The National Park System fossil record: Uncovering significant new paleontological discoveries through inventory, monitoring, research, and museum curation

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ABSTRACT

The fossil record preserved throughout the parks, monuments, and other areas administered by the National Park Service spans at least 1.4 billion years and reveals rich and diverse paleontological resources available for scientific research and public education. Fossils documented in at least 286 different NPS areas represent important and iconic components of the history of North American paleontology. Our knowledge of the fossil record within the national parks continuously expands based on new paleontological discoveries every year. Most of the new fossil discoveries are associated with four primary management activities undertaken by the NPS Paleontology Program, parks, partners, and cooperating scientists: paleontological resource inventories, monitoring, research, and assessment of fossils curated in museum collections. Paleontological resource inventories focus on documenting the scope, significance, distribution (both temporal and geospatial), and resource management issues associated with park fossils. Paleontological resource monitoring consists of the assessment of the stability and condition of non-renewable fossils that are present within the parks' geologic strata and subject to natural processes or anthropogenic activities. Paleontological resource research is typically an academic undertaking to gather new data, fossil specimens, and associated geological or paleoecological information to expand our understanding of these resources in parks. Finally, under the curatorial component, as of 2023 more than 650,000 fossil specimens are being curated in museum collections within the parks themselves or in outside repositories, and are available for future scientific research and use in exhibits or public education. The harmonious combination of inventory, monitoring, research, and use of museum collections has resulted in many new and important paleontological discoveries associated with park fossils. This article, and the others presented in this special issue of *Parks Stewardship Forum* dedicated to NPS paleontology, highlight some of these new paleontological discoveries from national parks associated with these four management activities.

INTRODUCTION

Paleontological resources, or fossils, are defined as the physical evidence of past life preserved within a geologic context. Fossiliferous strata are often subjected to weathering, erosion, and other geologic processes which may lead to the destruction and loss of fossils at the surface. These same forces may also result in the exposure of previously buried fossils, opening the door for new paleontological discovery, research, and scientific understandings. The fossil record documented within the 286 National Park Service (NPS) administrative units where they are known to occur collectively preserves an important record for life throughout much of geologic time in North America (Figure 1). NPS fossils (i.e., those cared for by the agency) represent a substantial cross-section of America's paleontological

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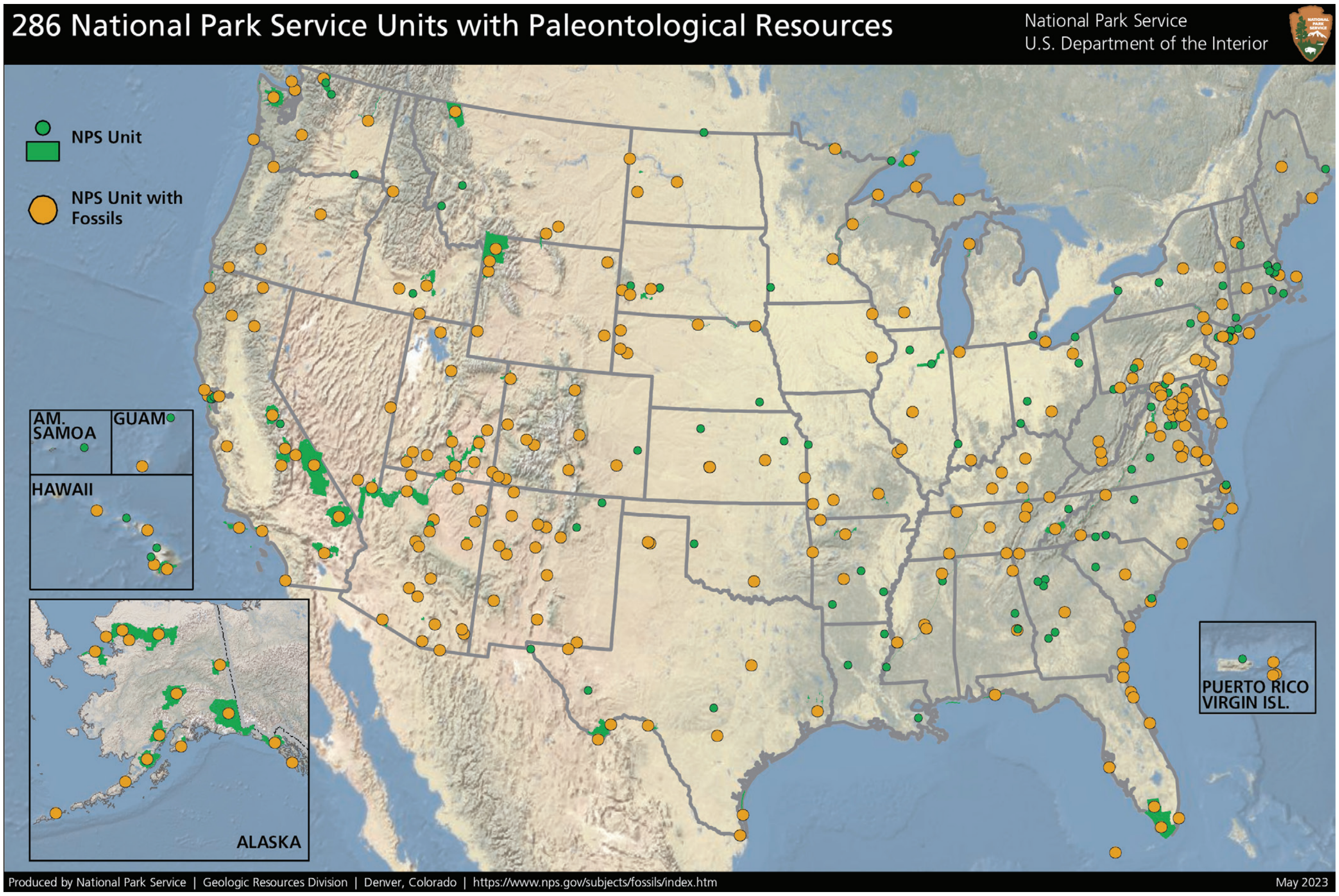


FIGURE 1. Map of the United States showing the location of the 286 National Park Service units where fossils have been documented. NATIONAL PARK SERVICE

heritage, recording evidence of past life, evolving ecosystems, dynamic geologic processes, changing climate, and other important information about the history of our planet Earth.

NPS fossils are managed and protected through law, policy, and management practices supporting their conservation, preservation, and curation, enabling opportunities for scientific research and public education.

NPS Management Policies (2006; Section 4.8.2.1) states that "Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected." Through this guidance, NPS has been able to apply scientific principles and resource management strategies in the stewardship of non-renewable paleontological resources. From it, we can derive four important management activities for paleontological resources: inventory, monitoring, research, and curation.

This volume includes a cross-section of recent and cutting-edge work undertaken by NPS that demonstrates the benefits derived through the inventory, monitoring, research, and curation of paleontological resources. These four management activities are based upon scientific principles and represent best management practices for non-renewable paleontological resources preserved in the national parks. The implementation of each of the management activities has resulted in new fossil discoveries in the national parks and enhanced stewardship of NPS fossils.

INVENTORY

Accurate and comprehensive baseline data are essential for the management and stewardship of paleontological resources on federal lands. During the 1990s an NPS initiative known as the Natural Resource Challenge resulted in congressional funding to establish an Inventory and Monitoring Program for natural resources. The fundamental questions raised in the NPS Natural Resources Challenge included, "How do we manage, how do we protect, how do we interpret, and how do we make decisions involving NPS natural resources without good baseline resource data?" The design and implementation of natural resource inventory and monitoring strategies by NPS was addressed in Section 204 of the 1998 National Parks Omnibus Management Act (54 USC Section 100101). In 1999 the secretary of the interior received a congressional request for information regarding the management of paleontological resources by the federal land-managing agencies. A *Report to Congress on Fossils on Federal and Indian Lands* was presented by the Department of Interior in 2000, incorporating information from federal agencies, the scientific community, and the public. Principle 5 in the *Report to Congress*, titled "Effective Stewardship Requires Accurate Information," states: "Inventories and monitoring of fossils on federal lands are critical for sound fossil management. Thorough inventory data enables informed decision making and enhances interagency collaboration." This information drafted by NPS for the *Report to Congress* was consistent with the principles of the Natural Resources Challenge regarding the need for inventory and monitoring of natural resources. This was carried over into Section 6302 of the Paleontological Resource Preservation Act of 2009 (16 USC Section 470aaa 1-11), which states, "The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources."

Inventory of paleontological resources is a core function and primary responsibility of the NPS Paleontology Program. NPS defines paleontological resource inventory as the compilation of baseline data to determine the scope, significance, distribution (both temporally and geospatially), and management issues associated with NPS fossils. Since a paleontological resource inventory strategy was piloted at Yellowstone National Park in 1996, fossil inventories have been undertaken in hundreds of NPS areas. A variety of inventory strategies have been adopted by NPS, ranging from park-specific fossil surveys to more widely based approaches focusing on regional networks or clusters of parks. In addition, thematic paleontological resource inventories have been coordinated across NPS to determine the occurrence and distribution of specific taxonomic groups of fossils, such as trilobites and dinosaurs, or even fossils associated with park caves (Santucci et al. 2001).

Multidisciplinary teams of paleontologists, geologists, student interns, and other partners have helped to inventory and document fossils across NPS (Figures 2a–c), documenting at least 286 parks as having paleontological resources (Figure 3). Through these proactive paleontological resource inventories NPS has been able to apply best management practices using scientific principles and new resource management strategies in the stewardship of non-renewable fossils, resulting in many important new fossil discoveries in national parks.

MONITORING

Many paleontological resources from NPS areas are managed and maintained *in situ* within their geologic context. The physical collection of all fossils from national parks is not feasible or warranted given the widespread occurrence of fossils and the long-term costs and accountability associated with collections. In addition, leaving fossils in place ensures educational opportunities for the public to discover and learn about them in their natural occurrence within geologic strata.

Monitoring of paleontological resources is not a practice traditionally undertaken by academic paleontologists and not a topic typically presented to students as part of their education. There is a general lack of published scientific literature and limited guidance addressing paleontological resource monitoring or the methods used in the management of *in situ* fossils. The monitoring of *in situ* paleontological resources within NPS areas is a fundamental resource management practice and, as noted above, is specifically addressed in Section 6302 of the Paleontological Resources Preservation Act of 2009.

CLOCKWISE FROM UPPER LEFT

FIGURE 2A. Scientists-In-Parks (SIP) paleontology interns Charles Salcido and Patrick Wilson undertaking field paleontological resources inventories of Paleocene strata at Theodore Roosevelt National Park. NATIONAL PARK SERVICE

FIGURE 2B. SIP paleontology interns Holley Flora and Summer Rose Weeks undertaking field paleontological resources inventories in caves at Grand Canyon-Parashant National Monument. NATIONAL PARK SERVICE

FIGURE 2C. Paleontologists participate in field paleontological resource inventories at Glen Canyon National Recreation Area in 2000. NATIONAL PARK SERVICE

Paleontological resource monitoring is the assessment of the stability and condition of *in situ* fossils to observe and document any natural or anthropogenic factors that may contribute to the deterioration or loss of these non-renewable resources. Starting in 2001 NPS began to develop and implement strategies and guidance for paleontological resource monitoring (Santucci and Koch 2003; Santucci et al. 2009). In 2009 Glen Canyon National Recreation Area was selected as the prototype paleontological resource monitoring park for NPS due to the dramatic fluctuations in the water levels for Lake Powell and the potential impacts of these changes on the abundant fossils along the shorelines in the park

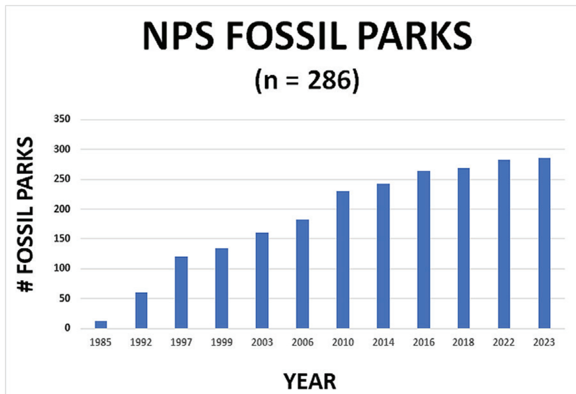


FIGURE 3. Paleontological resource inventories have expanded our list of NPS areas documented as having paleontological resources, going from 12 parks recognized with fossils in 1985 to our current total of 286. NATIONAL PARK SERVICE

(Kirkland et al. 2010, 2011). Monitoring at Glen Canyon also resulted in documentation of fossil theft, vandalism, and other paleontological resource crimes (Figures 4a–b).

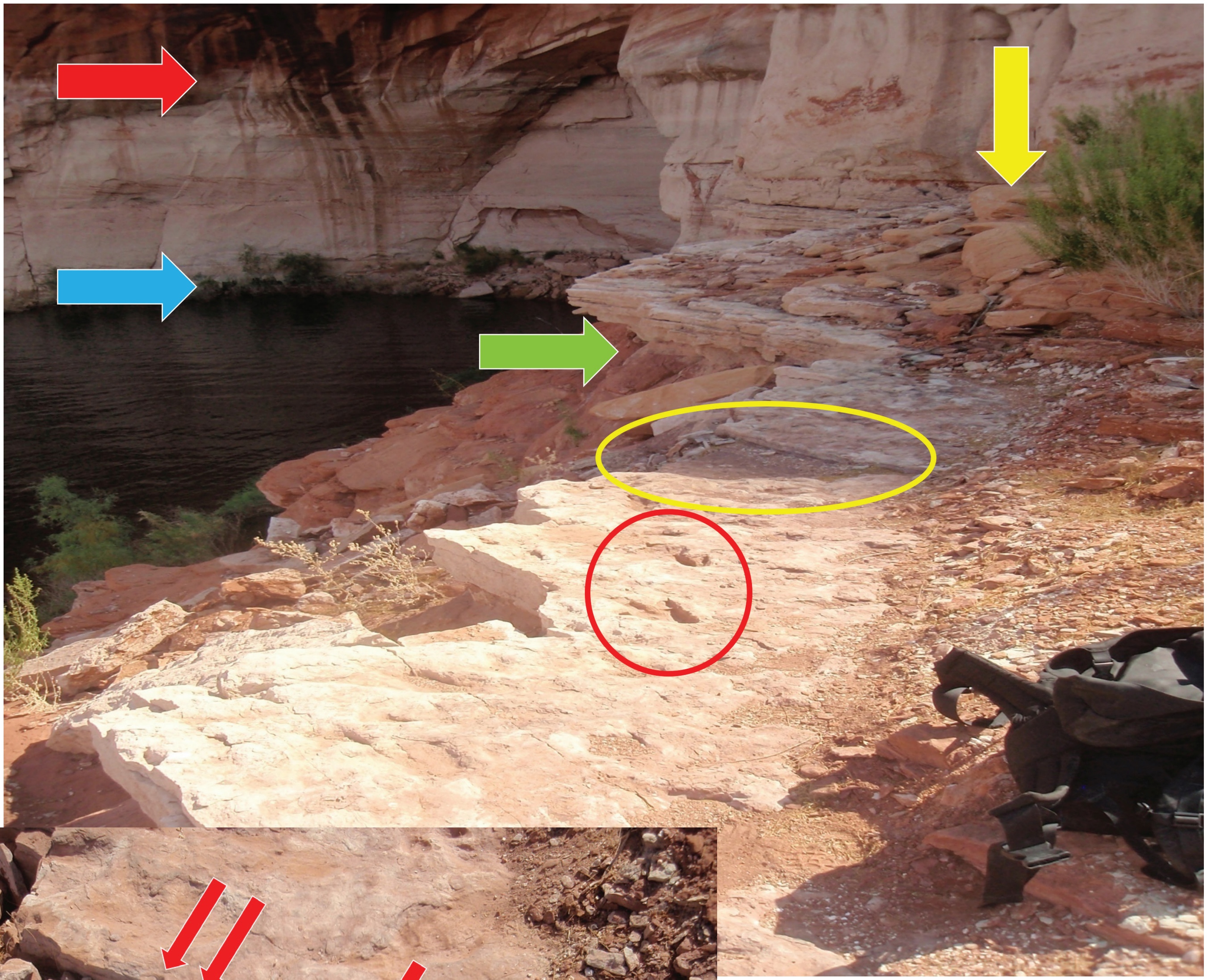


FIGURE 4A. The prototype paleontological resource monitoring locality at Glen Canyon National Recreation Area, established in September 2009. The area was selected for monitoring based on the occurrence of more than 145 individual dinosaur tracks preserved in the Jurassic Navajo Sandstone periodically submerged below the water of Lake Powell. Photograph taken from a photo point in September 2009 showing: (1) Red circle: dinosaur tracks preserved in the track-bearing sandstone layer; (2) Red arrow: high-water mark of Lake Powell; (3) Blue arrow: actual Lake Powell water level at time of locality documentation in September 2009; (4) Yellow arrow: downdropped sandstone blocks impacting track-bearing unit; (5) Green arrow: undercutting of a more rapidly eroding mudstone beneath the track-bearing unit; (6) Yellow oval: section of track-bearing sandstone showing evidence of where the dinosaur tracks were chiseled out and removed. NATIONAL PARK SERVICE

FIGURE 4B. Close-up view of the location in the track-bearing sandstone showing chisel marks where dinosaur tracks were removed illegally by park visitors (yellow oval in Figure 4a). NATIONAL PARK SERVICE

Paleontological resource monitoring by NPS has expanded rapidly during the past two decades and has incorporated new strategies and technologies to better understand the threats to fossils in parks. Monitoring NPS fossils has been integrated into resource management programs to support scientific research, resource stewardship, and the protection of paleontological resources. The impacts of coastal processes, climatological events, and sea level rise on fossils have been the focus of monitoring at parks such as Point Reyes National Seashore (Pearson et al. 2016) and George Washington Birthplace National Monument (Tweet and Santucci 2017, 2020). Paleontological resource monitoring has become an essential part of evaluating potential impacts on fossils during construction projects, oil and gas operations, and other activities involving ground disturbance. Pre-construction paleontological resource assessments undertaken recently at Buffalo National River, Mesa Verde National Park, and Theodore Roosevelt National Park have helped to inform the need for paleontological resource monitoring during ground-disturbing activities as part of National Environmental Policy Act (NEPA) planning.

Photogrammetry, ground-penetrating radar, and other technologies have been extremely useful in paleontological resource monitoring to establish baseline resource data and to enable assessing changes in the condition of these resources over time. The use of these technologies has recently helped researchers and resource managers at Death Valley National Park, Grand Canyon National Park, White Sands National Park, and other NPS areas to assess fossil footprints and gain better understanding of these fragile resources, leading to advances in their scientific study and improvement of their protection (Wood and Santucci 2014; Urban et al. 2019; Wood et al. 2020).

RESEARCH

National parks provide important opportunities for paleontological research on federal lands. Current NPS management policies state, "The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit" (NPS 2006). Historically and scientifically recognized fossil localities have been established as NPS areas by Congress or through presidential proclamation to preserve and protect these paleontological resources. Eighteen NPS areas specifically reference paleontological resources in their enabling legislation, establishing fossils as fundamental resources and values. Unlike other federal lands identified in the Paleontological Resource Preservation Act, casual collecting of fossils by the public is prohibited in NPS areas. Consequently, fossil localities on NPS lands are managed and protected to preserve the scientific integrity of natural occurrences of fossils that would potentially be disturbed or impaired by uncontrolled casual collecting.

The science of paleontology is in its infancy, largely spanning two centuries of field collecting and research around the world. Increased specializations within paleontology reflect a transformative understanding of a complex fossil record exhibiting changing biodiversity throughout geologic time, along with the many factors influencing the evolution of life. The traditional taxonomic specialists who dedicated their careers to specific groups of fauna and flora have been complemented by paleontologists who integrate fossils into research focused on biostratigraphy, paleoecology, paleoclimatology, paleogeography, depositional environments, taphonomy (i.e., the processes of fossilization), and a wide array of perspectives drawing on evidence preserved within the fossil and geologic records.

Research involving collaboration of multidisciplinary teams of specialists has yielded significant scientific contributions in national parks during the past few decades. During the 1990s the Morrision Extinct Ecosystem Project assembled a team of specialists to evaluate the fossil-rich Jurassic Morrison Formation exposed in more than a dozen NPS areas (Turner and Peterson 2004). More recently, a multidisciplinary team was pulled together to address specific scientific questions associated with the co-occurrence of human and megafaunal footprints preserved in Late Pleistocene playa lake deposits at White Sands National Park (Figure 5). The multidisciplinary teams engaged in scholarly interchange and debate on very focused topics as well as big-picture observations. In some cases, the intellectual exchanges answered specific questions or raised new questions, and at White Sands National Park have helped to rewrite the textbook account of the antiquity of humans in the New World (Bennett et al. 2021).

The explosion of new scientific and digital technologies has also led to transformative opportunities within the science of paleontology and applications to paleontological resources management. LiDAR, photogrammetry, unmanned aviation vehicles (UAVs), ground-penetrating radar, and other technologies have become standard field tools for the 21st-century paleontologist. For example, new techniques in the analysis of ancient DNA in Pleistocene mummified (desiccated) bats from a remote cave in Grand Canyon National Park present an extremely rare opportunity to look at microgenomic changes in individual species spanning more than 50,000 years (Mead et al. 2021).

Recent research undertaken by paleontologists at Petrified Forest National Park has continued to expand and uncover new fossils and information tied to the Chinle Formation and the Late Triassic ecosystem in northern Arizona (Stocker et al. 2019; Kligman et al. 2023). The NPS mission integrates science and stewardship, which certainly applies to paleontological resources in parks. This perspective has resulted in a greater understanding of the fossil record across NPS, contributing to a wide range of scientific and educational outcomes for the public.

CURATION

The National Park Service maintains more than 1.5 million catalogued paleontological specimens of fossil plants, invertebrates, vertebrates, and trace fossils within park museum collections and in outside museum repositories. The careful conservation and preservation of NPS fossils and their associated data is fundamental to the science of paleontology, and is supported by law, policy, and professional curatorial standards. NPS management policies state, "Scientifically significant resources will be protected by collection or by on-site protection and stabilization" (NPS 2006). Fossil collections represent the physical evidence for the history of life on Earth and changes in biodiversity over geologic time. These collections also provide other information needed for scientific research, as well as being available for public education.

Legal field collection of fossils in NPS areas is generally associated with research projects supported through an approved research and collecting permit. Fossils may also be collected under permit for administrative purposes,

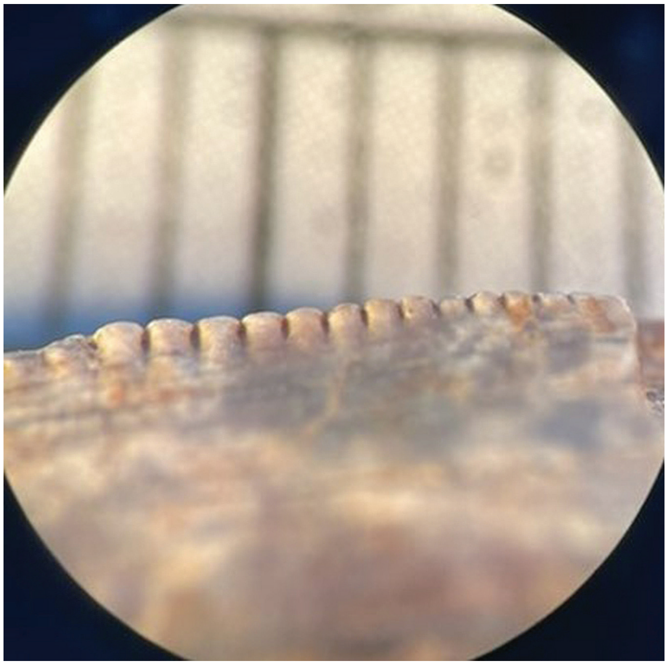
FIGURE 5. A multidisciplinary team of geologists, paleontologists, and archaeologists support inventories and research involving Late Pleistocene megafaunal and human footprints at White Sands National Park. NATIONAL PARK SERVICE

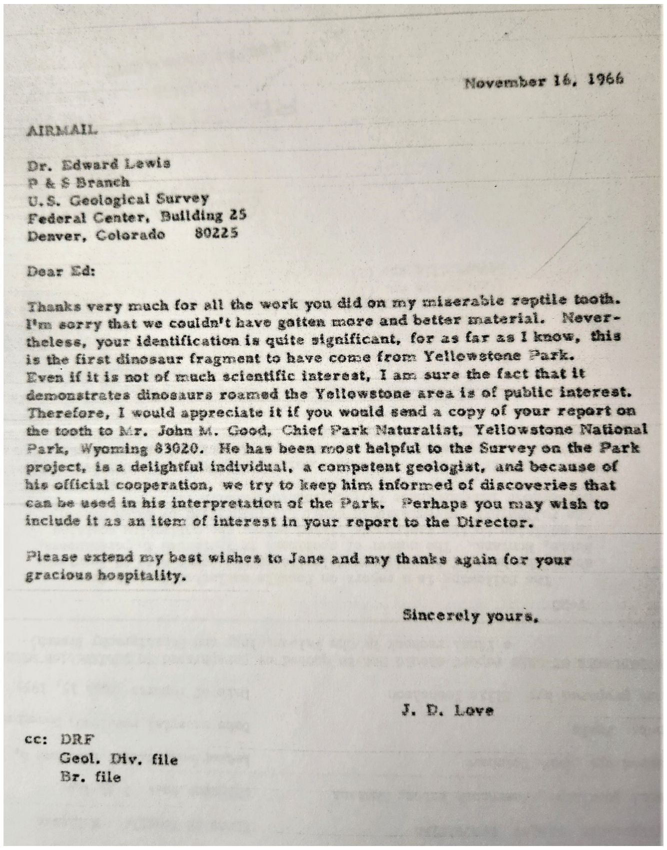
when those resources are determined to possess some scientific or educational value, or are threatened due to human activities such as construction or unauthorized collecting.

The national parks preserve places where fossils naturally occur within geologic strata (*in situ* conservation), while museums are where collected fossils are securely maintained and protected in perpetual storage by curatorial caretakers (*ex situ* conservation). This is an important relationship in which fossils are collected under permit and moved from their geologic context in parks to museums, which then maintain these paleontological treasures for future study and display. In rare instances, however, a failure of *in situ* conservation leaves *ex situ* conservation as the only option. For example, although Fossil Cycad National Monument was abolished as a unit of the National Park System in 1957 after its paleontological conservation value was ruined by wholesale looting and destruction, fossil specimens from this famous locality are permanently curated at the Smithsonian and several other museums.

Nearly 190 non-federal museums maintain NPS fossil specimens. Other than NPS museums, the Smithsonian National Museum of Natural History curates the largest number of NPS fossils, ranging from microscopic pollen to behemoth skeletal remains of dinosaurs and whales (Figure 6). Approximately 50% of the 2,358 name-bearing fossil specimens (specimens selected to define extinct species) from NPS areas are maintained by the Smithsonian. Each specimen is accounted for with unique catalogue numbers, along with associated hard-copy archives and digital data, and is safely protected in secured museum storage cabinets within climate-controlled environments. Each curated fossil specimen is annotated with a geologic locality where it was discovered and is assigned a storage location where it will rest in perpetuity, waiting for the next generation of young scientists to re-examine, apply new technologies, and ask new questions. An important but forgotten specimen of a tyrannosaurid dinosaur tooth collected in Yellowstone National Park by the US Geological Survey (USGS) during the 1960s was recently rediscovered at the Smithsonian National Museum of Natural History (Figures 7a–b). Similarly, a rare brain endocast of a Pleistocene

FIGURE 6. The Smithsonian National Museum of Natural History is the outside museum that maintains the largest number of catalogued fossil collections from NPS-administered lands. NATIONAL PARK SERVICE





November 16, 1966

AIRMAIL

Dr. Edward Lewis
P & S Branch
U.S. Geological Survey
Federal Center, Building 25
Denver, Colorado 80225

Dear Ed:

Thanks very much for all the work you did on my miserable reptile tooth. I'm sorry that we couldn't have gotten more and better material. Nevertheless, your identification is quite significant, for as far as I know, this is the first dinosaur fragment to have come from Yellowstone Park. Even if it is not of much scientific interest, I am sure the fact that it demonstrates dinosaurs roamed the Yellowstone area is of public interest. Therefore, I would appreciate it if you would send a copy of your report on the tooth to Mr. John M. Good, Chief Park Naturalist, Yellowstone National Park, Wyoming 83020. He has been most helpful to the Survey on the Park project, is a delightful individual, a competent geologist, and because of his official cooperation, we try to keep him informed of discoveries that can be used in his interpretation of the Park. Perhaps you may wish to include it as an item of interest in your report to the Director.

Please extend my best wishes to Jane and my thanks again for your gracious hospitality.

Sincerely yours,

J. D. Love

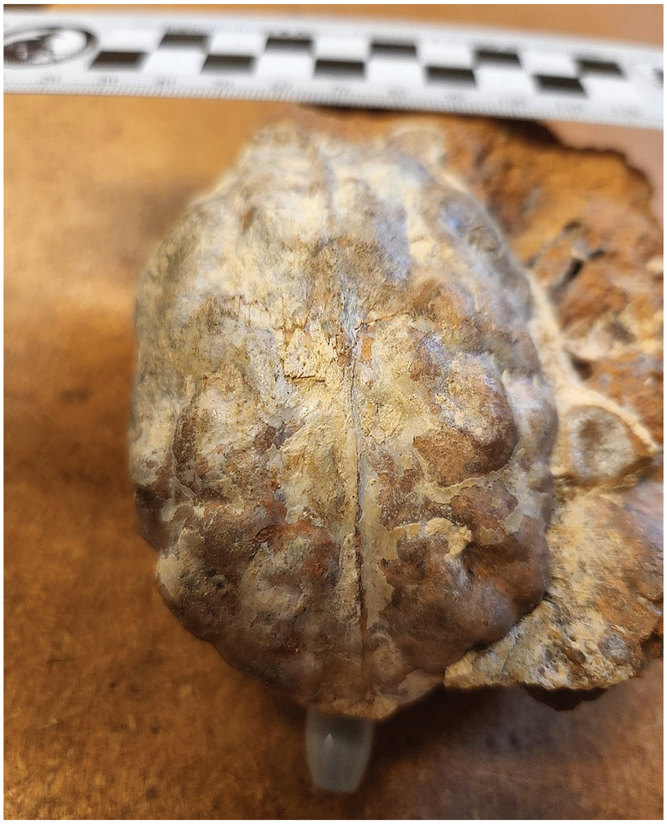
cc: DRF
Geol. Div. file
Br. file

ABOVE **FIGURE 7A.** Close-up view of a partial tyrannosaurid tooth collected from the Cretaceous Harebell Formation in Yellowstone National Park by a USGS geologist in 1966. This forgotten specimen was recently relocated in the collections at the Smithsonian National Museum of Natural History. NATIONAL PARK SERVICE

RIGHT **FIGURE 7B.** Letter dated November 16, 1966, by USGS Geologist J.D. Love to USGS Paleontologist Edward Lewis referencing the tyrannosaurid tooth discovered in Yellowstone National Park. NATIONAL PARK SERVICE

bear collected more than 100 years ago from Cumberland Bone Cave, along what is today the Potomac Heritage National Scenic Trail, was discovered in a small museum in Maryland (Hodnett et al. 2023) (Figure 8).

FIGURE 8. A rare and previously unreported brain endocast of a Pleistocene bear collected from Cumberland Bone Cave during the early 20th century was recently rediscovered in a small Maryland museum. NATIONAL PARK SERVICE



The articles dedicated to NPS paleontology in this special issue of *Parks Stewardship Forum* exemplify the value and importance of the four paleontological resource management activities: inventory, monitoring, research, and curation. Collectively, these paleontological resource activities constitute the scientific method applied to the conservation and preservation of NPS fossils. The interrelationships of these activities complement each other and represent a strategic approach and a progressive form of management for the stewardship and science of non-renewable NPS paleontological resources.

Important new fossil discoveries have been made within NPS areas using these four management activities. In addition to examples already discussed. paleontological resource inventories have led to the discovery of new fossil shark species at Mammoth Cave National Park and pterosaur feeding traces at Arches National Park. During paleontological resource monitoring, two fossil dolphin skulls were recovered from the shoreline at George Washington Birthplace National Monument, and a Jurassic bonebed with the remains of a rare mammal-like reptile was discovered at Glen Canyon National Recreation Area. Paleontological research has led to the discovery of the earliest records for fossil frogs and caecilians at Petrified Forest National Park. Finally, as detailed above, the evaluation of fossils curated in museum collections led to a nearly forgotten tyrannosaurid dinosaur tooth, collected from Yellowstone National Park in the 1960s, being rediscovered at the Smithsonian, and a rare brain endocast of a Pleistocene bear collected during the early 1900s from Cumberland Bone Cave, along what is now the Potomac Heritage National Scenic Trail, was recently found in a small Maryland museum.

Collectively, paleontological resource inventory, monitoring, research, and curation have been, and remain, valuable management activities adopted by NPS that have frequently resulted in new fossil discoveries in the parks.

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