New perspectives on NPS paleontological resource stewardship: Scientific, curatorial, and educational outcomes at Petrified Forest National Park

William G. Parker, Adam D. Marsh, Matthew E. Smith, Ben T. Kligman, Deborah E. Wagner, Phillip Varela, and Diana M. Boudreau, ***Petrified Forest National Park***

ABSTRACT

Petrified Forest National Park (PEFO) was established to preserve fossils from the Triassic Period. After long relying solely on external partners, an internal paleontology program was established consisting of permanent staff and appropriate facilities to manage these extensive resources, primarily through active collection and curation. Goals based on National Park Service (NPS) policies allow managers to guide internal research priorities and those of external partners, more effectively reducing repetitive studies and increasing collaborations. Student interns play a crucial part of this effort, and many have gone on to establish or augment paleontology programs at other institutions and federal agencies, developing new partnerships with the NPS. PEFO permanent staff grew as park and regional management recognized the utility of the program. PEFO staff collaboratively develop new collecting and laboratory processing techniques that preserve high quality data, including a public laboratory where visitors watch the conservation of fossil resources in real time, bettering public understanding while simultaneously furthering research goals. This program has published nearly 100 peer-reviewed publications over the last 20 years, highlighting Petrified Forest as one of the best places on Earth to learn about and understand the Triassic Period, and providing an example for other NPS units on how to best protect and promote fossil resources.

INTRODUCTION

Petrified Forest National Park (PEFO) originated in 1906 when President Theodore Roosevelt used the Antiquities Act to proclaim the area as a National Monument to protect the "mineralized remains of Mesozoic forests." PEFO was designated as a National Park in 1962. This site in northeastern Arizona presently encompasses approximately 59,900 hectares (148,000 acres) and preserves one of the best records of terrestrial life during the Late Triassic (approximately 228–208 million years ago at the park). Although primarily established to protect thousands of exposed petrified logs, it soon became apparent that the park also protected other types of significant fossils, including leaves, insects, trace fossils, and bones of vertebrate animals. The naturalist John Muir had made the first recorded collection of fossil vertebrate material in 1905. These fossils ended up at the University of California Museum of Paleontology (UCMP) at Berkeley and resulted in several collecting expeditions to the park by that newly founded institution in 1921, and again in 1981. Other notable institutions that have conducted significant paleontological collection work in the park, especially from the time between the 1920s and 2000s, include the Smithsonian National Museum of Natural History, the American Museum of Natural History (AMNH), and the Yale Peabody Museum. The present paleontological resource program at the park was started in 2002 and consists of research scientists, fossil preparators, and a museum curator. The park paleontology program has documented more than 900 fossil localities, and the museum curates more than 25,000 fossils including more than 100 holotypes (the

CORRESPONDING AUTHOR
William G. Parker
Petrified Forest National Park
P.O. Box 2217
Petrified Forest, AZ 86025
William_Parker@nps.gov

NPS PALEONTOLOGY

representative specimen for a fossil species). Guided by National Park Service (NPS) Director's Order 77 ("Natural Resources Protection") the primary goals of the paleontology program are to: (1), inventory and monitor fossil localities in the park; (2), collect, prepare (conserve), and curate scientifically significant fossil resources in perpetuity for protection, education, and research; (3), utilize scientific best practices to answer questions the relationships between Life and Earth Systems in the Triassic Period; and (4), share the results of this work with the public and scientific community.

NPS units preserve some of the best fossil resources in the world. In many instances fossils were primarily discovered after a park's establishment for other purposes (e.g., Grand Canyon National Park, Chaco Culture National Historical Park), but in some cases the park was specifically set aside for protection of fossils (e.g., Hagerman Fossil Beds National Monument, Agate Fossil Beds National Monument, Dinosaur National Monument, Florissant Fossil Beds National Monument, Fossil Butte National Monument). NPS units not only have strong protection mandates, but the NPS Organic Act of 1916 clearly states that this preservation is for visitor enjoyment and education. Research provides the evidence for parks to determine and tell their fossil stories. Furthermore, a site such as PEFO should style itself as the educational and research authority on the resources it was set aside to protect. Therefore, PEFO should be a leader in producing information about the Triassic Period and bringing that information to the public as well as the scientific community.

PHILOSOPHICAL APPROACH

PEFO was established to protect fossils from the Triassic Period on the premise that their quality and significance were of global importance and worthy of the highest level of federal protection for the good of all. More than 100 years of management in the park have demonstrated that this is certainly the case and that PEFO protects some of the most important Triassic fossil sites in the world. NPS policy stipulates that these resources will be managed using the best available science. Thus, PEFO serves as an indispensable scientific laboratory that provides a unique window into the Earth's past. The paleontological and museum work done at PEFO is cutting edge, making the park a leader in Mesozoic paleontology. Reflecting on the reasons for protection and the science mandate for management, national parks should be the best representative places for research and education regarding the resources they protect, and PEFO should be the place that members of the public can go if they want to learn about the current scientific understanding of the Late Triassic Period as represented by its fossils. Furthermore, it is critical that experts are on staff to manage the program, provide consistency, ensure partners are meeting park goals, and provide overall expertise. This simple approach has guided the current paleontology and museum programs since its inception: 1), to establish a credible science program to ensure that the fossils of the park are managed to the highest possible standard; 2), to use scientific approaches and techniques to uncover the park story (i.e., to learn as much as we can about the Triassic Period from this specific location on Earth); and 3), to ensure that this information is disseminated to the public and the scientific community so that understanding of the fossils, like their management, is at the highest possible standard, and that the fossils and their contextual information are professionally recovered, conserved, and curated to be available for research and education in perpetuity.

INVENTORY AND MONITORING

NPS Director's Order 77 and the 2009 Paleontological Resources Protection Act require National Park units to conduct inventories for paleontological resources. Currently PEFO has more than 900 recognized paleontological sites, with the number growing annually. Presently the park protects 59,000 hectares (148,000 acres, the majority of which are fossiliferous Triassic rock exposures. 22,000 of these hectares (54,000 acres) were added since the Petrified Forest Expansion Act of 2004, which was passed by Congress to protect fossil-rich areas adjacent to the original park boundary. That legislation allows for an additional 24,000 hectares (60,000 acres) to be added in the future.

The park hired its first permanent naturalist in 1934 who immediately began discovering and collecting Triassic fossils for exhibit, and by 1941 there were nearly three dozen documented localities in the park. The first broad paleontological inventory was conducted by the Museum of Northern Arizona (MNA) in 1979 (Cifelli et al. 1979) in conjunction with the creation of a parkwide geological map. MNA revisited some of the historic NPS, UCMP, and AMNH sites and discovered several new fossil localities. However, documentation of that work is incomplete, and the usefulness of the report is limited because each site description consists only of a few sentences and there are no known photographs.

The present monitoring program began in 2001 and focuses on rediscovering "lost" historic sites and collecting detailed information on known sites, especially type localities and sites with high levels of diversity or excellent preservation. In 2001 only 170 vertebrate sites were recognized with several dozen more plant, invertebrate, and trace fossils sites. Localities that were documented only in field notes and topographic maps were better documented with GPS data and photographs (Parker and Clements 2004: 201–210). New localities are discovered annually, such that there are currently 513 vertebrate, 188 invertebrate, 186 plant, and 35 trace fossil localities. Especially important was the 2016–2018 paleontological inventory of lands added to PEFO in 2011 and 2015, resulting in the discovery of 72 new localities across nearly 22,000 hectares (50,000 acres).

GEOLOGIC FRAMEWORK

A significant issue facing park paleontologists in the early 2000s was that the park lacked a completed geological map. It had long been recognized that the majority of the rocks in the park were from the Upper Triassic Chinle Formation, originally named for rocks in the Chinle Valley of the Navajo Nation (e.g., Camp 1930; Ash 1974: 43–50). However, the separation of the sedimentary layers of the Chinle Formation within the park into distinct members was not agreed upon between researchers and the numeric ages of the rock units were not known. From 2008–2010 park staff created the first geological map of the park and developed a new stratigraphic framework that is still in use today (Figure 1; Martz et al. 2012). This map and stratigraphic understanding have been critical to understanding the evolution of Triassic life in what is now Arizona and

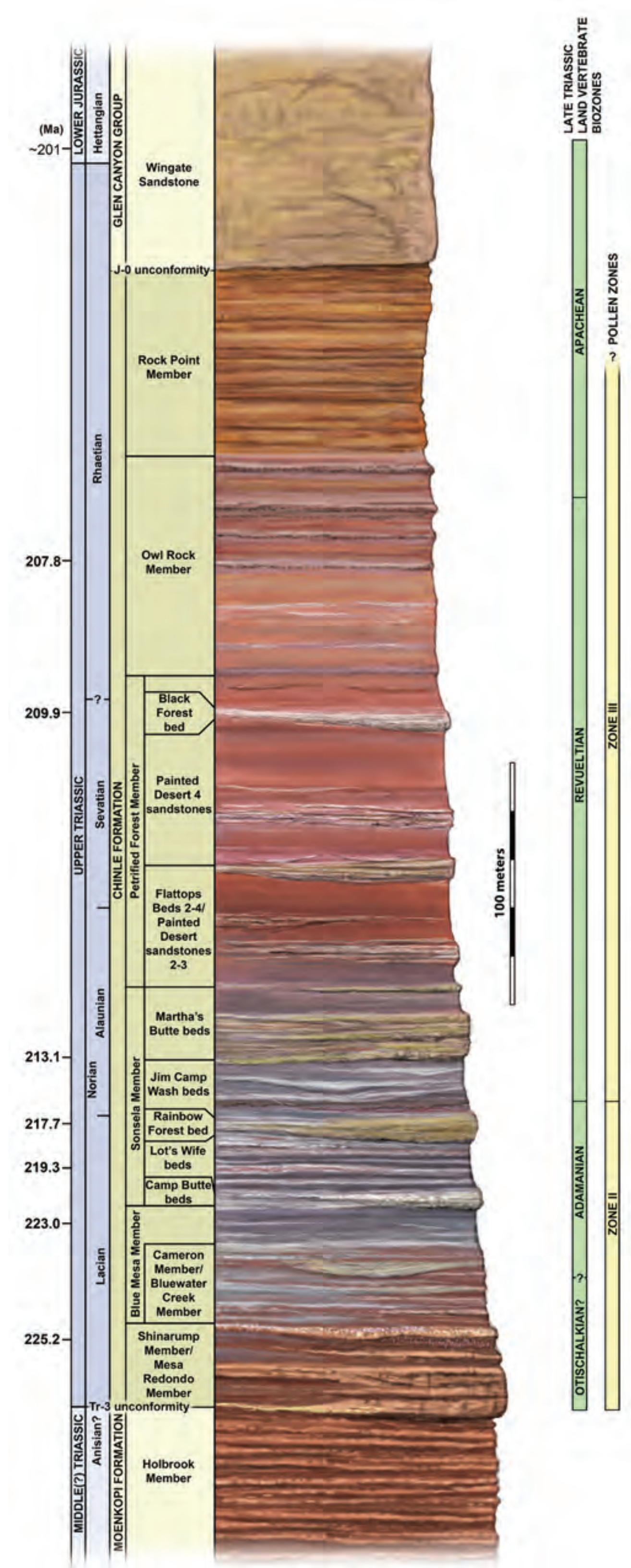


FIGURE 1. General stratigraphy of the Chinle Formation in northeastern Arizona based on geological mapping, stratigraphic correlations, and U-Pb geochronology. JEFFREY MARTZ

provides a geologic backbone upon which countless research projects rely (e.g., Olsen et al. 2018; Kent et al. 2019). The map allows for the placement of each fossil locality into the stratigraphic framework, revealing the relative ages of the sites in comparison with each other. Beginning in 2003, the first reliable radiometric dates for various rock units in the park were published, and today the Chinle Formation at PEFO is one of the best time-constrained Triassic rock sections in the world (Olsen et al. 2018).

Detailed geological mapping also affords paleontologists a method to place fossil occurrences more precisely in stratigraphic, and thus chronological, order. It had long been understood that the Chinle Formation in the park preserved at least two paleofaunal assemblages and possibly three paleofloral assemblages (Long and Murry 1995; Ash 2005: 59–70). When the mapping of fossil localities was completed, the presence of two distinct paleobiotas (Adamanian and Revueltian) in the park was confirmed. Furthermore, the stratigraphic level at which the composition of the plant and animal fossils changed was identified, and this boundary has been the focus of more detailed studies to further determine its significance (Parker and Martz 2010; Olsen et al. 2018). This is a good example of how an accurate geological map and detailed biostratigraphic work allows park scientists to target strata where our understanding is poor or entirely lacking.

FOSSIL COLLECTION

Fossil resources, especially fossilized bones, can be highly susceptible to damage and loss by erosion, vandalism, and theft. NPS has two recommended protection strategies: covering exposed fossils with a structure (e.g., the quarry building at Dinosaur National Monument), or collection and curation in an approved NPS museum facility. In addition to being important resources within a protected NPS unit like PEFO, fossil resources can have significant research importance. Fossils are the material remains of past organisms through time, and the fossils themselves are the physical evidence to support the park's significance. Many fossils at PEFO represent species new to science, and even fossils from already-known species are important because they provide information about populations, distributions (stratigraphic and geographical), and anatomical variation. The draft scope of collections at PEFO stipulates that fossils with a high research value (i.e., scientific significance) will be collected and reposited in the park museum collections. This includes voucher specimens for biostratigraphic documentation of species that are found at differing stratigraphic levels. PEFO paleontologists hold themselves to the same compliance standards as any external researcher would be, and in-house fossil collection done under inventory, monitoring, and targeted collections is done under an approved Scientific Research and Collecting Permit.

Fossils found directly on the surface are often broken and incomplete, in part because the expanding bentonitic clays of the Chinle Formation and other sites across the American West are destructive to fossils. Traditionally, paleontologists prospect for fossils by walking unvegetated hills of sedimentary rocks looking for fragments of bone from eroding specimens. After finding bone fragments, they search for the highest level with fragments and then dig into the outcrop in search of more complete material presumably in the process of being eroded. When the clay-rich rock containing the fossils gets wet from rainfall, it rapidly expands up to 30 centimeters (12 inches) perpendicular to a hill's slope, carrying portions of fossils with it and exposing them at the surface of the outcrop. Meanwhile, in the expanded clay between the exposed bone fragments and the fossil source material, repeated small changes in soil moisture steadily breaks fossils into a hash of bone almost too small to recognize. The behavior of this clay damages *in situ* fossils beyond recognition while moving the remnants uphill, leaving tantalizing clues well above the original occurrence of the productive layers. Recognition of this process in 2013, coupled with working downward through the disturbed clays, has allowed the discovery of very important *in situ* bonebeds that are providing new information about the evolution of Late Triassic faunas (e.g., Kligman et al. 2022; Marsh et al. 2022). Once the productive *in situ* deposits are identified, collections into the unweathered rock are made to provide more complete vertebrate specimens, as well as fossil leaves and pollen that typically are destroyed by even minor weathering processes. Likewise, bones from small, fragile animals that typically are obliterated by the weathering process are saved from destruction in the expanding clays. Targeted collection based on specific facies recognition is resulting in the discovery of numerous new fossils, not only of vertebrates, but also insects, as well as many new plant localities that fill significant gaps in the fossil record, both temporally and taxonomically (e.g., Parker et al. 2005; Kligman et al. 2017, 2022).

PREPARATION AND CURATION

Director's Order 77 stipulates that fossil vertebrate material can only be conserved/prepared by a qualified fossil preparator, and the NPS Museum Handbook provides a baseline for the actions, facilities, equipment, and staff required to properly conserve and curate fossil specimens. These requirements ensure the protection and long-term viability of the fossil materials for research and education.

Initially the park lacked a dedicated preparation facility and staff fossil preparator. Work was done mainly in offices and outside on picnic tables using small hand tools. In 2003 a book storage area in a disused laundry facility in the trailer court was emptied, and approximately $2,000 was spent on new equipment for a rudimentary preparation lab. Other used equipment was sourced from outside institutions and the park scrapyards. With this humble start a minimalistic, dedicated lab was established, allowing for safer conditions for the workers while assuring the security of specimens by keeping them out of personal workspaces, in line with NPS museum handbook recommendations. Publication of newly prepared materials of large archosaurs such as phytosaurs and aetosaurs began almost immediately (e.g., Parker and Irmis 2006). Concurrently, the antiquated state of the uninformative public displays at the Rainbow Forest Museum (RFM) was recognized, and the lab provided a productive space where skeletal mounts were updated as needed and new mounts made for an exhibit installed in 2006. The exhibit was made completely in-house for about $4,000 worth of primarily secondhand materials and $7,000 in personnel costs (two months of a GS-7 term employee's salary; Brown and Parker 2009: 103–110).

After this initial resounding success, exhibits were slated to be installed in a second display room in the RFM. Park management pivoted back towards traditional exhibit production through contracts with commercial entities. Museum staff were no longer involved in the process and costs rose precipitously. More than $100,000 was spent on products and infrastructure for the new exhibit space, yet after five years the exhibit was still not open to the public. After significant staff turnover the PEFO museum program was put back in charge of the exhibit. Two term GS-7 museum technicians who specialized in fossil preparation and a volunteer graphic designer removed $52,000 worth of the purchases, which were primarily recycled, and spent $26,000, including salary, to reconceptualize, fabricate, install, and open a new exhibit in just over a year while simultaneously providing collection access to researchers and completing all annual museum reporting requirements and curatorial services (Figure 2).

During that year of time the new exhibit expanded beyond the planned area because costs ran well below budget and time was spent on five other geological panels and exhibit cases in other rooms of the RFM. Almost immediately in 2014 after the RFM exhibits wrapped up, the decision was made that the museum collection needed to move from the mixed-use offices behind the Visitor Center to another building where the interpretive offices were located. These offices are situated in two large open-format rooms that serve well as a collection space. The collection move, which is always a complicated process, was accomplished almost entirely by the two GS-7 museum technicians who custom-built rolling cabinetry that securely held the museum cabinet drawers and sheltered the specimens from wind and rain. The entire collection moved without incident and the new space meets close to 90% of the standards outlined for NPS museum collections.

▶ **FIGURE 2.** Museum Technician Cathy Lash finishing up an exhibit on Triassic animals in the Rainbow Forest Museum in 2012. MATTHEW SMITH / NATIONAL PARK SERVICE

▼ **FIGURE 3.** The expanded fossil preparation lab at PEFO after moving into an adjoining space that was a fitness center. The PEFO lab celebrated its 20th anniversary in June 2023. JEANNINE MCELVEEN / NATIONAL PARK SERVICE

These events served as a proof-of-concept for PEFO park management, and two permanent positions sprang out of this work: a permanent GS-11 curator and a GS-9 museum specialist. The paleontology and museum staff also presented these results at professional society meetings where new students, interns, and avocational volunteers took note and started to come to PEFO to gain experience. There is very little training available at US universities for fossil preparation and conservation, and policies such as Directors Order #77 stipulate that fossil preparation should only be done by trained and qualified technicians. Therefore, on-the-job experience and training in labs like the one that was evolving at PEFO are indispensable for early-career technicians. In recognition of the new benefits provided to the park by the museum and paleontology programs, the PEFO maintenance staff used base funds to double the size of the lab by expanding into an adjacent room (Figure 3). Required equipment was purchased for the expansion primarily using donation money specifically earmarked by the donors for the lab, and the park matched this funding, radically improving the program's capacity to train aspiring museum technicians and to deal with more complex conservation challenges.

Finally, a fortuitous collaboration between paleontology and museum staff allowed for a novel workflow for handling the new microfossils that were being collected from the park's expansion lands. Limitations of early (1970s to late 1990s) microfossil collecting and preparation techniques led PEFO staff to use a variety of processes adapted from other disciplines (e.g., jewelers tools) in a carefully orchestrated series of steps to not only wash sediment from and collect microfossils, but to identify and prepare significant microfossils. These new techniques allowed staff to reassemble millimeter-sized fragments from washed sediments into complete identifiable elements significantly increasing the recovery rates of these delicate fossils which in turn led to near exponential growth in the rate of discovery of new taxa. This innovation accelerated the discovery of new taxa at PEFO and could, with appropriate training, potentially be applied to sites at other federal lands (Figure 4).

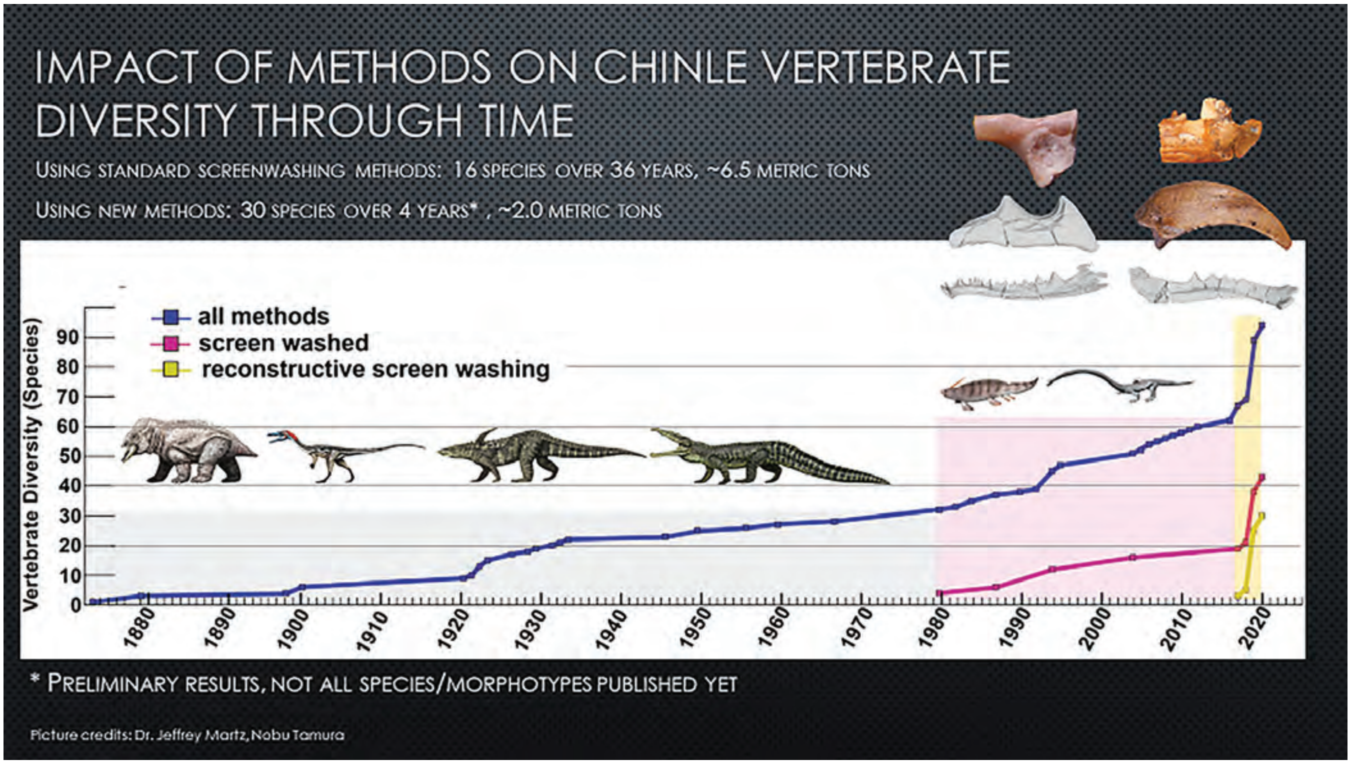
RESEARCH

In line with Director's Order 77, PEFO encourages and supports research in the park from external partners in addition to the science done by park staff. This allows development of new research ideas for the park by bringing in expertise not possessed by park staff, but then optimized by ensuring that all new research is in line with the overall park goals. Primary park research themes are: (1) determining the park stratigraphy and placing all fossil localities in a temporal framework; (2) looking at all fossils in the context of faunal relationships; (3) preparing all collected fossils and identifying them to the lowest taxonomic level possible, identifying and describing new species as applicable; and (4) examining how the park fits into the larger picture of our understanding of the Triassic at the global scale, especially regarding first appearances and evolutionary relationships of important groups such as squamates, amphibians, and even dinosaurs. Examples of research drawn from outside expertise include the recovery of a 460-meter (1,500-foot) geological core that tracks climate change and records evidence of the past movements of planets, such as Venus and Jupiter (Kent et al. 2018), and the identification of mineral signatures in the park that are very similar to those currently being discovered on Mars (Noe Dobrea et al. 2016). Present research is focused on the recovery of delicate and poorly understood animal groups, such as insects and other invertebrates.

PUBLIC OUTREACH

This ongoing research by staff and partners reinforces the importance of PEFO as a window into early Mesozoic time, preserving key events and biota with global implications. This information is shared with the public and scientific community through staff interactions, interpretive programs, outreach, and scientific publications and presentations. A Day Dig program run by the park's cooperating association allows visitors to take part in fieldwork and help make these important discoveries; one participant discovered the first record of a fish called *Saurichthys* in the park, which was also the earliest in North America (Figure 5; Kligman et al. 2017).

FIGURE 4. The impact of new collecting methods on Chinle Formation vertebrate diversity through time, showing the increase of discovered new fossil species at the park after implementing new prospecting, collecting, and preparation techniques in 2016. BEN KLIGMAN



▶ **FIGURE 5.** Members of the public participating in a Petrified Forest Field Institute Day Dig class in 2015. Participants join the paleontology field crew for the day and help collect important fossil specimens for research and outreach. ADAM MARSH / NATIONAL PARK SERVICE

From the beginning of the current PEFO paleontology and museum programs, in-person outreach by specialists to the public has been heavily encouraged. Public outreach and education is also a required component of the Paleontological Resources Preservation Act of 2009. Programs like the Junior Ranger Program have been revamped several times to include up-to-date information and activities associated with the new exhibits. At PEFO, Dinosaur Day, commemorating the day that the first known skeleton of the dinosaur *Chindesaurus bryansmalli* was literally flown out of the Painted Desert, is celebrated annually along with National Fossil Day, an event that celebrates fossils from federal lands across the US. During these outreach events, museum staff provide hourly tours of the museum collections and lab to members of the public on a first-come, first-served basis, and paleontology staff escort visitors on customized tours of the backcountry, including significant fossil localities. These behind-the-scenes tours are incredibly rewarding to visitors and encourage a deep sense of connectedness to the resource. Also, the paleontology and museum staff travel to share fossil conservation techniques with the public at venues such as the Navajo County Fair and the Flagstaff Festival of Science, where hundreds of individuals can share one-on-one time with park staff as they work on scientifically significant fossils.

Initially, a sizeable challenge was how to incorporate these activities into day-to-day operations at PEFO. In 2016, park staff started experimenting with opening a small room attached to the new museum collection space to the public where they set up a conservation station similar to what they provided to outside special events. Like the main lab, they were able to improve this “Demo Lab” with donations and with funds authorized by the Federal Land Recreation Enhancement Act (FLREA), since this is a direct benefit to the visitor experience. Staff wrote several successful FLREA projects that served to formalize the Demo Lab, improving worker safety and ergonomics, enhancing aesthetics, writing outreach materials, and increasing material-handling capacities. Initially, visitors entered the space with park staff and watched the staff perform fossil conservation while providing informal, conversational, interpretive programing, including short tours of the collections when possible. While the museum work seemed routine to the staff, it was anything but for the public, who got to see new species of animals revealed grain by grain by specialists in an intimate setting (Figure 6).

As a challenge of COVID-19 the park staff had to rapidly adapt to a new normal that required keeping visitors at a minimum six-foot distance. By adding microscope feeds connected to outdoor televisions and an improvised two-way radio system made from baby monitors, the Demo Lab was able to fully re-open in just two months, allowing the public to communicate with the staff members through the outdoor window while also providing for good social distancing. The Demo Lab has steadily gained popularity and, while it hasn’t fully returned to public walkthroughs, staff are allowed to use their discretion to open the doors and/or lead tours if they can do so while assuring the security of the specimens and a healthy environment for visitors and staff.

DISCUSSION

In 2001, the park’s understanding of its geological history and paleontology was generally poor. Various researchers had come and gone over the years, providing different and often conflicting explanations on the physical and biological changes in the park during the Late Triassic. Park staff had no way of evaluating which researcher had interpreted

FIGURE 6. View of the inside of the fossil demonstration lab. Originally the school building office, this space was turned into a spot where visitors can watch fossils being prepared and ask paleontologists questions five days a week. NATIONAL PARK SERVICE

the available data the best, and the choice of whom to believe came down to a popularity contest rather than science-based understanding. The park had established a research grant program through its cooperating association, but again, nobody on staff had the expertise to properly evaluate these proposals, and as a result funded projects were left incomplete and, in some cases never even started. Loans of museum specimens were completed without the proper paperwork, with some specimens, including holotypes, simply walking out the door unrecorded. Collateral duty museum staff lacked basic skills such as an understanding of taxonomic nomenclature, and paleontological specimens were often catalogued using nicknames rather than actual scientific names. Museum specimens were not properly stored and therefore subject to damage, and staff lacked the ability to make necessary repairs. Essentially the paleontological museum collection was unusable for research and education.

The hiring of professional staff, including a paleontologist in 2002, a fossil preparator in 2005, and a full-time curator in 2010, has greatly improved and stabilized these functions. Instead of sending dollars to researchers who were doing uncoordinated and sometimes unnecessary work, the funding was used to establish and build the student intern program. Fossils now are prepared in a safe and secure area to professional standards, and properly housed to minimize storage damage. Specimen loans are officially recorded and tracked, and outstanding loans are tracked down and returned. Museum databases have standardized taxonomy and fossils are catalogued throughout the year. Finally, with the development and maturation of the program, PEFO has been able to provide some paleontological expertise in conservation, research, and outreach to other NPS units including training staff, fossil preparation, serving as a repository, exhibit development, and paleontological inventory and monitoring.

Conducting field-based research and managing paleontological resources in a National Park can be challenging, mainly because non-specialists with limited understanding of the science often supervise resource management departments. Key fundamental requirements for successful paleontological resource management include: (1) surficial collection of sediments and fossils; (2) fossil preparation, conservation, and curation; and (3) peer-reviewed research disseminated to the public. All of these are time-consuming and can be viewed as expensive. Furthermore, the removal of objects of interest from the landscape can be seen as going against some of the National Park Service's management philosophy, where an emphasis on preservation and protection *in situ* is the norm in practice. However, paleontological resources and information require management strategies different than those for cultural resources. Archaeological and historic resources are preserved on the surface within their cultural context and can be easier to monitor and maintain, but paleontological resources are part of the natural Earth and require more targeted and active methods to gain the needed information and preserve significant specimens that are sure to be destroyed by physical processes. Collected specimens must be properly prepared to be stabilized. Only after collection and preparation are they useful for research and education.

Paleontological resources are best preserved in museum collections where they can be cared for by trained professionals. Collection of fossils from the surface does not result in significant impacts to or deterioration of the landscape. More sediment is removed from single heavy erosional events than can ever be disturbed through decades of paleontological work, and the scientific data obtained are of great significance for research and education. Furthermore, fossils continue to erode from PEFO badlands, ensuring the presence of fossils that can be enjoyed by the public. By finding and hiring specialist staff who can simultaneously achieve the trinity of goals of a good science program—conservation, research, and outreach—with spaces and opportunities like the museum Demo Lab and Day Digs, PEFO staff can share the process of excavating a new species or previously unknown bone of a poorly understood animal one day, and then conserving and preparing it in front of the public the next day, while advising students on how to publish a peer-reviewed article at the same time.

CONCLUSIONS

Developing a professional paleontology and museum program at PEFO has provided numerous benefits to the park, the NPS, and our visitors and partners. It has allowed for globally significant discoveries that reshaped what is thought about life during the Triassic Period. Visitors come away with better understanding and a unique experience. Park managers have an improved understanding of these resources and how to protect them.

NPS units with significant fossil resources should at a minimum make sure they have paleontological expertise on staff. Using in-house expertise ensures the park is getting the best results for its investment and that its primary resource is well managed. This does not have to be a dedicated paleontologist position, but it must be at least someone who can recognize significant fossils and understands how they are collected, prepared, and curated. Many units cannot afford a full-time paleontologist, but this does not mean they should settle for completely lacking expertise on staff. For example, at PEFO the resources program manager, museum curator, and staff archaeologist all have significant paleontological experience in addition to the staff paleontologist. Park paleontology staff can and should serve other needed roles in the park, including NEPA (National Environmental Policy Act) compliance, collections management (which is still needed even if collections are off-site), scientific research permitting, and air quality monitoring. Park paleontology staff can help other nearby parks that lack paleontological expertise with a variety of paleontological technical assistance requests. If paleontology parks are sufficiently staffed, they can help alleviate regional work backlog in parks that lack staff with paleontology experience. Paleontology parks especially benefit when they can hire interpretive or law enforcement staff who have paleontological expertise or knowledge of relevant laws and policies.

FIGURE 7. From left to right: Student Intern Will Reyes, Resource Management Program Manager Dr. Bill Parker, Student Intern Xavier Jenkins, Lead Paleontologist Dr. Adam Marsh, Visiting Researcher Bryan Small, and Student Intern Emily Patellos. Reyes, Jenkins, and Patellos are all currently in PhD programs across the country. BEN KLIGMAN / NATIONAL PARK SERVICE

Proper long-term management of paleontological resources also requires some type of lab space for preparation and an approved, suitable museum repository. Fossil preparation is particularly effective for the mission of the Park Service when it can be done in front of visitors because fossil resources are very difficult to recognize and interpret in the field because of erosion. Significant fossils should be collected and prepared, and sharing this work with the public is rewarding for both the park and the visitors. The use of seasonals and interns can round out field crews and provide needed professional experience for students, but interns should only be brought on if they are under the daily guidance of a professional paleontologist (Figure 7, above). Substituting student interns for professional staff is financially unfair to the students and can harm their own professional development by not providing proper mentorship.

Overall, National Park Service units perform better in their preservation and education mandates when they have staff expertise regarding their primary resources, whether it's a historian at Manassas National Battlefield Park, a geologist at Yellowstone National Park, or a paleontologist at Dinosaur National Monument. This model has worked extremely well at PEFO, benefiting visitors, partners, staff, and Triassic paleontology.

ACKNOWLEDGMENTS

We thank past and present staff who were instrumental in facilitating the park paleontology program, including Karen Dorn, Lee Baiza, Brad Traver, Jeannine McElveen, Howard Gourley, Randall Irmis, Michelle Stocker, Pete Reser, Matthew Brown, Kenneth Bader, Jeffrey Martz, Stephanie Metzler, and Cathy Lash.

REFERENCES

Ash, S.R. 1974. The Upper Triassic Chinle flora of Petrified Forest National Park, Arizona. In *Paleobotany Section, Botanical Society of America Guidebook to Devonian, Permian and Triassic Plant localities, East-central Arizona*. S.R. Ash, ed. St. Louis: The Botanical Society of America.

Ash, S.R. 2005. Synopsis of the Upper Triassic Flora of Petrified Forest National Park and vicinity. In *Guidebook to the Triassic Formations of the Colorado Plateau in northern Arizona: Geology, Paleontology, and History.* S.J. Nesbitt, W.G. Parker, and R.B. Irmis, eds. Bulletin 9. Mesa, AZ: Mesa Southwest Museum.

Brown, M.A., and W.G. Parker. 2009. Rapid in-house design, construction, and installation of a Triassic paleontology hall. *Methods in Fossil Preparation: Proceedings of the First Annual Fossil Preparation and Collections Symposium*, M.A. Brown, J.F., Kane, and W.G. Parker, eds. Petrified Forest National Park, AZ: Petrified Forest National Park.

Camp, C.L. 1930. Stratigraphic distribution of Arizona phytosaurs. *Geological Society of America Bulletin* 41:1–213.

Cifelli, R.L., G.H. Billingsley, and W.J. Breed. 1979. The paleontological resources of the Petrified Forest: A report to the Petrified Forest Museum Association. Unpublished report.

Kent, D.V., P.E. Olsen, C. Rasmussen, C. Lepre, R. Mundil, R.B, Irmis, G.E. Gehrels, D. Giesler, J.W. Geissmann, and W.G. Parker. 2018. Empirical evidence for stability of the 405-kiloyear Jupiter–Venus eccentricity cycle over hundreds of millions of years. *PNAS* 115(24): 6153–6158. https://doi.org/10.1073/pnas.1800891115

Kent, D.V., P.E. Olsen, C. Lepre, C. Rasmussen, R. Mundil, G.E. Gehrels, D. Giesler, R.B. Irmis, J.W. Geissman, and W.G. Parker. 2019. Magnetochronology of the entire Chinle Formation (Norian Age) in a scientific drill core from Petrified Forest National Park (Arizona, USA) and implications for regional and global correlations in the Late Triassic. *Geochemistry, Geophysics, Geosystems* 20(11): 4654-4664. https://doi.org/10.1029/2019GC008474

Kligman, B.T., W.G. Parker, and A.D. Marsh. 2017. First record of *Saurichthys* (Actinoptergii) from the Late Triassic (Chinle Formation: Norian) of western North America. *Journal of Vertebrate Paleontology* 37(5): e1367304. https://doi.org/10.1080/02724634.2017.1367304

Kligman, B.T., B.M. Gee, A.D. Marsh, S.J. Nesbitt, M.E. Smith, W.G. Parker, and M.R. Stocker. 2023. Triassic stem caecilian supports dissorophoid origin of living amphibians. *Nature* 614: 102–107. https://doi.org/10.1038/s41586-022-05646-5

Long, R.A., and P.A. Murry, 1995. Late Triassic (Carnian and Norian) tetrapods from the southwestern United States. *New Mexico Museum of Natural History and Science Bulletin* 4: 1–254.

Marsh, A.D., W.G. Parker, S.J. Nesbitt, B.T. Kligman, and M.R. Stocker. 2022. *Puercosuchus traverorum* n. gen. n. sp.: A new malerisaurine azendohsaurid (Archosauromorpha: Allokotosauria) from two monodominant bonebeds in the Chinle Formation (Upper Triassic, Norian) of Arizona. *Journal of Paleontology* 96 (Memoir 90): 1–39. https://doi.org/10.1017/jpa.2022.49

Martz, J.W., W.G. Parker, L. Skinner, J.J. Raucci, P. Umhoefer, and R.C. Blakey. 2012. *Geologic Map of Petrified Forest National Park, Arizona*. Arizona Geological Survey Contributed Map CR-12-A, 1 map sheet, 1:50,000 map scale, 18 pp. http://hdl.handle.net/10150/630688

Noe Dobrea, E.Z., A.C. McAdam, C. Freissinet, H. Franz, I. Belmahdi, M.R. Hamersley, C.R. Stoker, W. Parker, K. Ja Kim, D.P. Glavin, F. Calef, and A.D. Aubrey. 2016. Characterizing the mechanisms for the preservation of organics at the Painted Desert: Lessons for MSL, Exomars, and Mars 2020. Abstract. 47th Lunar and Planetary Science Conference, The Woodlands, Texas.

Olsen, P.E., J.W. Geissman, D.V. Kent, G.E. Gehrels, R. Mundil, R.B. Irmis, C. Lepre, C. Rasmussen, D. Giesler, W.G. Parker, N. Zacharova, W.M. Kuerschner, C. Miller, V. Baranyi, M.F. Schaller, J.H. Whiteside, D. Schnurrenberger, A. Noren, K.B. Shannon, R. O'Grady, M.W. Colbert, J. Maisano, D. Edey, S.T. Kinney, R. Molina-Garza, G.H. Bachman, J. Sha, and the CPCP Team. 2018. Colorado Plateau Coring Project, Phase I (CPCP-I): A continuously cored, globally exportable chronology of Triassic continental environmental change from Western North America. *Scientific Drilling* 24: 15–40. https://doi.org/10.5194/sd-24-15-2018

Parker, W.G., and P.S. Clements. 2004. First year results of the ongoing paleontological inventory of Petrified Forest National Park, Arizona; In *The Colorado Plateau: Cultural, Biological, and Physical Research*. C. van Riper III and K. Cole, eds. Tucson: University of Arizona Press, 201–210.

Parker, W.G., and R.B. Irmis. 2006. A new species of the Late Triassic phytosaur *Pseudopalatus* (Archosauria: Pseudosuchia) from Petrified Forest National Park, Arizona. *Museum of Northern Arizona Bulletin* 62: 126–143. https://doi.org/10.1017/S1755691011020020

Parker, W.G., and J.W. Martz. 2010. Constraining the stratigraphic position of the Late Triassic (Norian) Adamanian Revueltian faunal transition in the Chinle Formation of Petrified Forest National Park, Arizona. *Earth and Environmental Transactions of the Royal Society of Edinburgh* 101: 231–260.

Parker, W.G., R.B. Irmis, S.N. Nesbitt, J.W. Martz, and L.S. Browne. 2005. The pseudosuchian *Revueltosaurus callenderi* and its implications for the diversity of early ornithischian dinosaurs. *Proceedings of the Royal Society London B* 272(1566): 963–969. https://doi.org/10.1098/rspb.2004.3047