the glacier's bed surface, lubricating bedrock friction and speeding flow. Knowing timing of maximum flow rates would give information on the timing of maximum glacial melt. Otherwise, glacial melt volumes are measured only once per year, with information available on timing of maximum melt rates.

Determining the cause of melt — Modified degree day modeling

Multiple years of surface elevation measurements on index glaciers allows us to calculate changes in ice volumes. The first surface elevation survey was conducted on Schoolroom Glacier in summer 2014; the second will be conducted on Middle Teton Glacier in summer 2015. These surveys tell us what is happening to the index glaciers – are they growing, or shrinking? They do not, however, allow us to determine what caused that change. Was it an anomaly in snowfall (low/ high)? Was it an abnormally cloudy spring and summer, where sun melted only a small quantity of glacial ice? Was it a very hot summer, where temperature drove the melting, even if the summer was quite cloudy? We can answer these questions using two known inputs: incoming solar radiation (measured at the Lower Saddle & Kelly Teton Science School pyranometers), and high-elevation air temperature (our adjacent thermistors). With these, we can construct a modified degree day glacier melt model. Academic researchers commonly apply full energy-balance models containing information on latent heat fluxes, longwave radiation, and surface albedo, but that work is beyond the scope of this project, mostly due to increased cost of instrumentation, and higher uncertainties associated with model parameterization (including estimates of surface roughness, surface emissivity, and other quantities that are difficult to measure accurately in the field).

Temperature-index models are widely used operationally, by NOAA and the USGS for snowmelt runoff forecasting. A modified degree day model allows for use of a temperature-indexed model, while incorporating information about incoming solar radiation and allowing us to partition melt into that caused primarily by higher temperatures from that caused by incoming sunlight energy. A modified degree day model has far lower data requirements than an energy-balance model, incorporates data on solar radiation – known to be the dominant source of melt energy on most glaciers— and has a stronger physical basis than simple temperature-only index models. Additionally, the inclusion of a solar input term has been shown to improve melt modeling substantially across varied ecosystems (e.g., Hock 1999, Pellicotti 2005).

This modeling portion of the project is under development in conjunction with collaborators at the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado, and the North Cascades National Park Service Complex (NOCA). Its development will follow collection of data from summer 2015, and will take a form similar to

$$M = \begin{cases} [TF + SRF(1-\alpha)G]T & \frac{T>Tt}{T<Tt} \\ 0 & \end{cases}$$

where TF and SRF are empirical coefficients for temperature factor and shortwave radiation factor, G is incoming solar radiation, M is melt (in mm/day) and Tt is a temperature under which no melt will occur (1 ° C, following Pellicotti 2005). Model development will follow Huintjes (2010), Pellicotti (2005), Hock (1999) and others who have applied degree-day melt modeling to small, alpine glaciers. Our model will be calibrated against sub-annual (approximately monthly) surface melt measurements made in summer 2015 on the surface of Middle Teton Glacier. The calculated TF and SRF empirical coefficients can be assumed to be the same for other glaciers in the range, and allow potential extrapolation of melt modeling to all glaciers in the range, utilizing the 0.5 m Digital Elevation Model (DEM) derived from a 2014 LiDAR flight over GTNP. The melt model allows us to ask why the glaciers are melting – less snow, more sun, or higher temperatures – and additionally, gives us power to estimate melt on un-measured glaciers in the Tetons, such as Triple Glaciers, Falling Ice and Skillet, which remain unstudied largely due to access and safety issues. Until direct measurements can be made on these glaciers, modeling using adjacent glacial melt factors and site-specific, LiDAR-derived solar radiation information will allow us to make assessments of glacial volume change and higher confidence. Time-lapse cameras focused on these inaccessible glaciers will allow for a field-based check on modeling efforts.

✦ ADDITIONAL PRODUCTS

- Time-lapse videos of glacier motion, snowmelt, and alpine plant growth.
- Network of high-elevation temperature sensors: data useful for many applications.
- Increasing citizen science and engagement with climate and hydrology resource issues, through recruitment of public for repeat glacier photo points.
- Repeat and time-lapse photography at multiple high-altitude locations: useful for plant phenology and flower timing.

✦ LITERATURE CITED

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CLASS REPORT

<u>Summary of all 2015 Classes and Field Research Courses at the UW-NPS Research Station</u>
11 classes on Field Ecology, Geology, Social Science and Art from UW, LCCC-Cheyenne, CWC-Riverton, UW-Casper, NWCC, Nebraska, Oklahoma, California, Pennsylvania, Texas and Utah – 959 user-days

- Field Geology – Laramie County Community College - Cheyenne
- Field Geoscience – Chadron State University
- Field Ecology – Oklahoma City University
- Outdoor Studio Art Class – UW Art Department
- Field Geoscience – Mt. San Antonio College, CA
- Human Dimensions of Wilderness Use – S. F. Austin University, TX
- Field Geoscience – University of Nebraska
- Field Ecology/Geology – University of Pittsburgh
- Watershed Science Graduate Student Field Course – Utah State University
- Field Geology – Central Wyoming Community College - Riverton
- Wildlife Photography – Northwest Community College - Powell

METHODS IN GEOSCIENCE FIELD INSTRUCTION UNIVERISTY OF NEBRASKA-LINCOLN

DAVID HARWOOD ✦ KYLE THOMPSON
DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES
CENTER FOR MATH AND COMPUTER SCIENCE EDUCATION
UNIVERSITY OF NEBRASKA ✦ LINCOLN, NB

✦ CLASS OVERVIEW

Eight in-service teachers, one pre-service education student, three observers from other universities, and two instructors from the University of Nebraska-Lincoln engaged in an inquiry-based geology field course from June 13 to 28, 2015 through Wyoming, South Dakota, and Nebraska. This commnity of learners spent three days working in the Grand Teton National Park area. Geological features and history present in Grand Teton National Park are an important part of the course curriculum. Large-scale extensional features of the Teton Range and Jackson Hole, and the glacial geomorphology and related climate changes of this area are some of the unique features examined here.

Figure 1. An enthusiastic team of educators exploring geological features of Grand Teton National Park.

✦ COURSE BACKGROUND

This 3-credit graduate course offered by the University of Nebraska-Lincoln is a 16-day, inquiry-based field course for educators. Major goals are: (1) to enhance the 'geoscience experience' for in-service science educators and their students; (2) to teach inquiry concepts and skills that K-12 educators are expected to understand and employ; (3) to inspire science educators to use inquiry and geoscience as unifying themes in their teaching activities; and (4) to provide educators with an effective 'tool-kit' of scientific inquiry-based, and discovery-learning teaching practices.

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 and Jackson Hole.

Recent quotes from educators about their experience:

"I have never learned or done so much in 2 weeks ever in my life."

"I'm inspired to continually bring up opportunities for wonder in my students."

"I felt like I was on 'survivor' and I was succeeding."

"This is truly the best course I have ever taken. I have learned more about geology, myself, others, life, etc., than I ever have or could have in one year."

CONFERENCE AND WORKSHOP REPORTS

Summary of all 2015 conferences, meetings and workshops at the UW-NPS Research Station
13 conferences, meetings and workshops on climate and butterflies, international energy and environmental security, historic building restoration, ecophysiology, landscape painting, international wildlife issues and biomedical topics from UW and WY Community Colleges, Iowa, Germany, Botswana, Jackson Hole, regional game and fish agencies and GYA federal and state agencies – 513 user-days

- Iowa State University Debinski Ecology Lab Workshop/Retreat
- Grand Teton NP Science and Resource Management Division Staff Meeting
- UW Energy-Environment Security Workshop
- WY/ID/MT Game and Fish Agency Annual Tri-State Meeting
- Greater Yellowstone Coordinating Committee Meeting
- Alliance for Historic Wyoming Workshop and AMK Historic Building Tour
- GYA Revegetation Science Meeting and Tour
- Teton Plein Air Painters – Landscape Painting Session
- UW Dillon Ecophysiology Lab Workshop/Retreat
- UW INBRE Planning Workshop – UW & WY CC Instructors and Students
- Bavarian Forest National Park, Germany, Education Program Tour
- Wildlife Summit at JL Lodge
- Atlas of Wildlife Migration: Wyoming Ungulates

JACKSON ENERGY SECURITY WORKSHOP: AUGUST 6–7, 2015

JEAN GARRISON
CENTER FOR GLOBAL STUDIES ✦ UNIVERSITY OF WYOMING ✦ LARAMIE, WY

Jackson Energy Security Workshop participants at the UW-NPS Research Station AMK Ranch on August 7, 2015

✦ SUMMARY

The UW Center for Global Studies hosted a two-day workshop focusing on energy security involving interdisciplinary faculty from UW, faculty from the Free University of Berlin, and participants from the non-profit and business sectors. This two day event included presentation of six papers (see agenda below) in three panel sessions addressing a variety of issues including traditional and new approaches to energy security, governance and management issues, and community development and agency. A final roundtable session focused on engaging industry, practitioners, and activists in emerging solutions. The workshop was funded by the School of Energy Resources, the Center for Global Studies, and through a European Union grant through the Colorado European Union Center for Excellence at CU-Boulder. This report proceeds in three parts: 1) rationale and agenda, 2) participant list with bios, 3) a discussion of outcomes to date of the workshop.

✦ RATIONALE AND AGENDA

Access to cheap and reliable energy, specifically fossil fuels, has fueled economic growth worldwide, yet natural resources often lie at the heart of conflict and civil strife and can be used as geopolitical tools in foreign policy. Continued reliance on fossil fuels is a reality that also creates an energy future complicated by socio-economic and environmental tradeoffs, issues of sustainability, and the concern over carbon dioxide emissions and climate change. This workshop brought together an interdisciplinary group of scholars, practitioners, and industry and environmental representatives to discuss key issues in the energy security debate, governance and management issues, community development, and environmental values and trade-offs from local to global contexts.

Day 1. Thursday, August 6th

Opening & Session I: Tackling Energy Security – Traditional and New Approaches Internationally and in the United States (August 6 – 9-11:30)

Opening Remarks: Jean Garrison, University of Wyoming

Moderator: Stephanie Anderson, University of Wyoming

Papers:

Jean Garrison, University of Wyoming - *"Understanding Evolving Natural Resource Insecurities: Evaluating the Energy-Climate Nexus"*

Using a national security perspective combined with a focus on the politics of scarcity in key natural resources as a starting point, this paper examines the politics surrounding how energy and environmental security challenges, from local to global contexts are (and can be) addressed. This research situates environmental security within the classic security debate with a particular focus on the foreign policy challenges inherent in the global climate change debate. The paper presents a decision-making perspective to evaluate how people frame the issue, make decisions, and, thus, can shape what policy choices and decisions are possible.

Chuck Mason, University of Wyoming – *"Crude Behavior: How Lifting the Oil Export Ban Reduces Gasoline Prices in the U.S."*

Since the 1970s, the U.S. has effectively banned the export of crude oil produced in the US. Because the United States has imported most of the oil it consumed during that period, this ban was largely irrelevant. But this changed with the "fracking" revolution, which quickly opened up vast resources of "tight" oil to exploitation, reduced U.S. oil imports to new lows, and has led to bottlenecked oil supplies in the Midwest and a reduction in crude prices there. The situation has been exacerbated by the inability of most U.S. refineries to efficiently process the light crude coming from these fields. Allowing exports from the U.S. would allow this oil to fetch higher prices, motivating expanding supply over time, while simultaneously motivating US refineries to substitute into heavier crude oil, increasing their efficiency. Over time, these features will induce an increase in both global supply of and global demand for crude, with global crude prices falling slightly. In turn, this will lower gasoline prices globally.

Discussants: Tom Seitz, University of Wyoming; May-Britt Stumbaum, Freie Universität Berlin

Session II: Governance and Management Issues (August 6 – 1:30-3:30)

Moderator: Tom Seitz, University of Wyoming

Papers:

Tanja A. Börzel and **Thomas Risse**, Freie Universität Berlin – *"Environmental Governance is Areas of Limited Statehood"*

In the age of globalization, the state is still considered to be the main provider of common goods. While government no longer holds the monopoly on governance, state regulation remains a major instrument to curb negative externalities of private actor activities on the environment. Environmental degradation then tends to be conceptualized as a problem of state failure, where governments do not enact regulation and enforce it. Most states have signed and ratified the major international environmental treaties, and the developing world is catching up with the advanced industrial countries. It seems to be that compliance with, rather than commitment to, environmental regulation has become the main challenge. While industrial countries may lack the willingness to enforce environmental laws, governments in "areas of limited statehood" are often incapable of implementing central decisions including the law. It argues that consolidated statehood forms the exception rather than the rule in the contemporary international system and that "areas of limited statehood" are more widespread than is commonly assumed.

May-Britt Stumbaum, Freie Universität Berlin, and **Alfonso Martinez Arranz**, Monash University – *"Cooperation in Nontraditional Security: Energy Security and the Diffusion of Norms and Best Practices in EU-China Relations"*

The paper analyses the diffusion of norms from the EU to China on energy-related issues within the overall framework of European security policy. Energy has a direct impact on all factors of the "comprehensive security" concept that underpins EU security policies, with climate change acting as a threat multiplier. The travelling of norms in energy policy between the EU and China is one of the EU's means to further its security interests: Have norms and best practices been diffusing from the EU towards China? If so, how? The paper focuses on two case studies (transport, electricity generation) with sub-case studies analyzing if and how the EU has been able to promote norms in energy, notably through its environmental policy spilling over to the energy policy field. Bridging academic analysis with policy applicability, this approach aims to provide a basis for formulating future policy recommendations.

Discussants: Roger Coupal, University of Wyoming; Jessica Clement, University of Wyoming

Public Talk - Harlow Summer Series (6:30 p.m.) - **Tanja A. Börzel – "***On Leaders and Laggards in Environmental Governance and Management: The Case of the European Union"*

Day 2: Friday, August 7

Session III: Community Development and Engagement (August 7 – 9:30-11:30)
Moderator: Stephanie Anderson, University of Wyoming

Papers:

Jessica Clement and **Steve Smutko**, University of Wyoming – *"Why Talk? Incentives for the Energy Industry to Engage with Communities in Pursuit of Social License"*

This paper investigates the social, economic, and institutional incentives for energy development firms to participate in community engagement and collaboration in order to achieve "social license to operate." Social license in this context refers to society's or a local community's acceptance or approval of a firm's activities or operations. Incentives to collaborate are discussed from the point of view of the firm. We evaluate the effect of various regulatory compliance requirements on the incentive to collaborate, namely the Federal Advisory Committee Act, the National Environmental Policy Act, the Mineral Leasing Act, and the Federal Energy Regulatory Commission's Integrated Licensing Process. We assert that although the attainment of social license is emerging as a key principle in many firms' perception of a sustainable bottom line, institutional barriers to collaboration are a significant disincentive for firms to extend beyond minimum regulatory requirements.

Roger Coupal, University of Wyoming – *"Managing and Monitoring the Environmental Impacts of Oil and Gas Development around Communities"*

Oil and gas development brings substantial amounts of economic activity, new jobs, and substantial tax revenues for communities. However, the activity can create environmental costs to residents, especially those who do not receive benefits from increased economic activity. This paper explores how, through environmental bonding, reclamation and disturbance caps, communities can better manage environmental costs that can last long after the play ends.

Discussants: David Lawrence, Lawrence Energy Group LLC; Chuck Mason, University of Wyoming

Session IV Roundtable and Closing: Engaging Industry, Practitioners, and Activists in Emerging Solutions (August 7 – 1:00-3:30)

Moderator: Jean Garrison, University of Wyoming

Participants:

David Lawrence, Lawrence Energy Group, LLC
Thomas Risse, Freie Universität Berlin
Jonathan Schechter, Charture Institute
Sam Western, author and correspondent for the *Economist* and *Economist.com*

✦ WORKSHOP PARTICIPANT BIOS

Stephanie Anderson is associate director of the Center for Global Studies and associate professor of political science at the University of Wyoming. In 2011-12, she was a senior fellow at the KFG – Transformative Power of Europe at the Freie Universität Berlin researching EU security policy, identity-formation, and crisis management as well as the scholar-in-residence at the EU Centre in Singapore. She is the past recipient of Fulbright Senior Scholar awards to the German Institute for International and Security Affairs (SWP) in Berlin and to the Graduate School of International Studies at Sogang University in Seoul, Korea. Dr. Anderson's research focus is on the European Union (EU) as an international actor, international relations, and security issues. She holds a PhD from the University of Cambridge, UK.

Tanja Börzel is professor of political science and holds the chair for European Integration at the Freie Universität Berlin. Her research focus and teaching experience lie in the field of institutional theory and governance, European integration, and comparative politics with a focus on Western and Southern Europe. She is coordinator of the Research College "The Transformative Power of Europe" as well as the FP7-Collaborative Project "Maximizing the

Enlargement Capacity of the European Union." Börzel also directs the Jean Monnet Center of Excellence "Europe and its Citizens." She holds a PhD from the European University Institute, Florence, Italy.

Jessica Clement is director of the Collaboration Program in Natural Resources at the Haub School of Environment and Natural Resources at the University of Wyoming. She specializes in the study and practice of collaborative governance and collaborative learning related to forests, wildlife, recreation, public lands, and related issues. She has created and facilitated collaborative processes related to natural resource issues for more than 15 years in Colorado, Wyoming, and Montana. Clement has conducted social psychological research regarding the relationship between people and natural resources and taught natural resources policy related subjects for 20 years. She holds a PhD from Colorado State University.

Roger Coupal is department head and professor in the Department of Agricultural and Applied Economics at the University of Wyoming. His areas of expertise and teaching interests include natural resource policy, community development economic impact analysis, and public lands policy. Coupal's objective is to provide educational opportunities and information for community groups and public officials engaged in policy issues that reside in the nexus of community development and natural resource policy. He holds a PhD from Washington State University.

Jean Garrison is director of the Center for Global Studies and professor of political science and international studies at the University of Wyoming. Garrison is the past recipient of a Council on Foreign Relations International Affairs Fellowship and has worked in the Office of Chinese and Mongolian Affairs in the U.S. State Department. She also was a visiting fellow with the Maureen and Mike Mansfield Foundation in Washington, DC. Her research interests focus on U.S. foreign policy with an emphasis on U.S.-China relations, leadership, small group dynamics, and energy security. She holds a PhD from the University of South Carolina.

David Lawrence is an energy executive, investor, and advisor with extensive global experience across the energy industry. In addition, he has worked in academia and government. He is Chairman of Lawrence Energy Group LLC, with interests in emerging stage energy prospects and serves as Chairman of the Yale Climate and Energy Institute Advisory Board. Previously, he served as Executive Vice President of Exploration and Commercial for Shell Upstream Americas and Head of Global Exploration and Executive Vice President Global Exploration in Royal Dutch Shell. He also served the National Ocean Industry Association as Membership Chair, and was a Commissioner on the Aspen Institute Commission on the Arctic. Lawrence received his BA in geology magna cum laude from Lawrence University, and his PhD from Yale in geology and geophysics, receiving the Orville Award for outstanding graduate student research.

Chuck Mason is the H. A. "Dave" True, Jr. Chair in Petroleum and Natural Gas Economics in the Department of Economics and Finance at the University of Wyoming. He is an internationally known scholar who specializes in Environmental and Resource Economics. Mason served as the managing editor of the top international journal in this field, the Journal of Environmental Economics and Management, from 2006-2011. His current research interests include modeling prices for crude oil and natural gas, the role of delivery infrastructure in natural gas markets, and motivations to hold stockpiles of oil and gas. Chuck has a BA and PhD in Economics and a BA in Mathematics, all from the University of California at Berkeley.

Thomas Risse is professor of international relations at the Otto Suhr Institute of Political Science at the Freie Universität Berlin. His previous teaching and research appointments include the Peace Research Institute Frankfurt, the University of Konstanz, the European University Institute, as well as Cornell, Yale, Stanford, and Harvard Universities, and the University of Wyoming. He is coordinator of the Collaborative Research Center "Governance in Areas of Limited Statehood" and co-director of the Research College "Transformative Power of Europe," both funded by the German Research Foundation (DFG). He holds a PhD from the University of Frankfurt.

Thomas Seitz is associate professor in the Global and Area Studies Program at the University of Wyoming. Seitz has received two Fulbright awards to the Philippines and Indonesia and was a visiting professor at Seoul National University in the Republic of Korea. He is the author of *Lessons Learned, Lessons Lost: The Evolving Role of Nation Building in U.S. Foreign Policy* (University of Manchester Press, 2013). His research focuses on comparative political cultures, nation building, and Southeast Asian politics. He holds a PhD from the University of Cambridge, UK.

Jonathan Schechter is the founder and executive director of the Charture Institute, a Jackson, Wyoming-based think tank. Charture's focus is on "co-thriving," the state in which human populations and the natural world they inhabit both thrive. Geographically, much of Charture's work focuses on places such as Jackson Hole, communities whose character and economy are closely linked to the quality of the surrounding environment. For over 20 years, Schechter has written a bi-weekly column on the region's economy for the Jackson Hole News&Guide, and he has written and spoken broadly about topics relating to the intersection of the environment and economy. He holds an AB in Human Biology from Stanford University and an MPPM from Yale University.

Steve Smutko holds the Spicer Chair in Collaborative Practice and is a professor in the Department of Agricultural and Applied Economics and the Haub School of Environment and Natural Resources at the University of Wyoming. The focus of his work is on engaging with local governments, state and federal agencies, and the private and nonprofit sectors to enhance participatory decision-making on complex and often contentious environmental and natural resource policy issues. He teaches graduate and undergraduate courses in negotiation, negotiation analysis, and environmental problem solving. Smutko received a PhD in economics from Auburn University.

May-Britt U. Stumbaum is head of the NFG Research Group "Asian Perceptions of the EU" at the Freie Universität Berlin, which is funded by the German Ministry of Education and Research. Her previous positions include senior research fellow and executive director of the China and Global Security Program at the Stockholm International Peace Research Institute, among others. Stumbaum has worked as a Visiting Fellow at renowned think tanks in Europe, China and New Zealand and as a "Scholar in Residence" at the Political Section/EU Delegation to China. Her research interests include security policy in the Asia-Pacific and US/European security policies towards Asia (particularly India and China), non-traditional security challenges, and transfer, diffusion and the role of perceptions in EU-Asia Pacific security relations. She holds a PhD from the Freie Universität Berlin.

Samuel Western has served as a correspondent to the *Economist* and the *Economist.com* since 1984. Western's work was also published in the *Wall Street Journal*, *LIFE*, *Sports Illustrated, and High Country News*. He is two-time winner of the Wyoming Literary Fellowship (1999) for poetry (2011) for fiction. Previously, Western taught Economic History class at the University of Wyoming (2010-2013), served as Simpson Scholar (2003-2008), taught Ethics at Sheridan College (1999-2005). Western holds a BS degree in Journalism from Oregon State University and an MA in Creative Writing from University of Virginia.

✦ OUTCOMES OF THE WORKSHOP

The workshop represented part of an ongoing interdisciplinary transatlantic partnership between UW and the Free University of Berlin. The workshop organizer, Jean Garrison, is serving as a visiting senior research fellow at the KFG "Transformative Power of Europe" at the Free University of Berlin (Fall 2015). Her paper from the Jackson Energy Security Workshop was the basis for a research paper presentation at the Free University of Berlin on October 26, 2015.

As a follow up, participants in the conference have submitted short briefing papers which will be posted to the CGS website (www.uwyo.edu/globalcenter) in early 2016. It also has shaped a symposia series for Spring 2016 focusing on "Conversation on Regulating Carbon in Coal Country and Beyond – Local, National and International Considerations" – a two part discussion in linked panels in February and April 2016. The purpose of these events is to engage the panel in a frank conversation about the need for international cooperation on carbon, carbon regulation nationally and the reality of needing to prepare for the impacts of carbon regulation in the US generally, and in carbon-focused states like Wyoming more specifically. An interdisciplinary steering committee involving workshop participants is organizing these events. Two participants in the workshop, Dr. Tanja Borzel and Dr. Thomas Risse from the Free University of Berlin serve as senior fellows for the Center for Global Studies and participate in various events on the UW campus.

ATLAS OF WILDLIFE MIGRATION: WYOMING'S UNGULATES

BILL RUDD ✦ MATT KAUFFMAN
WYOMING MIGRATION INITIATIVE ✦ UNIVERSITY OF WYOMING ✦ LARAMIE, WY

Figure 1. Atlas production team reviews production goals and progress at AMK lodge (Matt Kaufman, Hall Sawyer, Matt Hayes, Emilene Ostlind, and Jim Meacham).

✦ OVERVIEW

For thousands of years ungulates have migrated between seasonal ranges in the vast and beautiful landscapes of Wyoming. From mule deer and pronghorn that travel across the Red Desert to the wilderness journeys of elk and moose in the Greater Yellowstone Ecosystem, Wyoming boasts some of the longest and most spectacular migrations in North America. These epic, terrestrial migrations are to many a symbol of Wyoming's vast intact landscapes. And although these migrations are part of the region's cultural heritage, they are poorly understood and threatened by rapidly changing landscapes. Recent research at the University of Wyoming has broken new ground in our understanding of Wyoming's ungulate migrations, raising awareness of the ecological benefits of these seasonal journeys, their rarity in a global context, and the threats they face amid accelerating land-use change. Although there is considerable interest in conserving ungulate migration routes in Wyoming and the West, a comprehensive story has never been told of Wyoming's extraordinary ungulate migrations.

The Wyoming Migration Initiative (migrationinitiative.org) is producing the *Atlas of Wildlife Migration* to help draw attention to the amazing journeys of Wyoming's migratory ungulates, to synthesize disparate spatial data on migration, and to elevate awareness of this ecological phenomenon as a means of advancing conservation and management efforts. The *Atlas* will draw upon a wealth of knowledge built through several decades of intensive study by biologists at the University of Wyoming, other state and federal agencies, and private firms, and it will benefit from the on-the-ground expertise of many of Wyoming's wildlife managers. We are partnering with the award-winning cartographic team at the University of Oregon Department of Geography's InfoGraphics Lab (the producers of the *Atlas of Yellowstone*) to bring their expertise in design to create new visualizations of these magnificent migrations.

Facing pages in the *Atlas* will cover more than 50 migration topics, ranging from ecology to conservation and management, illustrated with data-rich and visually stunning maps and graphics. Page pairs will illustrate topics such as the Teton bighorn sheep and their response to the loss of historical migration routes and the expansion of energy development in Wyoming and the challenge this poses for long-distance migrations. The *Atlas* will be published as a large format reference book. In addition, select migration stories from the Atlas will be accessible on a website in an interactive format (with animations, interviews, and other links).

The production team of the Atlas of Wildlife Migration includes Matthew Kauffman (senior editor), James Meacham (cartographic editor), Hall Sawyer (associate editor), Alethea Steingisser (production manager), Matt Hayes (spatial analyst), Bill Rudd (contributing editor), and Emilene Ostlind (text editor).

Figure 2. What an appropriate backdrop and historical setting for having this production meeting. The AMK lies in the center of many of the migration stories we are telling in the Atlas of Wildlife Migration.

✦ PRODUCTION TEAM ACTIVITIES

Members of the Atlas production team traveled to the UW-NPS Research Station at the AMK ranch during the middle of June 2015 to spend a few days to meet face-to-face to work on the Atlas. The production team led by senior editor Matt Kauffman and cartographic editor James Meacham met at the AMK to discuss production goals and timelines and to review content for the Atlas. Plans were made for a production timeline for completion of the Atlas and final publication.

During our time at the AMK the entire Atlas was laid out and reviewed with each page pair displayed in the order and chapters they will be presented. Each page pair will tell a unique story about ungulate migrations in Wyoming from the underlying science to the conservation of these magnificent movements by Wyoming's ungulates.

Figure 3. Page pairs are taped up to view the order of topics and content for the Atlas)

Cartographic editor James Meacham and production manager Alethea Steingisser oversaw the development of the Atlas of Yellowstone, which was published in 2012. They bring a wealth of experience and expertise to the Atlas of Wildlife Migration project. Each member of our team brings a unique set of skills and experience to this project. The Atlas project provides a great opportunity to shine the spotlight on Wyoming's landscapes and ungulates.

Figure 4. Cartographic editor James Meacham overlooks some of the books organization as displayed on the walls of the historic lodge at the AMK ranch.

Dr. Kauffman hosted a meet and greet Bar-B-Q with funders and friends of the Atlas in order to discuss the production of the Atlas, review many of the topics being developed and have an opportunity to provide an informal get together at the ranch which provides such a wonderful setting and backdrop. This project would never have been possible without the support of our partners and funders.

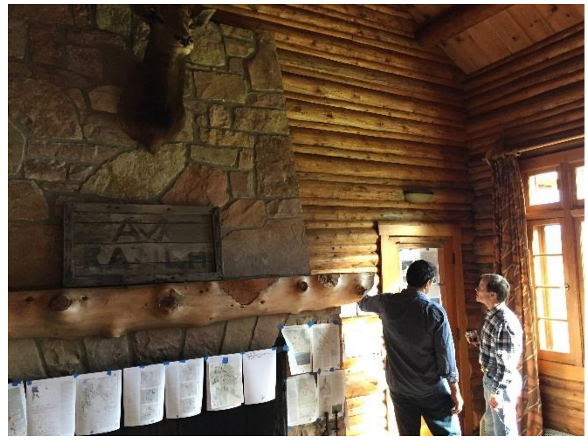

Figure 5. Matt Kauffman and Steve Sharkey discuss one of the many migration topics presented in the Atlas.

Figure 6. Wildlife Migration Initiative Spatial Analyst Matt Hayes cooks up burgers for the Atlas team and guests.