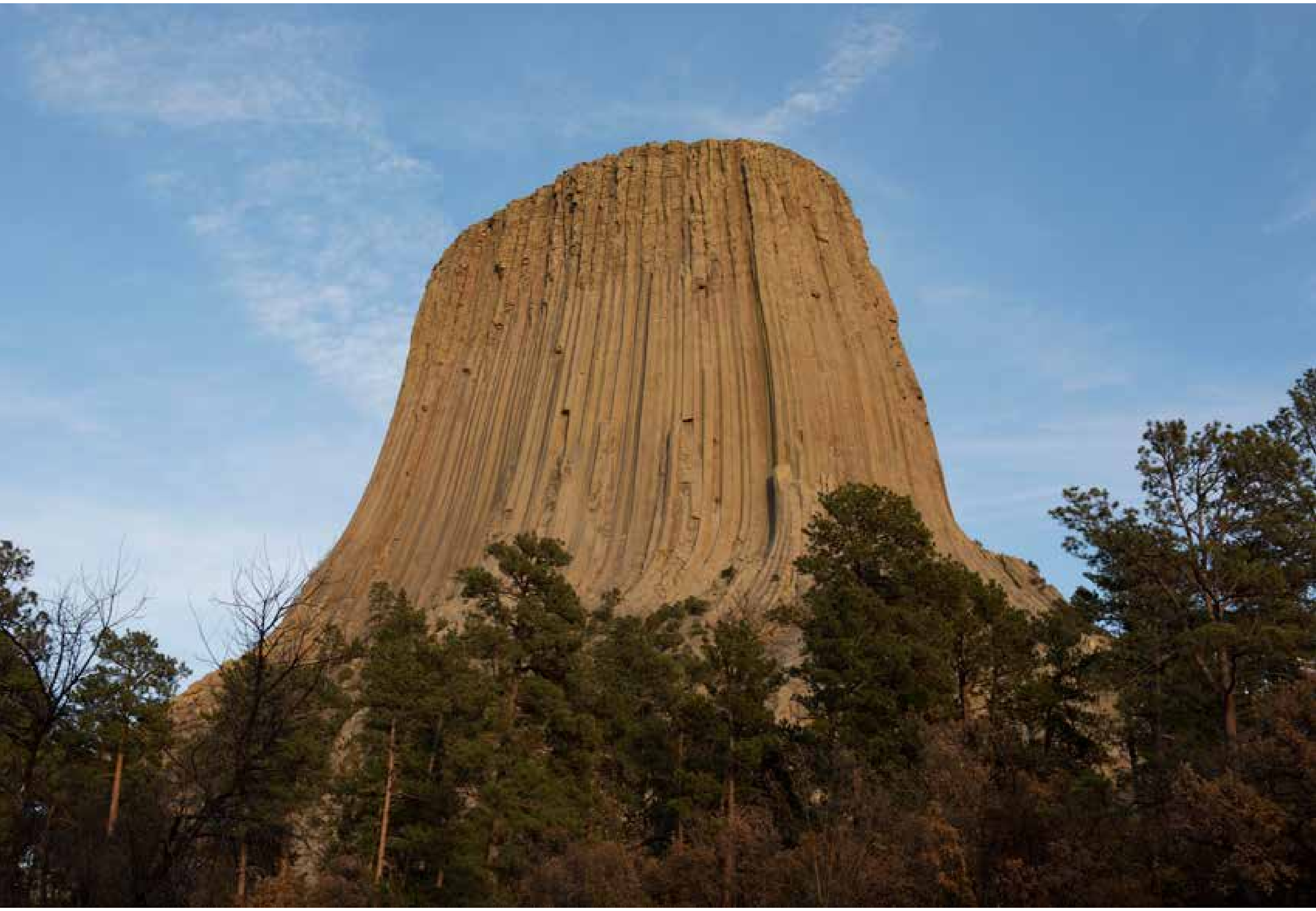
Intermountain Region
Resource Stewardship and Science

National Park Service
U.S. Department of the Interior

Crossroads in Science

Where the Intermountain Region's Resource Stewardship and Science Programs and Centers Meet

Spring 2018



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—NATURAL RESOURCES—

"Age Of Reptiles": Uncovering the Mesozoic Fossil Record in Three Intermountain National Parks

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Introduction

The Mesozoic Era, commonly referred to as the "Age of Reptiles," is a period of Earth history known for tremendous changes in faunal and floral biodiversity and ecosystem evolution. Spanning approximately 185 million years, the Mesozoic is subdivided into three time periods: the Triassic (250-200 million years ago), the Jurassic (200-145 million years ago), and the Cretaceous (145-65 million years ago). The "Age of Reptiles" is widely recognized as the time when dinosaurs dominated the terrestrial environments and giant non-dinosaurian reptiles (ichthyosaurs, mosasaurs, plesiosaurs, etc.) inhabited the marine environments.

Three National Park Service areas (all within the Intermountain Region) are internationally recognized for their significant Mesozoic paleontological resources that contribute to our understanding of the Triassic (Petrified Forest National Park), Jurassic (Dinosaur National Monument), and Cretaceous (Big Bend National Park) (Figure 1). Collectively these parks preserve an extraordinary paleontological heritage available for scientific research and public education. From the dawn of the dinosaurs at Petrified Forest National Park through the terminal Cretaceous

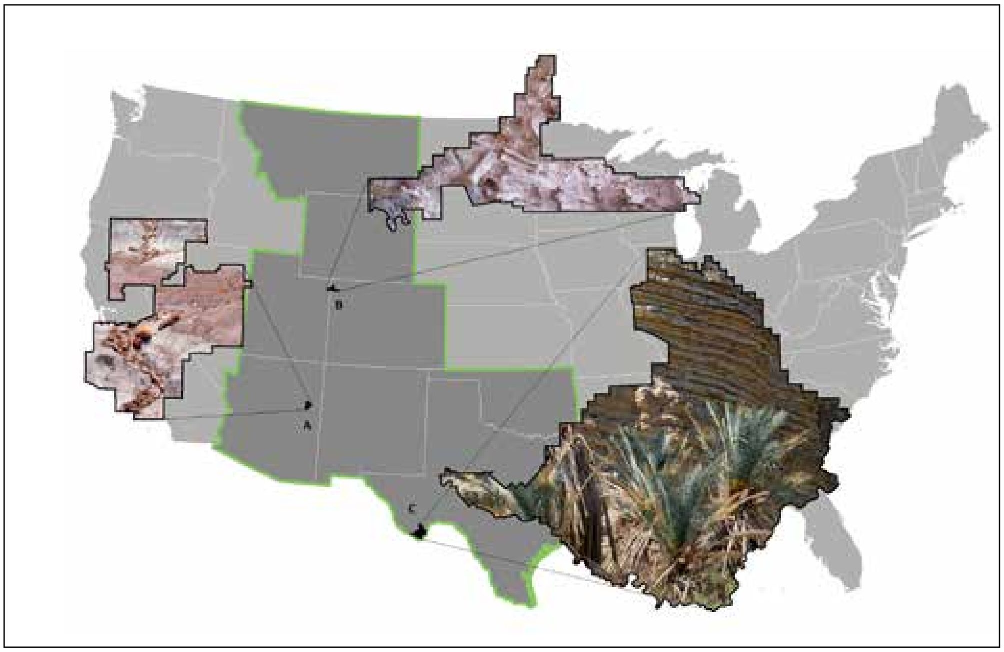

Figure 1. Map showing the location of three National Park Service areas which preserve outstanding fossils from the "Age of Reptiles" including: A) Petrified Forest National Park, Arizona; B) Dinosaur National Monument, Colorado and Utah; and, C) Big Bend National Park, Texas. (Graphic by Adam Marsh)

extinction event documented at Big Bend National Park, the fossils discovered in each park provides evidence for some of the most widely discussed scientific questions (Figure 2).

More than a century of paleontological field collecting and research has been undertaken in each of the park units. Museums across the United States and around the world display fossil specimens from Petrified Forest National Park, Dinosaur National Monument and Big Bend National Park. Remarkably, all three park units continue to attract researchers seeking to uncover new specimens and information to help expand our understanding of the "Age of Reptiles."

"Triassic Park" – Petrified Forest National Park

In western North America, the beginning of the Mesozoic Era is represented by the Moenkopi and Chinle formations. The geologic units were formed by a series of shallow marine carbonates and near-shore and fluvial mudstones, sandstones, and paleosols (fossil soils) of Early to Middle and Late Triassic age, respectively. The Chinle Formation is globally recognized for its vertebrate and plant fossils. Archosaurian reptiles such as phytosaurs, aetosaurs, and early dinosaurs make up the predominant fauna of the Chinle Formation (Figures 3 and 4). The abundant fossilized conifers, tree ferns, and cycads indicate a rich flora and diverse ancient ecosystem preserved at Petrified Forest National Park (PEFO) (Irmis, 2005; Ash, 2005). Established in 1906 through the authority of the Antiquities Act by President Theodore Roosevelt, Petrified Forest National Monument was set aside specifically to protect the *"scientific interest and value . . .[of] the mineralized remains of Mesozoic forests"* in the region (Proclamation No. 697). Because of this, fossil stewardship at Petrified Forest is identified within the park's enabling legislation.

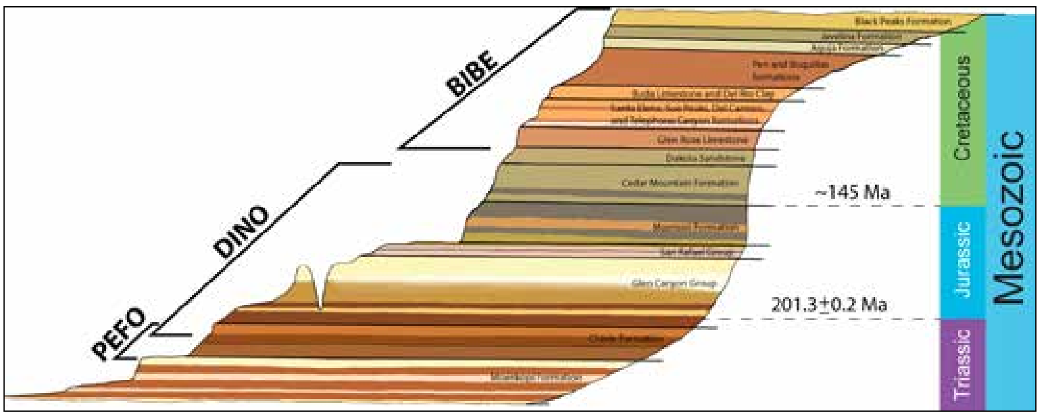

Figure 2. An idealized stratigraphic column showing the relationship of the various fossil producing geologic formations which span the "Age of Reptiles." Petrified Forest National Park (PEFO) preserves important Triassic rocks and fossils. Dinosaur National Monument (DINO) preserves important Jurassic rocks and fossils. Big Bend National Park (BIBE) preserves important Cretaceous rocks and fossils. (Graphic by Adam Marsh).

Figure 3. A phytosaur skull found near Crystal Forest at Petrified Forest National Park. (NPS Photo)

Figure 4. A portion of the snout from a new species of archosauriform reptile found at Petrified Forest National Park. (NPS Photo)

Paleontological field collecting at Petrified Forest National Park (PEFO) extends back over 100 years. Current research continues to uncover important new discoveries involving the geology and paleontology at the park (Parker, 2006; Parker and Martz, 2010). A recent research project in the park involved the drilling of a core through the entire geologic section at the park and confirmed that the Chinle Formation is almost 1,500 meters thick at the north end of the park (Olsen et al., 2014). The Triassic strata from the park consists of five subunits from top to bottom: the pink Owl Rock Member punctuated by thin limestone beds that are more prominent on the Navajo Nation to the north; the pastel red Petrified Forest Member of the Painted Desert; the sandier Sonsela Member; the dark blue and gray Blue Mesa Member; and the highly mottled Mesa Redondo Member (Martz and Parker, 2010; Martz et al., 2012). The recent emphasis on stratigraphy and geochronology has resulted in several high-resolution U-Pb detrital zircon dates throughout the section from around 208 Ma to 228 Ma (Riggs et al., 2003; Ramezani et al., 2011, 2014; Atchley et al., 2013; Nordt et al., 2015). These data indicate that the Chinle Formation at the park reflects more or less continuous deposition through almost 20 million years of the Late Triassic.

Figure 5. A histological thin section of a Late Triassic amphibian (metoposaur) intercentrum from Petrified Forest National Park. (Photo courtesy of B. Gee)

The current research focus at PEFO has been conducting a baseline fossil survey for new lands acquired in a boundary expansion. Student interns have been aiding this survey and have been publishing peer-reviewed papers on park topics like metoposaur bone histology (Gee et al., 2017) (Figure 5) and the first record of the actinopterygian fish *Saurichthys* in the Triassic of North America (Kligman et al., 2017). This fish specimen was discovered during an excavation in the boundary expansion-lands during a public field institute class. Additionally, a bonebed of a new species of archosauriform reptile was recently found and park paleontologists are preparing over 900 bones of the animal for publication and exhibition (Marsh et al., 2017). Of course, the origins of early dinosaurs remain an important part of the park story and researchers are discovering that PEFO's own dinosaur *Chindesaurus bryansmalli* was closely related to a meat-eating dinosaur found in Ghost Ranch, New Mexico, and not closely related to a group of more primitive South American herrerasaurids (Marsh et al., 2015).

Park paleontologists coordinate research within the park and continue working with institutions such as the Yale Peabody Museum, Los Angeles County Museum, and Burke Museum at the University of Washington to understand the wealth of fossil knowledge preserved at PEFO. While paleontological research in the area began over 100 years ago, the Chinle Formation at Petrified Forest National Park continues to be a rich source of information about the beginnings of the "Age of Reptiles" in North America.

Figure 6. Nearly lost amid a logjam of giant dinosaurs fossils on the face of the Carnegie Quarry, Geoscientist-In-Parks interns Nicole Ridgwell and Ben Otoo gather data for posting on the Carnegie Quarry website http://carnegiequarry.com/ (NPS Photo)

"Jurassic Park" – Dinosaur National Monument

The Carnegie Quarry, for which Dinosaur National Monument (DINO) was originally established in 1915, is one of the world's most famous fossil localities. Excavations from 1909-1924 resulted in the shipping of 800,000 pounds of fossils to the Carnegie Museum, the U.S. National Museum of Natural History, and the University of Utah. In 1958 the NPS took a radical new step in fossil resource stewardship by building the Quarry Visitor Center, an all glass building enclosing an unexcavated part of the quarry (Carpenter, 2013). Since then 1500 bones of 13 species of dinosaurs, turtles, and crocodiles have been excavated, exposed, and left in-place just as they were buried by an ancient river 150 million years ago (Chure and Englemann, 2013). Wildly popular with the public and the scientific community, this type of *in-situ* display has been copied at numerous fossil sites around the world. Because of the strong tilt of the fossil bearing sandstone, the Carnegie Quarry presents challenges for fossil preservation, curation, and stability not faced at other such fossil sites. Mitigating those threats has put DINO in the forefront of fossil conservation.

Figure 9. Three spectacular small crocodile skeletons, only 10 inches long, were found huddled together in the rocks of the Nugget Sandstone at Dinosaur National Monument. (NPS Photo)

The Carnegie Quarry has a rich historical record of excavation, study, resource management, and public education composed of photos, diaries, reports, correspondence, and publications (Figure 6). Launched in 2015, the Carnegie Quarry website http://carnegiequarry.com/ brings together the information from our archives and makes it freely available to the scientific community and the public.

Beyond the Carnegie Quarry, DINO contains 23 geologic formations preserving 1.1 billion years of earth history (Hansen et al., 1991). Ranging from ancient sea beds to fossilized desert sand dunes, on-going research and resource stewardship efforts focus on using paleontological and geological data to understand the evolution of each of the 23 ecosystems buried in those rocks. These projects have revealed an astounding fossil record.

The Carnegie Quarry is a gigantic fossil deposit which exhibits a strong bias in favor of the remains of large dinosaurs (Figure 7). However, that is only part of the picture. Excavation of quiet water lake deposits in the same formation has yielded a spectacular

Figure 7. This magnificent, uncrushed skull of the predatory dinosaur Allosaurus fragilis was found in the Carnegie Quarry and is now on exhibit in the Quarry Exhibit Hall at Dinosaur National Monument. (NPS Photo)

Figure 8. This tiny footprint, with four well preserved toe impressions, was made by a small reptile as it walked up the front of a sand dune in a 190 million year old desert now part of the Nugget Sandstone at Dinosaur National Monument. (NPS Photo)

record of fragile fossil pollen, amphibians, reptiles, and mammals, including some of the most complete fossil frogs and salamanders known to science. As a result of this work, a more detailed picture and richer understanding of the Morrison Formation ecosystem has emerged, one which integrates the plants and animals into the varied environments of this ancient ecosystem (Figure 7).

The ancient desert deposits of the Nugget Sandstone are generally considered by paleontologists to be lacking in fossils. However, focused field work examining the Nugget Sandstone has revealed a harsh environment populated by spiders, scorpions, small reptiles, and dinosaurs (Figure 8 and 9). One Nugget Sandstone dinosaur trackway in DINO is about half a football field in size.

Figure 10. The Western Interior Seaway spanned North America during the Late Cretaceous. (Photo with permission from Scott D. Sampson, Mark A. Loewen, Andrew A. Farke, Eric M. Roberts, Catherine A. Forster, Joshua A. Smith, Alan L. Titus (http://creativecommons.org/licenses/by/3.0/nl/deed.en)], via Wikimedia Commons

This research and stewardship effort is sustained through the efforts of park staff, outside researchers, universities and museums across the country, graduate and undergraduate students, volunteers, Geoscientists-In-Parks interns, and many, many others. Thus DINO contributes not only the growth of paleontological knowledge regarding the "Age of Reptiles," but nurtures the next generation of scientists who will continue to discover its fossil wonders and work for its preservation.

"Cretaceous Park"- Big Bend National Park

In many ways, the Cretaceous Period might be considered the beginning of our modern world. Although the ancient wildlife was dominated by reptiles such as dinosaurs, mosasaurs, and pterosaurs, many things that are familiar to us today evolved or were established during the Cretaceous.

Flowering plants (angiosperms) first appear in the Cretaceous fossil record, and, with them, bees, butterflies, and other pollinating insects. Grasses also first appear during the Cretaceous, leading to the rise of grazing animals. Africa split off from South America, and the continents moved more-or-less into the positions that we are familiar with today. Seasons began to grow more pronounced as the global climate became cooler. Forests began to look similar to present-day forests.

One big difference was a shallow trough that extended north-south through the center of North America, creating a seaway that geologists call the Western Interior Seaway (Hay et al., 1993) (Figure 10). From the Arctic Ocean to what is now the Gulf of Mexico, marine life thrived in the relatively shallow, sun-lit waters of the seaway (Everhart, 2005). Sediments deposited on the seaway floor would later harden into thick layers of limestone, preserving marine fossils such as mosasaurs in now-landlocked places like Kansas.

As the Cretaceous Period came to a close, the interior of the continent rose and the Western Interior Seaway narrowed. Eventually the seaway closed and the shoreline moved to its current location along the Gulf Coast.

The history of the Western Interior Seaway is crucial to understanding the geology and fossil record of Big Bend National Park (BIBE). Rocks exposed at Big Bend represent marine, coastal, and inland environments during the time that the seaway covered and then moved away from the Big Bend. The park preserves a relatively complete record of the past 130 million years and of the plant and animal life from that time (Turner et al., 2011).

Figure 11. Skull of Bravoceratops, a "new" species of ceratopsian dinosaur discovered at Big Bend National Park in 2013. (NPS Photo)

Over 1,200 taxa of fossils have been reported from BIBE (Schiebout, 1974; Rowe et al., 1992; Sankey, 2001). The park's fossil record is highly diverse and includes dinosaurs, mosasaurs, pterosaurs, crocodiles, turtles, lizards, birds, insects, frogs, toads, salamanders, boney fish, sharks, rays, sawfish, bivalves, ammonites, nautiloids, gastropods, sea urchins, corals, worms, sponges, plankton, saber-toothed cats, primitive dogs, early primates, early horses, camels, rhinoceroses, weasels, gophers, marsupials, tortoises, brontotheres, mammoths, and numerous plants, including many species of trees, ferns, leaves, algae, and fungi (Figure 11).

The park's fossil record includes numerous species that are new to science, and some that are found nowhere else in the world. For example, a new species of ceratopsian dinosaur, *Bravoceratops*, was discovered in 2013. The park's most famous fossil is *Quetzalcoatlus*, a giant pterosaur with a 35-foot wingspan, making it the largest known flying creature of all time (Lawson, 1975) (Figure 12).

BIBE is one of very few places in the world to have exposures of strata laid down during the terminal Cretaceous extinction, the asteroid impact event that wiped out the dinosaurs and three-quarters of species on Earth. The Cretaceous-Paleogene (K-Pg) strata in the park are unique, because they are the only known non-marine or continental deposits in the world that are in relatively close proximity to the asteroid impact site, bringing an end to the "Age of Reptiles" (Figure 13).

Figure 12. Strata deposited during the great terminal extinction event that ended the Cretaceous Period can be seen surrounding the Black Peaks landmarks in Big Bend National Park. (NPS Photo)

Figure 13. With its 35-foot wingspan, the pterosaur Quetzalcoatlus is the largest known flying creature of all time. (NPS Photo)

Conclusion

The Mesozoic fossil record connects three geographically-isolated national park units in the Intermountain Region. The strata and fossils exposed at Petrified Forest National Park, Dinosaur National Monument and Big Bend National Park conjoin to form a near-continuous record of Mesozoic geology and paleontology in North America. Scientists and visitors from around the world are offered the opportunity to journey through the "Age of Reptiles" while traveling to these world renowned fossil parks.

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—*Inventory & Monitoring Network*—

Big-River Monitoring on the Colorado Plateau

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Introduction

Water has always been in short supply in the western U.S., making it a consistent source of conflict. In the Colorado River drainage, an increasing human population fuels increased demands for water from the river and its tributaries. As a result, streamflow in virtually all of these systems has been altered by reservoirs and other water-development projects. In most cases, reduced flows have significantly altered peak flows and increased base flows that structure floodplain vegetation, stream-channel morphology, and water quality (e.g., temperature, suspended sediment, nutrients). The resulting changes in riverine and riparian habitats—that is, channel narrowing—can be quite complex. Channel narrowing can reduce the diversity and scale of geomorphic surfaces and associated habitats; disconnect floodplain surfaces from the river; and change riparian vegetation and biological diversity, as habitat for vegetation and aquatic organisms is altered and reduced.

In response to concerns expressed by resource managers in multiple National Park Service (NPS) units, the Northern Colorado Plateau Network (NCPN) has implemented a big-rivers monitoring project along the Green and Yampa rivers in Dinosaur National Monument, the Gunnison River at Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, and along the Colorado and Green rivers in Canyonlands National Park. The Yampa River is the longest relatively free-flowing river reach remaining in the Colorado River basin. The Green River is highly regulated by Flaming Gorge Dam but is partially restored below its confluence with the Yampa River. There have been large-scale changes to the Green River since Flaming Gorge Dam was completed in 1962.

Monitoring of these rivers and their riparian vegetation focuses on processes that affect the river channel, active bars, and riparian floodplains. To get a complete picture of river conditions, the NCPN has paired intensive monitoring at sentinel sites with coarse-scale measurements from remote sensing. This monitoring effort would be a large undertaking under any circumstances. With scarce resources, it is made possible only by strong partnerships with the U.S. Geological Survey, NPS Water Resources Division, and staff from the four NPS units where we monitor big rivers.

We hypothesize that streamflow regimes will shift in response to increasing human demands on regional water resources, coupled with anticipated climate change. Expected changes include lower annual flow, more droughts, and more instances of large, infrequent floods caused by extreme precipitation events and extreme winters. These shifts will likely lead to channel narrowing as (1) vegetation indicative of inactive and

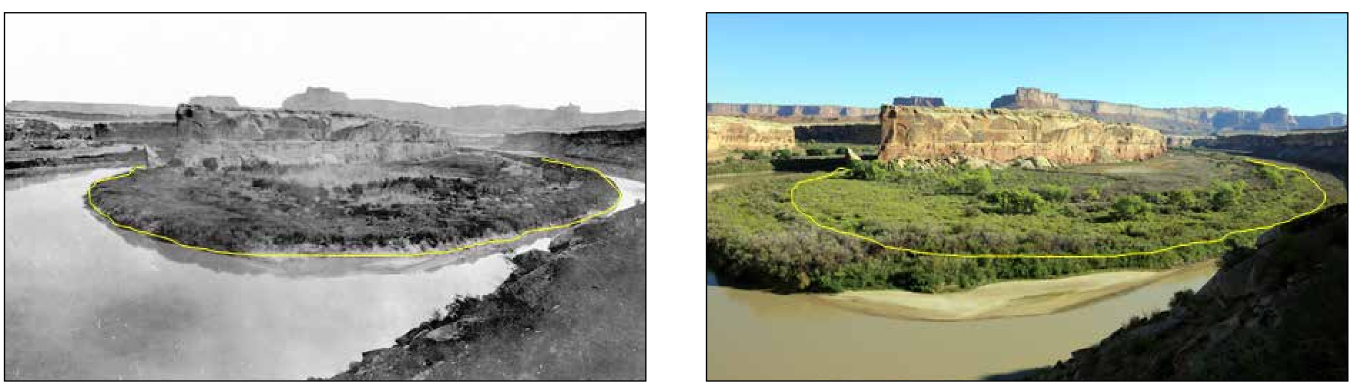

Figure 1. Paired photographs at Bonita Bend on the Green River in Canyonlands National Park by E. O. Beaman in 1871 (L) and M. Miller in 2012 (R). The pictures show extensive river-channel narrowing and vegetation encroachment at this site.

active floodplains encroaches, stabilizing formerly active-channel deposits, and (2) lateral and vertical deposition of alluvial sediments creates new, smaller active channel and active floodplain surfaces (Figure 1).

Early detection and quantification of the channel-narrowing process will allow NPS managers to (1) work cooperatively with water users to identify and possibly mitigate the effects of human-caused depletions on big rivers and related resources, and (2) identify reaches sensitive to narrowing so that management actions may be implemented in an efficient, cost-effective manner. This paper focuses on geomorphic and riparian conditions at two sentinel sites at Dinosaur National Monument (NM). Data from these sites demonstrate the range of information generated by this monitoring project and how it might be used to address relevant management questions.

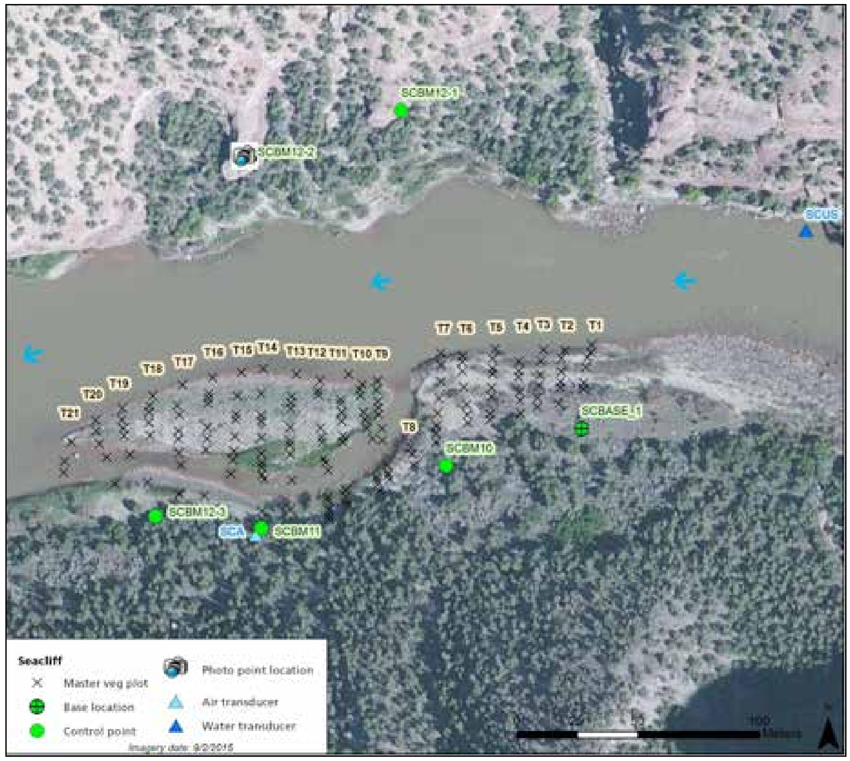

Figure 3. Seacliff sentinel site showing plot locations, benchmarks for surveying (base location and control points), air and water transducers, and photopoint locations. (Note: the downstream water transducer is not shown; it is located 200 meters downstream and depicting the location would have altered the scale.)

Methods

We established nine sentinel monitoring sites on the Green and Yampa rivers in Dinosaur NM. These sites broadly represent all channel types found within the monument, including alluvial and canyon-bound settings. The sites discussed in this paper represent the range of different habitats in the system. Deerlodge, on the Yampa River, is a broad, alluvial, restricted-meander reach. Seacliff, on the Green River below its confluence with the Yampa, is a debris fan-affected canyon site. For more details, see Scott and Perkins (in press).

We used RTK (real time kinematic) survey equipment to establish permanent, 1-m^2 vegetation quadrats across the active channel, active floodplain, and inactive floodplain of each sentinel site (see Figures 2, 3). Active channels are generally flooded every 1–2 years, and active floodplains every 3–15 years. Inactive floodplains are flooded less than every 15 years. We performed repeated sampling of vegetation cover, by species, to assess changes in overall vegetation cover over time.

Figure 2. Graphic representation of the active channel (blue), active floodplain (green), and inactive floodplain (brown) at the Deerlodge sentinel site.

At the same time, we placed water-level dataloggers upstream and downstream of each study site to measure water pressure. An air datalogger was placed nearby to measure air pressure. By subtracting the air pressure from the water pressure and figuring in the weight of water, we can calculate the number of days and percent of the growing season when each quadrat is inundated.

We surveyed topographic features (e.g., tops of banks, toes of banks, edge of water, chutes, sand caps) and created digital elevation models (DEMs; 10-cm resolution) from the topographic surveys. Using geomorphic change-detection software in ArcGIS, we overlaid paired years of DEMs to quantify the spatial distribution and volume of alluvial material eroded and/or deposited across the sentinel site.

Finally, we used photopoints that capture the entire site to document visual evidence of the changes occurring at each site.

In this paper, we compare data collected from 2010 to 2014.

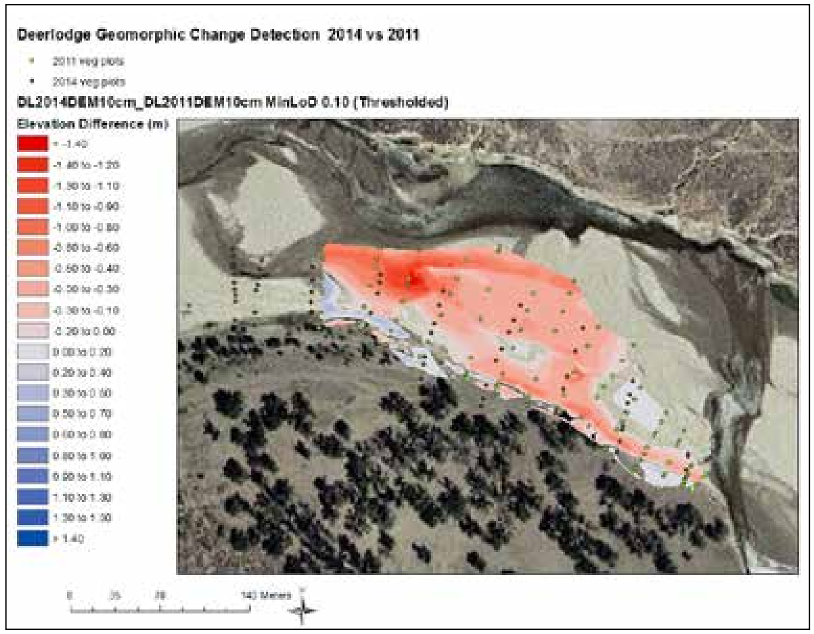

Figure 5. Plan view of the Deerlodge sentinel site depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2011 and 2014. The figure was thresholded to only show differences greater than 10 cm. Figure shows general erosion of the site. Flow is from right to left in the image.

Results and Discussion

In initial results, both sites showed similar levels and trends in total percent vegetation cover on active-floodplain surfaces. Both sites had distinct decreases in vegetative cover following a year with a high-flow event (2011) (Figure 4). Vegetative cover then remained low in the two subsequent, low-flow years (2012 and 2013). In 2014, vegetative cover increased back to near-2010 levels (~27% mean total cover at both sites), after a moderate-to-high peak flow and subsequent moderate-to-high base flows that year.

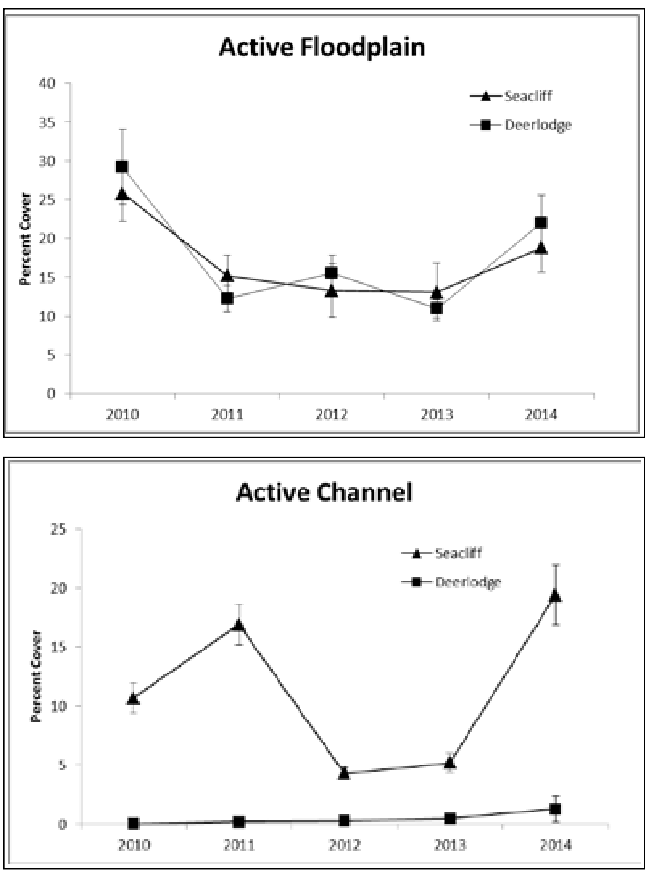

Figure 4. Percent cover of vegetation on active-floodplain and active-channel surfaces for the Seacliff and Deerlodge sentinel sites, as measured in the field for the years 2010–2014. Sampling dates in all years are July–September, post-snowmelt flooding.

On the other hand, the sites showed distinctly different levels and trends in vegetative cover on active-channel surfaces in the same years. In part, this reflects differences in channel setting, geomorphic processes, and flow modification between the sites (Figure 4). In years when peak flows exceeded the two-year average recurrence flow and base flows were elevated, the total average vegetation cover on active-channel surfaces at the Seacliff site approached that observed on active-floodplain surfaces at both sentinel sites. However, cover declined to 4.3 and 5.2% in low-flow years.

In contrast, the lateral bar that forms the active channel at the Deerlodge sentinel site is likely reworked and re-deposited during most peak flows, and thus is largely devoid of vegetation (total % cover was less than 1.5% for all years), except for annuals that establish each year following flow recession. Moreover, because of large stream-stage fluctuations on the relatively unregulated Yampa, the sandy, higher, and less-frequently inundated portions of the bar can become dry during the growing season and are not easily colonized by perennial vegetation.

One interpretation of these differences is that active-channel surface habitats on the Green River began to transition to floodplain surfaces following flow regulation. Growth of plant species generally found on active floodplains may expand into the active channel. In post-dam years when flows equaled or exceeded the average two-year recurrence flow (2010, 2011, and 2014), floodplain and transitional surfaces (characterized by the presence of floodplain and active-channel plant species) were inundated or sub-irrigated, and vegetation growth and cover was enhanced at Seacliff.

Stream-stage measurements collected at sentinel sites allow us to classify their vegetation and geomorphic surfaces (i.e., active channel, active floodplain) in terms of two hydrologic variables: (1) days a quadrat was inundated and (2) the percentage of the growing season a quadrat was inundated. Auble and others (1994; 2005) have demonstrated that the occurrence of riparian plant species is strongly related to the inundation duration of the surfaces on which they

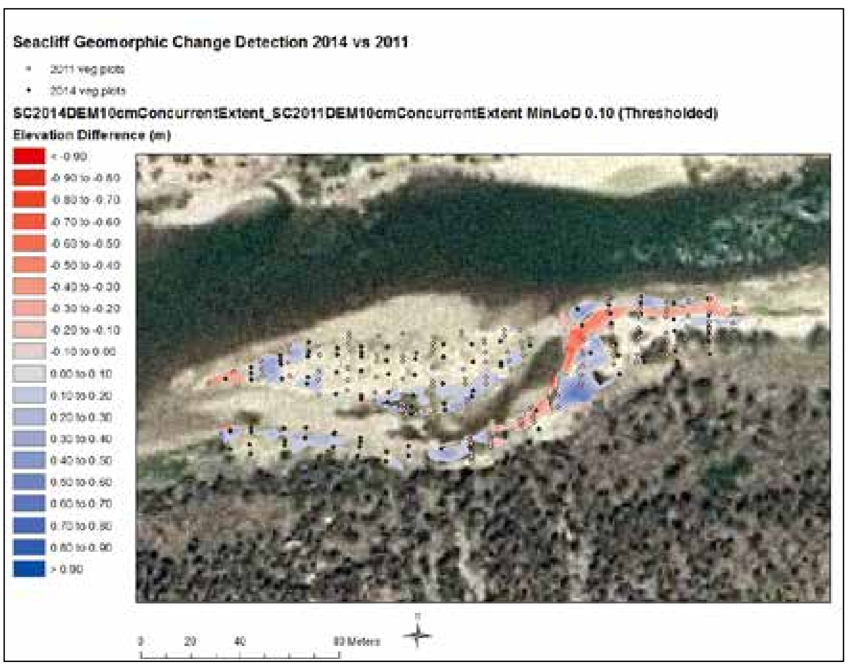

Figure 6. Plan view of the Seacliff sentinel site depicting spatial areas of erosion and deposition between 2011 and 2014. The figure was thresholded to only show differences greater than 10 cm. The figure indicates some deposition on the sand caps in the center of the site and mixed deposition and erosion at the downstream and upstream ends. River flow is from right to left in the image.

grow. This helps us to detect transitions from active-channel to active-floodplain related to channel narrowing. Hydrology measurements from both sites showed that active-channel quadrats were inundated close to 50% of the time, transitional quadrats (plots transitioning between active floodplain and active channel) inundated around 20% of the time, and active floodplain quadrats approximately 5% of the time.

Geomorphic change results also illustrated differences between the Deerlodge and Seacliff sites. The expansive, sandy, lateral bar at Deerlodge displayed comparatively large volumetric changes in both erosion and deposition between 2011 and 2014 (Figure 5). Overall, there was net erosion of nearly 8,000 m^3 of material during those years. In contrast, the Seacliff sentinel feature, an expansion cobble bar, showed only modest levels of erosion and deposition over the same period. From 2010 to 2014, there was net deposition of ~100 m^3, primarily on portions of the adjacent floodplain and on a narrow sand cap along the edge of the cobble bar (Figure 6).

Conclusions

Stream-channel narrowing is a widespread response of rivers to natural or human-caused changes in the flow regime—particularly, water withdrawals and reduced peak-flood events associated with dams. The NCPN can combine data from its big-river monitoring with data collected from its other monitoring projects (e.g., invasive plants, water quality, remote sensing) to gain more powerful, comprehensive insight into geological and ecological changes occurring in these systems. For example, our invasive-plant monitoring showed that levels of invasive-plant occurrence were highest on the regulated Green River above the confluence with the Yampa, more moderate on the partially restored Green River below the Yampa confluence, and lowest on the unregulated Yampa River (Perkins et al. 2015). In addition, preliminary analysis of invasive-plant data from Black Canyon of the Gunnison National Park shows that several invasive species have declined over the past 12 years (Perkins and Wight 2016), perhaps due in part to increased environmental flows that more closely mimic natural hydrographs.

Results from these two example sentinel sites over the first few years of monitoring demonstrate measurable, logical, site-specific responses to annual variation in streamflow. By linking hydrologic, vegetation, and geomorphic measurements, we can tie changes in riverine processes affecting specific surfaces to the amount of water that was on that plot in a given year. We can then connect those water amounts to annual hydrographs. In so doing, we can track the value of natural flows and large floods in the natural stream-habitat resetting process, which is essential to river health. These data will assist managers with myriad questions, such as evaluating the water right and high flows at Black Canyon of the Gunnison National Park; monitoring and evaluating proposed flows from the Aspinall (Gunnison River) and Flaming Gorge (Green River) dams; showing the value, differences, and resources of an unregulated river; and evaluating different invasive-species management options.

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—GEOGRAPHIC RESOURCES—

Unmanned Aerial Systems (UAS) Survey of Devils Tower National Monument

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Introduction

Devils Tower rises 867 feet above the surrounding landscape, and is a prominent monolith of igneous rock (Figure 1). A popular hiking trail circles the Tower, allowing park visitors to get up close to the formation and see it from all sides. Its vertical aspects and summit, however, can only be seen by those with technical rock climbing experience. Only about 5,000 of the Monument's 500,000 annual visitors are climbers that can access the Tower summit. For the rest, one of the most popular questions is, "What's it like on top?"

To help connect more park visitors with the monument's primary resource and key feature, Devils Tower initiated a project to use Unmanned Aircraft Systems (UAS) technology. This cost effective method is used to obtain high resolution imagery around a small area of interest (Grenzdorffer et al., 2008). The data will be used to create a 3D model in an interactive web viewer, which would be viewed by not only the public, but by researchers, climbers, park staff and search & rescue personnel. As an interpretive tool, the viewer would display features of the Tower that most people would otherwise not be able to see, up close and in high resolution detail.

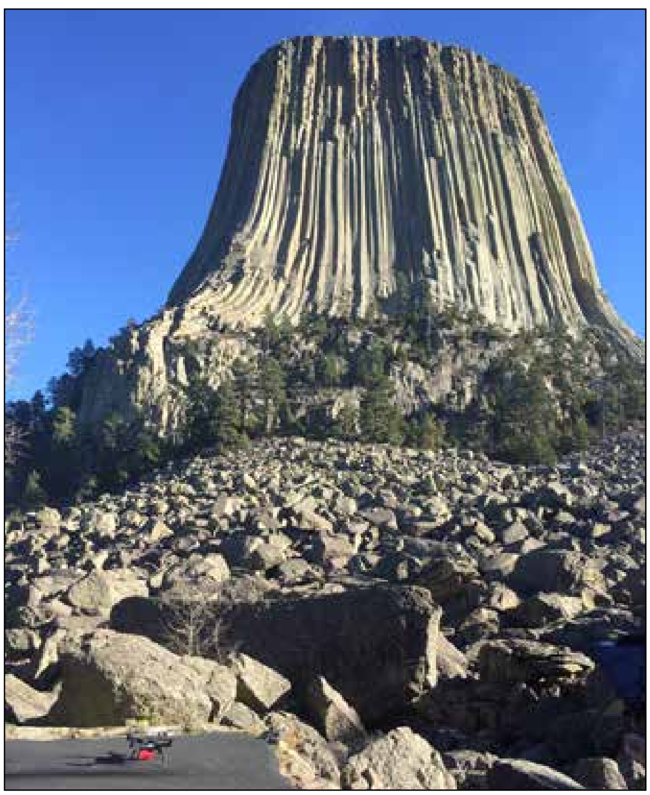

Figure 1. 3DR Solo Quadcopter used to collect the Devils Tower data. (USGS photo)

The products of 3D photogrammetry have long been used to visualize topographic details and surface points (Bemis et al., 2014). Such technology has many management uses and scientific implications. For example, high resolution imaging would allow park staff to discern fine details of the Tower surface, including details such as climbing anchors, and could be used as a baseline for comparison to evaluate rock fall potential. The 3D viewer would allow the park to display climbing routes and pre-plan for rescue operations. Visualizations can also help with natural resource management such as the examination of peregrine falcon nests, vegetation surveys, and invasive species assessment on the Tower.

Data Needs

Initially, Devils Tower National Monument (DETO) staff reached out to the Intermountain Region Geographic Resources Division GIS team (IMR GIS) for assistance in determining the best way to represent management data collected on the vertical aspects of the Tower, including exotic vegetation and climbing routes. IMR GIS found that there weren't any data options that showed the vertical sides of the Tower with acceptable detail, or the top of the Tower without deformation (Figure 2). Many previous orthophoto images depict the Tower as skewed and stretched, especially toward the top, due to the abrupt rise in vertical elevation (Rau et al., 2002). These inaccuracies make it difficult to create reliable GIS data.

Table 1. UAS Approval Tasks

Approval Needed:	Responsible Party:
FAA Clearance/ Certificates of Waiver or Authorization (COA)	USGS
Tribal Consultation	DETO
NEPA and NHPA Compliance	DETO
State Historic Preservation Office (SHPO) Consultation	DETO
Research Permit	DETO, USGS
Regional Letter for UAV Approval	DETO
NPS Operation Approval form	DETO, IMR, USGS
Project Aviation Safety Plan (PASP)	DETO, IMR, USGS

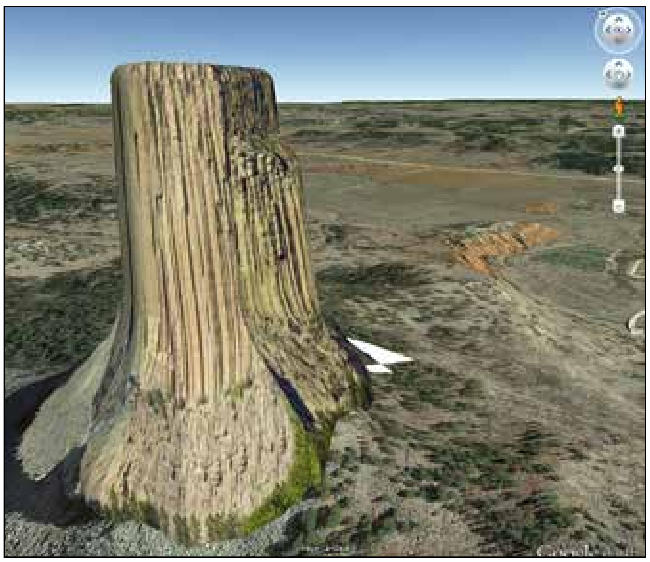

Figure 2. Devils Tower in Google Earth (IMR image)

Given that the Tower has more vertical elevation than circumference area on the ground, a more detailed version of the Tower in 3D, requiring high resolution photogrammetry, was needed to capture the vertical sides, topographic detail, and true elevation of the Tower itself. After the team researched different data collection methods, it was decided the safest and most cost effective solution was to collaborate with the U.S. Geological Survey (USGS) Unmanned Aircraft System (UAS) Project Office located in Lakewood, Colorado. IMR GIS and DETO obtained NPS approval to fly a UAS within park boundaries for research purposes. Devils Tower was the first park to start this approval process after the ban on UAS in National Parks began in February 2015.

Approval Process

At the beginning of this project, the public use of all UAS's in National Parks had just been banned. The new policy did allow for internal (administrative or research) UAS use with prior approval, but the process for gaining approval was a work in progress and had not been tested through all levels of NPS. With the help of Steve Sorenson, IMR Regional Aviation Manager, IMR GIS was able to navigate through the initial guidance. Gaining approval was a collaborative effort between park staff, USGS, and IMR. Table 1 shows the tasks that needed to be completed in order to gain NPS approval.

Navigating the draft guidance and coordinating with team member work schedules to gather all necessary documentation and gain the final approval took approximately one year. The final approval initially came from the Washington D.C. office. Then, in April 2017, this level of final approval was changed to the Regional Director level which will make future approvals more streamlined.

The current approval process is now estimated as several weeks, versus the several months the DETO project took.

Flight Preparation

Before the USGS could begin data collection processes, initial ground control needed to be installed at the monument to georeference the UAS-collected data to a location on the earth's surface. Ground control is used to cross reference the accuracy of the data collected by the UAS. Although 3D imaging can be processed without ground control, much greater accuracy and precision can be achieved with three or more points collected via survey-grade GPS (Bemis et al., 2014). Prior to beginning field work, the USGS provided a draft survey control point location map where they estimated the number of control points needed and their locations based on the area of interest. With the help of Neil Winn of Assateague Island National Seashore (ASIS) while acting as IMR GIS Coordinator, and Tim Smith, NPS National GPS Program Coordinator, the ground control survey was installed at the monument, including three temporary survey points on the top of the Tower. This project is the first Real Time Kinematic (RTK) GPS survey on the top of the Tower to date.

Figure 3. USGS UAS Flight Crew station (K. Shakarjian photo)

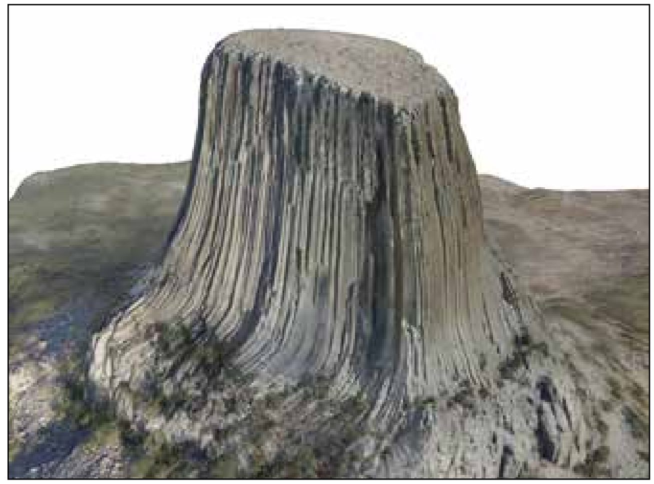

Figure 4. Devils Tower UAS-collected photogrammetry data (USGS image)

UAS Flights

The UAS data collection flights took place in October 2016 (Figure 3). The flights occurred over a three day timeframe based on the flight plans developed by the USGS. Utilizing the pre-approved safety plan, park staff cleared all nearby trails to make sure no visitors were underneath the UAS while in flight. Weather was also closely monitored to protect the equipment from damage, as well as to insure the imagery had similar brightness for consistency within the final product. The twenty flights resulted in approximately 1,200 photographs and 200 gigabytes (gb) of imagery data

Post-Flight Work

During the weeks following the flights the USGS processed the point cloud orthoimagery and digital surface models from the collected data. The USGS also developed high resolution 3D model files that depict the sides and top of the Tower in fine detail (Figure 4). Once the processed datasets were received from the USGS, IMR GIS and Denver Service Center Planning (DSCP) GIS have been continuing to work to develop an effective procedure for creating 3D data based on the highly accurate elevations from the photogrammetric data outputs (Figure 5). Neal Jander, a GIS specialist with DSCP GIS, has determined two methods for developing vector 3D data using ArcGIS Pro 2.0 and Global Mapper 18.2 that will allow for accurate acreage estimates of invasive plant treatment areas. The methodology Neal is developing will be available service wide for GIS users to apply to their own projects.

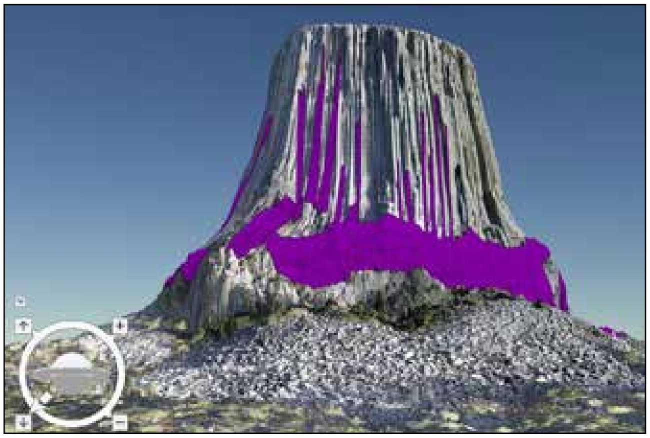

Figure 5. GIS Exotic Plant Treatment polygon data created in 3D (DSC image)

The project team is also working with the Smithsonian Institute on hosting the 3D data on the Smithsonian X3D platform to provide an open platform for visitors to view and explore a 3D version of Devils Tower, whether it be at the park or from their own homes. The website exploration would enable the visitor to take a closer look at aspects of the Tower, such as the top of Tower, that are inaccessible unless through climbing. Additionally, the USGS has commissioned a 3D printed model of the tower which they are gifting to the monument (Figure 6).

Conclusion

This project serves not only as a great example of collaboration between park staff, the Intermountain Regional Office, and other DOI agencies, but as an outstanding example of how high resolution data can benefit both visitor experiences and resource management. Photogrammetric imagery captured through UAS are becoming increasingly more common throughout forestry, agriculture, and geosciences research (Grenzdorffer et al., 2008; Siebert and Teizer, 2014). The monument can benefit from the high resolution imagery and elevation products by applying the data to geologic hazard assessment, erosion monitoring, resource interpretation, cultural resource identification and documentation, and 3D area calculations just to name a few.

The IMR GIS program is currently working with the USGS UAS Project Office to develop an Interagency Agreement that will formalize the partnership that began with the DETO project. Additional projects are currently being executed with the USGS UAS pilots in the Intermountain Region and future projects are also currently under consideration.

Figure 6. 3D printed, hand painted model of Devils Tower courtesy of USGS

Acknowledgements

Jeff Sloan, UAS Project Leader, USGS National UAS Project Office

Mark A. Bauer, Geospatial Analyst, USGS National UAS Project Office

Todd Burton, Geospatial Analyst, USGS National UAS Project Office

Neil Winn, GIS Specialist, Assateague Island National Seashore

Stephen Sorenson, Aviation Manager, Intermountain Region

Tim Smith, GPS Coordinator, Washington Office, Resource Information Services Division

Neal Jander, GIS Specialist, Denver Service Center Planning Division

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— NATURAL RESOURCES —

Dogs Working for Resource Conservation in the National Parks

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Canis familiaris, the domestic dog, was domesticated by humans from Eurasian gray wolves at least 15,000 years ago. We affectionately call them "man's best friend," and they are, in fact, humankind's oldest "friend" in the animal kingdom. Dogs reduce our stress and lower our blood pressure after a busy day at work, help keep us active, and are some of our closest companions. They also can be our eyes and ears, assist us with mobility, alert us to medical needs, help us to hunt and herd other animals, and perform law-enforcement and search-and-rescue tasks. In the U.S. national parks and elsewhere, they are increasingly being used for resource conservation and protection.

Olfaction, the act or process of smelling, is a dog's primary special sense. A dog's sense of smell is said to be a thousand times more sensitive than that of humans. In fact, a dog has around 300 million olfactory receptors in its nose, while humans have only about 6 million (Tyson 2012). This, along with other qualities, makes many dogs well-suited for training in conservation-related scent detection.

At locations around the world, dogs are being used to detect many invasive plant, animal, and aquatic species, including Chinese bush clover, spotted knapweed, yellow starthistle, and Dyer's woad; feral swine, Argentine ants, emerald ash borers, and non-native trout; and zebra and quagga mussels. In many cases, properly trained dogs have proven better at locating these species than their human counterparts. They are able to find invasive plants before they flower (reducing seed production and dispersal), can search a boat for mussels faster than a human, and are better able to detect mussels in the larval stage (WDC 2017).

Dogs can also detect plants and animals of conservation interest, such as Kincade lupine, grizzly bears, Pacific fishers, San Joaquin kit foxes, rosy wolf snails, and desert tortoises. Some can be taught to detect disease in free-ranging wildlife (e.g., brucellosis in elk), or to detect environmental contaminants, such as rodenticides, heavy metals, and organophosphates (WDC 2017).

Scent detection is just one way in which dogs are assisting with conservation. Specialized breeds can also be trained to disperse nuisance species and help ensure that wildlife and humans stay a certain distance from each other, helping both to remain safe.

This issue of Crossroads includes two articles on conservation working dogs in the National Park Service. The first tells the story of Gracie, a border collie being used for wildlife shepherding at Glacier National Park. The second introduces readers to Ridley, a cairn terrier who helps locate the nests of Kemp's ridley sea turtles at Padre Island National Seashore. Both articles demonstrate ways in which dogs, with the proper training and handling, can be an effective tool for resource conservation.

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"Cooper" - Dogs are our beloved companions. (Photo provided by Mike Wrigley 2017)

—NATURAL RESOURCES—

Bark Ranger Gracie Reports for Duty: Use of a Specially Trained Wildlife Shepherding Dog to Manage Habituated Wildlife in Glacier National Park

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In July 2016, Glacier National Park became the first National Park Service unit to use an employee-owned dog to help manage habituated wildlife. Now in its second year, Glacier's wildlife shepherding program has proven both popular and effective—though there is much still to be learned. The project was made possible by the park's friends group, the Glacier National Park Conservancy.

Background

Located at an altitude of 6,646 feet along the Continental Divide in Glacier National Park, Logan Pass is one of the most popular visitor stops on the park's iconic Going-to-the-Sun Road. The pass is noted for its scenic views and abundant wildlife. Historically, Logan Pass has reached visitor capacity by the late-morning hours, meaning that all of the approximately 230 parking spots were full. Now, with increased visitation, the parking lot is filling up by early morning (Figure 1) (NPS 2016).

Figure 1. Logan Pass parking lot. (NPS photo)

The increase in visitation has also impacted wildlife. A recently completed study (Sarmento and Berger 2017), funded through the Going-to-the-Sun Road Corridor Management Plan Environmental Impact Statement project (GTSR CMP/EIS), indicated that increased human presence has altered the behavior of mountain goats and bighorn sheep in the Logan Pass area. The study found that these wildlife tolerate the high number of visitors in return for safety from predators. With approximately 6,000 people and 1,900 vehicles visiting the pass each day, grizzly bears, mountain lions, and wolves tend to avoid the area, creating a "safe zone" for goats and sheep. A secondary benefit to these animals is the salt provided by fluids leaking from vehicles (Figure 2), sweaty backpacks left unattended, and urine deposits along the Hidden Lake Trail.

Figure 2. Mountain goat licking antifreeze from the Logan Pass visitor center parking lot, with a visitor far too close. (NPS photo)

All this puts visitors and wild ungulates in increasingly close proximity. Habituated wildlife have been documented at Logan Pass at least since the 1970s. Scoping for the GTSR CMP/EIS revealed that human–wildlife interactions are a source of concern for both the public and park employees. And like other parks, Glacier has seen its visitors engaging in increasingly risky behaviors around wildlife in recent years (Figures 3 and 4). At Logan Pass, examples include approaching mountain goats and bighorn sheep for selfies and other photos, attempting to feed wildlife, and using their vehicles to chase bighorns through the parking lot. [1]

The park's response to this growing problem has been a combination of visitor education and wildlife hazing. Signage and personal contacts provide visitors with information on how to safely view and enjoy park wildlife. Park employees also employ various methods of wildlife hazing in the Logan Pass parking lot.

Figure 3. Visitor taking a selfie with bighorn rams in the Logan Pass parking lot. (NPS photo)

Figure 4. The mistaken assumption that habituated wildlife are "tame" often leads visitors to approach them too closely. (NPS photo)

These include shaking plastic bags or a box of rocks, clapping hands, shouting, and/or snaking a bullwhip along the ground (Figure 5). Law-enforcement rangers also may use their sirens or aversive-conditioning rounds (crackershells and rubber bullets) to move wildlife away. However, the animals soon learn that these noises and techniques do not always carry consequences, and the actions lose their effectiveness.

Figure 5. Park ranger attempting to haze a bighorn sheep using a plastic bag. (NPS photo)

The Idea

In 2015, in response to continued concern from the public and park employees, I began looking for creative ways to keep wildlife and visitors safely apart. From Sarmento and Berger (2017), I knew that even habituated mountain goats retain some of their natural aversion to predators, and that they exhibit that aversion even in response to something that only resembles a predator—such as a graduate student dressed up in a bear suit (yes, Sarmento and Berger 2017 is a pretty fascinating read). And then one night, as I sat petting my family's new border-collie puppy, Gracie (Figure 6), I wondered: could we leverage ungulates' innate fear of carnivores and use a dog as to haze ungulates at Logan Pass?

There was plenty of precedent. In recent years, Glacier's Canadian sister park, Waterton Lakes National Park, contracted with a company that used trained border collies to haze habituated mule deer out of the Waterton town site. Because it offered refuge from predators, the deer would enter the town site to have their fawns. Then they became aggressive toward residents, visitors, and their pets. After several injuries occurred, the border collies were hired to haze the

[1] In June 2017, the park's popular Avalanche Creek trail was temporarily closed after a group of people nearly completely surrounded a grizzly bear along Avalanche Lake, causing the bear to swim out into the lake to create distance between itself and the crowd.

Figure 6. Gracie, prior to the start of her training. (NPS/A.W. Biel)

deer out of the developed area (D. Mattson, pers. comm.). The program was so successful that after five years, the park took a year off from hiring the dogs to see if the deer returned. In spring/summer 2016, no fawning was reported in the town site and there were no human–wildlife encounters.

Following a $32 million renovation of the National Mall's Reflecting Pool, National Park Service officials, in Washington, D.C., contracted with the border-collie "Geese Police" (Figure 7) to keep the pool and lawn areas free of goose droppings, potentially saving many thousands of future tax dollars in cleanup and repairs. The success of this program to date has been well documented. Even Glacier itself is on this list: in the 1990s, the park contracted with the Missoula-based Wind River Bear Institute to haze habituated grizzly bears away from park roads using Karelian bear dogs. This program was successful but also labor-intensive and expensive, costing up to $1,000/day for each dog/handler team.

Realizing it would be far more economical to have my dog and me trained to perform wildlife hazing/shepherding than it would be to hire contractors—and that my own border collie was an appropriate breed for the job—I started floating the idea with park leadership, wildlife-management peers, and regional-office staff. In response, I was encouraged to go forth and find funding to make the project happen. I wrote a proposal that built on the park's existing model of combining wildlife hazing and visitor education: Gracie and I would be not only a wildlife shepherding team, but also ambassadors for wildlife safety.

Figure 7. In Washington, D.C., the "Geese Police" help keep the National Mall and Reflecting Pool free of geese (and their excrement). (Photo courtesy Doug Marcks)

Training, Funding, and Questions

NPS sources declined to fund the project. Instead, the park's friends group, The Glacier National Park Conservancy, stepped in and agreed to support it via private donation. This meant training for both Gracie and me. After the necessary project compliance was completed, the Wind River Bear Institute (WRBI), in Florence, Montana, was chosen to do the training. WRBI's experience and knowledge of human–wildlife interactions (including at Glacier), their impeccable safety record, and their experience and track record of training Karelian bear dogs to shepherd habituated black and grizzly bears throughout the world all figured into this decision.

First, Gracie and I underwent an assessment to determine if we both had the proper temperament and aptitude to conduct the work. WRBI decided that we did, in fact, appear to be trainable. Then, over a period of 10 weeks, we developed our skills. Gracie learned verbal commands that allowed her to work at a distance from her handler. These included commands designed to control her direction and speed of movement; order her to stop and lay down at a distance; to wait and stay, regardless of temptation; and the all-important recall command that ensures she can be called off of anything at any time and immediately return to her handler.

Considerable focus was also given to her human socialization skills. Gracie and her trainers spent lots of time learning how to properly meet and greet strangers in local businesses, on Missoula's busy bike path, and at crowded community events. I learned how to administer the verbal cues and properly handle Gracie on a lead in crowds. Then we both learned to move domestic sheep from one place to another in a safe, low-stress manner, by applying pressure from a distance (Figure 8).

Once we both graduated from the training, Gracie and I continued to practice our skills until the GTSR opened to Logan Pass. In the meantime, I worked with park staff from multiple divisions to develop a consistent message about how visitors can safely view park wildlife. I also tried to address concerns raised by the public and park employees: Would visitors still be able to see mountain goats and bighorn sheep at Logan Pass? Would it be harder to convince visitors to keep their own dogs on-leash if they saw Gracie working off-leash? Was there potential for injury to wildlife, Gracie, or park visitors? How would Gracie's training with domestic sheep translate to larger, more intimidating bighorn sheep and mountain goats?

Figure 8. Gracie and the author honed their herding skills by practicing on domestic sheep. Gracie was trained not to come in contact with the animals. Instead, she and her handler move sheep by applying pressure from a distance. When the sheep feel the dog and her focused "border-collie stare" are getting too close for comfort, they move away. (NPS/A.W. Biel)

Aside from my own experience-based opinions, the answers to these questions would remain largely unknown until Gracie actually made an appearance at Logan Pass.

The Initial Test

On that first evening, Gracie and I arrived at the pass with our WRBI trainers in tow. Two bighorn rams were in the parking lot, cleaning up food scraps and garbage left behind by visitors (Figure 9). Gracie was immediately interested in the sheep and the sheep were definitely interested in her. With Gracie on-leash, we slowly approached the sheep, which turned and moved 35 yards away, according to our rangefinder—a bit beyond the 25-yard distance that Glacier's visitors are required to keep between themselves and this type of wildlife. The sheep remained out of the parking lot for over one hour, continually casting a wary eye toward Gracie and me as we patrolled the lot's perimeter.

Figure 9. Bighorn rams in the Logan Pass parking lot.

The next morning, we arrived to find six rams in the parking lot. In less than five minutes, we had moved them all safely across the Going-to-the-Sun Road, to a distance of about 75 yards from visitors and into a more natural setting (Figure 10). These animals remained out of the parking lot for nine hours.

Figure 10. After wildlife are moved a safe distance away from the parking lot, the shepherding stops. This helps ensure that visitors can still view these animals at Logan Pass. (NPS/A.W. Biel)

The Results

Over the course of the summer, park staff and volunteers collected data documenting the effectiveness of the different hazing techniques. The distance that wildlife moved in response to Gracie ranged from 30 to 75 yards, versus a range of 33–100 yards for the traditional techniques described earlier in this article. When Gracie was used to move wildlife, they remained out of the area for 15 minutes to 9 hours, versus 10–15 minutes with the traditional techniques. Data collection and analysis are ongoing—but to date, it appears that Gracie can safely move wildlife away from areas of high visitor use to a point where visitors can still enjoy them and the wildlife remain out of the area for a longer period of time than when more traditional techniques are used.

The results and experiences from summer 2016 helped us to address the concerns raised by visitors and staff. To maximize safety of visitors, wildlife, and Gracie in the busy parking lot, we quickly decided that Gracie would only work on-leash at Logan Pass—especially since on-leash work had proved effective at moving sheep. We also found that when hazed, the sheep consistently moved at least the desired distance away (25 yards) but not so far that visitors could no longer easily view them. Not only could they still be photographed, but they could also be photographed in a more attractive, natural setting (Figure 11) than that of the paved parking lot, surrounded by vehicles (see Figure 9). There were no injuries to wildlife, visitors, or Gracie over the course of the summer and, as per her training, Gracie never came in contact with any animal. The use of domestic sheep for training purposes proved an effective tool that translated well to bighorn sheep and other ungulates.

Figure 11. Bighorn rams graze on a hillside after being hazed from the Logan Pass parking lot. Wildlife shepherding encourages these animals to move a safe distance away, but not so far that can no longer be seen by visitors. This photo, showing the same rams in roughly the same spot seen in Figure 10, was taken with a point-and-shoot camera from the vantage point of Figure 10. (NPS/A.W. Biel)

As the wildlife shepherding program begins its second year, we are continuing to collect data for each wildlife shepherding event, regardless of method. I am working with the Rocky Mountain Cooperative Ecosystem Studies Unit coordinator and a teacher of advanced math at a Missoula junior high to analyze the existing data and assist with data collection. The data will be used for a class project analyzing the effectiveness of using a wildlife working dog versus other hazing techniques.

Winter Work

With the success of the summer behind us, it was determined that Gracie would also work through the winter months in the park's headquarters (HQ)/ residential area. In winter, white-tailed deer frequent the housing area because the plowed roads make for easy travel and the presence of people discourages the presence of predators—for the most part. In recent years, there have been so many deer at HQ that mountain lions have been a frequent sight—even in daylight hours (Figure 12). This creates safety concerns for park residents with small children and pets, and a lion was removed from the population after one such encounter a couple years ago. I thought if we could move the deer out of the housing area, at least during the daylight hours, then there might be a reduction in the sign and sightings of mountain lions, making the area safer for residents and employees. In short, I wanted to try moving the lions' grocery store out of the neighborhood.

Figure 12. Mountain lion photographed from an employee's office window in 2015. (NPS/R. Lawrence)

Gracie and I patrolled the perimeter of the housing area at least once a day and shepherded any deer within its boundaries to places outside the developed area. After two or three days, the deer learned that when they saw Gracie coming, they needed to move away (Figure 13). Through this work, we learned that there are four main ingress/egress areas the deer use to enter or leave the housing area. When we showed up, they would quickly move toward one of these routes.

After the initial shepherding events, the deer started to leave as soon as they saw Gracie. Over the course of winter, I received only two reports of mountain-lion tracks around the perimeter of the housing area and no reports of sightings among the houses, where they had been commonly seen in previous winters. While several other factors may have also helped determine mountain-lion distribution, I feel confident that moving the deer out of the area contributed to the low number of lion sightings.

Figure 13. In winter, deer are moved out of the park headquarters/residential area to discourage the presence of mountain lions in the developed area. (NPS/A.W. Biel)

Public Response

Although the wildlife-shepherding part of Gracie's job gets most of the attention, her work as an ambassador for wildlife safety may be even more important. The actual shepherding events are often completed in less than five minutes. After that, she and I make visitor contacts, usually upwards of 100 per night. We use this time to explain what Gracie does for the park and to remind people to be safe around all wildlife—especially habituated animals that may seem tame. People's interest in the dog make this possible; she is a people-magnet, which gives me the chance to spread our messages. Gracie and I have also made presentations to about 15 local school and community groups in the past year, and there is a social-media outreach component. Gracie's Instagram feed, with almost 13,000 followers, allows us to communicate messages about wildlife safety, pet regulations, and myriad other issues to people before they ever arrive in the park (Figure 14).

The most surprising aspect of this project has been the degree to which it has captured the public's imagination. After some initial local print, television, and radio coverage, Gracie's story was picked up by National Public Radio and has subsequently appeared in the Washington Post, Outside Magazine, and countless other online outlets, including the U.S. State Department's ShareAmerica website. Earlier this year, our daughter was reading a cartoon adventure in her Ranger Rick magazine when she suddenly realized

Figure 14. Gracie's Instagram account allows the park to reach the public with messaging before they arrive in the park.

the story was about Gracie and me (the cartoon me is much younger and blonder than the real me). Gracie has marched in local parades, appeared at a park Instameet, and met several visiting VIPs, including former Secretary of the Interior Sally Jewell, U.S. Senator Steve Daines (Figure 15), and Facebook mogul Mark Zuckerberg. In addition, the project earned an award for "Outstanding Public Engagement of the Year" from the Public Lands Alliance, by popular vote. It's exciting to have a national platform from which we can promote the goals and messages of this project.

Project Enhancements

In 2017, we enhanced our wildlife-safety messaging with the addition of a set of trading cards (Figure 16). The cards help park staff to reinforce positive visitor behavior around wildlife and try to couple corrective actions with a positive message.

For example, a card might be given to a person who encounters a mountain goat on the trail and chooses to move away from it, or encourages others to move away. On the other hand, a card might also be given to a person who had to be told to move away from that same animal—as a way to reinforce the message of why it's important to stay away and allow that visitor to take something positive away from their interaction with park staff.

Each of the 11 cards has a nice photograph, some fun facts, a safety slogan, and the possible consequences if an animal starts looking to humans as a source of food. One card provides general information and advice about safe wildlife viewing. Nine cards feature different park animals that park staff identified as commonly habituated. The last card shows Gracie and explains the wildlife shepherding program. All cards prominently display the message, "Wildlife may not know better, but YOU do! Stay away 25 yards" (100 yards for bears). With support from the Glacier National Park Conservancy, 100,000 cards were professionally printed and are being distributed for use by staff across the park.


Figure 15. U.S. Senator Steve Daines talks with the author after meeting Gracie at an Instameet celebrating the NPS Centennial. (NPS/A.W. Biel)

Several park staff have expressed interest in participating in the wildlife shepherding program. If these staff show aptitude for handling a dog and reading the body language of wildlife, and funding is available, we may work with their supervisors to explore the possibility of creating additional dog/handler teams that can cover other areas of the park where wildlife shepherding and associated visitor outreach might be useful.

Figure 16. Trading cards are being used to enhance the park's wildlife-safety messaging.

Conclusion

To date, Glacier's wildlife shepherding program has proven to be a cost-effective tool for safely moving habituated wildlife and educating the visiting public, as well as a public success story. It is by no means "the solution" to the issues it addresses, but is another tool in box for wildlife management. The ultimate goal is less about changing wildlife behavior than it is about changing human behavior. We want to help bring about a paradigm shift in public perception of habituated wildlife—where instead of wanting to approach them, visitors are more inclined to give wildlife the respect and room they need to safely co-exist with humans (Figure 17).

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Figure 17. Gracie watches a group of bighorn rams that she and the author prevented from entering the Logan Pass parking lot. (NPS/A.W. Biel)

—NATURAL RESOURCES—

"Ridley Ranger" finds Kemp's Ridley Sea Turtle Nests at Padre Island National Seashore

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Kemp's ridley sea turtles (*Lepidochelys kempii*) are the most endangered of all sea turtles. In the 1960s, they were on the brink of extinction. Thanks to laws that protected their nesting beaches in Mexico and reduced accidental capture in fishing gear, the species has begun a slow but steady comeback. Since the 1970s, Padre Island National Seashore has been the site of a bi-national, multi-agency program to form a secondary nesting colony as a safeguard against extinction of this endangered, native species that nests primarily in Tamaulipas, Mexico. The program has seen success; although nesting individuals numbered only 200 in the 1980s, their population has risen to an estimated 7,000–9,000 individuals today.

Figure 1. Ridley is a cairn terrier trained to help park biologists find Kemp's ridley turtle nests. (NPS photo)

The park's Division of Sea Turtle Science and Recovery monitors and protects these animals. In spring and summer, nesting turtles are protected, examined, and tagged. A few are tracked using satellite telemetry. Eggs are located and gathered so they can be protected from predators, high tides, and human threats. Collected eggs are then incubated and the hatchlings later released to ensure the highest probability of survival. The program is assisted by many staff, volunteers, and one dog: "Ridley Ranger" (Figure 1), owned by program director Dr. Donna Shaver, Unfortunately, Ridley passed away during January 2018.

Figure 2. Ridley on the scent of Kemp's ridley sea turtle nests. (NPS photo)

Ridley was a Cairn Terrier who used his sense of smell to find Kemp's ridley nests at locations where biologists could not. Here on the Texas coast, high winds often blow away tracks left in the sand by nesting females, making it difficult or even impossible for humans to follow the tracks to the nests. However, a dog's nose has 50 times more smell receptors than a human's. Entered Ridley.

Figure 3. Dr. Shaver excavates nest found by Ridley.

Dr. Shaver aimed to bring a dog into her family that could be part of the Turtle Team to help find the precious nests that people were unable to locate, despite hours of trying. She and her husband Stephen Kurtz first started Ridley's training with the command "find the treat". They hid small treats in a room and encouraged Ridley to locate them by scent, using the command "use your nose". Then, after mastering those commands, Ridley's training advanced to being exposed to the command "find the nest". They trained Ridley to find sea turtle nests by introducing him to the scent of actual nest sites and residual egg fluid, and the mucus coating left by the mother on the eggs. In just ten short weeks of initial training, Ridley was able to locate nests that no one else had been able to find. Ridley's training was reinforced annually with refresher training of "find the nest" and "use your nose" by allowing him to enter the Padre Island National Seashore Sea Turtle Egg Incubation Facility and safely locate where eggs that were held inside of incubation boxes residing in the facility. Other training aids included mounds of discarded sand that had been in boxes of incubating eggs, hampers that held drapes that went over boxes of hatching eggs, and used boxes that had held incubating eggs. Every year, Ridley was exposed to these materials it helped reinforce his training and expertise.

Once at a track site, Ridley began sniffing out the scent of eggs (Figure 2). When he detected a nest, he pawed at the sand so the biologists knew where to start digging (Figure 3). In a matter of minutes, Ridley could find nests that people have spent hours searching for. By finding the eggs, Ridley helped save hundreds of Kemp's ridley sea turtles. Ridley was always eager to get to work and help give turtles a brighter future.

Ridley was 12 years old when he passed away from a stroke. He was a smart dog who recognized that the sea turtle eggs and hatchlings were important to protect, and he enjoyed doing so. He led a happy and playful life until the end. He will be missed greatly. His companion Kayleigh has received initial training and will be deployed at sites this year, with the hopes that she can "follow in the paw prints" of her Big Brother Ridley (Figure 4).

Figure 4. Ridley and his sister Kayleigh. (NPS photo)

—COOPERATIVE ECOSYSTEMS STUDIES UNIT—

Binational Conservation Collaboration in the Intermountain Region - With Examples from the Transboundary Rio Grande - Río Bravo Region

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Long before political boundaries cleaved the remote arid expanses of southwestern North America, the land was occupied -- as it is today -- by a breathtaking variety of plants and wildlife, adapted over eons to thrive in the desert sun. The rich Chihuahuan and Sonoran deserts, the Apache Highlands nestled between them, along with the subtropical Tamaulipan Thornscrub of the Lower Rio Grande Valley and Gulf Coast Prairies and Marshes (Figure 1; TNC terrestrial ecoregions) comprise the borderlands of the Southwest. Figures 2 and 3 illustrate two of the many varied landscapes of two of these areas. Human habitation has also left its mark on the region, and to this day traces of ancient trade routes crisscross the terrain, zig-zagging from one life-sustaining watering hole to the next, evoking the ghosts of travelers bearing loads of salt, brilliantly colored feathers, copper bells, turquoise, seashells and other exotic treasures.

Figure 1. Twenty Intermountain Region National Park Service "border" units in Arizona, New Mexico and Texas (Table 1), Mexican sister parks (Table 2), and transboundary TNC terrestrial ecoregions. Three National Historic Trails (NHT) that continue into Mexico are shown; the NHT designation applies only to the USA portion of each trail.

Table 1. Intermountain Region border area parks and National Historic Trails (NHT).

Share a Physical Border with Mexico	Located in the Border Region	U.S.-Mexico National Historic Trails
Amistad NRA	Carlsbad Caverns NP	El Camino Real De Los Tejas NHT
Big Bend NP	Casa Grande NM	El Camino Real de Tierra Adentro NHT
Chamizal N Mem	Chiricahua NM	Juan Bautista de Anza NHT
Coronado N Mem	Fort Bowie NHS	
Organ Pipe Cactus NM	Fort Davis NHS	
Rio Grande WSR	Guadalupe Mountains NP	
	Padre Island NS	
	Palo Alto Battlefield NHP	
	Saguaro NP	
	Tumacácori NHP	
	White Sands NM	

Today, even as the NPS Intermountain Region U.S.-Mexico border, spanning the southern boundaries of Arizona, New Mexico and Texas, faces challenges, we invite the reader to join us in an exploration of a few of the many ecological and human connections that comprise the heart and soul of the border region, with a special focus on Big Bend National Park (BIBE) and Rio Grande Wild and Scenic River (RIGR).

Twenty Intermountain Region National Park Service units in Arizona, New Mexico and Texas celebrate rich cultural heritage and diverse ecological associations with our Mexican neighbors to the south (Table 1, Figure 1).

Transboundary Partnerships

The NPS Sister Park program fosters collaborative partnerships between NPS units and protected areas with common interests in other countries. Twelve of the NPS units listed in Table 1 have established formal sister park relationships with Mexican parks and protected areas. These relationships involve a commitment to working together in resource management, interpretation, research, or other park activities important to both partners. Table 2 lists established sister park relationships between border area parks and Mexican parks and protected areas. Locations of these sites are shown on Figure 1.

In addition to the sister parks program, informal relationships are also nurtured between NPS units and Mexican partners. Binational collaboration in the management of the Kemp's Ridley Sea Turtle by Padre Island NS staff (e.g., participation in the Bi-National Kemp's Ridley Sea Turtle Recovery Team in 2002-2011) and joint interpretation of the Kino Missions in the Pimería Alta region of northern Sonora and southern Arizona by Tumacácori NHP staff are but two examples.

Transboundary Resource Management (highlights from BIBE and RIGR)

Throughout the arid border region, water is the central formative resource that shapes ecosystems, challenges residents, tests through-travelers, and perplexes politicians. Two major rivers, the Colorado and the Rio Grande, or Río Bravo del Norte as it is known in Mexico, traverse the arid borderlands, cradling the precious flow that remains after thousands of upstream straws have taken their apportioned shares. The following section introduces the reader to four significant binational conservation efforts that have transcended political boundaries, framed action and achieved progress in the understanding,

Figure 2. Sonoran desert landscape at Organ Pipe Cactus National Monument. NPS photo

Figure 3. Apache Highlands grasslands landscape at Coronado National Memorial, Mexico in the distance. NPS Photo

protection and restoration of vital water resources in the Chihuahuan Desert borderlands of the greater Big Bend - Río Bravo region.

The Rio Grande - Río Bravo del Norte (Figure 4) is the aquatic centerpiece of a nearly 4 million acre binational protected area in the Chihuahuan Desert (Figure 5). The borderlands of the Chihuahuan Desert, in the Big Bend - Río Bravo region, showcase one of the highest levels of diversity and endemic species among the world's arid and semiarid ecosystems (CEC 2014). This large binational protected area offers a unique opportunity for conservation due to its isolation from human settlements and the unfragmented nature of its landscape (Figures 4 and 5).

The northern branch of the Rio Grande drains the southern Rocky Mountains in Colorado and New Mexico and much of the western half of New Mexico. Diversions for irrigation and municipal use consume most of its flow. The southern branch (Río Conchos), which joins the northern branch at Presidio, Texas, drains the Sierra Madre Occidental in Chihuahua, Mexico, and historically provided up to 75 percent of the flow downstream of Presidio, Texas and Ojinaga, Chihuahua. Dams and diversions in both countries mean that the Rio Grande - Río Bravo del Norte no longer experiences the high flows of the spring freshet or monsoonal floods. This condition elevates the importance of springs and perennial tributaries which now often exceed flows from the Río Conchos.

Transboundary Conservation Assessment

From 2011 to 2014, aided by the support of the Commission for Environmental Cooperation (CEC), BIBE, RIGR and AMIS staff joined with more than 60 representatives from U.S. and Mexican states, federal agencies, NGOs, universities, landowners and local experts in a major binational project known as the *Big Bend - Río Bravo Collaboration for Transboundary Landscape Conservation*. The goal of the project was to identify shared resources, affirm shared resource values, and develop focused conservation strategies in the greater Big Bend - Río Bravo (BBRB) region. Of the many products from the project, two of the most notable were the *Conservation Assessment for the Big Bend – Río Bravo Region: A Binational Collaborative Approach to Conservation* (CEC, 2014; http://www3.cec.org/islandora/en/item/11495-conservation-assessment-big-bend-r-o-bravo-region-binational-collaborative-approach-en.pdf) and a binational project for restoration of stream tributaries

Table 2. Established sister park relationships between border region parks and Mexican partners (data from Office of International Affairs and other sources).

National Park Service Unit	Mexican Park or Protected Area
Big Bend NP and Rio Grande WSR	Maderas del Carmen Biosphere Reserve & Cañon de Santa Elena Flora and Fauna Protected Areas; Ocampo Flora and Fauna Protected Area, and Monumento Natural Río Bravo del Norte
Casa Grande NM	Archaeological Zone of Paquimé World Heritage Site
Chiricahua NM and Coronado NMem	Ajos-Bavispe Forest Reserve and Wildlife Refuge
Chiricahua NM	Sierra de Alamos Biosphere Reserve
Coronado NMem, Fort Bowie NHS, Tumacácori NHP	El Chico National Park
Guadalupe Mountains NP	La Michilía Biosphere Reserve
Organ Pipe Cactus NM	Alto Golfo de California Biosphere Reserve El Pinacate y Gran Desierto de Altar Biosphere Reserve and World Heritage Site
Padre Island NS	Acuario de Veracruz
Saguaro NP	Sierra de San Pedro Mártir National Park
White Sands NM	Cuatrociénegas Flora and Fauna Protected Area

Figure 4. The Rio Grande/Río Bravo del Norte is the aquatic centerpiece of 4-million-acre binational protected area in the Chihuahuan Desert. NPS photo

to the Rio Grande - Río Bravo. The conservation assessment details binational agreement regarding the conservation values and threats to 29 priority conservation areas of great ecological significance in urgent need of protection and restoration. The assessment's goal is to assist local stakeholders in identifying opportunities, strengthening existing partnerships, and reaching out to new cooperative initiatives across the BBRB landscape.

Groundwater Contributions to the Rio Grande - Río Bravo

Managers in three state and federal agencies from the border region [the National Park Service (Big Bend National Park and the Rio Grande Wild and Scenic River), the Texas Parks and Wildlife Department (Big Bend Ranch State Park and Blackgap Wildlife Management Area), and the Comisión Nacional de Áreas Naturales Protegidas (CONANP, an agency similar to NPS in Mexico)] are focused on the protection and restoration of springs and perennial tributaries essential to sustaining baseflows in the Rio Grande - Río Bravo. Understanding the source of groundwater sustaining these springs and perennial streams is critical to their protection and restoration.

With this end in mind, the NPS and partners at Sul Ross State University and the United States Geological Survey have been documenting the role that groundwater plays in augmenting flows in the Rio Grande - Río Bravo (Figure 6). This science is needed to understand threats and opportunities to protect groundwater discharges to the river. A study of river flow gain-loss was initiated in 2005 to better quantify groundwater contribution and add to a growing data set documenting the natural resource value of Rio Grande - Río Bravo springs.

The project has shown that groundwater contributions to the Rio Grande - Río Bravo from springs discharging from limestone aquifers sustain aquatic habitats during dry years and mitigate water quality impairment (Bennett and Cutillo, 2007). In the Rio Grande - Río Bravo, the addition of groundwater improves the water quality in the river because groundwater is generally better quality than surface water. Thermal springs occur along the river from below Mariscal Canyon in Big Bend NP to below Foster's Weir and just above AMIS (Figure 5). Groundwater contributions from thermal springs can account for as much as two-thirds of the base flow at Foster's Weir and the river entering AMIS. Between the International Boundary and Water

Figure 5. Points of interest and protected areas in the greater Big Bend region.

Commission (IBWC) stream gages near Johnson Ranch and Foster's Weir, gains in flow account for 23% of the mean annual flow for the period 1961 to 1985 (Saunders, 1987). Sources include runoff and ecologically significant springs. These data provide strong support for the importance of protecting watersheds and aquifers contributing flow to the Rio Grande - Río Bravo.

Stream Restoration

Historical accounts of perennial or intermittent streams within the Big Bend indicate that many were lined with large stands of cottonwood and willow. Mining and agricultural activities during the late 19th and early 20th centuries resulted in the harvest of many riparian forests for fuel and structural material. For example, in 1933, Terlingua Creek was described as a *"bold running stream, studded with cottonwood timber as was alive with beaver"*. Once the forest was gone, normal annual flows were sufficient to scour young plants. Grazing animals helped prevent seedlings from getting established. Aside from a small area above Terlingua Abajo, the riparian forest has not returned despite 70 years of protection. Resource managers currently hypothesize that the riparian forest provided the nursery conditions necessary for cottonwood and willow recruitment by reducing hydrologic forces during high flows. They propose that reforestation will increase riparian habitat as well as increase resilience to climate change by altering hydrologic conditions such that the channel aggrades, increasing the depth and extent of the riparian aquifer.

The stream restoration project focuses on a pair of Rio Grande - Río Bravo tributaries at the west end of BIBE. Arroyo de San Antonio and San Carlos in the Mexican Protected Area of Cańon de Santa Elena received a first-ever biological inventory and threat assessment before receiving restoration work. Next, several hundred willow and cottonwood trees were planted in an area recently excluded from grazing by the local ejido. At Terlingua Abajo along Terlingua Creek, managers hope to reestablish extensive riparian forests that were lost a hundred years ago. The current project involves planting thousands of coyote willows in bundles on the floodplain in diamond shapes, an arrangement that mimic the natural floodplain arrangements (Figures 7 and 8A). By letting these willows establish first, they hope to nudge the hydrology back in the direction of the predisturbance regime so that larger tree species like cottonwood and Goodings' willow, and the wildlife species they support, can once again become established. Results to date have been promising (Figure 8B). Recently, the

Texas Parks and Wildlife, Sul Ross State University and the World Wildlife Fund, have initiated a stream restoration plan on a large privately held ranch in the headwaters of Terlingua Creek. The Rio Grande Joint Venture, with Southwest Border Resource Protection Program funding, will begin work this winter just upstream of BIBE. In addition, the partners have identified the space and water supplies necessary for the establishment of a large native plant nursery near Presidio, Texas.

Sister Parks Monitor Resources in the Chihuahuan Desert region

Big Bend NP resource managers have also worked closely with their counterparts at sister parks on many endeavors throughout the years. In 2015, Big Bend NP, Guadalupe Mountains NP, and White Sands NM and the Chihuahuan Desert Network hosted a binational monitoring workshop at Big Bend NP. Representatives from four Mexican sister parks as well as regional- and national-level staff from Comisión Nacional de Áreas Naturales Protegidas (CONANP) participated in the meeting. The primary goal of the workshop was to develop further collaboration between sister park protected areas in Mexico and the U.S. through an exchange of ideas, approaches, and techniques of scientific monitoring, data management, and application. Participants shared the vital signs that they were monitoring, their monitoring methods, and the data that they were currently collecting. Following the workshop, resource managers from both sides of the border began working on a binational report summarizing the status of monitored Chihuahuan desert resources. When completed, the report will consolidate and synthesize ongoing monitoring results and form the basis for a joint assessment of shared resources. The partners plan to meet again in the spring of 2018 to continue collaborative work on shared conservation priorities.

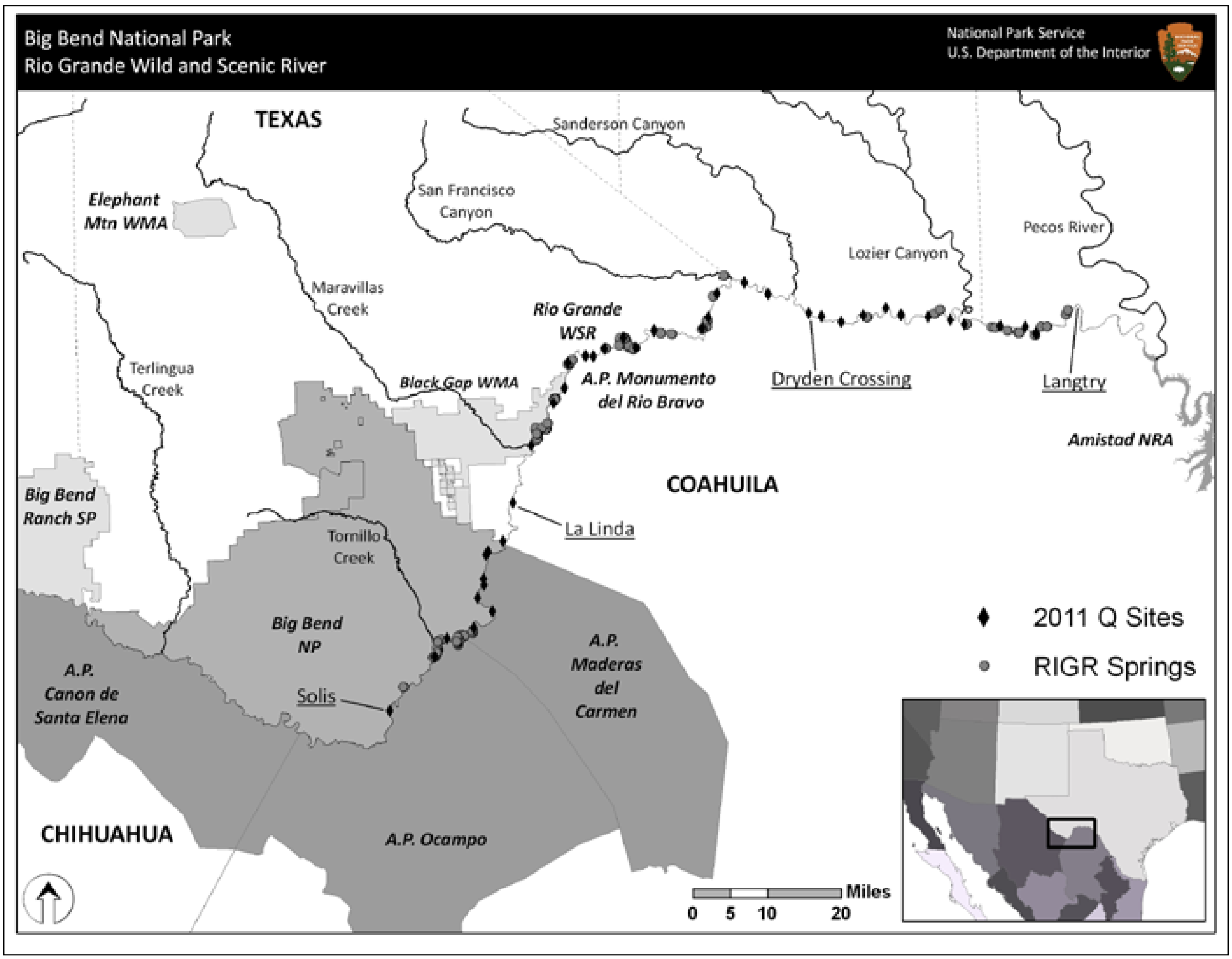

Figure 6. 2011 Groundwater study location map showing discharge (Q) measurement sites and springs along the Rio Grande Wild and Scenic River.

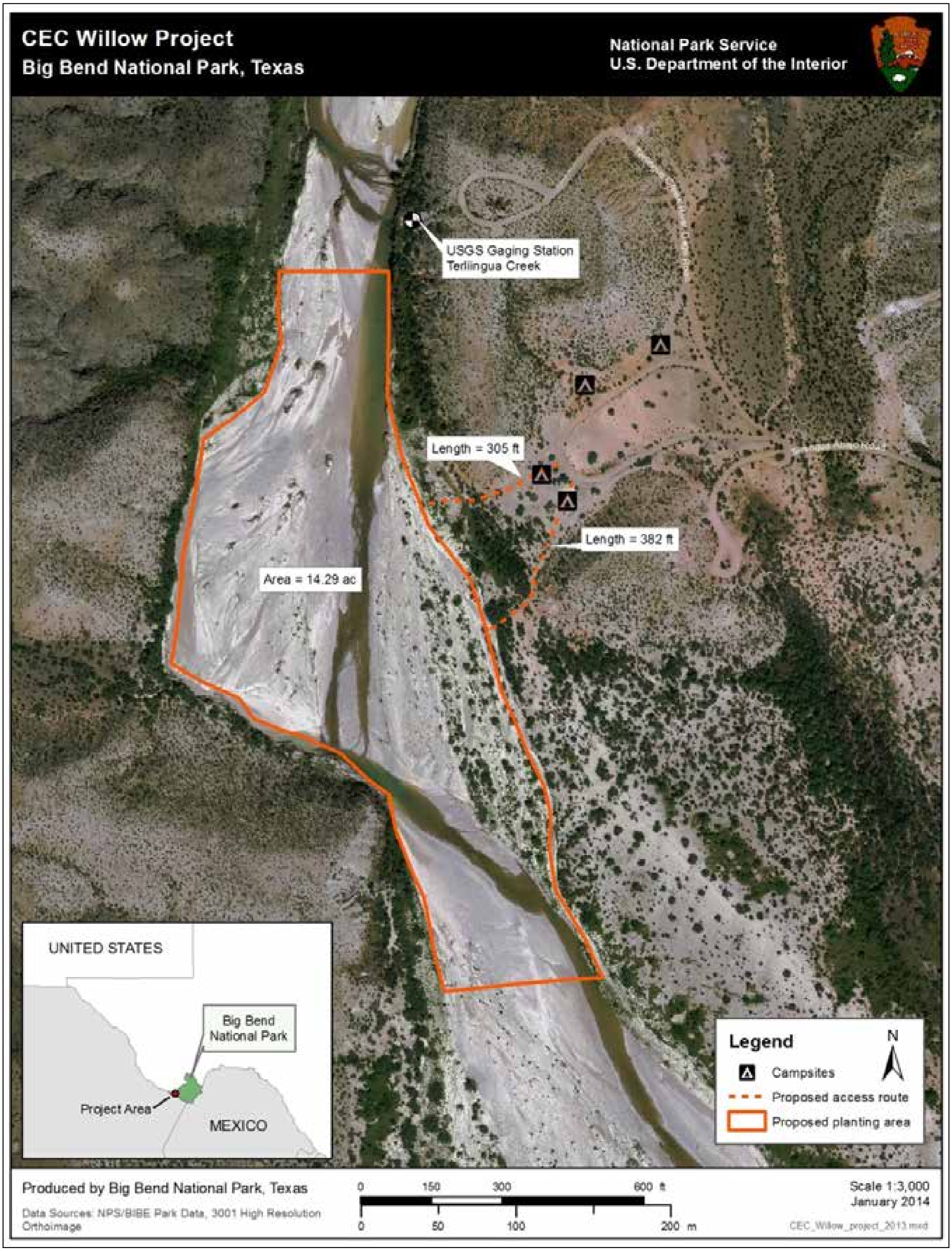

Figure 7. CEC stream restoration project area at Terlingua Creek before willow plantings.

Conclusions

Big Bend - Río Bravo Collaboration for Transboundary Landscape Conservation project, the Conservation Assessment for the Big Bend – Río Bravo Region (CEC, 2014), the innovative restoration project on the Rio Grande, and continued work between U.S. and Mexican sister parks have built a solid foundation of binational collaboration in the transboundary Rio Grande- Río Bravo region. Big Bend NP and Rio Grande WSR staff look forward to continuing collaborative work in the protection and conservation of this spectacular region.

Acknowledgments

We greatly appreciate help from Zara Hickman, University of Colorado Research Assistant, IMRO Geographic Resources Division. Zara created the maps shown in Figures 1 and 5. Contact information for Zara is zara_hickman@contractor.nps.gov; (303)-969-2963.

Figure 8. Terlingua Creek restoration site after willow plantings. A) Diamond planting scheme for the arrangement of willow at Terlingua Creek restoration project. B) Simulation of floodplain evolution provides evidence that a cluster of willows can increase sedimentation within and immediately downstream of itself.

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—Natural Resources—

Creation of the Crown of the Continent Ecosystem High 5 Working Group

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Abstract

In March 2016, the Crown Manager's Partnership convened a workshop to investigate how governments, agencies, organizations, communities and individuals could work together to address the precipitous decline of five-needle white pines in the Crown of the Continent Ecosystem (CCE) in western Montana and southern Alberta. The CCE includes two high elevation five-needle white pines (known as the 'High Five'). Whitebark pine (*Pinus albicaulis*) is a foundation and keystone species of treeline forest communities. Limber pine (*Pinus flexilis*) occurs from the lower forest to the higher elevations. Both pines produce large, wingless seeds which are important food for wildlife, including grizzly and black bears as well as birds and small mammals, and have a rich culture of traditional uses by indigenous peoples. Whitebark and limber pine are declining rapidly. The main agent of decline is the introduced fungal pathogen *Cronartium ribicola*, which causes white pine blister rust in five-needle white pines. The CCE has the highest infection and mortality rates across the range of both pines. As a result of the workshop, a working group has been formed to protect and restore functional whitebark and limber pine ecosystems by fostering transboundary collaboration and coordination to transfer sound scientific knowledge, leverage funding opportunities, and optimize restoration and conservation efforts within the CCE.

Photo 1. Blister Rust. NPS Photo.

Background

The Crown of the Continent Ecosystem (CCE) is one of North America's most ecologically diverse and intact ecosystems, covering 7.3 million ha in the Rocky Mountains of western Montana, southern Alberta and southern British Columbia. Overlaying this extraordinary landscape is a complex arrangement of borders that delineate lands managed by numerous federal, provincial, state and local governments, tribes and First Nations, private landowners, industry and conservation interests, each with their own objectives and mandates. Recognizing that no single agency has the mandate or the resources to focus on the ecological integrity of the entire region, the Crown Manager's Partnership was formed in 2001 to provide a venue for cooperation and stewardship of the CCE. In March, 2016, the Crown Manager's Partnership, in partnership with the Crown Conservation Initiative, the Wilderness Society, Whitebark Pine Ecosystem Foundation, and the Whitebark Pine Ecosystem Foundation of Canada convened a workshop to investigate how governments, agencies, organizations, communities and individuals could work together to address the precipitous decline of five-needle pines in the CCE. The result was agreement to establish a working group, inclusive in nature, to work towards the shared objective of conserving and restoring five-needle pines in the CCE.

The CCE includes two high elevation five-needle white pines (known as the 'High Five' from the pine subgenus *Strobus*), which provide wildlife habitat and ecosystem services, including snow retention, regulation of downstream flows, and protection from avalanche and soil erosion. Whitebark pine (*Pinus albicaulis*), a foundation and keystone species of upper subalpine and treeline forest communities, is widely represented throughout the CCE, growing at the highest elevations (> 1524 m) and on the harshest sites. Limber pine (*Pinus flexilis*) forms small to large stands after fire or other disturbance, and occurs from the lower forest boundary to the higher elevations (1200-1800 m). It also grows as a dominant in climax stands on harsh sites or alongside whitebark pine in subalpine and treeline communities.

Figure 1. Map of the Crown of the Continent Ecosystem. Crown Managers Partnership image.

Both pines produce large, wingless seeds which are important food for wildlife, including grizzly and black bears as well as birds and small mammals, and have a rich culture of traditional uses by indigenous peoples. Both pines depend on Clark's nutcrackers for seed dispersal. Whitebark and limber pine are declining rapidly as a consequence of anthropogenic disturbances (Bockino, 2012; Chang, Hansen, & Piekielek, 2014; Keane, Morgan, & Menakis, 1994; Smith et al., 2008b; D. F. Tomback & Achuff, 2010; Diana F Tomback et al., 2014). The main agent of decline is the introduced fungal pathogen *Cronartium ribicola*, an invasive fungal pathogen introduced from Europe, which causes white pine blister rust in five-needle pines. The CCE has the highest infection and mortality rates from this pathogen across the range of both pines. Blister rust impacts trees of all ages, killing seedlings, saplings, and mature seed producers, diminishing seed production and the future forest structure. This loss is compounded by mortality of large diameter trees from historical mountain pine beetle (*Dendroctonus ponderosae*) outbreaks as well as recent outbreaks, which are exacerbated by warming trends (Bockino, 2012; Smith et al., 2008b; D. F. Tomback & Achuff, 2010; Diana F Tomback et al., 2014.

Furthermore, fire suppression practices have led to advanced successional replacement of both pines within seral communities, while global warming trends are shifting pine distributions, altering local hydrology, and leading to mortality of large, old pines Keane, Morgan, & Menakis, 1994.Without these two species and the communities that they anchor, carrying capacity for wildlife declines, high and low elevation forests are more geographically restricted and homogeneous, and multiple ecosystem services are diminished. Restoration protocols, tools, and technologies are available and being implemented for whitebark pine and, to a limited extent, limber pine, by individual agencies, each conducting this work independently. However, consensus exists that the pace and scale of restoration must be dramatically increased and sustained if these species are to persist within the CCE.

Cooperation and a partnership among all interested jurisdictions is essential to enable this level of restoration to be achieved. For this reason, a High Five Working Group is necessary to prioritize and advance collective efforts to effectively monitor, conserve, and restore five-needle pines in the Crown of the Continent.

Coming Together: The CMP Workshops

The "We Need the Needles: Coordinating Action to Conserve 5-Needle Pine in the Crown of the Continent" workshop was held at the Crown Managers Partnership 16th Annual Forum in Fernie, British Columbia from March 15-17, 2016. This workshop was the fourth in a series of workshops organized by the Crown Adaptation Partnership (CAP), and was co-sponsored by the Whitebark Pine Ecosystem Foundation (U.S.) and the Whitebark Pine Ecosystem Foundation of Canada.

Eighty-seven people participated in the workshop, representing 43 different federal, provincial, state, municipal, tribal and First Nation governments, as well as conservation organizations, universities, industry and communities. The workshop focused on four objectives:

- Deliver best available science and data products on the climate adaptation strategies and tactics necessary to maintain 5-needle pine in the Crown of the Continent Ecosystem (CCE) in an era of rapid climate change;
- Discuss existing challenges and/or barriers that may be impeding 5-needle pine restoration, and develop recommendations to address these issues;
- Catalyze a formal CCE-wide working group whose purpose is to promote the long-term viability of 5-needle pines in the CCE by sharing information, leveraging capacity and resources, and promoting 5-needle pine protection and restoration; and
- Initiate a process to develop a CCE-wide 5-needle pine restoration strategy that identifies and prioritizes the type, amount and location of restoration activities, protection measures and monitoring that are necessary to restore 5-needle pine in the CCE.

Workshop participants agreed to work towards the development of a formal "High-Five" Crown-wide working group, which would function as a sub-committee of the Crown Managers Partnership. The purpose of the working group would be to advance our collective effort to effectively prioritize, monitor, conserve, and restore five-needle pine to the Crown of the Continent Ecosystem. The working group would house the various "task forces" that will deliver on other workshop outcomes, including the delivery of a Crown-wide monitoring database and network, the development of a Crown-wide restoration strategy and action plan, etc. The working group would set up a governance structure that is approved by agency leadership, and is capable of enabling delivery of all identified outcomes (including, if identified, the ability to pool funding and/or resources across jurisdictions). The working group would include all jurisdictions and stakeholders, and should weave cultural, ecological, economic and political factors together from the start.

Potential Executive Committee members for the working group were identified and invited to attend an initial meeting of the full High 5 Crown-wide working group coinciding with the Whitebark Pine Ecosystem Foundation Conference in Kalispell, September 15, 2016. All who attended the Fernie, BC workshop were invited to attend our initial High 5 Working Group Meeting on September 14, 2016. This first meeting was organized to approve a governance structure (Executive Committee), begin discussions regarding a charter, and to create sub-committees to address

Photo 2. Limber Pine in Glacier National Park. NPS Photo.

the other workshop outcomes. These outcomes were addressed during the meeting as follows.

Outcome #1: Draft (And Implement) A Crown-Wide Recovery Plan

Whitebark and limber pine are in peril, and securing these species ability to persist across the Crown (and throughout their range) will require a concentrated and coordinated set of restoration actions. Workshop participants expressed a desire for a Crown-wide Recovery/Restoration Plan that would address the following:

- prioritize areas for conservation and restoration,
- incorporate clear guidelines for restoration where applicable,
- identify mechanisms for sharing resources (including people/teams, contracts for work, funds, seeds, and seedlings),
- identify opportunities for new funding (e.g. through foundations/partnerships with NGOs, etc)
- and ensure the strategy fit into broader scale restoration priorities beyond the Crown.

Participants noted that other regions (the Greater Yellowstone, the PNW) also have region-wide restoration plans that are aligned with the Whitebark Pine Range-wide Restoration Strategy, which provide a strong template from which a CCE-wide recovery plan can be built.

Workshop participants identified three sets of tasks that are necessary to initiate a Crown-wide Recovery Plan:

1. Formal support to participate in the development (and presumably implementation) of the Recovery Plan needs to be secured from participating jurisdictions;

2. A workshop is needed to identify the structure and substance of a recovery plan.

1. First, agencies/organizations should be inventoried to determine their existing program status (plus trees, planting, propagation, resources, successes, challenges)

2. Second, a landscape-scale analysis needs to be done to identify synergies, efficiencies, gaps, opportunities for collaboration, and interim priorities. The restoration strategy should have annual or bi-annual work plans.

Outcome #2: Launch A CCE-Wide Monitoring And Inventory Database

A clear and detailed understanding of where whitebark pine and limber pine occur across the Crown, as well as their condition (tracked through time), is crucial to inform an effective landscape-scale restoration action plan. Currently, this knowledge is fragmented: some jurisdictions have good occurrence and condition data, and some, including private lands, have nearly none at all. Data are better for whitebark pine, but very limited for lower-elevation limber pine. Workshop participants agreed that a CCE-wide common database of stand-level occurrence was necessary to inform a CCE-wide restoration strategy. Participants also expressed a desire for an information hub that could house the following types of information: case studies of restoration successes, failures, effectiveness levels and lessons learned; best management practices for operating in five needle pine (5NP); standard

Photo 3. Whitebark Pine in Glacier National Park. NPS Photo.

inventory and mapping protocols; and results of CCE-wide mapping products. Participants also discussed the importance of expanding the footprint of long-term monitoring across the landscape, and to focus on the collection of absence data if that is truly important. A committee was formed to determine the following:

1. What are the driving management questions, and what data needs to be collected to effectively answer those questions?

2. What data are agencies/organizations currently collecting? Where/how is this data currently stored?

3. What are the opportunities/needs to design a centralized database (either a single database, or a networked database). Where could such a centralized database and information hub be hosted, designed and accessed?

Outcome #3: Develop Recommendations To Guide Pro-Active Fire Management In Five-Needle Pine Forests

Fire has both positive and negative implications for whitebark and limber pine. Regeneration of these species is closely linked to newly burned areas, and fire is important for removing competitors. However, high-intensity fires can kill five-needle pines, which pose a threat to important individuals (Plus trees, reproductively mature trees), climax stands and planted groves. Wildland fire use and prescribed fire are important restoration tools, particularly in the Crown given anticipated increases in productivity (leading to increased competition) and increases in the size and intensity of fires as a result of climate change. Workshop participants discussed several needs, including the need to engage fire managers directly in five-needle pine restoration objectives, the need to develop common best practices for using/fighting fire in the context of five-needle pine forests, and to accelerate post-fire monitoring using standardized monitoring protocols, so we can learn more about effective fire use.

The following tasks were identified:

1. Draft a five-needle pine “Best Practices of Fire Use and Management” guide, and encourage agencies/organizations to incorporate it into their fire plans to ensure a consistent approach to the application of fire, with clear objectives (this should also be included as part of the Crown Recovery Strategy).

2. Develop an email list of fire managers and other relevant people to aid in communication and sharing of information.

3. Coordinate spatial data between fire managers and mapping specialists to ensure appropriate and consistent wildfire responses in five-needle pine forests.

Outcome #4: Develop Recommendations For 5Np Restoration In Highly Protected Areas

A large amount of whitebark pine occurs in highly protected areas (in the U.S., approximately 50% of whitebark pine occurs in designated Wilderness areas). The protection level afforded to these areas can discourage or even prohibit certain restoration activities. Workshop participants discussed whether there might be recommendations developed to help protected areas managers and decision makers thoughtfully address restoration of five needle pine forests in highly protected areas.

Some key areas for discussion include:

- Guidance for development of a Crown-wide Recovery Plan, specifically how might highly protected areas best fit into a landscape scale strategy (as control areas, or areas for beneficial wildland fire use, etc.);

- How might the Aldo Leopold Wilderness Research Institute decision-making framework guide our thinking about restoration in wilderness areas where the default alternative is for managers not to intervene (how might we think about thresholds/triggers for action); and

- How can a deliberate tracking of restoration actions inform future thinking about restoration in highly protected areas (how might we monitor existing restoration outside of protected areas to accelerate learning about efficacy where managers do decide to intervene, determine what might be suitable (or necessary) within protected areas to sustain the larger meta-population – need to link to Outcome #2, monitoring efforts).

Outcome #5: Develop A Mitigation Strategy And Best Management Practices To Avoid Degradation Or Loss Of Five-Needle Pine

While five-needle pine (5NP) is not targeted for harvest, industrial development does lead to the loss and degradation of whitebark and limber pine. Where mitigation is required, it is typically done ‘on-site’ of the industrial footprint, which may or may not be the most effective way to mitigate for impact. Workshop participants expressed an interest in developing a unified mitigation strategy that could direct mitigation activities to the areas where they could be most effective, even if this was ‘off-site’ from the permitted activity. Workshop participants also discussed the need to develop detailed scientifically-based best management practices when working in areas where 5NP is present. Workshop participants expressed an interest in executing three discrete tasks:

1. Develop a 5NP Mitigation Strategy that would a) develop appropriate mitigation measures, b) identify best opportunities for ‘off-site’ mitigation, and b) explore mechanisms and avenues (e.g. a mitigation bank) to enable effective mitigation at multiple scales.

2. Identify detailed “Best Management Practices” for operations carried out in 5NP forests to most effectively avoid loss and degradation. These BMPs would be sent to Environment Canada for incorporation into the forthcoming WBP Critical Habitat rule.

3. Develop a training webinar for permit reviewers on 5NP that can live on-line (perhaps on WBEF website) that explains the obligations of the critical habitat rule, how to identify “terminal” WBP stands, and other topics to ensure 5NP is consistently conserved and restored under all permit operations.

In addition, Environment Canada committed to identifying legislative gaps and pursuing mechanisms to fill those gaps as related to implementation of the WBP Critical Habitat rule (e.g. two issues raised included Alberta’s Wildlife Act current lack of regulations related to plants, and BC’s lack of legal protection for whitebark pine).

Objective #6: Develop A Multi-Faceted Communications Strategy To Raise Awareness And Support For Five-Needle Pine Restoration And Conservation

Despite the imperiled status of whitebark and limber pine in the Crown, these species do not command the same level of support and priority that other imperiled species do. Part of what will enable more vigorous conservation and restoration of these species is increased awareness and support from the public, policy makers, decision makers, industry and community stakeholders. A multi-faceted communications strategy would identify the key audiences to target, and identify and prioritize communications to those audiences, with the end goal of supporting an increase in the pace and scale of restoration across the Crown.

Photo 4. Planted Whitebark Pine in Glacier National Park. NPS Photo.

Workshop participants expressed an interest in a multi-faceted communications strategy to raise awareness and broaden support amongst multiple audiences, for the purposes of increasing the pace and scale of restoration across the Crown. Participants did note that a communication strategy would have to be tightly knit to other collaborative activities, so the communications doesn’t get out ahead of “clear messages” and can be matched well with “key asks”, also certain types of "branding" and other activities already in place can be promoted from the start. Ideas for elements of a communications strategy included:

- Branding – a common slogan, common messaging, common solutions
- Interpretive signing (can borrow from PNW region), tours for the public
- Development/promotion of an app, that serves to educate and also can serve as inventory tool
- Curriculum-based education services, extension materials, and education that can be promoted via social-media.
- Organize field tours with key decision and/or policy makers
- Partner with key constituencies to help disseminate the message (e.g. tourism industry, newspaper/other media, youth groups, backcountry rangers, etc).
- Include the important role of fire in communicating/educating the public

Since the organizational meeting in September of 2016, progress has been made and continues. High 5 Working Group accomplishments include finalizing the charter with the following mission statement: To protect and restore functional whitebark and limber pine ecosystems by fostering transboundary collaboration and coordination to transfer sound scientific knowledge, leverage funding opportunities, and optimize restoration and conservation efforts within the Crown of the Continent Ecosystem. The role of the High 5 Working Group was also defined: The CCE High Five Working Group will: (1) collaborate on and coordinate restoration protocols, tools, technology and resources across jurisdictional boundaries, wherever possible and beneficial; (2) include representation from all government and private jurisdictions and interested organizations, including federal, tribal, First Nation, state, provincial, industrial, nonprofit, and private within the region; (3) function as a collaborative group whose primary responsibility is to promote the conservation and restoration of CCE whitebark and limber pine to levels that will enable the persistence of these species; (4) accomplish its work through exchange of information, leveraging and sharing work capacity and resources where possible, and providing guidance for cost-efficient conservation and restoration of whitebark and limber pine; (5) guide its work by (a) identifying where whitebark and limber pine are in need of conservation and restoration, (b) identifying appropriate conservation and restoration actions, including climate change adaptation actions, (c) prioritizing restoration activities with respect to consensus-based guidelines, and (d) establishing consistent methods for monitoring of species' condition and trends, and restoration activity outcomes. The CCE High Five Working Group acknowledges that accomplishment of its role and mission may require decades of persistent effort to ensure that whitebark pine and limber pine ecosystems remain important, functional components of the CCE landscape.

The Restoration Strategy sub-committee developed and sent out an Information Needs survey. The Inventory and Monitoring sub-committee is developing a database template; with a draft out in September 2017. The Fire Management sub-committee has drafted a Best Management Practices Manual which will be ready for distribution in October 2017. The Best Management Practices group has a draft being prepared and should be ready for review by the fall meeting. Communications is developing a framework for a communication strategy which will be ready for review at the fall meeting. We have been able to secure funding for a GIS tech to support our efforts and the Crown Mangers Partnership (CMP) is willing to host a website for our High 5 Working Group so we can post our developments and products. A fall meeting has been scheduled for Nov 6 -7, 2017 in Missoula, MT. This meeting will coincide with the National Leadership Summit on Whitebark Pine on Nov 7-9.

The amount of progress that has been made since March of 2016 has been amazing. The coordinated effort is proof of how a group of very motivated individuals with a common goal can accomplish so much.

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Rockfall and Landslide Assessments and an Unstable Slope Management System, Zion National Park

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Introduction

Rockfalls and landslides are a fundamental form of erosion and a significant geologic hazard in Zion National Park. Major and minor slope failures have occurred throughout the park's history. Some of these landslides have been catastrophic and central to the shaping of Zion National Park's topography. The Sentinel Landslide, ~4,800 years ago, dammed the Virgin River for hundreds of years. Others, such as recent, road-blocking rockfalls in 2015, 2016 and 2017, present significant risks to the public, park staff, and park operations. Unstable slope hazards in Zion and other National Park Service units have generally been managed retroactively—that is, after an event has occurred. In support of potential proactive management in the future, we collected quantitative field data and calculated slope ratings along major transportation corridors in Zion National Park using methodology developed by the interagency Unstable Slope Management Program. In late autumn 2016, this system was used to evaluate 236 unstable slopes. Shortly after these slopes were rated, winter storms caused some slopes to fail, testing our ability to preemptively identify unstable slopes in a cost-effective manner. The results were promising.

Located on the western margin of the Colorado Plateau in southwestern Utah, Zion National Park is an iconic landscape formed by active geologic processes. The park's numerous canyons have eroded rapidly because of a steep stream gradient facilitated by tectonic uplift in the Colorado Plateau and the topographically lower Basin and Range Province near to the west. The erosion rate of the landscape in and around Zion Canyon is exceptional—estimated to be 1.3 feet per thousand years in the soft, sedimentary rock that also forms its canyon walls (Biek et al. 2004). Zion National Park owes its magnificent scenery to canyon downcutting by the Virgin River and canyon widening from rockfalls and landslides (Biek et al. 2010).

Landslides and rockfalls have been documented throughout the park's geologic and historical record. The largest known landslide, the 4,800 year-old Sentinel Landslide, collapsed 370 million yds^3 of Navajo Sandstone, forming a 300-foot deep lake that lasted 700 years (Hamilton 2014; Castleton et al. 2016). Similar large-magnitude events have blocked canyons along Hop Valley, Coalpits Wash, Willis Creek, and the South Fork of Taylor Creek. Intermediate and smaller landslides have displaced or dammed rivers and blocked roads and trails. In 1990, a slide in the Middle Fork of Taylor Creek caused a short-lived dam that failed catastrophically three years later, producing

Figure 1. Historic rockfall at the maintenance yard in Zion Canyon in 1947. Zion Canyon is a site of many historic and modern rockfall events. This boulder damaged buildings and vehicles, crushing this dump truck.

flash-flooding that knocked over vehicles on Interstate 15 and injured two people. Small reactivations of the Sentinel slide in 1923, 1941, and 1995 washed out part of the road in lower Zion Canyon (Sharrow 2016). The 1995 landslide, containing roughly 110,000 yds^3 of rock, displaced the Virgin River over its banks, stranding over 300 people at Zion Lodge (Solomon 1995).

Large rockfall events are also part of the park's history. In 1880, a rockfall at the Grotto region covered a spring and large pine trees (Woodbury 1950). Other large rockfalls have been observed in Zion and Kolob canyons. Medium-sized falls also affect the park. In the 1920s, a road worker was crushed by a boulder during the construction of the switchbacks on the Zion–Mount Carmel Highway. In 1947, a boulder from the Springdale Sandstone formation above the park's maintenance yard damaged buildings and vehicles (Figure 1). In 2015 and 2016, blocks of Springdale Sandstone broke off and landed on the Zion Canyon switchbacks, closing the Zion–Mount Carmel Highway for up to four days and forcing travelers to take a 170-mile detour. Smaller rockfalls occur regularly and have injured visitors. People have been struck at least twice in the Narrows region, causing minor injuries. Rockfalls have repeatedly hit the maintenance yard, and regularly fall into roadways. Debris flows also affect the Kolob Canyons Road, with one flow depositing up to 12 feet of debris over 200–300 feet of road in 2005.

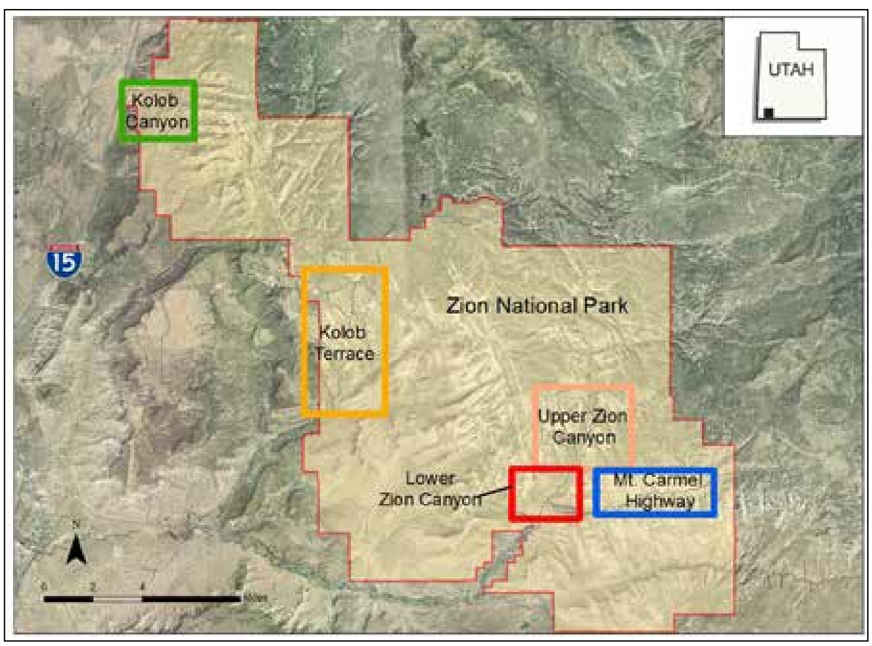

Figure 2. Location of Zion National Park in southwest Utah, and the corridors within the park that were rated with the Unstable Slope Management Program methodology.

Despite the historical frequency of landslides and rockfall, few people have been seriously injured or killed by them in the park. However, these slope failures threaten park infrastructure, staff, and visitors, necessitating an understanding of the locations and severity of slope hazards in high-use areas, transportation corridors, and points of interest, such as Zion Lodge.

To identify and rate slope hazards in a timely, cost-effective manner, the authors of this paper adopted and implemented the Unstable Slope Management Program (USMP) rating protocol. The USMP is a set of proactive management decision-support tools, database frameworks, and guidance documents currently being developed for federal land-management agencies by the Federal Highway Administration's Western Federal Lands Highway Division, with support and guidance from the National Park Service, U.S. Forest Service, and Bureau of Land Management. Justin LaForge, a Geoscientist-in-the-Parks intern, rated potentially unstable slopes using the USMP tools with guidance from park staff and physical scientists from the NPS Intermountain Region and Natural Resource Stewardship and Science Directorate.

Slope Rating Methods

The slope-rating portion of the USMP requires quantitative site information and includes 18 categories for rating unstable slope hazards from either rockfall or landslide. The rating categories fall into three groups: preliminary rating, detailed hazard, and detailed risk.

- Preliminary-rating categories capture some basic elements of hazard and risk, such as frequency, magnitude, and potential consequence. Preliminary ratings can be used to reduce workload if slopes rate under a predetermined score. Conversely, preliminary ratings scores are added to detailed-hazard and detailed-risk scores if a full slope rating is accomplished.

- Detailed-hazard ratings seek to assess the general likelihood that an adverse event will occur at a given site. In general, the larger and more active an unstable slope is, the more likely it is to require unplanned and potentially extensive maintenance attention.

- Detailed-risk ratings seek to describe the potential impacts of an adverse event on an asset adjacent to the unstable slope.

The USMP rating system is designed to allow an experienced practitioner to rate 10–20 slopes in one work day. After two days of intensive training, a Geoscientist-in-the-Parks intern rated slopes along corridors that threaten park roads and buildings: Zion Canyon, Zion–Mount Carmel Highway, Kolob Terrace Road, and Kolob Canyons (Figure 2). These corridors represent paved roads heavily used by visitors.

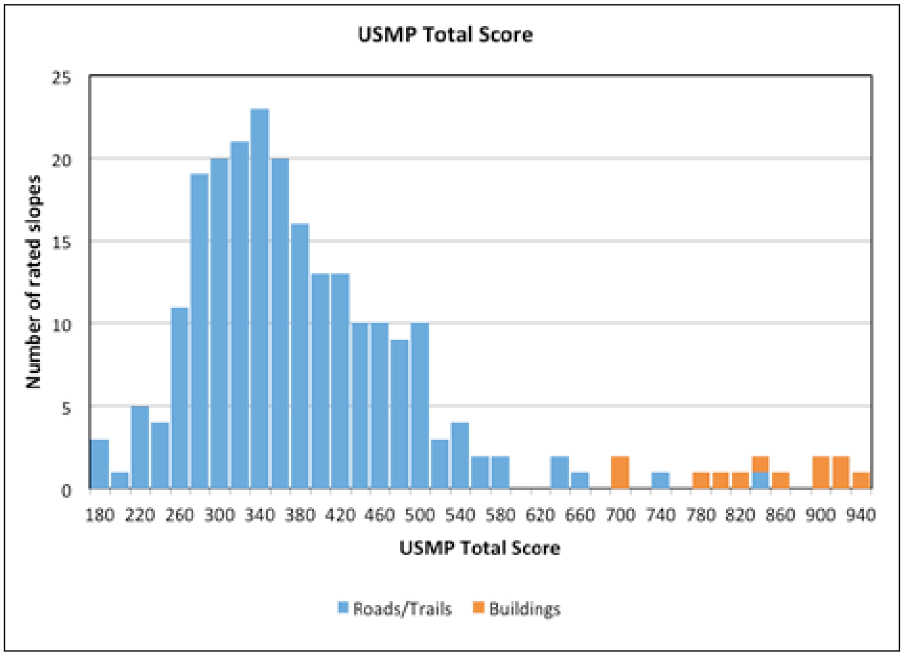

Figure 3. Histogram of USMP total scores for slopes in Zion National Park. These scores indicate the combined potential for an unstable slope event and the consequence it would have. Slopes that threaten roads or trails are blue; slopes that threaten buildings are orange. Note the skewed distribution of higher scores toward buildings. The four quartiles of his dataset are superimposed on the histogram.

All rating categories use an exponential numeric rating system, 3^x. This results in either a subjective score of 3, 9, 27, or 81 points or a calculated score capped at a total of 100 possible points. For example, the rockfall block size category is calculated as 3^x (max 100) where x is the representative rock block size in feet. Clear guidance dictates which conditions constitute which score. Total scores are the sum of the 18 categories. This exponential system, and the 18 categories, are intended to reduce differences in scoring between practitioners and highlight slopes that present higher risk, while expediting the process of conducting a condition assessment. Total scores are intended as a part of the USMP decision-support toolset to help identify slopes that could benefit from proactive management.

Results

We used the USMP methodology to rate 236 hazardous slopes throughout Zion National Park. Rockfall is the dominant geologic hazard at Zion. Along the rated transportation corridors, there are more than 230 rockfall slopes and only six landslide-affected slopes. We analyzed 12 slopes threatening buildings, 1 slope threatening a trail, and 223 slopes threatening roads. The coverage of this survey can be considered nearly complete for roads, partial for buildings, and only an initial test for trails. Figure 3 is a summary of total USMP ratings for the 236 rated slopes. The minimum slope rating score was 167 points. The maximum score was 932 points, with a mean of 386 points. Many slopes in the park would score below the minimum; we did not rate these in order to focus our attention on the most hazardous slopes. Comparing the scores for slopes along the road to the knowledgebase of the park road crew showed that the USMP scores were successful in identifying the slopes with a history of being most problematic.

Unstable slopes adjacent to buildings rated higher than unstable slopes along road corridors because of the high exposure of people to the slope hazard and the potential for damage to historic structures. The period of time when people are exposed to the hazard is much greater in occupied buildings than on roadways, even for roads in the park that are relatively heavily traveled. The Zion Canyon had the highest USMP total scores of the rated corridors (Figures 4 and 5) and also the highest number of scores in the fourth-quartile or top 25% (40).

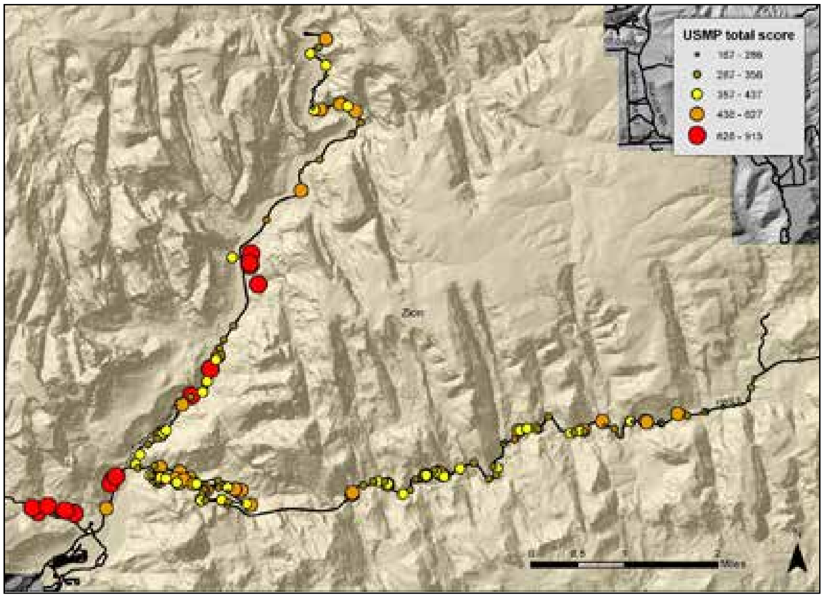

Figure 4. Unstable slope ratings for the Zion Canyon and Zion–Mount Carmel Highway corridors presented on a topographic map. Areas outside Zion National Park are grey.

The rockfall on the Zion Canyon Road trapped 12 vehicles up-canyon, prompting emergency shuttling of trapped park visitors past the rockfall. Critically, the USMP documentation of the slope prior to failure (Figure 6) allowed park staff both to understand the mechanism of failure (undermining) and gauge the potential of subsequent rockfall during cleanup. While the slope that failed (Figure 7) was not the highest-rated unstable slope (45 of 236), it had been identified and inventoried, and its mechanism for potential failure was recognized.

Photographs taken during the survey before the rockfall allowed park staff to determine that the undercut portion of the cliff had failed and that other portions of the cliff were not at immediate risk for failure. However, two large rocks partly dislodged during the rockfall had to be removed before cleanup could safely begin on the road below. While waiting for a blasting contractor to arrive on site (estimated to take three days), a park ranger suggested using a fire truck and water cannon to manually undermine the rocks by assisting the previously identified failure mechanism. After two five-minute sessions of spraying, both rocks came down and, after a drying period, cleanup began (Figure 8).

Rockfall after slope rating

The early winter months of 2016–2017 produced a number of unstable-slope events. Monthly precipitation for December and January was over an inch greater than the average 1921-2010 precipitation for each month. It is likely that this wet winter played a significant role in producing rockfall. The Zion Lodge was struck by rockfall twice, with only minor damage. Trails were closed due to rockfall, and a significant, road-closing rockfall blocked the Zion Canyon Road north of Zion Lodge.

Slopes responsible for the rockfalls at Zion Lodge and the Zion Canyon Road had been rated prior to these events. Both slopes rated in the fourth quartile of the USMP total scores. The slope behind Zion Lodge rated high largely because of the presence of the lodge. The slope that failed and blocked the Zion Canyon Road rated high based simply on application of the USMP rating criteria—just like hundreds of other potentially unstable slopes rated during the USMP trial in Zion National Park.

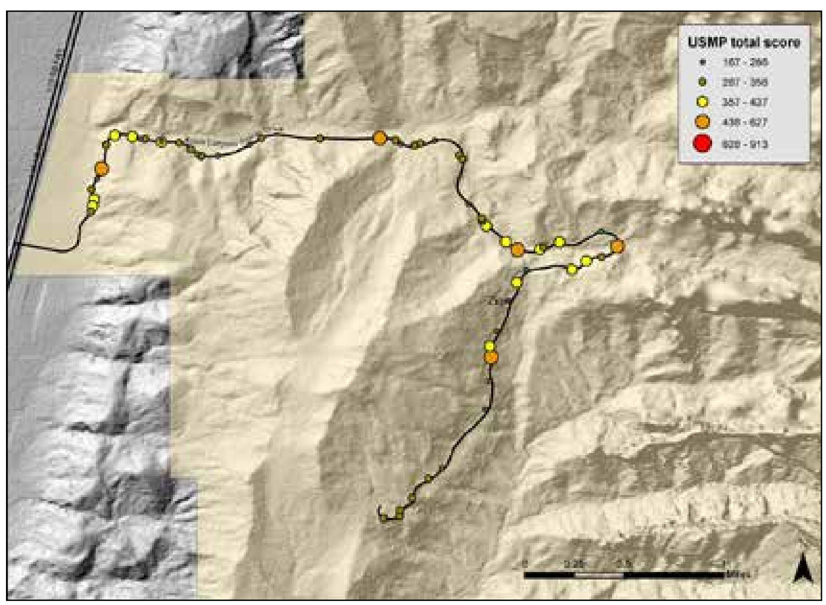

Figure 5. Unstable slope ratings for the Kolob Canyons corridor presented on a topographic map. Areas outside Zion National Park are grey.

Figure 6. A photo of the slope that produced road-closing rockfall in January 2017. This photo, along with several others, was taken during USMP slope-rating activities and stored in the USMP database. The database identified this slope as unstable and prone to rockfall, with a potential failure mechanism of undermining as well as the presence of fractures to facilitate large-block release.

Figure 7. The rockfall that closed the Zion Canyon Road in January 2017, trapping 12 vehicles up-canyon. This rockfall—composed of large, sandstone blocks—occurred after a precipitation event due to undermining of the sandstone blocks, as identified in the initial USMP rating.

Discussion

The USMP slope inventorying and rating methodology is a cost-effective, efficient way of identifying potential unstable-slope hazards and providing a transparent ranking system that could assist with proactive slope mitigation in the future. Emergency responses to road-blocking rockfall in Zion (such as the 2015 closure of the Zion–Mount Carmel Highway), are estimated to be 4–5 times more expensive than if slope mitigation was planned and executed at a time of the park's choosing. We suggest that the failed slope that blocked Zion Canyon Road in January 2017 could have been mitigated if identified earlier. This unstable slope, while rating 45 of 236, was not a towering, vertical cliff

Figure 8. The successful use of a directed water jet to undermine two unstable sandstone blocks. The slope was permitted to dry for 24 hours afterward before crews could begin removing rock debris from the road below.

and thus did not present the complex, costly mitigation options that some other, higher-rated slopes do. This rockfall provided some validation of the USMP method to efficiently inventory and rank unstable slopes threatening assets on public lands.

Importantly, the USMP rating is only a starting point for proactive management of unstable slopes. Slope ratings alone do not include a cost-benefit analysis for slope mitigation; they lay the groundwork for proactive management. Using the USMP to identify and provide a first-cut ranking for unstable slopes allows a more detailed cost-benefit or risk-reduction analysis to be completed. Without the initial and efficient USMP rating work, the task of potential proactive management can seem insurmountable in parks renowned for their natural scenery, which is often formed through processes that involve natural hazards.

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—CULTURAL RESOURCES—

A Review of Changing Ruins Conservation Approaches at Tumacácori National Historical Park: A Case Study of the Convento Compound

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Abstract

The convento compound at Tumacácori National Historical Park reflects changing preferences for how to preserve a deteriorating ruin. Protective sheltering and synthetic chemicals have been tried and additional approaches - reburials, replica walls, and reconstruction - have also received considerations. The article reviews how ruins intervention decisions have been reached amongst the stakeholders and how these decisions have affected the ruins in the last century. The review revealed that discussions over ruins are iterative and will remain an ongoing process as long as the original fabric remains. This is viewed as a positive rather than a negative, in that it engages people to think about the value and relevancy of their heritage.

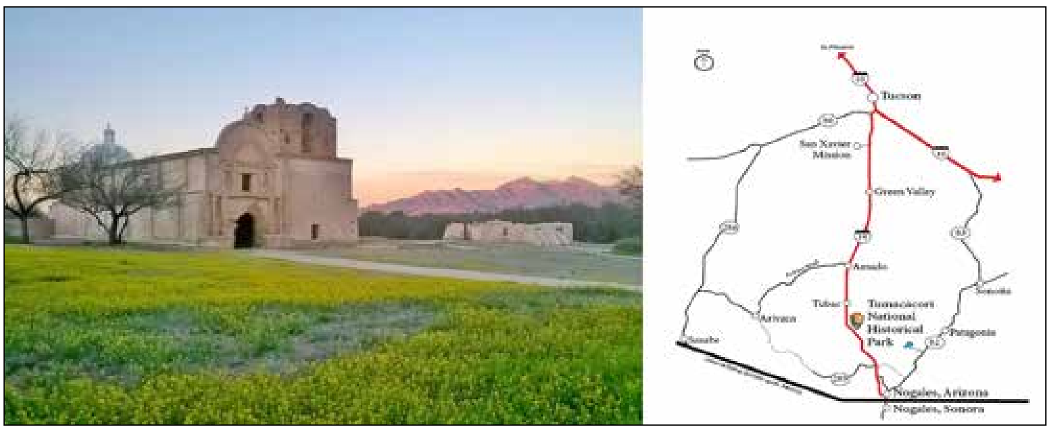

Figure 1. 1a: (Left) Mission San Jose de Tumacácori, Author, 2015; 1b: (Right) Map of Tumacácori National Historical Park, www.nps.gov/tuma, 2016.

Introduction

Preserving and interpreting ruin sites is contentious. What drives the decision making process and why do decisions change through time? The preferences for the experience and the protection of a ruin site vary widely. Some prefer an abandoned setting with only ruin features amidst the landscape. Some prefer to arrest all processes of weathering and vandalism. Yet another group believes in minimizing the time and labor on the ruins. Still others want to highlight the associated history through the physical remains and dictate how to experience a ruin. Not surprisingly, all good intentions lead to complexities and even conflicts.

Mission San Jose de Tumacácori, a part of Tumacácori National Historical Park (TUMA), is an excellent case study (Fig. 1). Due to an abundance of ruin features available at Tumacácori, the decisions for preservation have been contentious, often inconsistent, and on occasions even devastating to the ruins. In order to avoid the mistakes of the past, reviewing how the past decisions were made is crucial, if only to ensure that as public servants, the NPS does due-diligence as a caretaker of nationally significant sites. This article reviews the conservation history of the convento compound of Mission San Jose de Tumacácori. The article will show how the intervention at each feature was handled case-by-case, constantly reviving the similar discussions of which intervention method is best. The lessons from the review are summarized in the conclusion.

Background

Mission San Jose de Tumacácori was originally established by Jesuit missionary Eusebio Kino in 1697 and was abandoned in 1848. Between 1848 and 1908, the site was left neglected, was struck by an earthquake, and provided housing for travelers and settlers. To halt natural deterioration as well as deliberate vandalism and alterations to the ruins, the site became a National Monument in 1908 and was later classified a National Park. The early stewards of Tumacácori were preoccupied with the task of arresting the severe losses, and their choice was partial restoration.

funding was partial. Decisions were often stalled due to the difficulties in consensus-building. Emergency repairs also diverted attention from 'less important' ruins.

In particular, the convento structures, although collectively parts of one compound, currently stand disconnected from each other (Fig. 2). A convento is an enclosed space, defined by rooms usually arranged in a polygonal alignment that are accessible and connected by arcaded walkways along the interior-court-facing walls. It is also accessible from the church. The daily mission activities took place in workshops for metalwork, food production, and craft works. Priests resided in some of the rooms. The convento compound was constructed over time and continued to expand. It perfectly showcases the entire history of the mission including the Jesuit and Franciscan periods.

Figure 2. 2a: (Left) Mission foundations at TUMA; 2b (Right) Structures currently visible above ground, modified from 1934 Beaubien's map.

The condition of each structure varies widely. The Convento's leaning south wall is buttressed, while interior finishes on the adobes are disintegrating and detaching. The Granary, fully excavated in 1969, is losing its plaster on the interior and on the west exterior face. The northwing of the convento compound was excavated and re-buried twice and currently forms a mound. Even though it is not visible, it is very likely the best preserved part of the convento. The Jesuit church foundation, with all the walls gone, was outlined above ground.

During the three decades after 1908, Frank "Boss" Pinkley and the newly created National Park Service focused on stopping all vandalism at the site and on stabilizing the ruins (Barrow 2009, Moss 2007). Pinkley mainly focused on the Church by restoring the volume, massing, and certain design details to re-create the church in full scale. Yet, he abhorred the perspective of making the ruin look like a newly constructed church. Instead, he exercised enormous restraint against a total restorative impulse. When the aged and weathered features accentuated the ruin feel and were not at risk of failure, he left them alone. As a result, the visitors were encouraged to complete the reconstruction of the ruin in their own minds, instead of being dictated to through conjectural reconstruction based on partial evidence. Pinkley wanted the visitors to experience the ruin as broken and incomplete (Merriam-Webster, accessed on January 2016). The result of keeping intact even the past scars and deficiencies of the ruin - despite some irked visitors - was the opportunity to showcase the site's entire life, even after abandonment, as a document of history. Pinkley wanted partial restoration on other features at the mission but he never completely carried out the work. They were approached individually from 1940 until recently. Many factors contributed to this. People changed and

By the 1940's, the initial enthusiasm for the holistic ruins preservation work had subsided. Instead, repeated and similar discussions on how to intervene on each individual structure took place. Having multiple stakeholders, who always changed over time and represented the hierarchy of the NPS, ensured that the final decision for each convento structure, sometimes took a long time to reach. This was sometimes at the cost of irreversible loss of the ruin they all wished to save.

Convento Compound

Early Preservation Approaches

Unbeknownst to most visitors, the whole of Mission San Jose de Tumacácori is extensive, consisting of

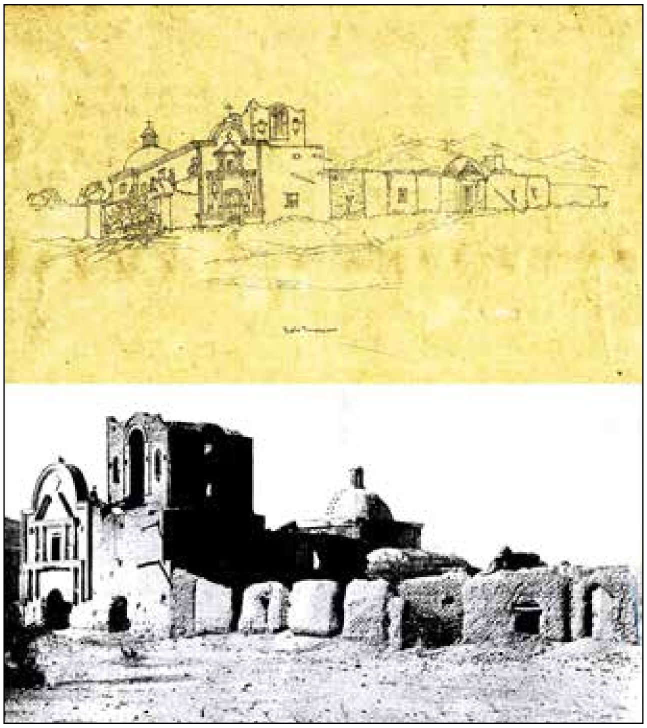

Figure 3. 3a (Top) A sketch of Mission Tumacácori, unknown, circa 1850, TUMA Archives; 3b (Bottom) Convento south wall, unknown, circa 1880, WACC Archives.

over a hundred rooms (see Fig. 2a). Roughly seventy rooms made up the convento compound. Only the foundations remain for most of them and they are currently not visible.

Early drawings from the 1850's show the intact convento south wall, complete with a dome over its main entrance space (Fig. 3). From the bell tower, the convento covered the area to the acequia/orchard. Even until 1890's, significant portions of the walls remained standing. A series of excavations - Beaubien in 1934, Caywood in 1962, among others - revealed that in addition to the main church and other above ground features, there were more extensive walled spaces that sustained mission living (Fig 4 and 5). Over time, most walls disintegrated and collapsed to mounds. Only the two rooms of the convento compound on the south side survived above ground (see Fig 2b). Although they do not represent the whole convento compound, they are often called the convento. To avoid confusion, the entire complex will be referred to as the convento compound and the two-room structure above ground as the Convento.

The adaptive reuse of the Convento was extensive. Between circa 1915 to 1923, it was used as a schoolhouse and Sunday school for area residents (Bourgeouis file, accessed in 2016). It was also used briefly as the residence for the site caretaker George Boundey between 1929 and 1930. After his family moved out, the building was used as the site museum between 1932 and 1937. Once the official Museum was constructed in 1939, the Convento became unoccupied.

In 1935, a report of Attwell and Gordon outlined the overall approach for the protection of the ruins (Attwell and Gordon 1935). The authors proposed that the Convento be restored, complete with roof over reconstructed walls, with the adobe arch fill by the previous dwellers removed to allow people to walk through, as the missionaries had done in the past (see Fig 4b). They also proposed the restoration of the buried walls for the purposes of interpretation (Attwell and Gordon 1935). In 1940, Frank Pinkley died suddenly and the tin roof was removed the next year. It is unclear whether this was to initiate restoration, but it never took place. For thirteen years until 1955, the Convento was left untreated and exposed, including the un-plastered exterior adobe walls as well as the plastered interior walls. It continued to erode.

Figure 4. 4a (Left) Convento excavation, notice the paved brick floor, P. Beaubien, 1934, WACC Archives; 4b (Right) A conceptual drawing of the arched entrance, A. Saunders, 1955, TUMA Archives.

Exploring Options

In 1953 TUMA superintendent Ringenbach predicted irreversible damages to the Convento during the rainy season (Ringenbach 1953). He wanted to avoid the 'unsightly' effect of a protective shelter over a convento. An alternative proposal by Dale King was to place restorative roofs and protective walls - later known as curtain walls - on all four sides of the exterior, mainly to protect the wall faces from wind-driven rain.

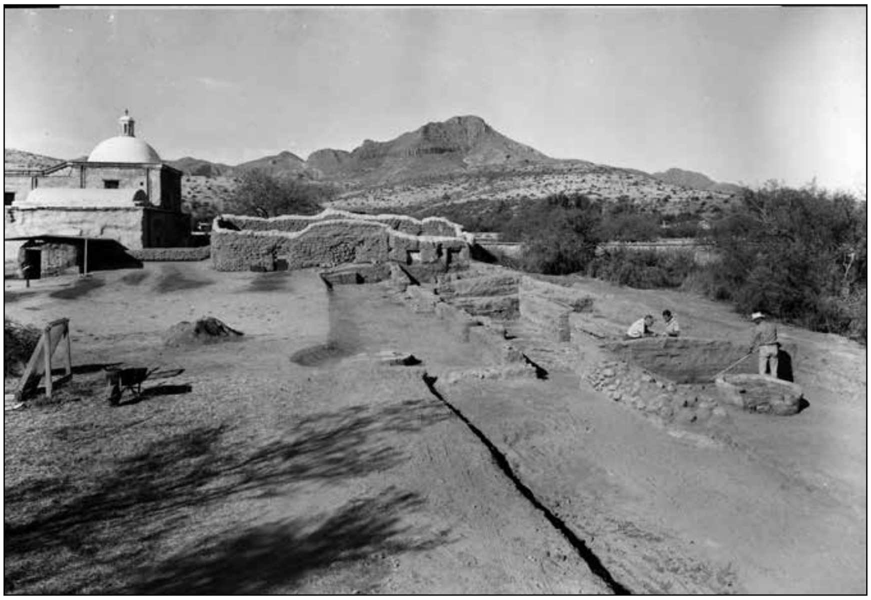

Figure 5. Exposed northwing convento, 1964, Caywood, TUMA Archives.

In the meantime, others investigated an experimental surface coating called silicones (or ethyl silicates) to avoid protective shelters. Through experimentation, they were still getting to know the effect of silicone coating on adobe walls. Unsure of its complete effectiveness, however, the NPS continued to keep all the intervention options available, including protective sheltering. To that end, a protective shelter was placed over the Corridor in 1953 and the silicones were sprayed on the adobe walls of the Convento in 1954.

Exposed adobe walls face numerous problems. The exposed adobe walls get hit by rain, sometimes wind driven. Rain drops physically abrade the wall surfaces. Wet clay particles, now coming loose, no longer act as a cementitious material and begin to run down the wall surfaces. As a result, the wall tops begin to narrow and the runnelling carves a path on walls. Wall bases erode somewhat differently. The water from the ground is wicked up by the dry adobe wall base through capillary action. The water carries dissolved salts in the ground and deposits them in the walls. The salty water travels upward at the base until water evaporates from the wall at a certain height. Crystallizing salts underneath the wall surface begin to exert pressure on adobes, leading to disintegration and coving. Typical basal coving is slow, but when left unchecked, can be quite damaging (Fig. 6a). In particular, when the wall base becomes too narrow, a whole wall, will collapse of its own weight.

We now know that the silicone coating is ineffective to arrest disintegration of adobes. Since ruins are exposed, water, both in liquid and vapor forms, will find its way underneath the protective film. Since the silicone coating has effectively sealed off all surfaces, any water now inside the wall is trapped and cannot naturally evaporate. As a result, adobes remain wet all the while the silicone coats bubble up and detach from water vapor pressure trying to escape. Dry adobes are excellent building blocks, but when wet, they crumble easily (Fig. 6). Permanent loss is only a matter of time.

The same principles apply for any material used to keep water from entering the walls. Rather, the emphasis should be on how to facilitate prompt removal of water from the ruin based on familiarity with environment, construction and design types,

Figure 6. 6a (Left) Basal Erosion at Guevavi, Author, 2015; 6b (Right) Northeast sacristy wall collapse, Unknown, 2011, TUMA Archives.

building materials as well as use and maintenance routine. Portland cement stucco on adobe walls prevents the walls from drying and so do plastic sheeting, elastomeric paints, and even overly-thick lime plaster. All have been applied on adobe walls at various earthen construction sites with devastating results (see Fig. 6). A wet wall copes with the stress by simply shedding the unnecessary repair coat by following the laws of physics.

By 1955, neither sheltering nor silicone coating were fully adopted by the Park Service due to their respective drawbacks. Many felt the shelters were disruptive to the ruin landscape. As King noted earlier, they feared that once a shelter is in place, more shelters will be introduced to all exposed walls. To make matters worse, the basal erosion continued despite the protective shelter, which greatly puzzled the NPS (Gastellum 1955).


Figure 7. Detached lime plaster in Room 45 of the convento, Ringenbach, 1955, WACC Archives.

Protective Shelter

While the debate continued, lime plaster inside the Convento dramatically detached and shattered to pieces in early 1954, prompting a flurry of correspondence between Ringenbach and Gastellum (Fig. 7) (Gastellum 1954). By summer of 1954, additional people were called in for ideas.

On April 16-17, Ray Ringenbach, Charles Steen, Dale King, and Gordon Vivian gathered to decide the fate of the Convento (Vivian 1955). No two people shared the same view. Steen proposed a very limited protective shelter over the arch, considered the most important feature of the Convento. King preferred a canopy over the entire structure. Vivian stated his preferred choice, the use of silicone coating (Vivian 1955). The group did not come to consensus and the decision was postponed until the fall of 1954:

> *. . .It was the considered opinion of the group that measures to protect them [the ruins] must be undertaken as soon as possible and that* ***there is no further time in which to experiment.***
>
> *(1) Contour Plastering*
>
> *While direct contour plastering of somewhat similar walls has proved effective in other cases, in was determined that in this instance, many sections of the schoolhouse are too fragile to support either the weight of plaster or the shock of having the necessary nails down into the walls and the application of metal lath. This method was therefore eliminated from consideration.*
>
> *(2) Surface Applications*
>
> *During the past year, Superintendent Ringenbach made three applications of a surface preservative, ethyl silicate, to various parts of the building. While it appeared to be effective in shedding rain, it also formed a hard crust on the wall which separated easily from the material behind it. It does not appear that in the foreseeable future, we will be able to secure sufficient penetration to make this or similar compounds effective on structures of this type.*
>
> *(3) Curtain Walls*
>
> *The solution proposed by Naturalist King appeared to the group to be the only effective long-term remedy. This is, in effect, the construction of a building over the schoolhouse. It would consist of a roof supported entirely by posts or uprights, set within the schoolhouse. This roof would extend in cantilever fashion beyond the historic walls on all four sides. At the base of the historic walls a curtain or cut-off wall of water-*

proofed concrete would be laid to prevent the entrance of subsurface moisture. Between this foundation and the roof and as close to the historic wall as possible [underline by Vivian] would be erected curtain walls of stud, lath and plaster construction whose appearance would be similar to the plastered portions of the mission church.

Under this proposal, to which all present agreed, the appearance of the finished structure would be that of a small building, with flattish roof with a slightly projecting cornice molding, whose walls were a gray to tan plaster. No part of the historic building would be seen from the outside. Inside, the present fill would be removed to the original floor level and all visitation would be through the interior of the building. (Vivian 1954)

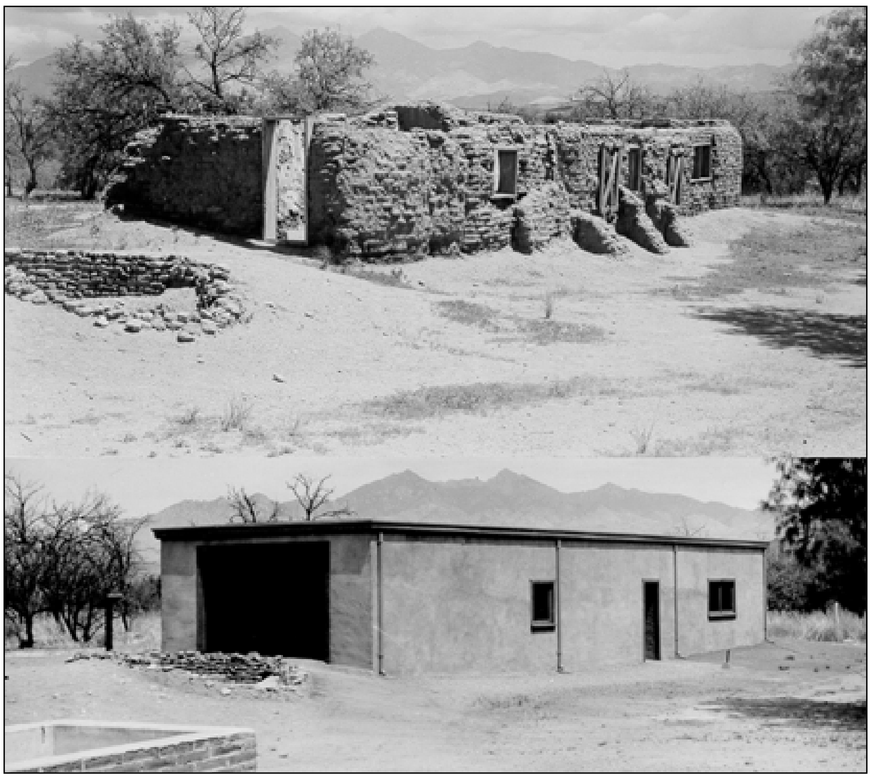

Figure 8. 8a (Top) Convento, unknown, 1947, TUMA Archive; 8b (Bottom) Convento shelter west opening, unknown, 1955, TUMA Archives.

The result was a complete box-shape structure (Fig 8). Despite some occasional changes to the original sketch for the shelter– most notably, removing the west protective wall so that visitors walking by could peep inside, the protective shelter, complete with side 'curtain' walls, were finally placed over the Convento in 1955 (Gastellum 1954). The plan to place a glass in front of the arch was dropped due to the reflection on the glass. Instead a porch was added over the window for the Spanish arch by September of 1955.

Even after the shelter construction, Ringenbach continued to monitor the Convento:

There is a definite dampness which has permeated sections of wall. Wall on the west end, which is open, receives some of the driving rains from that direction. The arch is only partially protected and receives some driving rain from the north. The east section of the north wall, inside, shows a definite water saturation approximately 24 inches above the ground level, for a height of 12-18" only. Since the foundation of the protective cover is beneath the walls of the adobe schoolhouse we are at a loss to explain the dampness.. (Ringenbach 1955).

He also mentioned the perpetual problem of basal erosion at the Corridor despite the shelter over it:

. . .Also, I feel that we should do something to the corridor this winter to try to eliminate, if possible, the basal erosion... [T]here is quite a bit of mounded dirt on each outside wall of the corridor which is a moisture collector and container. We discussed the possibility last March of removing this side fill to a lower ground level and then going beneath the ground level foundation and applying some type of preventive against further capillary action... (ibid)

What to do after a mound is excavated

With the Convento issue settled for the time being, the NPS now turned its eyes on other parts of the convento compound, the northwing of the convento and the Granary (see Fig 2). Albert Schroeder, an interpretative archeologist, had this to say:

I cannot honestly give a justification for the construction of a protective shelter over the granary at Tumacácori. . . We have a curtain-walled structure over the school house now. If this new proposal for the granary were put into action we'd have another curtain-walled structure or shelter roof. Since it conceivably will be necessary to eventually cover or protect everything above ground at Tumacácori in one fashion or another, in years to come we'll wind up with a monument to preservation measures and techniques. The end result will be a confused public looking at a variety of modern exteriors, inside of which remnants *of old walls will be visible, all of which will require considerable interpretation in order to separate the old from the new. The entire atmosphere and appearance of a mission exterior and its adjoin buildings will have been largely covered, destroying the impact of the original appearance of the site... (Schroeder 1955)*

He then suggested an alternative.

. . .I believe the average visitor will derive more pleasure going through a restored building, such as the Great Kiva at Aztec, or a historic structure or site, such as Williamsburg, than seeing a remnant of a pueblo or a broken down shack or outlines of foundation walls. By this I don't mean to imply that we should restore everything. However, when the problem of preservation of a unit of or entire historic structures does arise, I believe restoration should be considered first... (ibid)

Charlie Steen had a different idea:

At the present time the ruins of the Tumacácori Mission church stand almost alone, with little evidence of the large establishment which once surrounded the church. Most visitors find it difficult or impossible to re-create, in their minds, the buildings which once stood where there are now only low mounds. . . A possible method of presenting and interpreting these structures, which I personally am inclined to favor, would be to backfill the ruins to a predetermined grade and construct replicas of the existing wall remnants atop the fill. What we have in mind is the sort of thing that was done with individual house remains at Jamestown Island.

The new work would be done with the same type of materials as the old, except that we will be able to treat mortars, bricks, and adobe bricks in order to check disintegration by weathering. . . (Steen 1959)

Without the final preservation option firmly in place with full support from all the involved, Louis Caywood began re-excavating the northwing convento in 1962 (Fig. 10). The ruin was exposed to the elements for the first time since Beaubien's 1934 excavation. With preservation in limbo, a new, and even fiercer discussion than the 1955 shelter stormed over Tumacácori.

As one might expect, chemical coating and protective shelter options resurfaced. A colleague of Vivian, Roland Richert, had been experimenting with Pencasula spray coating which was ineffective (Richert 1966). With chemical option out of the question, three new additional approaches were explored. Reburial

Figure 9. Convento shelter, unknown, 1993, TUMA Archives.

of the feature was listed as the number one option but most people did not like it for taking away the interpretive potential. The second option included replica walls on top of the re-buried walls. Finally, plastic sheeting over the exposed walls was mentioned as a temporary measure, which eventually took place while the discussion continued. Yet another approach, wall veneering and partial reconstruction, by historic architect Russell Jones, was suggested to use 'the original wall remains as a core, veneer the sides and vault over the top with soil cement adobes' (Jones 1966). He further proposed that 'after these are in place they could be chipped and wire brushed to give an aged effect' and that 'in places, windows could be installed to allow a view of the original remains' (ibid).

Not surprisingly, with more options on the table, a consensus was impossible. Chester Thomas summarized the frustration:

. . .It is obvious from the correspondence that some decisions need to be made and before we take any action leading to permanent or semi-permanent stabilization for the outbuildings attached to the Mission proper.

It appears that Tumacácori has been treated as a kind of stray cat. Each time we propose to stabilize the structures either the interpreters, the historians, the Regional Director or the Superintendent himself does not agree… I don't believe it was the intent to backfill the convento and also place a protective shelter over it. In passing it might be well to observe that Tumacácori has, in the past several years been the subject of an undue amount of equivocation and indecision. To come up with a straight forward plan, it is my suggestion that a hard hitting team study the whole layout and hammer out a plan of action for the preservation of the convento, granary, lime kiln and ore furnaces as well as taking a close look at the mission with its corridor and barrel vault sacristy. The corridor has a jerry-rigged corrugated iron roof.

We shall be glad to participate in any way possible but it is not our province to make the decisions as to what is to be done with the various facilities.

Please, can we not get straight with the area and get going on a plan to save the ruins before it is too late. (Thomas 1968)

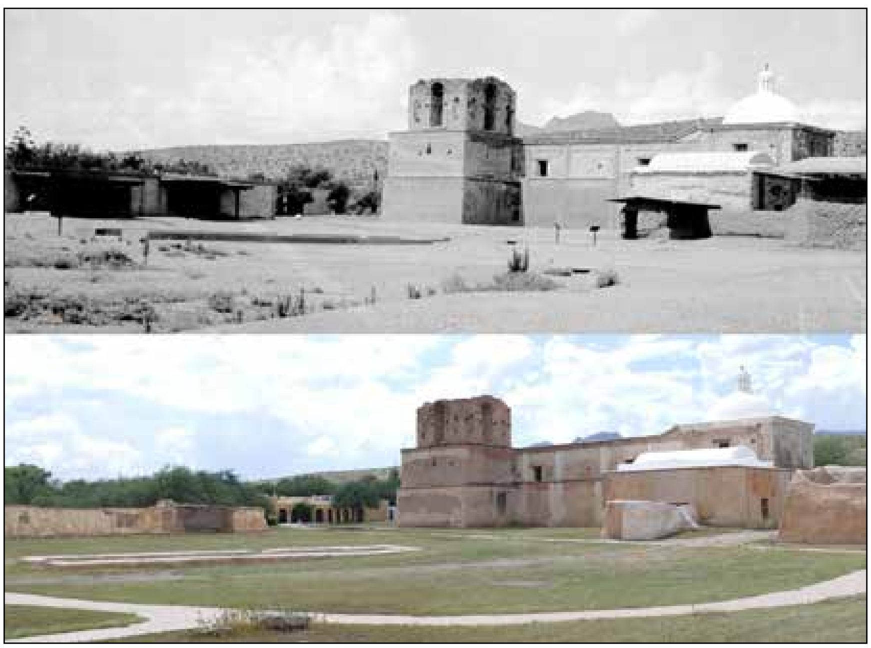

Figure 10. 10a (Top) Convento compound, unknown, 1973, WACC Archives; 10b (Bottom) Convento compound, Author, 2017

In the end, superintendent Ringenbach decided on the reburial. The northwing convento remains buried to this day (see Fig. 10).

Granary

Unlike the Convento and the northwing, the decision on how to protect the Granary was rather prompt and lacked extensive documented discussions. It was driven largely by archaeologists in charge of the excavation. Until the excavation by Richert and his team, the Granary had received minimal preservation work except for 1962 soil-cement cap on the wall tops (see Fig. 5). When Ronald Richert and Martin Mayer reburied the north wing convento and excavated the Granary interior, they took measures to ensure that the protective shelter would be placed over the Granary walls. To do this, they dug eight holes through the original floor of the Granary to host shelter posts. By 1971, a simple metal roof shelter was placed over the Granary (see Fig. 10a). The shelter lasted eight years.

New Approach

All Shelters Go Down

In 1979 both the shelters over the corridor and the Granary were removed by Anthony Crosby, a historic architect. He wrote:

…This structure (corridor) is representative of a preservation philosophy that too often leads to exaggerated deterioration. The most appropriate method for preserving extant, above grade, ruin walls is the incorporation into the preservation plan of a cyclic maintenance program. However, once such a dramatic step as a separate protective roof is installed, it is assumed to be permanent, and any maintenance would appear to be unnecessary. But, in fact, if the roof had not been erected in 1953 and instead the structure had simply been maintained using compatible materials, it would certainly be in better condition today… (Crosby 1985)

Regarding the shelter over the Granary, Crosby also emphasized that '...the roof was a significant visual intrusion on the entire site as well as on the granary itself'. (ibid)

The shelter over the Convento was still standing in 1981 but with significant changes:

…Although no work was done on the south convento, or schoolhouse, itself, all of the siding was removed from its protective shelter in anticipation of the eventual complete removal of the obtrusive structure… Deterioration along the wall bases was more severe than expected, with deep cavities on the north and south sides caused by burrowing rodents. In addition,

> *in spite of its earlier bracing with a tie rod, the south wall of the school house had obviously leaned to the south after installation of the protective shelter, as could be seen by pressure on one of the studs by the adobe wall. (Chambers 1981)*

In 1985 Crosby wrote:

> *...In addition to not providing the best protection, primarily because of the significant increase in the ambient moisture under the enclosure, the shelter effectively screened the ruin itself to all but a limited inspection. In conjunction with the removal of the protective shelters over the corridor and the granary (in 1979), a determination was made to also remove this shelter and protect the ruin by preservation maintenance. However, when the exterior plasterboard was removed and the entire building could be adequately assessed, it appeared that the structure was in far worse condition than originally thought. The shelter was serving to some extent to support a portion of one of the adobe walls, but even if that problem was adequately resolved, the building could not withstand direct exposure. Therefore, it was recommended that either the existing shelter be modified to adequately protect the building or a new one should be constructed. After an evaluation of various alternatives was completed, the National Park Service decided to modify the existing shelter… (Crosby 1985)*

In other words, while the shelter may have arrested the active deterioration of the interior surface finishes and the Spanish arch, overall it led to increased wetness at the wall base, further displacing the already weak south wall. The problem was such that, even though Crosby advocated for removing shelters, out of a concern for the total collapse of the walls, he was forced to not remove the shelter! In short, the shelter made the convento even weaker (Fig. 9).

Ultimately, the Park removed the shelter over the Convento in 2000 after forty-six years of existence (see Fig 10b). Steve Gastellum recalled the negative impacts of microclimate created by the shelter (personal communication, January 4th, 2016). In particular, he noted that there was a continuous wetting on both the interior and exterior bases of the east wall. David Yubeta also mentioned the Park's desire to remove the unsightly shelter before it turned fifty years old (personal communication, January 8th, 2015). Both Gastellum and Yubeta felt strongly that the shelter was unsightly and believed they could maintain the Convento without it through cyclic maintenance.

The sheltering idea died hard. Between 2001 and 2003, a temporary canopy was placed over the Convento during the summer monsoon season. In 2003, the University of Arizona was approached to study a new shelter design (Jeffery and Messina 2004). In the end, however, the shelter was never constructed.

Summary And Conclusions

Everyone is told ruins are a shared heritage and is asked to take ownership in them. Yet, when it comes time to protect them, everyone puts forth different points of view. The convento compound discussions demonstrate this clearly. The debate is still continuing.

Ruins preservation is a collective decision done over time. In the U.S., at least in principle, all inputs from the society members are encouraged, even though certain designated entities, such as the National Park Service, may serve as a representative for all and pull the inputs together.

By engaging every stakeholder in preservation work, the ruins can become a catalyst for getting people together, reaffirming shared values, and celebrating diversity. However, as the convento compound illustrates, coming to a long-lasting consensus requires diligent and timely planning. Several lessons are drawn:

- All stakeholders should participate in the decision-making process. Leaving out a group may seem convenient, but in the long run, it excludes opportunities for exploring all options.
- Put in place a long-term preservation goal and planning. Without a long-term goal of resource stewardship, an individual intervention runs the risk of lacking consistency and landscape-level cohesion.
- A preservation approach thought to be most reliable at the time trumped speculative science, controversial design solutions, or well-intentioned but impractical interpretative initiatives.
- The ultimate decision maker and of the specific responsibilities of each participant based on expertise need to be clearly identified and be understood by each other.
- The final decisions on intervention are not really final in the continuing life of a ruin site. Even after implementation, the chosen interventions require constant evaluation for improvement, modification, and even replacement.

- All discussions should be documented and archived, complete with photographic evidence and any data. This ensures that the intention and the actual effectiveness of each option could be reviewed and evaluated later, even after changes in staffing.
- Science-based decisions after empirical studies, quantifiable and visual recording of change over time of the original fabric, and the objective evaluation of the effectiveness of the repair materials and techniques may take time. However, they are fundamental to the transparent and evaluable site stewardship.
- Interventions should be preventive, and go beyond remedial. The participants should diagnose current problems and symptoms, evaluate previous interventions, and prescribe solutions and designs aimed at resolving underlying causes of problems.
- One should avoid looking for a universal solution to ruins problems. All ruin features are different despite similarities.
- Clear performance criteria for each intervention should be laid out. The basic principles of ruins conservation apply.

The final message is the importance of educating and reminding people why a specific option was chosen and for what purpose. Any intervention is a direct reflection of how and in what aspects a ruin site is appreciated and valued. If a chosen method cannot be shared and supported broadly, it cannot be sustained. Soon, it will lose public support. Heritage is collective, not individual.

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—NATURAL RESOURCES—

Bats of Devils Tower: Searching for Answers in Unusual Places

By Rene Ohms (Chief of Resource Management), Amy Hammesfahr (Biological Science Technician), and Philip Knecht (Climbing Biological Science Technician)

It's not surprising that the landscape of Devils Tower National Monument (DETO) provides suitable habitat for bats. How could a bat not love such a warm, sheltered and prominent geologic monolith, a diverse forest, and an endless insect buffet?!

History of Bat Work at Devils Tower

On several warm summer nights in 1997, the first bats were caught in a mist net at Devils Tower, and included the big-brown bat, long-legged myotis, fringed myotis, silver-haired bat and little brown bat (K. Geluso 1997, unpublished data). Years later, in 2010 and 2011, the University of Wyoming's Wyoming Natural Diversity Database (WYNDD) conducted an acoustic and mist net survey at DETO (Griscom and Keinath 2011). Additional species were documented (hoary, eastern red, northern long-eared, and western long eared bats), bringing the total known bat species at DETO to nine. These surveys were initiated not only to provide baseline inventory data, but also due to concerns about the spread of white nose syndrome.

White Nose Syndrome

White nose syndrome (WNS) is an often-fatal fungal disease in bats caused by *Pseudogymnoascus destructans*, known as *"Pd."* Since the introduction of the fungus in New York in 2006, WNS has decimated bat populations, especially *Myotis* species in the eastern United States. In March 2016, WNS was discovered in Washington state, thousands of miles from the last known Pd-positive county. This unexpected spread underscores the need to compile basic ecological data about bats in WNS-free areas and to take action to prevent the introduction of the disease.

Over the last decade, researchers have made great progress toward understanding how the disease spreads, discovering possible new treatments to cure infected bats, developing protocols to disinfect Pd-contaminated equipment or surfaces, improving surveillance methods, and creating a list of questions to guide future research on the disease.

Northern Long-Eared Bats at Devils Tower

One of the species that has been hit particularly hard by white nose syndrome is the northern long-eared bat, *Myotis septentrionalis*. Although it is primarily an eastern species, the bat's far western range includes

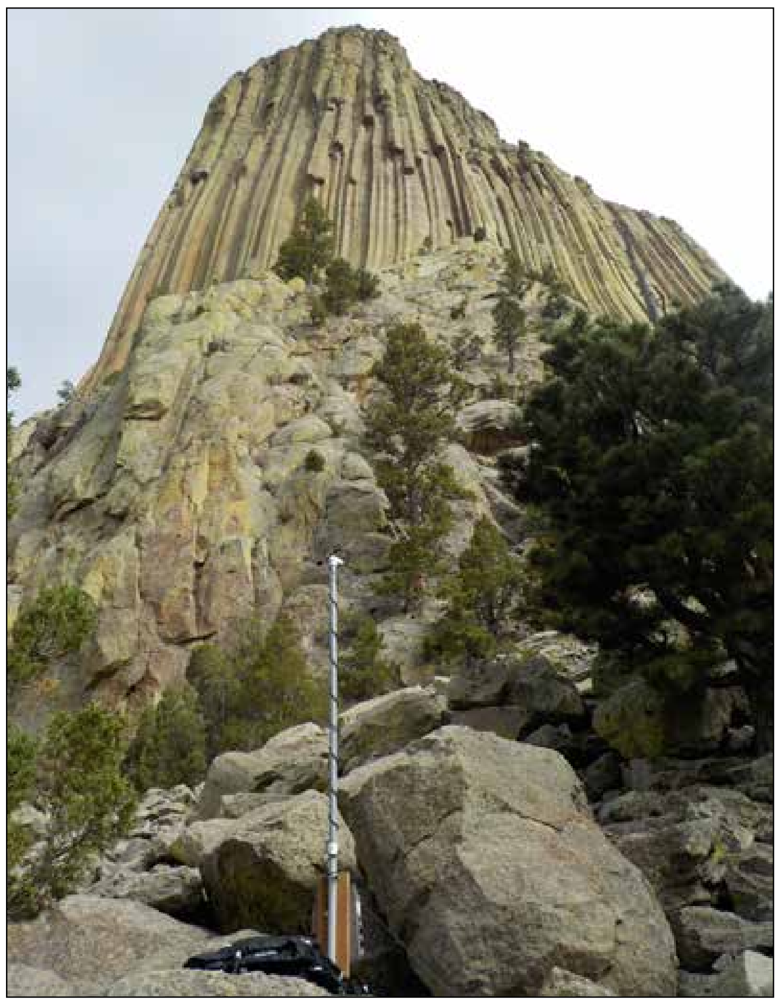

Figure 1. An acoustic monitor and ultrasonic microphone at the base of Devils Tower.

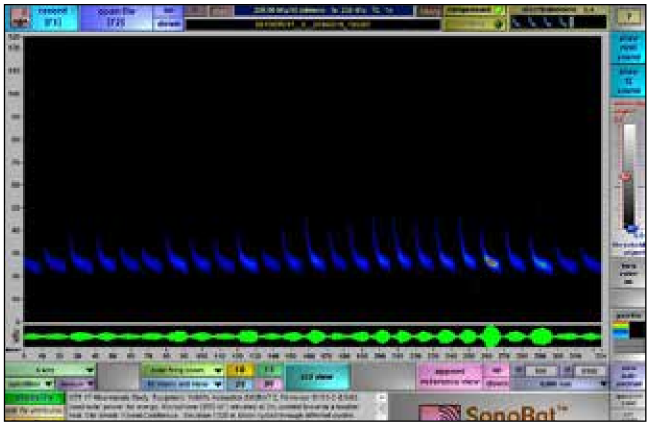

Figure 2. Specialized software is used to analyze echolocation call data and identify the species that produced the call.

Devils Tower. To learn more about the northern long-eared bat at DETO, the park began its first park-wide acoustic survey in 2014. Passive echolocation call monitors were deployed, and in addition to northern long-eared bats, several other species were recorded. (See Figures 1 and 2)

In May 2015, the northern long-eared bat was listed as threatened under the Endangered Species Act. Northern long-eared bats in the West live in different vegetation types, at higher elevations, and in different climates than their eastern counterparts. Much of the existing literature has focused on northern long-eared bats in eastern ecosystems, and information on the bat's preferred habitat along the western edge of its range is limited. Learning where the bats roost is critical to the protection and recovery of the species, and without these data, the park lacks the knowledge to make informed management decisions.

To fill this data gap, DETO initiated a two year radio-telemetry project under a CESU agreement with the University of Wyoming. In 2015 and 2016, several adult male northern long-eared bats were captured and radio-tagged, then tracked to their day roosts. (See Figures 3 and 4.) These bats were tracked to bur oak and ponderosa pine trees. The roosts included dead and down trees (with the bat less than 2 feet from the ground!), decaying portions of live trees, snags, and small-diameter oaks. All preferred trees had one in thing in common, some component of decay, and the bats were found in cavities or under sloughing bark (Abernethy et al. 2017). During this project, two new species were also added to DETO's species list, the western small footed bat and Townsend's big-eared bat.

Figure 4. Biological science technician Andrew Lyons-Gould tracks a bat in 2016.

Figure 3. Ian Abernethy, UWY Lead Zoologist for WYNDD applies a radio transmitter to a bat in 2016.

What About The Winter?

Devils Tower lacks caves or mines, and although it had been assumed that DETO's bats migrated elsewhere to hibernate, no one had actually looked for them in the winter until recently. Late in 2014, park staff set up an acoustic monitor and let it run during the winter months, and were a bit surprised to pick up some bat activity! Now the question was, "If bats are in the park in the winter, where exactly are they?"

Figure 5. The talus field below Devils Tower may be a winter hibernaculum.

Continued acoustic monitoring in subsequent winters has helped the park zero in on the area near the Tower, but a specific hibernaculum has yet to be found. The most suitable hibernation sites at DETO are likely beneath the boulders in the talus field at the base of Devils Tower (see Figure 5), or possibly in cracks of the Tower itself. Finding hibernacula is key to protecting bats from winter disturbance and the introduction of white nose syndrome, and is a top priority for bat management at DETO.

Searching for Bats in the Tower

To see if the Tower and surrounding boulders provide suitable bat habitat at any time of the year, DETO began focusing the search to these areas. In 2016 and 2017, the park hired two climbing biological science technicians to investigate cracks on the Tower and locate bat roosts. Because looking for bats in rock crevices with the naked eye can be like looking for a needle in a haystack, the team developed a systematic method to help them narrow the search.

The night before a climb, the climbers laid beneath the Tower, ensuring they had good contrast between the rock and sky, and waited for bats to emerge. They took detailed notes each time they saw a bat emerge, pinpointing specific areas of the Tower to prioritize their survey. The next day, they would climb a route to the summit, or an area above where the bat was observed, establish anchors, and rappel down to investigate the crack.

Once the crack was located, the climbers looked for bats using an endoscopic camera that can take both still photos and videos. (See Figure 6) If a bat was found, the aspect, depth, width, height from the Tower base, and orientation of the crevice was recorded to determine any trends. These data were used to determine which crack characteristics the bats prefer. The sample size is small (with just 8 bat roosts identified in the Tower to date), but so far the bats seem to prefer cracks that are horizontal, with roofs above them. Although the bats were not handled or measured for identification, most of the bats found in the Tower appear to be big brown bats. (See Figure 7)

Figure 6. Climbing biological science technician Phil Knecht searches for bats in cracks of Devils Tower, using an endoscopic camera.

Figure 7. A bat roosting in a crack on Devils Tower, photographed by climbing biological science technicians with an endoscopic camera.

In addition to the bats found by the climbers, Townsend's big-eared bats and fringed myotis were found roosting on both the Tower feature and in the boulder field in 2016. These bats were radio-tagged and tracked to these locations with the help of WYNDD staff. (See Figure 8) Female fringed myotis were tracked to the talus field, which indicates that the boulder field is a maternity site. The Townsend's big-eared bats were all males, and they chose roosts deep in the talus field, and along the eastern face of the Tower.

Future Work and Implications for Management

The introduction of WNS in Washington presents a puzzling predicament. The disease was found in an area without caves or mines, which is a game-changer when it comes to management and protection of bats in terrestrial environments. This discovery has pushed biologists to look for bats in unusual places, and to change the way we think about bats and their preferred roosts.

Bats have now been confirmed inside cracks of Devils Tower and the surrounding talus field for the first time, and from acoustic data, we now know that bats overwinter in the park. White nose syndrome continues to advance ever-closer, with new discoveries of the fungus or disease being added to the map each winter. Although the disease is spread primarily from bat-to-bat, research indicates that it is possible for people to spread the fungus if they bring contaminated clothing or gear into an uninfected site. With 5,000 climbers scaling the Tower each year, and thousands more visitors scrambling over the talus field, DETO is taking action to educate climbers and the general public about the spread of WNS and ways to protect bats.

Finding where bats of Devils Tower hibernate in the winter months is now the most important question facing park biologists. Winter weather conditions make it difficult to physically survey the Tower and surrounding boulders in the winter. Instead, DETO plans to partner with the WYNDD to capture and tag bats in the fall and spring, to track the bats to

Figure 8. Applying a radio transmitter to a Townsen's big eared bat.

hibernacula. As bats settle in for hibernation in the fall, and when they arouse in the spring, they will emerge to forage and then return to their hibernation site over a period of weeks. This is an ideal time to track the bats to hibernacula.

Devils Tower now has an extensive database of acoustic bat calls, and the park has learned much about the roosting habits of many of its 11 bat species, including the threatened northern long-eared bat. The results of the northern long-eared bat roost study are already being used to guide management decisions regarding forest management and development projects, for the protection of the bat and its roost trees. Additional work will continue to aid in the management and recovery of the species, the prevention of white nose syndrome, and the understanding of bats in this isolated and unusual landscape.

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