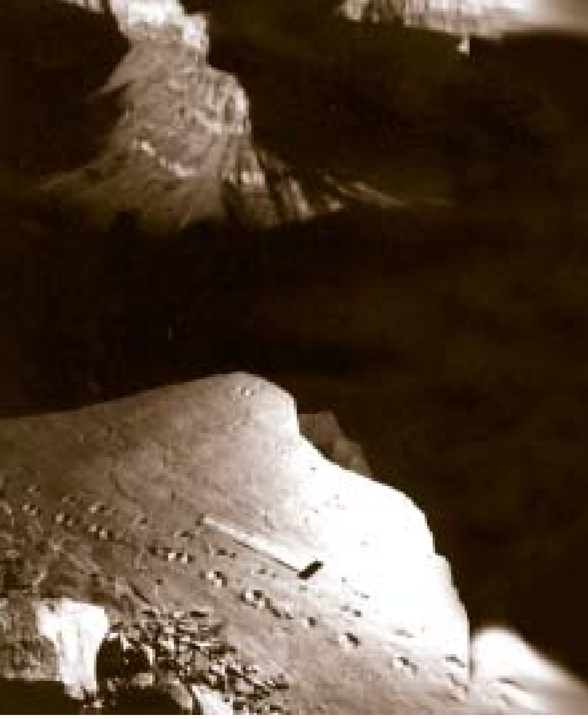

PALEONTOLOGICAL RESOURCE MONITORING STRATEGIES for the National Park Service

By
Vincent L. Santucci
and
Alison L. Koch

The ability to manage and protect fossils is contingent upon an understanding of their occurrence and distribution, both geologic and geographic, and the factors threatening their stability. Paleontological resources at or near the surface will ultimately deteriorate over time.

Within the National Park Service, a paleontological resource inventory strategy has been established to compile baseline paleontological resource data. These data support both scientific and management objectives and are crucial prerequisites for the development and implementation of fossil monitoring in national parks.

This work represents a first effort to establish the critical elements for monitoring in situ paleontological resources in the National Park System. The monitoring design identifies natural and human variables that threaten or impact in situ fossils. Rates of weathering and erosion, climate, topography, and a wide variety of human-related activities are considered as part of this assessment.

Figure 1. A great variety of fossils are preserved in more than 160 units of the National Park System, including (clockwise from top) Late Paleozoic reptilian or amphibian tracks at Grand Canyon National Park, Arizona; tracks of a camel *(Pecoripeda)* and cat *(Besiopeda)* at Death Valley National Park, California; a petrified tree (a conifer called *Cupressinoxylon*) at Big Bend National Park, Texas; and burrows from a worm-like animal at Arches National Park, Utah. Fossil conservation in the national parks hinges on knowledge of their presence and distribution and is enhanced through inventory and monitoring.

Why monitor paleontological resources?

Legislation and ethics support the establishment of natural resource monitoring within the National Park Service. The National Park Service Organic Act (1916) and the National Parks Omnibus Management Act (1998) authorize the preservation and stewardship of all park natural resources and identify the need for park managers to use sound science in making decisions about resources.

The conscience of the National Park Service management regarding natural resource preservation was elevated through the writings of Richard Sellars in his book *Preserving Nature in the National Parks: A History* (1997). Sellars' work inspired a movement that resulted in the Natural Resource Challenge, which established funding and guidance for milestone programs, including a focused effort to inventory and monitor natural resources.

More than 160 units of the National Park System have been identified with paleontological resources. Collectively these fossils span all ages of geologic time from the Precambrian to recent, and preserve a variety of paleoecosystems, providing key information about the history of life (fig. 1). Millions of visitors are attracted to national parks by the spectacular fossils they preserve, ranging from charismatic dinosaurs, mammals, and trees to remarkable assemblages of the life of ancient oceans, lakes, forests, and prairies, including their small animals, insects, and plants.

Paleontological resource inventory and monitoring are necessary to preserve park fossil resources as required by the NPS Organic Act and longstanding NPS policy. Inventory is the comprehensive compilation of baseline resource data. Monitoring is the establishment of measurable indicators ("vital signs") to assess the condition and stability of resources.

A variety of natural and human variables threatens the condition and stability of paleontological resources. These threats may result in the deterioration or loss of fossils, a scenario contrary to the established resource preservation mission of the National Park Service.

What are the threats?

A threat includes any natural or human factor that may adversely impact a paleontological resource. These threats have the potential to cause the deterioration or loss of paleontological resources at or below the surface (table 1, page 24). Typically, multiple threats work concurrently to affect the stability of in situ paleontological resources.

Physical, chemical, and biological factors, although natural processes, may adversely affect the stability of paleontological resources. For example, high rates of erosion within fossiliferous rock units in Badlands National Park and Hagerman Fossil Beds National Monument result in the exposure and loss of paleontological resources at the surface (fig. 2). Loss of resources may occur very quickly, as in Channel Islands National Park, where mammoth fossils can be exposed in sea cliffs, then fall into the sea during a single winter storm season.

Human activities can be assessed in consideration of how they may benefit or adversely impact natural resources and processes. In 1999 the National Park Service compiled data on 721 incidents of fossil theft or vandalism, demonstrating a significant human threat to paleontological resources (Santucci 1999). High levels of souvenir collecting of petrified wood have resulted in Petrified Forest National Park being listed as one of the National Parks Conservation Association's 10 most endangered parks. The potential human-related threats to paleontological resources are best illustrated through the story

Figure 2. A primary factor in fossil stabilization, erosion is monitored closely by park staff at Fossil Butte National Monument, Wyoming. Changes in measurements between the substrate and the top of a reference stake (not visible) are recorded along with local temperatures, precipitation, wind speed, and other factors that affect erosion. Together, the data help the park anticipate management action necessary to preserve park fossils.

Table 1.
Factors that Affect the Stability of In Situ Paleontological Resources

SURFACE

Physical	Chemical	Biological	Human
Tectonics • seismicity • folding/faulting • extrusive events (lava flows) *Weathering/Erosion* • solar radiation • freeze/thaw • wind • water • fire • gravity • mass wasting • abrasion during transport	• surface water • soil/lithologic pH • mineral replacement • oxidation (rust, pyritization)	*Displacement* • pack rats • harvester ants *Destruction/Damage* • burrowing organisms • trampling ungulates • vegetation (root & lichen growth)	• construction (buildings, roads, dams) • mining • military activities (construction, vehicles, ballistics) • theft/vandalism • poor science and recovery technique • livestock • agriculture • recreational activities (off-road vehicle travel)

SUBSURFACE

Physical	Chemical	Biological	Human
Tectonics • seismicity • folding/faulting • intrusive events • metamorphism *Weathering/Erosion* • freeze/thaw (permafrost) • water movement (piping, cavern formation) • gravity • mass wasting • compaction • rock falls	• groundwater • soil/lithologic pH • mineral replacement • metamorphism (partial melt, recrystallization)	*Displacement* • root growth • bioturbation *Destruction/Damage* • burrowing organisms • root growth	• construction (buildings, roads, dams) • mining • military activities (construction, ballistics) • theft/vandalism • poor science and excavation technique (dynamite)

of Fossil Cycad National Monument. This unit of the National Park System was established in 1922 and abolished in 1957 following years of poor management practices that resulted in the extreme degradation and eventual loss of the fossil resource (Santucci and Hughes 1998).

From a management perspective, inadequate baseline paleontological resource data is an additional threat. Although the National Park Service has made significant advances in paleontological resource management through comprehensive inventories, targeted research, and better documentation of resource degradation, many park managers still lack sufficient paleontological data to assess threats and resource conditions.

> “Inadequate baseline paleontological resource data is an additional threat.”

How do we measure and monitor loss?

In order to quantify loss, the National Park Service has established a system using vital signs as measurable indicators of change to resource conditions. Paleontological localities vary widely in terms of rock types, fossil preservation, geomorphic characteristics, and human accessibility. Therefore, any specific indicator may not be useful or appropriate at all fossil sites. Surface condition may be an approximate indicator of subsurface stability. Only a few studies have attempted to assess or measure impacts to in situ paleontological resources. Colbert (1966) established methods for monitoring rates of erosion. Fremd (1995) presented strategies for periodic surveys, called cyclic prospecting, that assess surficial occurrences of fossil vertebrates at a locality. Hockett and Roggenbuck (2002) conducted a social science study assessing human attitudes and behaviors relative to fossils. This study represents the

Standing petrified trees are among the 147 species of fossil plants that have been discovered on Specimen Ridge in Yellowstone National Park, Wyoming. Wood and leaf fossils made the identifications possible, including 81 species new to science.

first effort to establish specific vitals signs for fossil resources, which we refer to as paleontological resource stability indicators (PRSI), as in the following list.

Climatological Data Assessment PRSI: This indicator assesses data on annual precipitation, rainfall intensity, relative humidity, wind speed, and freeze-thaw index (number of 24-hour periods per year when temperature fluctuates above and below 32°F [0°C]).

Rates of Erosion Assessment PRSI: This indicator assesses data on both inherent and dynamic factors such as specific rock (lithologic) characteristics, slope, soil loss, vegetation cover, and rates of denudation for fossiliferous rock units.

Human Activity/Behavior Assessment PRSI: This indicator assesses data on visitor use, visitor access routes and their proximity to fossil localities, documented cases of theft or vandalism, and commercial market values of fossils.

Periodic Site Assessment PRSI: This indicator assesses data on the relative turnover rate of specimens at each fossil locality by monitoring the numbers of specimens destroyed (lost) or exposed (gained) at the surface. This information can be obtained through cyclic prospecting, photographic monitoring, and other spatially predictive models.

Conclusion

Establishing strategies and guidance for paleontological resource monitoring has clearly emerged as the critical next step for the management of fossils in the national parks. Managers in more than 160 parks with fossils often lack a staff specialist and need reasonable and consistent standards and methods for monitoring paleontological resource conditions. The use of paleontological resource stability indicators provides a multidimensional approach to assessing the conditions of in situ fossils. Paleontologists, geologists, archeologists, and climatologists are being consulted in order to develop resource-specific protocols. In addition, a conceptual model for paleontological resource monitoring that identifies cause-and-effect relationships is currently being developed. Adoption of Servicewide protocols for monitoring these resources will further enable assessment of the threats and conditions affecting fossils throughout the National Park System.

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About the authors

Vincent L. Santucci *is the Chief Ranger of George Washington Memorial Parkway, Turkey Run Park, McLean, VA 22101. He can be contacted by email: vincent_santucci@nps.gov.*

Alison L. Koch *is a Paleontological Technician at Santa Monica Mountains National Recreation Area, 401 W. Hillcrest Dr., Thousand Oaks, CA 91360. Her email address is alison_koch@nps.gov.*