TWENTY-FIVE YEARS OF PALEONTOLOGICAL RESEARCH IN GRAND STAIRCASE-ESCALANTE NATIONAL MONUMENT, UTAH:
Public Lands in Service to Science and the Public

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ABSTRACT

On September 18, 1996, Grand Staircase-Escalante National Monument (GSENM) became the first national monument managed by the US Bureau of Land Management (BLM) and one of the first to protect a landscape based partly on its *opportunity* for scientific discovery. Its creation was a watershed moment in public land management, because to meet the mandates for its first monument, BLM opted to implement unprecedented support of resource investigations for numerous natural and cultural sciences, including establishing its first ever in-house paleontological field program. The rationale for this was taken directly from the establishing presidential proclamation (6920) which called out GSENM's untapped paleontological treasure trove as "world-class." The proclamation also singled out the Late Cretaceous vertebrate fossil record of the Kaiparowits Plateau, largely known at the time through the pioneering work of Drs. Jeff Eaton and Rich Cifelli, who had spent years teasing out the mammalian evolutionary story preserved within. Their work on Mesozoic mammals, alongside sporadic work by other institutions (mainly the University of Utah and Brigham Young University) in the 1970s and 1980s, demonstrated that the Kaiparowits Plateau also held a substantial macrovertebrate record that included beautifully preserved dinosaur skeletons. However, a lack of coordinated effort and the difficult nature of fieldwork in the rugged badlands led to what can only be described as desultory results. The leverage that came with monument status, including logistical and financial support provided by BLM, made this resource more accessible to the paleontological community, stimulating a sudden burst of new field research and discovery. Initial, coordinated, and collaborative fossil inventories started in 2000 by joint BLM, Utah Museum of Natural History, Museum of Northern Arizona, and Utah Geological Survey teams led to a cascade of discoveries, including sites preserving plants, invertebrates, trace fossils, microvertebrates, and macrovertebrates, contextualized by new geological insights. Many of these new fossil finds represent species entirely new to science, with some sites preserving intact snapshots of Late Cretaceous ecosystems that are unmatched globally. Unique geologic conditions resulted in spectacular preservation, sometimes even including soft tissue traces. This renaissance in North American Late Cretaceous paleontology would not have been possible without the focused resources and effort facilitated by the creation of GSENM and the subsequent prioritization of inventory and basic research in its mission. In addition to the science, the public benefits of these efforts have been immense, providing opportunities for direct involvement in the scientific process through volunteer programs, training for several generations of future paleontologists and geologists, innumerable educational programs, and exposure in national and international media outlets through articles, television, and interviews. The collaborative and far-reaching paleontological effort at GSENM has highlighted an often overlooked aspect of public lands management: the importance of US public lands for scientific discovery and education.

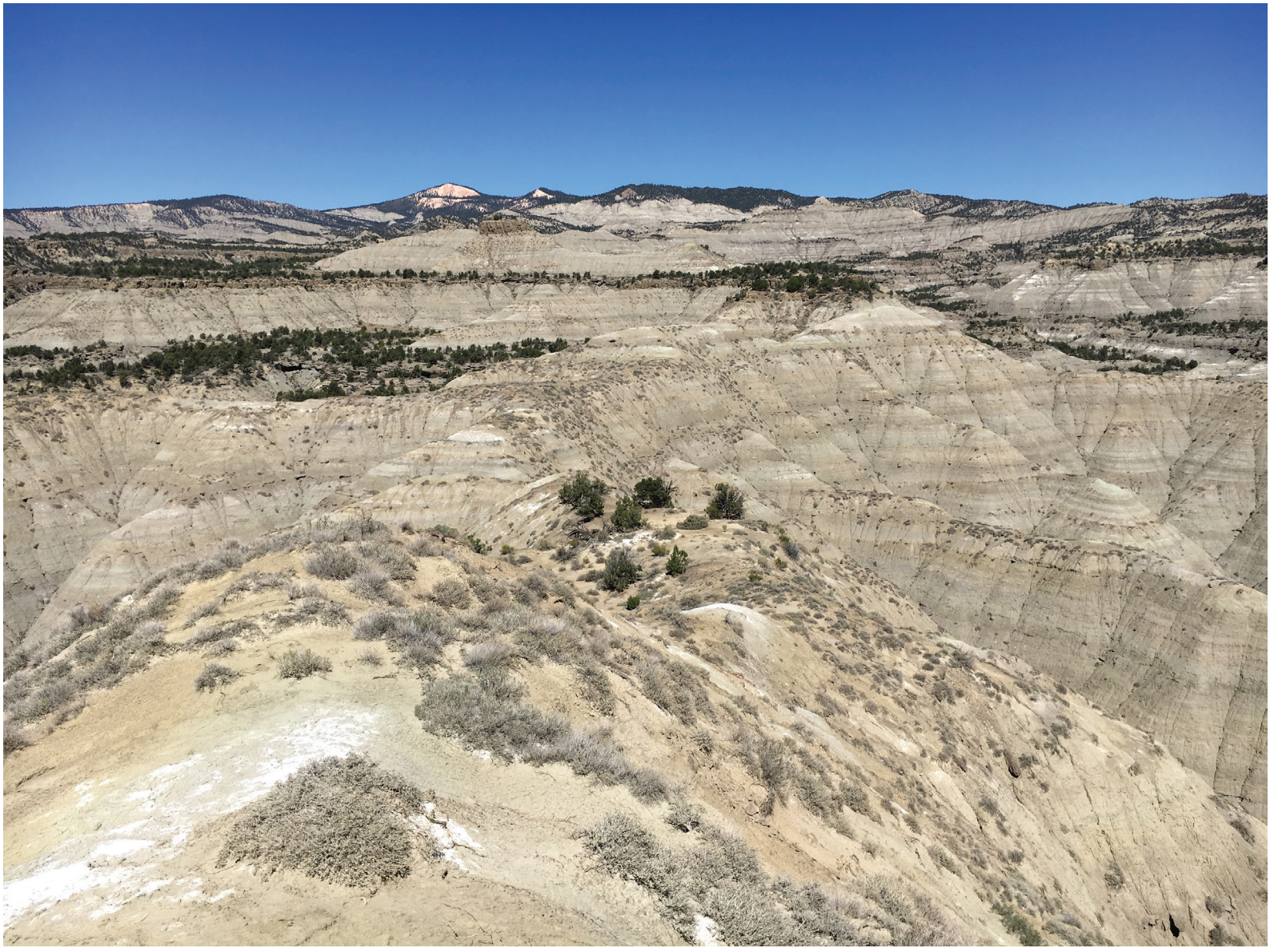
PROLOGUE

In the fall of 1999, shortly after joining the University of Utah in a new dual role—assistant professor in the Department of Geology and Geophysics and curator of paleontology at the Utah Museum of Natural History (now NHMU, the Natural History Museum of Utah)—I ventured to southern Utah for my first visit to the newly formed Grand Staircase-Escalante National Monument. I'd learned that the nearly 2-million-acre monument was burgeoning with largely unexplored badlands, some of which had already yielded a smattering of fossils. As we entered the Blues—a region along Utah Highway 12 in Garfield County where spectacular badlands of the Kaiparowits Formation are exposed—my heart soared. Later that same day, while our truck crawled along the deeply rutted road to Horse Mountain, my jaw literally dropped as I gazed at the incredible expanses of terrestrial sediments dating to near the end of the Late Cretaceous (Figure 1).

All of this dramatic paleontological potential was a mere five-to-six-hour drive south of my new office. For a young dinosaur scientist, it was quite literally a dream come true!

Nevertheless, we soon learned firsthand why GSENM had received minimal attention from fossil hunters—indeed, why the region was the last major expanse in the lower 48 states to be formally mapped. "Badlands" is a word generally

FIGURE 1. Fossil-rich badlands formed on the Upper Cretaceous (Campanian Stage) Kaiparowits Formation, northern Kaiparowits Plateau, inside Grand Staircase-Escalante National Monument, Utah.



used to refer to hilly places brimming with exposed rock that are poor for both farming and ranching. But GSENM takes the meaning to another level. The towering, steep-sided slopes, often covered in marble-sized rocks, transform fossil prospecting into a high-risk, sometimes full-contact sport. Much of the time, even the most intrepid paleontologists must settle for looking on the tops of buttes and in the gullies and valley bottoms below. Water is scarce to the point of non-existent, and even today, only a handful of roads penetrate GSENM, making it problematic even to drive close to most of those fossil-rich outcrops.

Now imagine what happens if you are fortunate enough to come across, say, the fossilized skeleton of a 30-foot-long duck-billed dinosaur or tyrannosaur. Camping and excavation supplies must either be loaded into backpacks and hiked to the site or delivered via helicopter. Whichever method is used, costly helicopter support will likely be essential to remove that skeleton, preferably divided up into multiple chunks weighing less than 1,000 lbs.

Thankfully, paleontologists and geologists from multiple institutions—among them the University of Utah, the Utah Geological Survey, the Denver Museum of Nature & Science, and, of course, GSENM itself—were up for the challenge. Many others participated in the ensuing expeditions and research, enabling numerous interdisciplinary insights.

Two-and-a-half decades later, we can proudly say that GSENM has yielded one of the best-known Mesozoic ecosystems anywhere in the world. This treasure trove from the Age of Dinosaurs includes not only an exquisitely preserved panoply of previously unknown dinosaur species, but a wondrous array of fossil plants, invertebrates, fishes, amphibians, birds, mammals, and reptiles—the latter including not only dinosaurs but crocodilians, turtles, snakes, and pterosaurs.

Though GSENM is by far the most difficult place I have ever conducted paleontological fieldwork, I am still very grateful that the terrain posed so many obstacles. After all, if the work were easy, most of our discoveries would have been made by others many decades prior. As it was, we were fortunate enough to be in on the ground floor of one of the most exciting projects of the past century.

Scott Sampson
San Francisco, 2024

INTRODUCTION AND BACKGROUND

Grand Staircase-Escalante National Monument was created by President William J. Clinton via executive proclamation (Proclamation 6920) under the authority of the Antiquities Act on September 18, 1996. Chief among the resources, objects, and values called out in its establishing proclamation were fossils touted as "world-class." Although the term "world-class" is subjective, it was not pulled from thin air. Ten years prior, paleontologists Rich Cifelli and Scott Madsen published the first paper describing a Cretaceous mammal from southern Utah (Cifelli and Madsen 1986), a description of one of the youngest known occurrences of an archaic form known as a "symmetrodont." In tandem with the publication of this groundbreaking paper, Cifelli was joined by doctoral student Jeff Eaton (University of Colorado, Boulder) in the search for Cretaceous mammals in Utah's Kaiparowits Plateau region (Figure 2). Eaton's 1986 field efforts were rewarded with the discovery of what was, at the time, the oldest known marsupial fossil in the world. Encouraged by these initial results, Eaton and Cifelli embarked on a decade-long quest to thoroughly document Cretaceous mammalian evolution and ecology from fossils found in what is now GSENM, ultimately demonstrating that the region contained a unique, globally significant Late Cretaceous terrestrial vertebrate fossil record spanning nearly 30 million years.

Coincidentally, 1986 also saw the Dutch mining company Andalex acquire rights from California Edison to mine coal in the Kaiparowits Plateau, a controversial proposal that environmental groups had vigorously opposed since the late 1960s. When one tallies coal reserves in the Kaiparowits Plateau (11 billion short tons in beds 7–14 feet thick; 6 billion short tons in beds greater than 14 feet thick; Hettinger et al. 2000), it is not surprising

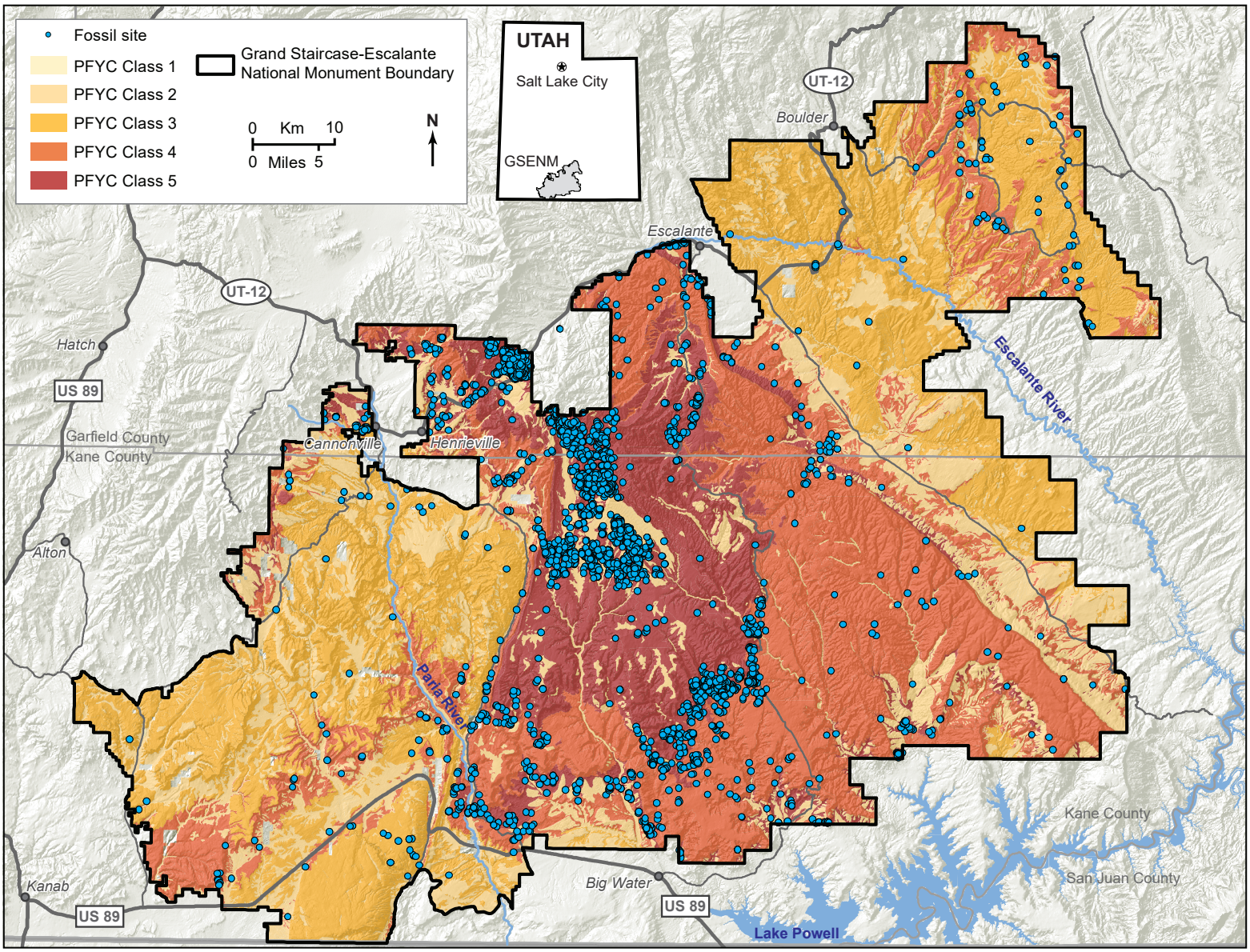


FIGURE 2. Map of Grand Staircase-Escalante National Monument showing distribution of significant fossil sites (blue dots) overlain on the distribution of potential fossil yield classifications (PFYC) for the monument. Note that many significant sites are located in areas assigned to PFYC classes III and IV, such as in the Circle Cliffs area east of Boulder.

that energy interests had been seeking to mine them since the early 1960s (Clinton's 1996 proclamation was the culmination of the second attempt to establish a national monument in the region; the first, in the 1930s, ultimately failed due to ranching and mining lobbying efforts against it). After Eaton learned that Andalex was planning to mine the Kaiparowits Plateau, he sent a letter to BLM during the preparation of the mine's environmental impact statement expressing his concerns that mining could significantly impact what he and Cifelli had come to conclude was one of the most significant terrestrial vertebrate fossil records for the Late Cretaceous known anywhere in the world. Bringing this fact to BLM's attention added impetus to protect the Kaiparowits Plateau region.

What was far from certain on September 18, 1996, was the Kaiparowits Plateau's potential to yield larger vertebrate fossils such as dinosaurs. Desultory work in the Kaiparowits Formation during the 1970s and 1980s by the University of Utah and Brigham Young University was promising but resulted in only three dinosaur fossils identifiable to genus (Titus 2013). During the previous 100 years, only a handful of dinosaur bone fragments had been collected by geologic mappers and paleontologists, largely due to the remote and rugged nature of the Kaiparowits Plateau (Titus 2013).

Fossil hunting in the area before 1996 was driven primarily by the need for geological mappers to correlate rock layers across the region. For this purpose, fossils of non-vertebrate animals are particularly useful, especially

those from marine deposits. Therefore, it was the shelly remains of marine invertebrates that were pursued by paleontologists as they slowly worked out the details of five major oceanic inundations over the region and their age relationships across the Grand Staircase, Kaiparowits Plateau, and Escalante Canyons-Circle Cliffs areas (Stanton 1893; Noble 1928; McKee 1938; Peterson 1969; Cobban et al. 2001). The only other fossils to receive much scientific scrutiny before GSENM's designation were early Mesozoic tetrapod footprints, which occur in great abundance in Triassic and Jurassic sedimentary rocks (Hamblin 1998; Foster et al. 2001).

PALEONTOLOGICAL WORK AFTER CREATION OF GSENM

The initial inspiration for GSENM's paleontological resource management was found in National Park Service (NPS) units such as John Day Fossil Beds National Monument, Oregon (JODA) and Dinosaur National Monument, Utah. In 1996, BLM had no comparable program to serve as a model. At JODA in particular, NPS, through the efforts of paleontologist Ted Fremd, fostered a dynamic partnership with multiple academic institutions that leveraged resources toward an unprecedented effort to integrate regional stratigraphy, paleontology, and paleogeography into a sophisticated synthesis that firmly established JODA as an important North American reference for Eocene to Miocene terrestrial ecology and evolution (Hunt and Stepleton 2004; Albright et al. 2008; Dillhoff et al. 2009). One of the hallmarks of the fossil resource management program at JODA was involvement of NPS staff at every level of research, from fieldwork and laboratory preparation to publication of peer-reviewed papers. A key feature of this model was a fully functioning NPS paleontological preparation and research laboratory located within JODA. The JODA model amply demonstrated that having federal specialists involved led to continuity, focus, and conflict mitigation that would be impossible to achieve by letting competing academic interests simply run their course. In 2000, GSENM began establishing a similar program, with the final piece coming into place in 2005 when BLM's first functioning paleontology laboratory was set up and staffed by volunteers in Kanab, Utah.

The first BLM-funded paleontological fieldwork was a GSENM-wide survey of paleontological resources within its authorized boundary (Foster et al. 2001). Building on a literature-based survey conducted between 1997–1998, 866 sites (1.5% Permian, 7.9% Triassic, 7.6% Jurassic, and 83% Cretaceous) were documented within GSENM (Gillette and Hayden 1997; Foster et al. 2001: table 1 therein).

Soon after, in 2000–2001, three partner institutions began BLM-funded paleontological field inventories and research in Cretaceous strata within GSENM, with the Museum of Northern Arizona focusing on the Tropic Shale and Straight Cliffs Formation, the Utah Geological Survey on the Wahweap Formation, and NHMU (then the Utah Museum of Natural History) on the Kaiparowits Formation. Beginning in 2002, the Yale Peabody Museum conducted a non-federally supported three-year field inventory of the Upper Triassic Chinle Formation, principally in the Circle Cliffs area. These programs were later joined by the Denver Museum of Nature & Science in 2011, also focusing on the Kaiparowits Formation. Together with the work of GSENM paleontologists, these long-term field studies have documented thousands of significant fossil sites (Figure 2) spanning nearly every formation-level geologic unit.

As just one example, to date NHMU alone has conducted 1,210 days of fieldwork comprising 72,960 person-hours of work, surveying over 62,730 acres of fossil-bearing outcrops, and documenting over 2,000 new fossil sites. It should be noted that a key component of these field inventories for all of the teams has been funding for helicopter support to aid in surveying and retrieval of significant fossils. Air support enables inventory and fossil collection in remote and rugged parts of GSENM that are miles away from roads and otherwise inaccessible.

This work has resulted in the preservation, curation, and scientific study of over 10,600 plant, 3,500 invertebrate, 15,500 vertebrate, and numerous ichnological (trace fossil) specimens across seven major museum collections: NHMU, Denver Museum of Nature & Science, University of California Museum of Paleontology, Raymond M. Alf Museum of Paleontology (California), Museum of Northern Arizona, Idaho Museum of Natural History, and Yale Peabody Museum (Figure 3). These globally important fossils, which otherwise would be lost to theft or the inexorable process of erosion, are now preserved in perpetuity in public trust and available to all Americans for education, scientific study, and enjoyment. Though these collections are overwhelmingly from Cretaceous horizons, many significant fossils have also been collected and curated from Triassic and Jurassic strata (e.g., Frederickson and Davis 2017; Schachner et al. 2020).

Scholarly output on this fossil record exploded after GSENM's establishment. The novel conclusions from this research have been shared via presentations at numerous professional conferences, including two specifically dedicated to GSENM (Learning from the

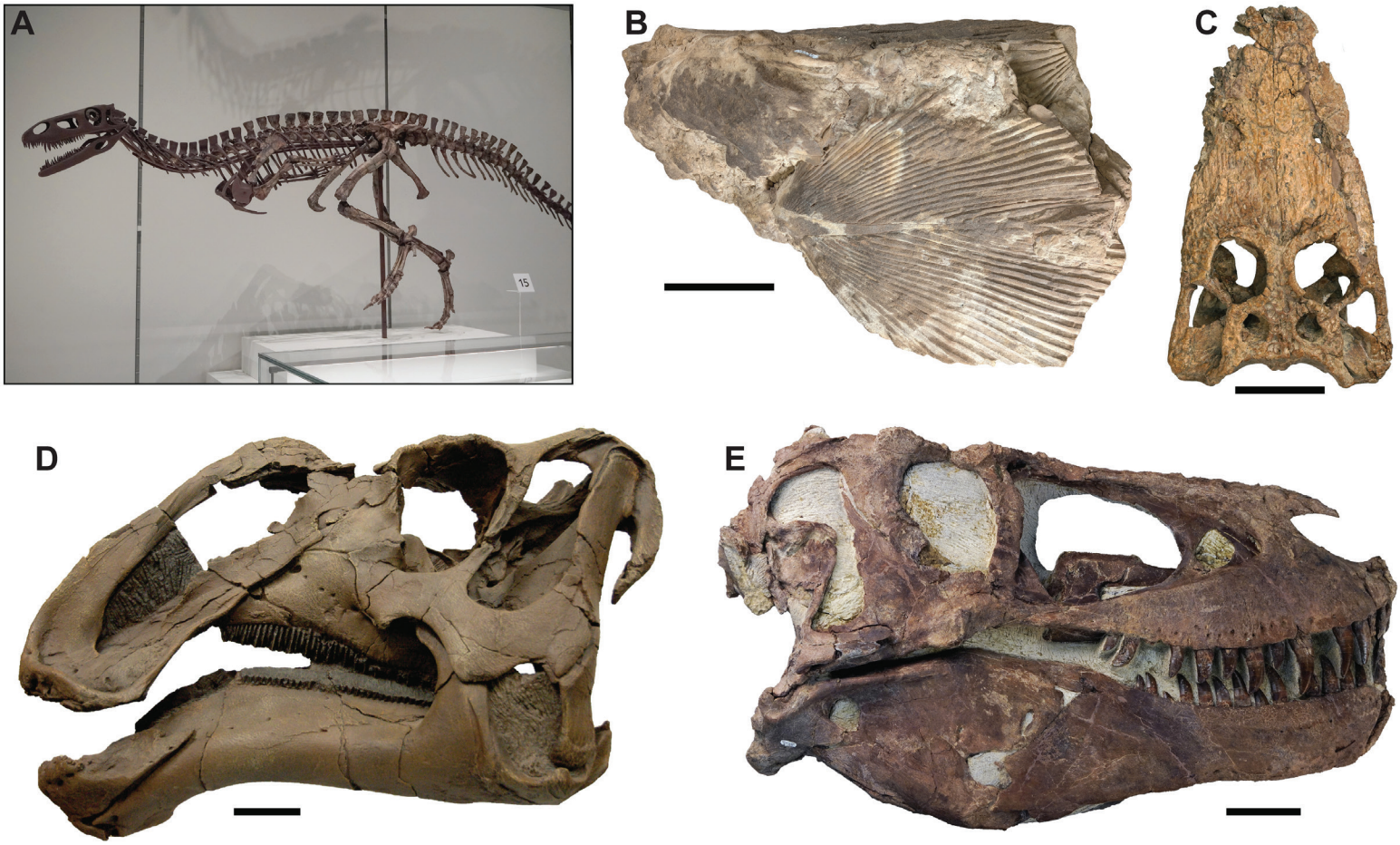


FIGURE 3. Examples of spectacular fossil specimens from Grand Staircase-Escalante National Monument. (A) Reconstructed skeleton of the Triassic archosaur *Poposaurus gracilis* (YPM VP 057100) on display at the Yale Peabody Museum. (B) Fossil palm leaf *Phoenicites* sp. (UMNH PB 2084) from the Upper Cretaceous Kaiparowits Formation. (C) Alligatoroid crocodyliform skull (UMNH VP 21150) from the Kaiparowits Formation. (D) Holotype skull (RAM 6797) of the hadrosaurid dinosaur *Gryposaurus monumentensis* from the Kaiparowits Formation. (E) Tyrannosaurid dinosaur skull (UMNH VP 21100) from the Kaiparowits Formation. Scale bars are 10 cm for B, D, E, and 5 cm for C.

Land 1997; At the Top of Grand Staircase 2009), as well as several special symposia at annual meetings of the Society of Vertebrate Paleontology and Geological Society of America. Peer-reviewed publications on the paleontology of the region only appeared occasionally up through 1986. Starting with the work of Jeff Eaton and others, publication output picked up between 1986 and 1996 (Figure 4), steadily increasing until it more than doubled shortly following establishment of GSENM. Perhaps most impressive is the order-of-magnitude increase in published peer-reviewed science on GSENM fossils since 2000, when intensive BLM support began. Though biased toward the abundant and charismatic Cretaceous vertebrate fossil groups, these scientific publications touch on all geologic periods and types of fossils preserved within GSENM. Collectively, at least 139 peer-reviewed paleontological contributions have been published since the creation of GSENM in 1996, and as of this writing these papers have been cited at least 4,476 times in the scientific literature (according to Google Scholar), and continue to be regularly cited.

BENEFITS TO SCIENCE

One of the primary benefits to science from research in GSENM is the vast database of reference fossils now housed in the various partner institutions. This extends far beyond the type specimens of dozens of new species named from the region. Tens of thousands of curated fossils are now available for study by future scientists to test as-yet-unimagined hypotheses on biospheric evolution. With the broad diversity of fossil flora, fauna, and ichnofauna curated in these institutions, answers to big-picture questions on evolution, ecology, climate change, biogeography, and extinction are now accessible. In particular, the ancient ecosystem preserved in the approximately 76-million-year-old Kaiparowits Formation—informed by a vast diversity of plant, invertebrate, and vertebrate fossils—provides not only one of the most in-depth glimpses of any Mesozoic ecosystem on the planet, but one that existed scarcely 10 million years before the infamous mass extinction event that ended the Mesozoic Era and radically altered the trajectory of life on our planet.

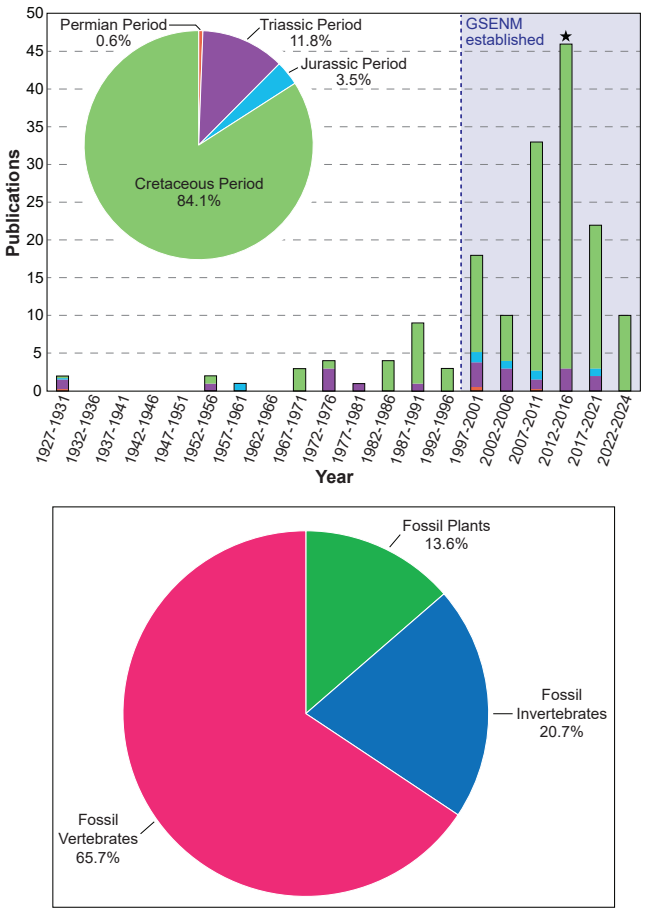


FIGURE 4. Summary of scientific publications on paleontological resources within Grand Staircase-Escalante National Monument broken down by year and geologic time period (top), and type of fossil resource (bottom). The black star indicates a peak in publication rate during 2012–2016 partly as a result of the publication of a major multi-authored volume on the Cretaceous paleontology of the monument (Titus and Loewen 2013). Note that the most recent time bin (2022–2024) is artificially low because it does not comprise a full five years. See supplementary information for full list of publications.

Among the first major breakthroughs catalyzed by GSENM paleontological research was a recognition of latitudinally arrayed endemism in the Late Cretaceous of North America. Because many of the mammalian species described by Eaton and Ciffeli were endemic to the Kaiparowits Formation, questions arose about the precise age of the mammalian bearing horizons. Were they inhabitants of a time period not represented elsewhere or did the Kaiparowits mammals reflect a generalized pattern of north-south endemism originally observed by dinosaur workers in the 1980s? Answering this question required more precise dating of the fossil-bearing strata using methods other than mammalian biostratigraphy. Over the past 20 years, with GSENM support, a detailed integrated chronostratigraphic framework has been constructed for the Late Cretaceous using paleomagnetic stratigraphy, radiometric dating, geologic mapping, and additional biostratigraphic work, resulting in arguably one of the most precise examples of such frameworks in the world (e.g., Roberts et al. 2013; Albright and Titus 2016; Beveridge et al. 2022; Ramezani et al. 2022; Kirkland et al. 2024). This temporal framework is still a work in progress, continually being refined for its use as a tool for global correlation and spurring additional research in rocks of similar age across North America.

From these chronostratigraphic studies, it became clear that the endemism signal Eaton and Cifelli observed in Cretaceous mammals was part of a larger pattern seen in many other vertebrate taxa from the Kaiparowits region. Moreover, these studies showed that the Kaiparowits fauna was contemporaneous with well-known, but completely different faunas described from Montana and Alberta, Canada (Ramezani et al. 2022). Understanding the reasons for these regional/latitudinal differences, aided by continued efforts to place fossil localities within precisely resolved stratigraphic frameworks, will remain a fruitful avenue of research for the foreseeable future.

The abundant, well-preserved, largely endemic fossil remains provide the foundational data for major new research insights elucidated by growing teams of paleontologists at many partner institutions. The vast potential of GSENM as a natural paleontological laboratory has led directly to the growth of major paleontological research programs at a number of public institutions (e.g., NHMU and Denver Museum of Nature & Science). These programs have trained dozens of undergraduate students in field, lab, and curation techniques, together with hundreds of "citizen scientists" (i.e., volunteers who are also sometimes labeled as "community scientists" or "public scientists"). More than a dozen MS and PhD students have written theses and dissertations focused on the paleontology of GSENM. Many of these former students have subsequently gone on to start their own research programs as university faculty and museum curators (e.g., co-authors Zanno, Sertich, Roberts, and Irmis), in turn returning to GSENM to train their own students.

The repository nexus between BLM and non-federal partners also benefits science by creating public support for research as a result of the appreciation people gain for their natural heritage through exhibits and outreach. As an example, the 90,000-square-foot *Past Worlds* gallery at NHMU, which showcases current research on GSENM's Late Cretaceous fossils, has been a major draw for local, national, and international visitors. Visitation to NHMU, currently over 250,000 annually, has more than doubled since the opening of this exhibit, and the museum now consistently ranks as a top "must-see" attraction in the

Salt Lake City area (according to Tripadvisor as of January 2025). Although no hard polling data has been gathered, it is certain these exhibits leave the average visitor with an appreciation for the value of science, not just for understanding our past, but also our future.

RESOURCE BENEFITS

Obviously, the perceived benefits of paleontological resources depend on the stakeholder. Nevertheless, much of the value of fossils, beyond being used as raw materials for construction or energy, is tied to human fascination with them as objects of aesthetic beauty, antiquity, and sources of knowledge about our planet's past. From this perspective, tremendous benefits are gained from conservation and scientific study, *which are core to the mission of every national monument*, whether managed by NPS, BLM, or other federal agencies.

Prior to GSENM's formal designation, the region was popular with recreational and commercial fossil collectors and was featured in several fossil collecting guides. In particular, large oyster shells from the Naturita Formation, ammonites and shark's teeth from the Tropic Shale, shark teeth from the Tibbett Canyon Member of the Straight Cliffs Formation, dinosaur bone and other vertebrate remains from the Morrison and Kaiparowits formations, and petrified wood from the Chinle and Morrison formations and the Drip Tank Member of the Straight Cliffs Formation were among the most sought-after fossils (Carter and Sargent 1983). However, the collecting of some of them (i.e., vertebrate fossils) was done illegally. It is impossible to estimate the magnitude of the loss of scientifically or educationally significant fossils to non-scientific collecting prior to 1996, but it is likely substantial.

All non-permitted hobby-level collecting was closed by Proclamation 6920, which states: "Warning is hereby given to all unauthorized persons not to appropriate, injure, destroy, or remove any feature of this monument and not to locate or settle upon any of the lands thereof." Such closures are at the core of the Antiquities Act (Public Law 59-209, 1906), which authorizes US presidents to create national monuments to ensure the protection and proper care and management of "objects of historic or scientific interest" (i.e., cultural and natural heritage resources). Both the Paleontological Resources Preservation Act (Public Law 111-11, Subtitle D: 16 USC 470aaa, 2009) and resulting federal regulations (43 CFR Part 49 §49.30) require BLM to manage, preserve, and protect paleontological resources using scientific principles and expertise. With few exceptions (such as large *in situ* fossil trackways), the only way to ensure the preservation and protection of scientifically significant fossils is through careful collection, preparation, and curation in a public repository such as those at "reputable museums, universities, colleges, or other recognized scientific or educational institutions" as specified by the original language of the Antiquities Act (also see Department of Interior Manual Part 411, "Identifying and Managing Museum Property"). Ultimately, and especially for scientifically significant specimens, this is the only practical method of preservation.

Between September 1996 and February 2000, when the first resource management plan went into effect, hobby collecting continued throughout much of GSENM, fueled by minimal law enforcement and a general lack of understanding of the rationale behind establishing the monument. With an approved plan, attempts to enforce collecting prohibitions began, and greater efforts to educate the public about the closures were initiated. Although illegal collecting, particularly of petrified wood and Tropic Shale fossils, has continued in GSENM, monitoring of frequently targeted areas (e.g., Morrison Formation outcrops west of Escalante) suggests anecdotally that the combined enforcement and messaging strategy has worked, resulting in a significant drop in fossil poaching over the last 20 years. Notably, after the boundaries of GSENM were (temporarily) reduced in 2017, hobby collecting was considered for two specific areas, similar to what is allowed in Mojave Trails National Monument (also managed by BLM). However, thanks in large part to local support, it was decided that administering such a policy with so many sensitive vertebrate fossil sites would be problematic and the proposal was abandoned.

The scientific study and subsequent public notoriety gained by announcements of new fossil discoveries, particularly the naming of 14 new dinosaur species to date, has greatly increased awareness of GSENM's fossil resources and the need for their protection among both the public and state and federal politicians. There has also been a noticeable shift among local stakeholders in the towns surrounding the borders. Whereas during the first years of GSENM, concerns focused mainly on grazing rights and jobs related to resource extraction, an emerging and strong sense of ownership and stewardship for the area's fossil heritage became evident among citizens and local and state elected officials. Currently, there is even growing enthusiasm for a museum in the GSENM area to showcase the region's fossil riches and serve as a catalyst for future research.

Scientific field inventories have been able to recognize areas of significant resource concentration with active

looting, enhancing resource management and law enforcement activities. Given GSENM's nearly 2 million acres with, at present, only four law enforcement officers, this ongoing inventory has greatly increased the efficiency of resource protection by concentrating patrols where they are most needed. In addition, annual monitoring of key paleontological sites, something rarely done in areas not under a special designation, has allowed BLM to track trends and conditions, and note which areas need more intensive management. Furthermore, high-profile resources like those of the Kaiparowits Plateau create excitement among members of the public, who can then be recruited as volunteers to assist with inventory, research, and resource protection. In one striking example, a BLM volunteer reported amateur fossil enthusiasts suspected of illegally collecting Kaiparowits Formation dinosaur bones. Follow-up contact with the suspected looters by GSENM paleontologist A. Titus resulted in the location of an associated tyrannosaur fossil site and education of the enthusiasts.

In short, creation of GSENM and subsequent funding of paleontological surveys, scientific collection, and research through BLM has been nothing short of a watershed for the preservation of scientifically significant paleontological resources originating in GSENM. Effective management of these resources has benefited local and state stakeholders, while ensuring compliance with federal laws and regulations (e.g., the Paleontological Resources Preservation Act).

The success of the GSENM paleontology program has also inspired other federal land management units to adopt similar approaches, most notably at Petrified Forest National Park, Arizona (PEFO), but also within Utah at BLM's Canyon Country District. The spectacular successes of the PEFO paleontology program, which now has a fully functioning fossil preparation laboratory and multiple paid interns, ultimately led to its nomination as a UNESCO World Heritage site, a direct result of the same targeted, collaborative approach first adopted by JODA and later implemented for the first time by BLM at GSENM (Figure 3).

The unique, exceptionally preserved, and abundant fossils from Upper Cretaceous strata of the Kaiparowits Plateau region of GSENM are certainly "outstanding examples representing major stages of earth's history, including the record of life," one of four natural heritage criteria for selection as a World Heritage Site (https://whc.unesco.org/en/preparing-world-heritage-nominations/). The physical landscape and extant biological diversity of GSENM also satisfy the remaining two criteria, given that GSENM contains "areas of exceptional natural beauty and aesthetic importance" together with "important and significant natural habitats for in-situ conservation of biological diversity." While GSENM clearly is a strong candidate, it remains to be seen if it will ever receive such a designation even though it could be key to securing reliable long-term funding for future research.

PUBLIC BENEFITS

The deep-time archive of ancient life entombed within GSENM has proven to have far-reaching societal benefit. Perhaps most impactful is GSENM's role as a community engagement platform, providing extensive volunteer and youth opportunities in field-based research. The very nature of paleontological data collection, including the discovery, excavation, preparation, and long-term conservation of fossils, plus the associated contextual information, requires the deployment of large teams and is almost universally dependent on the contributions of individuals outside the professional sphere. Since 1999, hundreds, if not thousands, of volunteers have directly participated in the recovery and preservation of fossil resources, primarily through high-profile research programs at the NHMU, Raymond M. Alf Museum of Paleontology, Denver Museum of Nature & Science, Utah Geological Survey, Museum of Northern Arizona, and BLM itself. Many of these community volunteers have participated in citizen science projects in direct collaboration with professional scientists from these institutional partners (Robinson et al. 2018). Participatory field and laboratory experiences in GSENM have also provided experiential educational opportunities for high school students, an approach demonstrated to promote a personal sense of connection to public lands and science stewardship (Lepore et al. 2023). For example, the Paria River District's paleontology lab in Kanab has repeatedly served as a training ground for local high school students wishing to compete in the science category of Utah's Sterling Scholar competition. Also, because of the Alf Museum's unique position as a nationally accredited museum and federal repository affiliated with a high school, its students routinely participate in both field and lab-based scientific research on GSENM sites and specimens, in addition to education on care for fossil resources in the field and the museum collection.

Precise replicas of GSENM fossils in the museum's collection have been harnessed for K–12 educational programs, reaching every fourth-grade classroom in the state via the *Museum on the Move* and *Teaching Toolboxes* programs, and digitally reaching hundreds of classrooms

nationwide through *Research Quest*. These outreach efforts ensure that the fossils collected on federal lands are shared with all US citizens. Other institutions, in addition to the Alf Museum, such as the Denver Museum of Nature & Science, the Museum of Northern Arizona, and the Yale Peabody Museum, have benefited similarly.

Research stemming from the paleontological and geological resources of GSENM also contributes broadly to increasing scientific literacy. The public, for example, benefits from exhibits featuring GSENM fossils, such as those found at the NHMU (Figure 5), BLM's Big Water Visitor Center, the Alf Museum, and the Denver Museum of Nature & Science, whose collective annual visitation exceeds 1.5 million. These exhibits serve as sources of inspiration for people curious about the history of our natural world and give them a sense of place, in turn allowing for reflection on the grand procession of evolution and the concept of deep time. The unbridled excitement of exploration experienced by scientists working within GSENM inspires the public to think critically about the natural world, asserts the societal benefits of research on ancient ecosystems reflecting our planet's vast geologic history, and demonstrates the effectiveness of pluralistic conservation projects, including, particularly, the multidimensional benefits of combining natural resource protection with the preservation of recreational land (Santucci et al. 2016).

The media interest generated by many of the GSENM discoveries demonstrates the public's appetite for new knowledge about ancient life. For example, two species of theropod dinosaurs discovered in GSENM (*Talos sampsoni* Zanno et al. 2011; and *Lythronax argestes* Loewen et al. 2103) received international press attention by notable outlets such as *National Geographic*, NPR, BBC, NBC, ABC, Live Science, *Highlights* magazine, and *Smithsonian* magazine. These two dinosaurs alone

FIGURE 5. **Kaiparowits Formation section of the Past Worlds exhibit at the Natural History Museum of Utah featuring full mounted skeletons of several Grand Staircase-Escalante National Monument dinosaurs. Shown are *Utahceratops gettyi, Gryposaurus monumentensis, Akainacephalus johnsoni,* and *Ornithomimus* sp.**

have generated approximately 1 million hits on Google. To give another example, media coverage following the 2018 publication of the new species of armored dinosaur, *Akainacephalus johnsoni* (Wiersma and Irmis 2018), was covered by over 800 media outlets and reached an audience of 1.2 billion people, generating almost $12 million in comparative advertising value. Far from reaching its zenith, the description of new dinosaur taxa within GSENM continues to provide a steady source of fodder for connecting the global public with the value of scientific discovery. There are currently more than 15 new dinosaurs awaiting formal description. Amazingly, dinosaurs from GSENM have even been featured in pop cultural phenomena such as the *Jurassic World* movies, bringing the discoveries to new global audiences.

Of equal importance is the power of GSENM to raise awareness about future changes to the climate and environment through the lens of research on the past when our planet experienced similar conditions. The Cretaceous rocks of GSENM and the fossils they contain record the effect of global warming and sea-level rise under high atmospheric CO2 concentrations expected to mirror those our planet will likely face by the end of the 21st century (Lee et al. 2023). As a result, research on GSENM fossils can spark conversations on how to best mitigate changes to the planet and improve societal outcomes from this clear and present challenge.

SUMMARY AND CONCLUSIONS

In summary, the ongoing 25-plus years of paleontological resource inventory within Grand Staircase-Escalante National Monument has been spectacularly productive, serving as a model for successful scientific partnership in National Conservation Lands units between the BLM and non-federal institutions. The results of this work have vastly improved our understanding of paleontological resources within GSENM, allowing managers to make more informed and effective resource management decisions in accordance with the Paleontological Resources Preservation Act. This long-term field project has also resulted in the curation of tens of thousands of significant fossil specimens into public museum collections for scientific research, education, and public enjoyment. These fossils, representing dozens of previously unknown species and ancient ecosystems found nowhere else on Earth, have engaged millions of schoolchildren and other members of the public, allowing them to learn about the immense paleontological heritage preserved on their public lands. Significant opportunities remain in developing exhibits and public programming on GSENM fossils through the proposed creation of a regional museum located in one of the local communities.

Given the relatively brief history of paleontological research within GSENM, especially when compared to that on similarly aged fossil-rich sediments elsewhere in western North America, we anticipate that, with continued support, the pace of scientific discovery will only accelerate in years to come. Undoubtedly, many more new species of fossil plants and animals remain to be discovered, and it is likely that many more sit in museum collections waiting to be identified and described. Furthermore, additional specimens of already known species will provide unique insights into the life histories of these organisms, how they interacted as predators and prey, and how they responded to environmental changes over geologic time. It is also important to emphasize that, to date, field and research efforts have been overwhelmingly biased towards the Upper Cretaceous rock layers, and the number of documented fossil sites scales proportionally with these efforts. Thus, more concentrated field surveys of Permian, Triassic, and Jurassic rock layers will certainly reveal hundreds of new fossil sites and thousands of scientifically significant fossils in the large areas of GSENM that have not yet been systematically inventoried.

The structure and success of this collaboration serve as a powerful framework that can be duplicated for scientific research and inventory initiatives in other National Conservation Lands units as long as appropriate long-term funding and personnel support are maintained. These partnerships elevate science on public lands; ensure that local, state, and national communities can engage with this science; and ensure the proper management and preservation of natural and cultural resources on public lands. For GSENM, it is certainly true that the past is the key to the future.

The findings, conclusions, and opinions in this article are those of the author(s) and do not necessarily represent those of the Bureau of Land Management.

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