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Assessing the Stability and Sustainability of Rock Art Sites: Insight from Southwestern Arizona

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Abstract In light of global trends in human population growth and urbanization, burgeoning cultural heritage tourism industries, and climate change, cultural heritage places in nearly every corner of the world are significantly threatened, and will remain so into the foreseeable future. Rock art sites are some of the most imperiled, with their exposed contexts posing unique challenges to conservation. Consequently, effective management of publically accessible rock art sites necessitates a sustainable approach that weighs visitation in regard to cultural significance and site stability. This essay integrates rock art stability and sustainability assessment methodologies at the Painted Rock Petroglyph Site in southwestern Arizona. The study specifically applies the Rock Art Stability Index (RASI) to evaluate the natural and anthropogenic weathering forces impacting the site, and the Heritage Asset Sensitivity Gauge (HASG) to assess site sustainability under existing management practices in relation to current and forecasted rates of visitation. A spatial analysis of aggregated RASI data shows that visitor foot traffic has had some of the most profound impacts to the petroglyphs. Unrestricted access to the site area is also highly correlated with the presence and location of vandalism and graffiti, and visitor-related trampling has adversely affected the site's surface artifact assemblage. Application of the HASG projects that, while existing management practices are fairly sustainable, they become less so under forecasted increases in visitation. Further, the HASG appraises the site's cultural significance as outweighing its market appeal, indicating management efforts should prioritize conservation over tourism-related development.

Keywords Rock art · Sustainability · Stability · Condition assessment · Weathering · Conservation

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Introduction

Rock art is renowned the world over for the multitude of values afforded it by local communities, cultural resource professionals, scholars, and the generally interested public. Indeed, rock art is actively studied and managed on six of the earth's seven continents (Bahn *et al.* 2016)—the exception being Antarctica, of course, where evidence of an indigenous population at any point in the past has yet to surface (Zarankin and Salerno 2014, p. 115). As of 2011, the United Nations Organization for Education, Science and Culture (UNESCO) had added 37 places, representing each of the six continents, to the World Heritage List based on the outstanding universal value of rock art, with another 42 rock art localities on the tentative list for inclusion (Sanz 2012). Understandably, rock art's ubiquity and appeal to diverse bodies of stakeholders in nearly every corner of the globe have given rise to organized international interest groups focused specifically on its study, interpretation, and conservation, notably the International Scientific Committee on Rock Art (a focus group of the International Council on Monuments and Sites) and the International Federation of Rock Art Organizations, as well as multiple social networks serving the global rock art community (*e.g.*, Haubt 2015a, b; Hoerman 2017).

Coincident with this expanding interest has been the growing awareness of rock art's vulnerability to a sundry array of decay processes and destructive agents (Agnew *et al.* 2015; Berltilsson 2008), many of which are unique to rock art due to its physical structure, visual allure, and highly exposed nature relative to most other types of cultural heritage properties. In fact, threats to rock art sites are rapidly expanding and changing in unexpected ways in concert with global population increases and concomitant development pressures (*e.g.*, Brink 2014), a burgeoning cultural heritage tourism market (Deacon 2006), especially in rural and developing regions (*e.g.*, Di Lernia 2005; Duval and Smith 2013, 2014; Kinahan 2003; Little and Borona 2014; NMCON 2003; Norder and Zawadzka 2016; Rossi and Webb 2007), the rise of air pollution and acid rain (Åberg *et al.* 1999; Black *et al.* 2017; Laver and Wainwright 1995; Varotsos *et al.* 2009), and climate change (*e.g.*, Carmichael 2016; Giesen *et al.* 2014a, b).

In light of these compounding stressors and the unfortunate scenarios to which they all too often lead, the conservation and management of rock art sites has emerged as a critical field of research and specialization within the larger domain of cultural heritage management (Anati *et al.* 1984). The past several decades have witnessed the preparation of numerous synthetic works from across the globe covering approaches, methods, techniques, politics, and ethics concerning the diverse ways local communities approach the conservation, preservation, and management of rock art (*e.g.*, Crotty 1989; Darvill and Batarda Fernandes 2014; Dean 1999; Kim 2014; Lee 1991; Malla 1999; Pearson 1978; Pearson and Swartz Jr. 1991; Sánchez *et al.* 2008; Thorn and Brunet 1995; Ward and Ward 1995). Nevertheless, since this emerging discipline continues to evolve in tandem with the realization of the myriad challenges it faces, and because the number of places in need of conservation action and greater management attention typically far exceeds locally available resources and capabilities, efforts are, more often than not, "reactionary" (Agnew *et al.* 2015, p. 17; Marshall and Taçon 2014, p. 214; Watchman 2005, p. 14; Whitley 2006, p. 18) rather than proactive.

From a conventional perspective, proactive custodianship and management of rock art necessitates a baseline knowledge of the amount, type, and diversity of rock art at a site, awareness of its cultural and natural contexts, communication with all stakeholders and consideration of the values they ascribe to the rock art, thorough assessment of the rock art's physical condition, and identification of past, current, and foreseeable threats to its integrity (Loubser 2001; Magar 2012). Even though formal management planning for rock art involves different stages of design and implementation, the process should be iterative rather than linear (Fig. 1). The ongoing review of current management efforts can accommodate new information and differing perspectives, thus providing the requisite flexibility and adaptability for unexpected and unknown situations. Nonetheless, because rock art is so fragile and imperiled—with today's known corpus representing a mere fraction of what was actually created in the past (Clottes 2006)—detailed assessment of its condition and identification of the agents of stone decay and other threats are essential early steps in management planning (Deacon and Agnew 2012, p. 252; Loubser 2014, p. 127; Magar 2012, p. 540; Sundstrom and Hays-Gilpin 2011; Whitley 2011, p. 183). Holistic condition assessments, which take into consideration the role of human *and* non-human agents in weathering and decay processes, diagnose the physical condition of rock art and identify threats based on observation of existing and pending impacts. From an operational perspective, such evaluations serve to equip cultural heritage managers with information that can aid in prioritizing conservation efforts and funding, if so warranted. Rock art condition assessments also yield baseline records to which future evaluations can be compared in order to monitor decay processes through time and across weathering agents.

The remainder of this essay presents a holistic site condition assessment of the Painted Rock Petroglyph Site, an actively promoted and frequently visited cultural heritage place in the Sonoran Desert of southwestern Arizona. Specifically, this study employs the Rock Art Stability Index (RASI) to analyze the stability of hundreds of petroglyph-bearing boulders in light of the geomorphological factors and anthropogenic forces conditioning the stone decay process and impacting the site's integrity more generally. The RASI analysis is augmented with an evaluation of graffiti and comparison of surface artifact

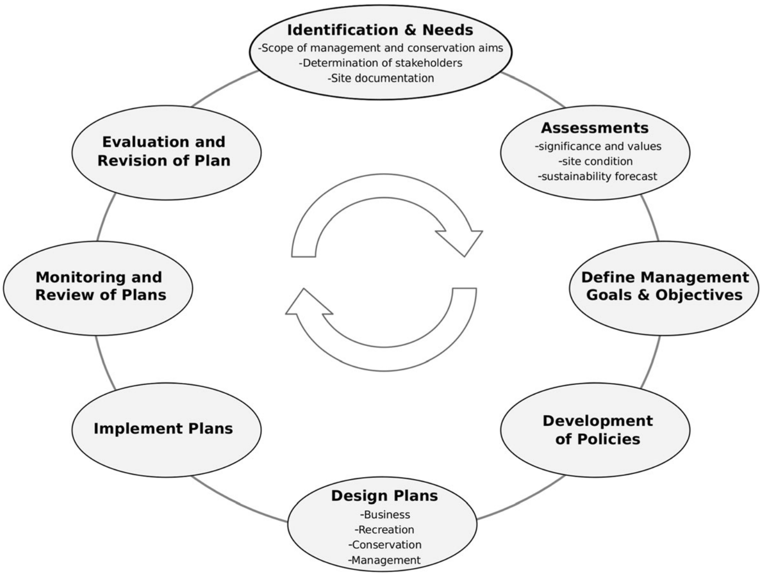

Fig. 1 The management cycle (adapted from Magar 2012, Figure 30.1)

sizes between 1952 and 2017, both of which inform on human impacts to the site that do not directly affect the rock art. From that foundation, the sustainability of the site under current management practices and forecasted conservation demands is evaluated.

The Petroglyphs at Painted Rocks

The Painted Rock Petroglyph Site, AZ S:16:1(ASM), is located in the Dendora Valley of southwestern Arizona, a rural setting along the lower Gila River located approximately halfway between the urban centers of Phoenix and Yuma (Fig. 2). Situated at just 180 m above sea level and enveloped by the Sonoran Desertscrub biome (Turner and Brown 1982), the climate at Painted Rocks can be considered sultry and xeric, with average rainfall under 18 cm annually and mean July temperature hovering around 43 °C. The petroglyphs are localized to a small boulder inselberg formed by the spheroidal weathering of a granodiorite pluton (Nicholson 2004). With an area of nearly 6100 m^2, this small but conspicuous inselberg appears as two small spires of dark, heavily varnished boulders jutting approximately 9 m upward from the surrounding desert floor. Over eons, corestones have eroded from the exposed granodiorite basement; these corestones now stand as the sub-rounded, darkly varnished boulders on which the petroglyphs are emblazoned. Boulders near the top of the inselberg rest upon the bedrock mass whereas those around the periphery float upon a thin lens of salt-and-pepper-colored grus (Fig. 3).

Although today the site consists entirely of petroglyphs, its “painted” moniker derives from eighteenth and nineteenth century accounts that some of the petroglyphs had, in fact, been painted over (Browne 1864, p. 702; Disturnell 1881, p. 110; Harris 1960[1849], p. 83; Sedelmair 1856[1748], p. 19). Due to their open-air nature, any macroscopic evidence of paint or pigment upon the Painted Rocks has since weathered away. The petroglyph cluster is located alongside an ancient trail that connected large indigenous population centers in the Phoenix and Gila Bend Basins with one centered on the Gila/Colorado confluence at present-day Yuma (Wright *et al.* 2015). As the principal travel corridor through a rather challenging terrain, this ancient trail would come to play a key role in the colonization of California and the westward expansion of the USA. Once known as the Gila Trail and memorialized today as the Juan Bautista de Anza National Historic Trail, this well-trod footpath eventually gave way to a formal, maintained wagon road (Fig. 4). Built in 1846/1847 by the Mormon Battalion of the Army of the West, Cooke’s Wagon Road guided tens of thousands of California-bound gold-seekers and migrants (Brigandi 2009, p. 7) and later served as the southern route of the Butterfield Overland Mail and Stage Line (Ahnert 2011). It remained the principal travel corridor between southern California and southern Arizona until the arrival of the Southern Pacific Railroad in 1877.

History of Management

The Painted Rock Petroglyph Site (Fig. 5) is on land administered by the U.S. Bureau of Land Management (BLM). In the 1930s, there was an unsuccessful grassroots effort to set aside Painted Rocks as a national monument in order to preserve this unique landmark (Miller 1938). In 1962, the BLM erected a steel chain-link fence and turnstile around the site’s eastern spire, where the petroglyphs are concentrated (Fig. 6). From 1965 to 1991, the site was patented to the Arizona State Parks Board who managed it as the Historic

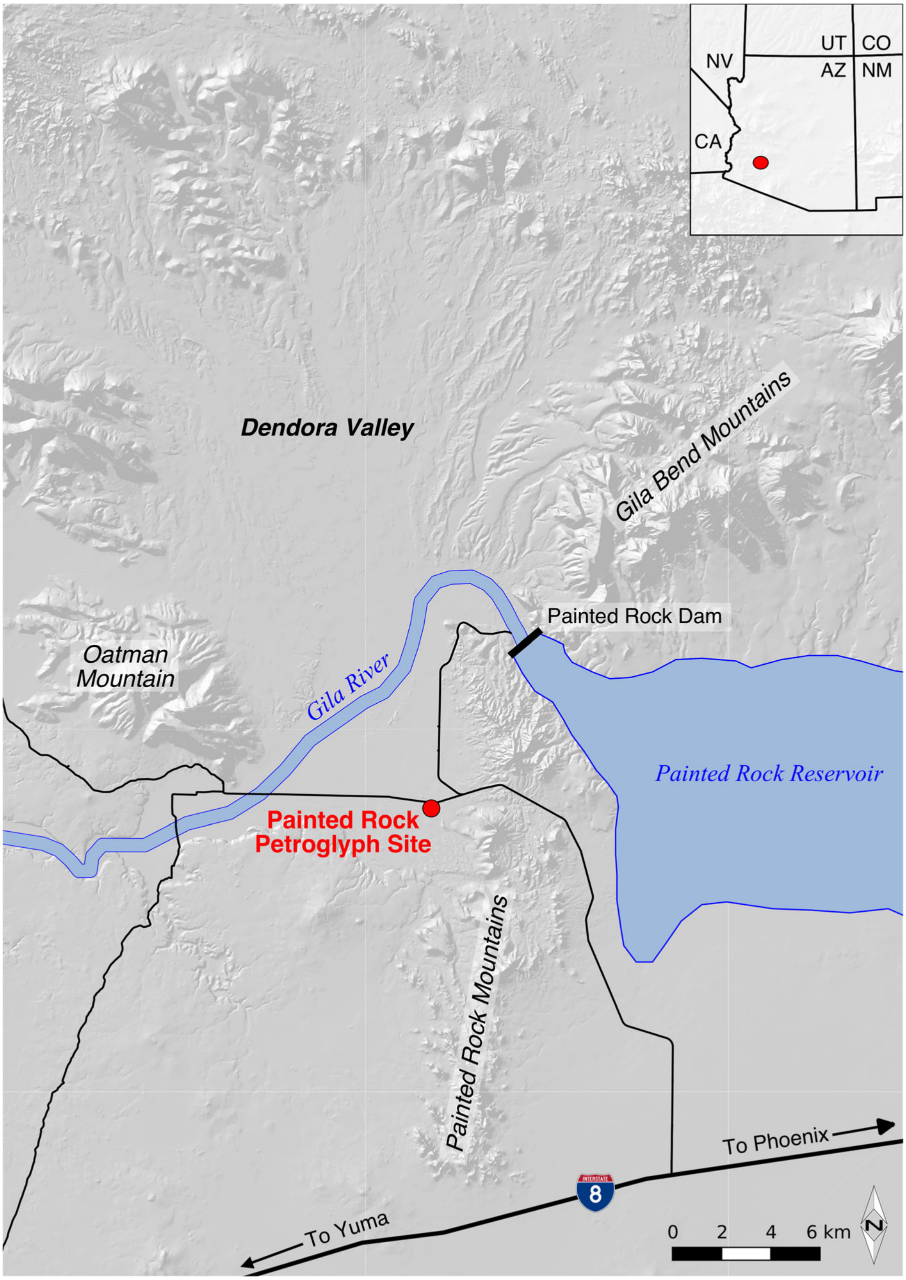

Fig. 2 Location of the Painted Rock Petroglyph Site

Unit of the Painted Rock State Park (Eatherly 2006). The State Parks Board installed a number of facilities, including access roads, parking lots, ramadas, picnic tables, restrooms, and primitive camp sites. In 1972, they received another patent from the BLM for additional land around Painted Rocks to provide more space for camping and better amenities for the burgeoning level of visitation (*Tucson Daily Citizen* 1972a,

Fig. 3 The petroglyphs at Painted Rocks adorn corestones that have eroded from an exposed granodiorite pluton (photo by Lance Trask)

1972b), undoubtedly tied to the postwar boom in recreational vehicle (RV) sales and emerging RV culture (Harmon 2001). With growing national acclaim, the Painted Rock Petroglyph Site was eventually added to the National Register of Historic Places in 1977, but the attention also fueled a rise in vandalism and graffiti at the site (Heltsley 1971).

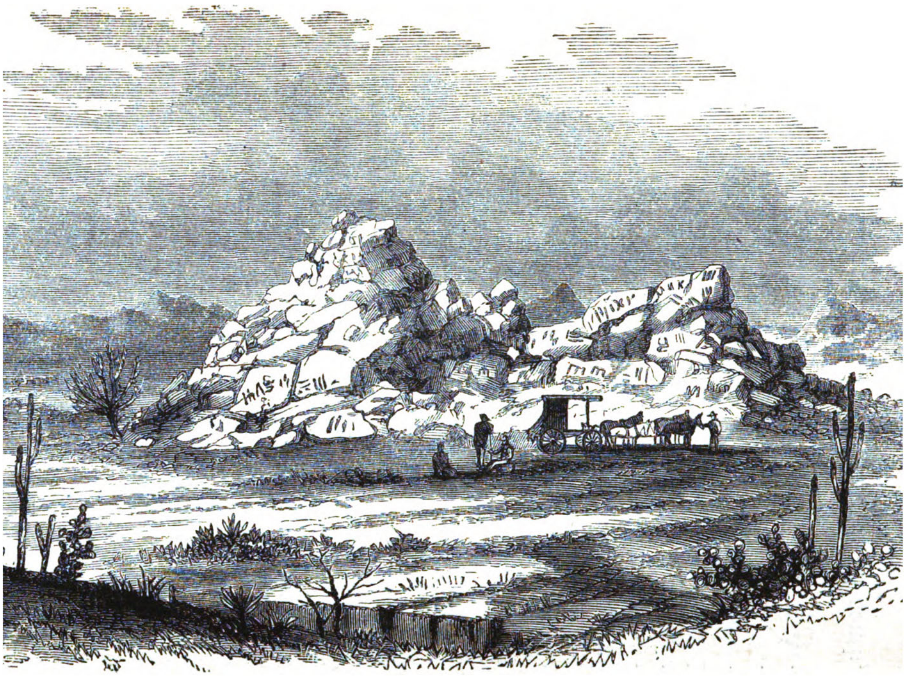

Fig. 4 J. Ross Browne's illustration of his idyllic stop at Painted Rocks during a stage tour in 1863 (from Browne 1864). The view is from the current campground facing north. The tree at the left edge of the rocks still stands

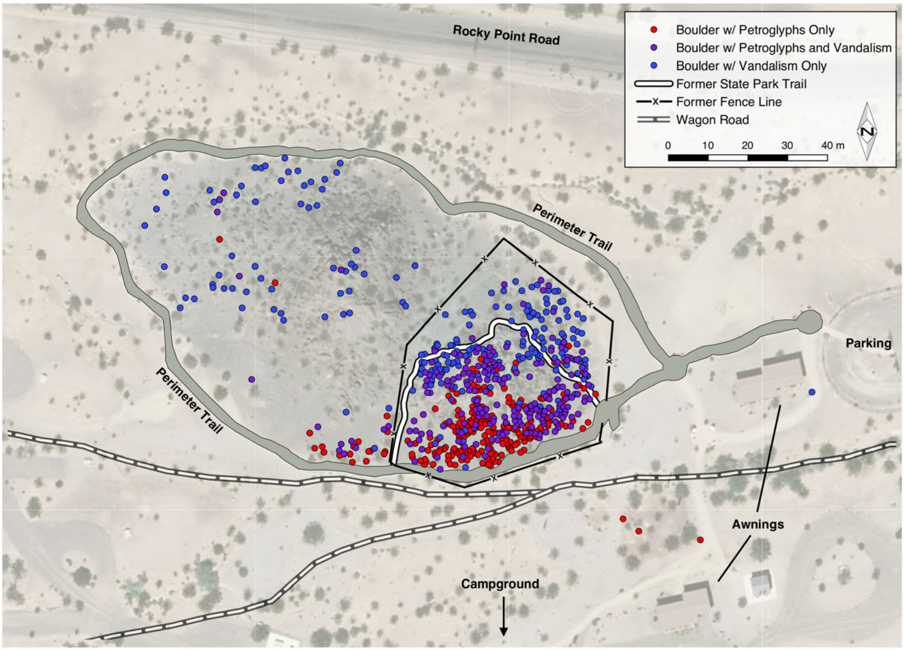

Fig. 5 Overview of the Painted Rock Petroglyph Site

By 1982, visitation to Painted Rocks was estimated at between 8000 and 10,000 people per year (*The Arizona Republic* 1982); however, in 1989, the park's nearby Lake Unit was closed due to pesticide contamination (Van Der Werf 1989). As a result, the state began retracting their interests in the entire Painted Rock State Park, first by relinquishing their patent to the Historic Unit (the Painted Rocks) followed by their lease of the Lake Unit (Eatherly 2006). Title and management of Painted Rocks were re-conveyed to the BLM in 1991, who immediately prepared a Recreation Project Plan to rehabilitate what had become a dilapidated, abandoned park (BLM 1991). Under renewed management, visitation to Painted Rocks quickly soared to an estimate of 15,000 people annually (BLM 1998). Between 1995 and 2005, the BLM invested more than one-half million dollars to stabilize and upgrade facilities, redesign the trails, and develop interpretive signage (BLM 2005). This remodeling and change in management practices included the removal of the chain-link fence and the implementation of a camp-host program during peak visitation season (October through April). Coincident with Painted Rocks' revitalization has been a renewed grassroots campaign to incorporate the site within a new national monument (Wright and Hopkins 2016; Wright *et al.* 2015). Despite the mounting attention, any semblance of a conservation management plan for the Painted Rock Petroglyph Site has yet to be developed. The following condition assessment is a step in that direction.[1]

[1] This condition assessment of the Painted Rock Petroglyph Site originated through communication with descendant communities and consideration of their interests. During meetings with the Fort Yuma Quechan Indian Tribe's Cultural Committee and Tribal Council regarding the proposed Great Bend of the Gila National Monument, participants voiced concern for how cultural heritage places would be managed, citing the impact of high levels of unrestricted visitation to Painted Rocks as a case in point (Wright and Hopkins 2016:112). Similar concern was voiced by advisors from the Salt River Pima-Maricopa Indian Community during a presentation to the Four Southern Tribes Cultural Resource Working Group on August 18, 2017.

Rock Art Condition Assessment Methods

Rock art condition assessments can be highly specialized endeavors requiring technical training and costly instrumentation (*e.g.*, Bemend *et al*. 2014; Fitzner *et al*. 2004). However, the dire forecast for many rock art manifestations, the breadth of assessment work needed, the limited number of professional rock art conservators, and oftentimes the constrained budgets of site owners and land managers demand the development and implementation of rapid, reliable, systematic, cost-efficient, non-technical approaches. Several assessment instruments tailored toward these criteria have been presented, and these are reviewed below.

The Motif/Area Method

The Motif/Area (MA) Method (Giesen *et al*. 2014b) is adapted from the Unit-Area-Spread Staging System designed for assessing the decay of architectural stone (Warke *et al*. 2003), which itself is modeled after the internationally recognized Tumor-Node-Metastases Staging System used in the evaluation and treatment planning for cancer patients (Brierley *et al*. 2016). The MA method ranks observations ("stage estimates," scored from 0 to 3) on the amount of deterioration to the rock art motif and the surrounding stone matrix, or panel. As a means of ensuring reliability, each rock art panel is assessed by independent scorers, and their stage estimates are pooled and averaged. Based on the paired averages of M and A, the panel's condition is then given a "stage value" between 1 (good) and 4 (poor). Albeit expedient, cost-efficient, and designed explicitly for non-experts and volunteers (Giesen *et al*. 2014b, p. 50), the MA method has several drawbacks, the most significant being its disregard for identifying what factors have contributed to the rock art's condition. For this reason, the MA method was deemed insufficient for the current study.

The Rock Art Stability Index

The Rock Art Stability Index (RASI) was formulated to provide cultural heritage managers with a fast, efficient, non-technical tool for evaluating the stability of rock art panels (Allen *et al*. 2018; Cerveny 2005; Dorn *et al*. 2008). Designed for non-specialists with a minimal amount of training, RASI offers replicable and systematic holistic rock art condition assessments using a field-based classification scheme. RASI examines and scores 37 indicators of stone decay grouped into five dimensions: site setting (geological factors), weaknesses of the rock art panel (impending loss), evidence of large erosion events on and below the panel (large losses), evidence of small erosion events on the panel (incremental loss), and rock coatings on the panel. Each indicator is ranked on a scale of 0 (no present), 1 (present), 2 (obvious), or 3 (dominant). A sixth dimension highlighting vandalism and other issues allows scorers to describe observations not accounted for in other areas of the index or to elaborate on stone decay agents they perceive as major concerns.

With 37 indicators across six dimensions, RASI yields a unique stability profile for each rock art feature scored. As a composite indicator (JRCEC 2008), this index also permits the aggregation of the 37 indicator scores into a final stability "grade" for each rock art feature (Table 1). By grading stability in this relative way, managers can make informed decisions on the prioritization of conservation efforts across differentially graded rock art features. Accordingly, RASI has potential for wide appeal and has been

Fig. 6 Former fence and turnstile entrance to the Painted Rock State Park (photo from The Stone Age Library 1964)

employed in a number of previous case studies (*e.g.*, Allen and Groom 2013; Allen *et al.* 2011; Groom 2017). The index is interoperable with condition-monitoring approaches such as repeat photography (*e.g.*, Groom 2017), and it can accommodate more technical analyses that provide greater insight on particular stone decay agents (*e.g.*, Cerveny *et al.* 2016). RASI data can also be integrated into a Geographic Information System (GIS) to visualize the stability of rock art across the landscape and analyze the spatial relationships among stability, stone decay agents, and other factors.

The Urgency Intervention Scale

The Urgency Intervention Scale (UIS) was developed specifically for the Paleolithic petroglyphs in the Côa Valley of northeastern Portugal (Batarda Fernandes 2014), one of the premiere rock art sites on UNESCO's World Heritage List. Many of the stone decay factors and other risks specific to the Côa Valley petroglyphs had been previously identified in a commissioned conservation report (Rodrigues 1999), which proved instrumental in the UIS's formulation (Batarda Fernandes 2014, p. 76). The UIS was fashioned in response to RASI's presumed bias toward arid contexts (Batarda Fernandes 2014, p. 48), even though the latter has been successfully employed in wet tropical environments (Allen and Groom 2013).

The UIS draws explicitly from RASI theory, methodology, and structure (Batarda Fernandes 2014, p. 117), and like RASI, it is a composite indicator that generates a score of overall risk to a rock art feature based on six dimensions: rock mass strength, tilting, physical weathering, slope, biodeterioration, and flooding. Unlike RASI, the UIS differentially weighs these six categories based on their perceived impact, and this has admittedly introduced an immeasurable degree of subjectivity into the instrument (Batarda Fernandes 2014, p. 124). Equally problematic is that UIS's reliability—the extent to which it yields consistent and compatible results across scorers and trials (Carmines and Zeller 1979)—remains to be shown. As of now, only one case study involving one scorer has been completed.

Reliability issues aside, since the UIS was tailored to the unique rock art and specific environment of Portugal's Côa Valley, its applicability in other contexts remains in question. The scale's emphasis on flooding and certain topographic factors that are irrelevant at Painted Rocks (*i.e.*, titling and slope) leave it inappropriate for this case study. The irony here is that several of the risk indicators and measured criteria in the UIS were reactions to what was considered RASI's "general 'all-catching' fashion" (Batarda Fernandes 2014, p. 48), yet the resulting specificity renders this assessment instrument unsuitable for this project and likely many others. Consequently, RASI is, at present, the most appropriate rock art condition assessment tool for the Painted Rock Petroglyph Site, especially given the composite indicator's purported bias toward arid settings.

A Holistic Condition Assessment of Painted Rocks

Holistic site condition assessments require complete and informative inventories of the site's heritage assets, as well as their current condition. With rock art sites, this includes consideration of not just the petroglyphs and pictographs but also their physical state and setting. It also necessitates an inventory of penetrative vandalism (as defined

Table 1 Rock Art Stability Index (RASI) Scale

Final RASI score	Grade	Corresponding color code
< 20	Excellent condition	Blue
20–29	Good status	Green
30–39	Problem(s)	Brown
40–49	Urgent danger	Yellow
50–59	Great danger	Orange
60+	Severe danger	Red

below) impacting the site. Short of three-dimensional modeling (*e.g.*, Fernández-Lozano *et al.* 2017), high-resolution photography of each and every instance of rock art and penetrative vandalism, coupled with high-precision mapping, is arguably the most appropriate means for inventorying rock art sites, and this is what was carried out at Painted Rocks. Such records are an essential foundation for any site condition assessment and conservation management planning because they provide the requisite baseline information for monitoring changes and impacts over time. This information can also be compared with previous photographs and records to better understand how rock art and the larger site in question have changed in the past.

RASI Case Study

RASI was employed by the author and five volunteers to document and evaluate the stability of 644 boulders at the Painted Rock Petroglyph Site. Per RASI guidelines (Dorn *et al.* 2008, p. 42; Cerveny *et al.* 2016, p. 874) and tenets of learner-centered education (Allen and Lukinbeal 2010), the rock art stability assessment project at Painted Rocks initiated with a four-hour interactive seminar in which RASI's 37 indicators were illustrated and described, followed by a four-hour in-field training where volunteers worked on the same panels under the tutelage of the instructor. Full-day training sessions of small groups in the sequence of seminar, field introduction, and group scoring (as done in this study) have been shown to provide the most replicable and reliable scores across trainees (Cerveny 2005, pp. 123–127; Dorn *et al.* 2008, pp. 56–58; see also Allen 2008, pp. 92–100). Each boulder exhibiting a human-generated impression was subject to RASI analysis. While the current conservation emphasis is on the indigenous petroglyphs (Fig. 7), names and dates (of Euro-American, African-American, and/or Hispanic origin) as well as indecipherable graffiti that have been permanently impressed into rocks—hereafter referred to as "penetrative vandalism" so as to distinguish them from potentially removable painted graffiti (Sanmartín *et al.* 2014)—were also inventoried (Fig. 8).[2]

Since RASI tutorials (Cerveny 2006; Dorn 2006) and an illustrated atlas of weathering forms (Cerveny *et al.* 2007) are available online, the specificities of the index will not be repeated here. However, the implementation of RASI at Painted Rocks required several deviations from the guidelines and prior case studies and are therefore worth describing. For one, the typical unit of organization and analysis for RASI is the rock art panel, generally understood as a contiguous rock surface on which rock art occurs and which is oriented in a single direction (Loendorf 2001, p. 61; Sanger and Meighan 1990, p. 207). Because microenvironmental conditions are a

[2] Penetrative vandalism can be cosmetically treated by camouflaging it with pigment matched to the host rock's surface (Griswold 1999) or even through the creation of artificial desert varnish (Elvidge and Iverson 1983, pp. 238–240; Elvidge and Moore 1980). Even if treated in such ways, the vandalism has not actually been removed, and its physical imprint can often still be detected under close inspection. Land managers made two prior attempts to use color-matching pigment to "hide" penetrative vandalism at Painted Rocks, one being a cluster of recent peck marks and the other a group of names, initials, and dates from 1981 and 1982. Those attempts proved ineffective since the pigment has since changed color and faded, with the vandalism once again readily visible. It is possible to remove penetrative vandalism through abrasive techniques, such as controlled sand blasting, and then color-match. However, such methods remove more of the host rock and any protective rock coating, thus weakening the rock. The best methods to mitigate penetrative vandalism should be determined on a case-by-case basis with input from all stakeholders.

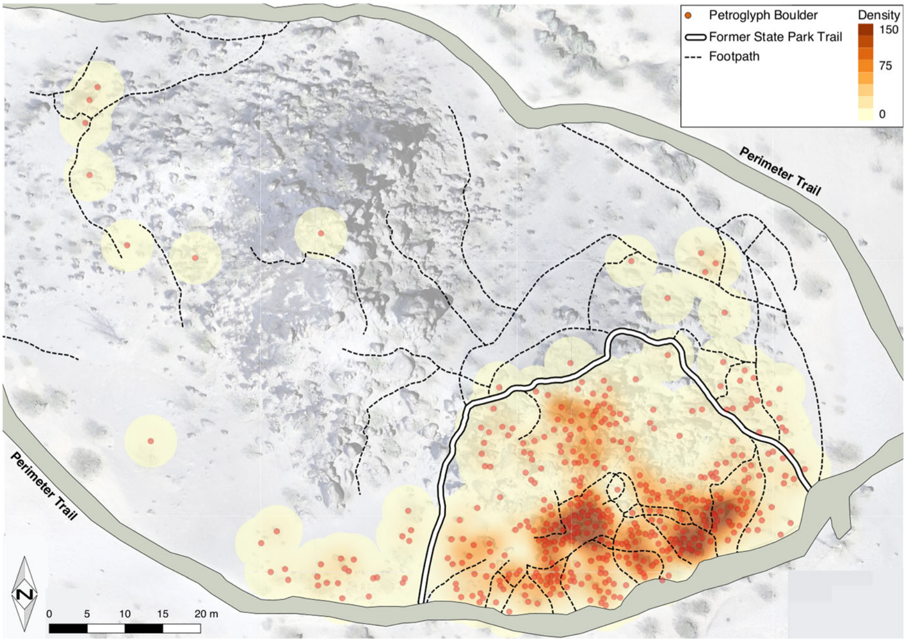

Fig. 7 Heat map of petroglyph density across the Painted Rocks. "Heat" has been calculated using a kernel density estimating algorithm set at 3.5 m around each petroglyph-adorned boulder, and weighed by the number of petroglyphs on them. Included here are 3803 petroglyphs across 428 boulders

strong determinant of the type and degree of rock weathering affecting a boulder or rock outcrop, the stability of its different faces, or panels, can differ dramatically. In those contexts, it would be appropriate to assess rock art stability at the panel level. At Painted Rocks, however, most of the boulders are rounded rather than angular or blocky, with the physical conditions of their various sides differing only slightly. Moreover, the petroglyphs often extend continuously across the boulders' convex surfaces, and any division of the boulders into panels would thus be arbitrary. For these reasons, RASI was carried out at the boulder level.

The displacement of boulders at Painted Rocks, through both anthropogenic and natural forces, has long been a major conservation concern. Indeed, suspicion of boulder theft—where people could drive up to the site and cart off boulders—is what prompted the erection of a fence and turnstile in 1962 (*The Arizona Republic* 1962; The Stone Age Library 1964, p. 42; Wasley and Johnson 1965, p. 74). Whereas assessing the condition and stability of a boulder that no longer exists is seemingly paradoxical, some boulders at Painted Rocks have been dug up and moved around the site area. It is prudent to consider this factor during a site condition assessment. Likewise, since the Painted Rocks boulders rest upon an elevated bedrock basement, they are highly prone to falling and rolling downslope (Durgin 1977). Earthquakes have damaged and displaced petroglyph boulders in other areas of southern Arizona (Holmlund and Wallace 1994), and seismic activity may very well have caused some of the Painted Rocks boulders to shift or roll.

Displacement is an obvious impact to a boulder's stability, but unfortunately, this phenomenon is not explicitly accounted for in RASI. Rather than alter the index,

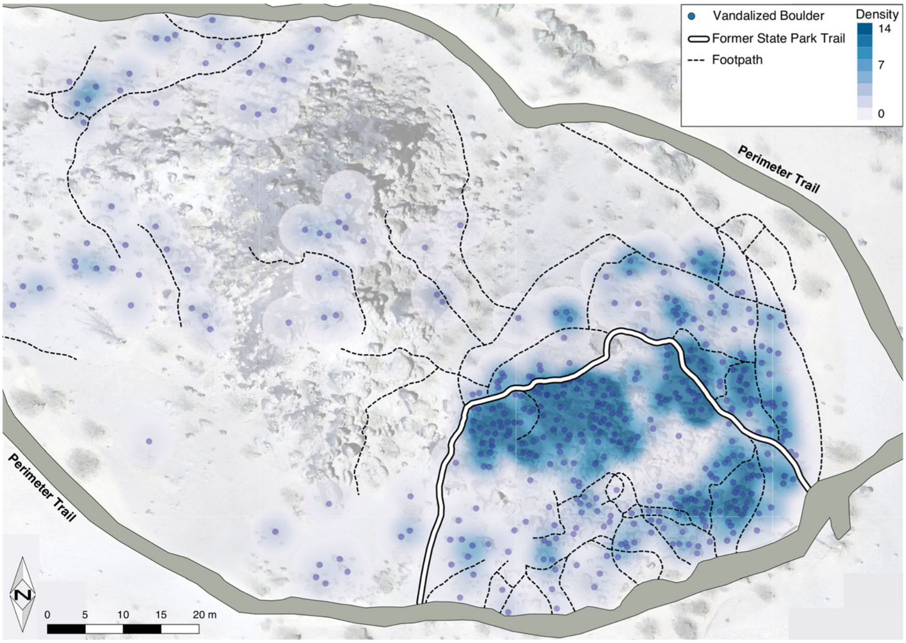

Fig. 8 Heat map of penetrative vandalism density across the Painted Rocks. "Heat" has been calculated using a kernel density estimating algorithm set at 3.5 m around each vandalized boulder, and weighed by the number of instances of penetrative vandalism on them. Included here are 1023 instances of penetrative vandalism across 423 boulders

boulder displacement at Painted Rocks was coded under two existing RASI indicators within the dimension of "evidence of large erosion events on and below the panel." If the boulder had been moved through human agency, it was coded under "anthropogenic activities," and if natural forces were suspected, then it was coded under "other natural causes of break-off." As with the other indicators, the rank scale includes 0 (not an issue), 1 (suspected displacement, but not certain), 2 (obvious displacement, but boulder remains close to its original location), and 3 (severely displaced, where original context is uncertain).

A third deviation from prior RASI applications considers the impact of petroglyphs on the stability of the host rock. As several of RASI's weathering indicators attest (*e.g.*, scaling, flaking, disintegration, abrasion), removal of desert varnish, weathering rind, and host rock renders stone more susceptible to erosion and likely hastens and exacerbates decay. The production of petroglyphs and other engravings has the same effect. From a weathering and stone decay perspective, a boulder covered by deeply pecked petroglyphs is less stable than one bearing a single, faintly scratched design. This is a significant factor at Painted Rocks, where the repeated production of petroglyphs on several boulders has removed nearly the entirety of their protective rock coating (Fig. 9). RASI does not take this into explicit consideration, though it can be accounted for by "anthropogenic cutting" in the "evidence of small erosion events on the panel" dimension, an indicator intended to capture the impact of penetrative vandalism. As for the situation at Painted Rocks, each boulder was rank scored based on a visual estimate of the combined area of petroglyphs and penetrative vandalism

Fig. 9 Boulder no. 338 along the perimeter trail at Painted Rocks. The abundance of petroglyphs on this boulder has destabilized it surface and led to advanced rates of stone decay (photo by Lance Trask)

relative to the boulder's surface area: 1 (< 25%), 2 (25–75%), and 3 (> 75%). Since all of the boulders considered here exhibit either petroglyphs or penetrative vandalism, a score of "0" was never applicable.

RASI Results and Analysis

RASI data are typically described and analyzed on a case-by-case basis (*e.g.*, Allen *et al.* 2011; Allen and Groom 2013). However, the large number of features at Painted Rocks precludes such a detailed treatment here. Following Groom's (2017, pp. 57–86) lead, this study undertakes an aggregate analysis of RASI data from Painted Rocks. The goal is to assess the site, as a whole, in order to identify general trends and informative spatial patterns. Although each case has its own issues and undergoes a unique process of stone decay, aggregate analysis facilitates site management by identifying key factors affecting the larger site area. By focusing on these broader factors rather than panel- or boulder-level issues, management efforts have the potential to be more efficient, cost-effective, and impactful. This is not to downplay the significance of particular weathering issues or anomalies, which in and of themselves are important conservation challenges that may presage pending scenarios for which other portions of the site will face. In fact, aggregate analyses that consider site-wide processes and phenomena help illuminate anomalous cases in need of focused attention and special management and conservation needs.

Summary RASI data and descriptive statistics for each weathering indicator are presented in Table 2. Since the cultural heritage significance of Painted Rocks centers squarely on the petroglyphs, the 216 boulders exhibiting only penetrative vandalism are hereafter excluded, with the following analyses focusing solely on the 428 petroglyph-adorned boulders—though 207 of these also bear penetrative vandalism. A Shapiro-Wilk test on final RASI scores, as well as on each of the weathering indicators, for these 428 boulders preclude assumptions of normality (Table 2). Consequently, the data are not amenable to parametric statistical tests, and while the means (μ) and standard deviations (σ) are reported, the medians offer a more robust measure of the impacts of certain weathering forms at Painted Rocks.

RASI scores for the 428 petroglyph-adorned boulders cover the spectrum of grades (Fig. 10), from those in excellent condition (blue) to several outliers in severe danger (red) of continued weathering. Nevertheless, over 60% of the Painted Rocks boulders are in either good or excellent condition, with 43% of petroglyphs at the site found on those boulders (Fig. 11). This insight is initially surprising considering the intensity of visitation over the years and the abundance of penetrative vandalism. These relatively good scores are attributable to the site's geology, particularly the hardness of the granodiorite (6 on Mohs scale), the presence of thick coats of desert varnish on many of the boulders, and the resultant case hardening, each of which effectively lowers the boulders' final RASI scores. Moreover, given the arid and hot climate, lichen-related issues are at a minimum. Further, salt efflorescence (calcium carbonate, or $CaCO_3$) is quite rare at Painted Rocks. On the few undisturbed boulders that exhibit it, the $CaCO_3$ is restricted to a thin lens at the base of the boulder, just above the ground surface and below the petroglyphs, which is likely due to erosion of boulders' footings in response to heavy foot traffic across the site area. $CaCO_3$ is most prevalent on the boulders that have been tipped over or dug up, with their formerly buried, unvarnished, and caliche-covered surfaces now exposed (*e.g.*, Fig. 12). Salt efflorescence is obviously just one of several serious problems those boulders face.

Few of the boulders show evidence of large erosion events on or below them. This is because the majority rest on either a relative level surface of grus or a bedrock basement, albeit undercutting remains a problem. Pronounced weathering forms include a number of weaknesses of the host rock and evidence of small erosion events to the boulders. Based on median scores reported in Table 2, scaling, flaking, abrasion, rock coating detachment, rounding of petroglyph edges, undercutting, fissuresols, and the development of weathering rinds are persistent problems impacting more than half of the boulders. Indeed, six of these weathering forms affect over 90% of the boulders. A more surprising insight is the apparent impact the production of rock art has had on the stability of the boulders. One of the unique qualities of Painted Rocks is the incredible density of petroglyphs on the boulders, many of which exhibit a "newspaper rock" effect in that their surfaces are literally covered in rock art, sometimes to the extent that it renders the petroglyphs indiscernible. Nearly 70% of the boulders ($n =$ 297) exhibit petroglyphs covering more than a quarter of their surfaces, with a fair number ($n = 59$) having petroglyphs carved across more than 75% of the rocks' faces.

Table 2 Summary RASI data and descriptive statistics

Stone decay dimensions and indicators	Descriptive statistics				Normality test*	
	No. scored	Median	μ	σ	W	p
Site setting (geological factors)						
Fissures independent of stone lithification	148	0	0.5	0.8	0.68	0.00
Fissures dependent on lithification	2	0	0.0	0.0	–	–
Changes in textural anomalies	14	0	0.0	0.3	0.14	0.00
Rock weakness	428	−2	−2.0	0.0	–	–
Weaknesses of the rock art boulder						
Fissuresol	275	1	0.9	0.8	0.83	0.00
Roots	32	0	0.1	0.4	0.27	0.00
Plant growth near or on panel	195	0	0.6	0.8	0.73	0.00
Scaling and flaking	412	2	1.6	0.6	0.79	0.00
Splintering	136	0	0.4	0.7	0.67	0.00
Undercutting	221	1	0.9	1.1	0.78	0.00
Weathering-rind development	426	2	1.9	0.6	0.78	0.00
Other concerns	123	0	0.4	0.7	0.61	0.00
Evidence of large erosion events on and below the boulder						
Anthropogenic activities	103	0	0.3	0.6	0.48	0.00
Fissuresol/calcrete wedging	170	0	0.5	0.7	0.71	0.00
Fire	0	–	–	–	–	–
Undercutting	1	0	0.0	0.0	–	–
Other natural causes of break-off	25	0	0.1	0.4	0.26	0.00
Evidence of small erosion events on the boulder						
Abrasion	236	1	0.6	0.7	0.77	0.00
Anthropogenic cutting	428	2	1.8	0.7	0.78	0.00
Alveolization	190	0	0.6	0.7	0.72	0.00
Crumbly disintegration	74	0	0.2	0.5	0.47	0.00
Flaking	389	1	1.2	0.6	0.79	0.00
Flaking of the weathering rind	401	1	1.2	0.6	0.73	0.00
Granular disintegration	17	0	0.0	0.2	0.19	0.00
Lithobiont pitting	96	0	0.3	0.5	0.54	0.00
Lithobiont release	37	0	0.1	0.3	0.32	0.00
Loss parallel to stone structure	41	0	0.1	0.4	0.33	0.00
Rock coating detachment	376	1	1.2	0.7	0.82	0.00
Rounding of petroglyph edges	308	1	1.1	0.8	0.85	0.00
Scaling	396	1	1.4	0.7	0.82	0.00
Textural anomaly features erode differentially	34	0	0.1	0.3	0.30	0.00
Splintering	163	0	0.5	0.7	0.69	0.00
Other forms of incremental loss	23	0	0.1	0.3	0.23	0.00
Rock coatings on the boulder						
Anthropogenic (chalk, paint, *etc.*)	4	0	0.0	0.1	0.07	0.00
Rock coating present	426	−2	−2.1	0.7	0.82	0.00
Case hardening	409	−2	−1.7	0.7	0.83	0.00
Salt efflorescence or subflorescence	117	0	0.3	0.6	0.60	0.00
Final RASI scores	428	26	27.2	11.5	0.93	0.00

*Shapiro-Wilk test; assumption of normality is rejected when p values on the W statistic fall below 0.05. The test is not applicable when the sample size is less than three or when all cases have the same score (*i.e.*, rock weakness)

Petroglyph-Level Observations

Although prior incidents of theft, vandalism, and erosion preclude a complete tally of the petroglyphs that were placed upon the Painted Rocks boulders, the recent inventory identified 3803 discernible cases spread across 428 boulders. Since RASI's focus is on the rock art feature, it offers less specific information at the scale of individual petroglyphs. To ascertain a closer perspective on the stone decay processes affecting the rock art at Painted Rocks, certain weathering forms—specifically the presence of lithobionts, spalling, and superimpositioning—were documented for each petroglyph independent of the boulders' RASI evaluations. With regard to lithobionts, only a paltry eight petroglyphs (less than 0.05%) currently have colonies of lichen growing directly on them. Scaling has impacted a far greater number of petroglyphs ($n = 199$, or 5%), but this is quite negligible in light of the fact that nearly all of the boulders exhibit some degree of scaling or flaking (Table 2). In many instances, the host rock exposed by the scaling at Painted Rocks is more weathered and more fully varnished than the petroglyphs on the same boulders, indicating that although scaling is a significant concern, it has apparently not hastened with increased human activity at the site.

Rather than natural weathering processes, perhaps the largest impacts to the petroglyphs at Painted Rocks, and consequently the greatest threat they still face, owe to anthropogenic forces, past and present. Of the 3803 documented petroglyphs, just over 7% have been superimposed by either other petroglyphs ($n = 129$, or 3.3%), penetrative vandalism ($n = 149$, or 3.9%), or a combination of the two ($n = 2$, or $< 0.1\%$). Even though the superimposing petroglyphs are part of the overall corpus of rock art at Painted Rocks and thus add to the site's significance, their production has intrinsically adversely impacted the preexisting imagery, and their invasiveness has ultimately escalated the rate of stone decay by removing more of the desert varnish and underlying host rock. Though culturally and temporally distinct, penetrative vandalism perpetuates this scenario. Nearly half of the petroglyph-adorned boulders ($n = 207$) also exhibit some form of penetrative vandalism, with 4% of the petroglyphs ($n = 151$) directly impacted by scratched, pecked, or abraded names, dates, indecipherable scribbles, or deliberate acts of defacement.

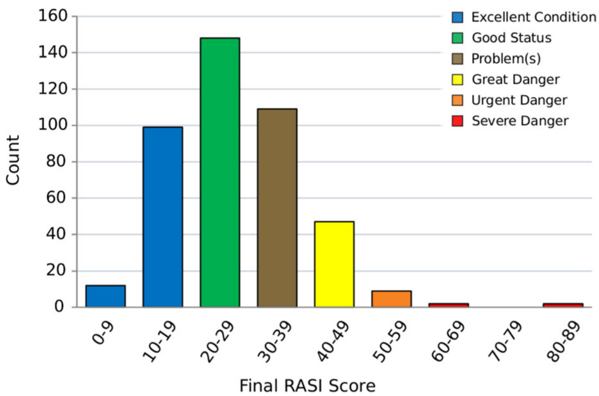

Fig. 10 Histogram of final Rock Art Stability Index scores for 428 boulders at Painted Rocks

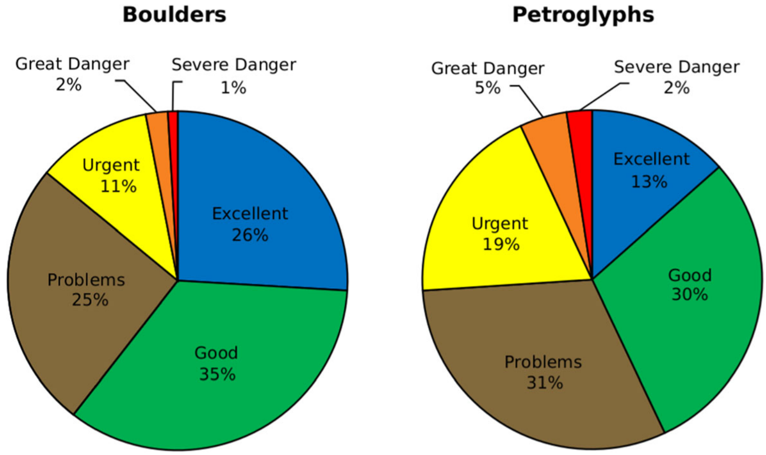

Fig. 11 Rock Art Stability Index grades for the Painted Rocks. *Left*: grades for the 428 boulders; *right*: the grades when scaled relative to the number of petroglyphs on the scored boulders

Patterns in Weathering Forms Across the Painted Rock Petroglyph Site

Whereas the foregoing aggregate analysis of the RASI data provides a characterization of stability for the Painted Rock Petroglyph Site, a look at spatial disparities in RASI data provides keener insight into the nuances of weather forms across the site area and their possible causes. A key question about the conservation of the Painted Rock Petroglyph Site is the impact of unrestricted foot traffic on the stability of the petroglyph boulders. Without adequate safeguards, high rates of tourism can lead to unanticipated damage to rock art sites as people trample the site area and stir up

Fig. 12 Boulder no. 134 along the perimeter trail at Painted Rocks. The white crust is calcium carbonate ($CaCO_3$), a salt efflorescence that accumulated below the ground surface. This crust marks the former soil line and indicates this boulder has been dug up from another place, though presumably from this site, and place here (photo by Lance Trask)

sediments (Loubser 2001, p. 101; Whitley 2011, p. 187). With the abundant grus around the boulders at Painted Rocks, it is reasonable to suspect that boulders close to trails and footpaths would have experienced a greater degree of anthropogenic impact than boulders further afield. Impacts may be deliberate and malicious, as in vandalism, or they can be unintentional, such as when peoples' hands, feet, clothes, and other accoutrements abrade the boulders when passing by. Nonetheless, there is not a strong association between boulders with poor RASI grades relative to their proximity to trails and footpaths, as might be expected (Fig. 13). Indeed, a Kolmogorov–Smirnov (K–S) test ($D_{\max} = 0.0325$, $p = 0.999$) confirms RASI grades for boulders within 1.5 m of a trail or footpath and those further away do not differ in any significant way (Fig. 14).

Although proximity to foot traffic does not correlate with final RASI scores at Painted Rocks, a closer look at certain RASI indicators suggests boulders closest to trails have experienced a greater degree of weathering to their surfaces and the rock coatings protecting them. Table 3 enumerates eight RASI weathering forms pertaining to the stability of boulder surfaces and compares cases between boulders near (within 1.5 m) trails and those further afield. The left half of the table presents the rank scores for boulders relative to their proximity to all trails and footpaths across the site. Two weathering indicators, abrasion and the rounding of petroglyph edges, stand out as having had more of an impact on boulders close to trails and footpaths. The fact that abrasion and edge rounding are more pronounced on these boulders implicates foot traffic as a significant contributing agent to the overall stone decay process. As visitors pass close to the boulders, their feet kick up sands and silts, which scrape against and settle upon the boulders. Visitors often inadvertently step on smaller boulders, their

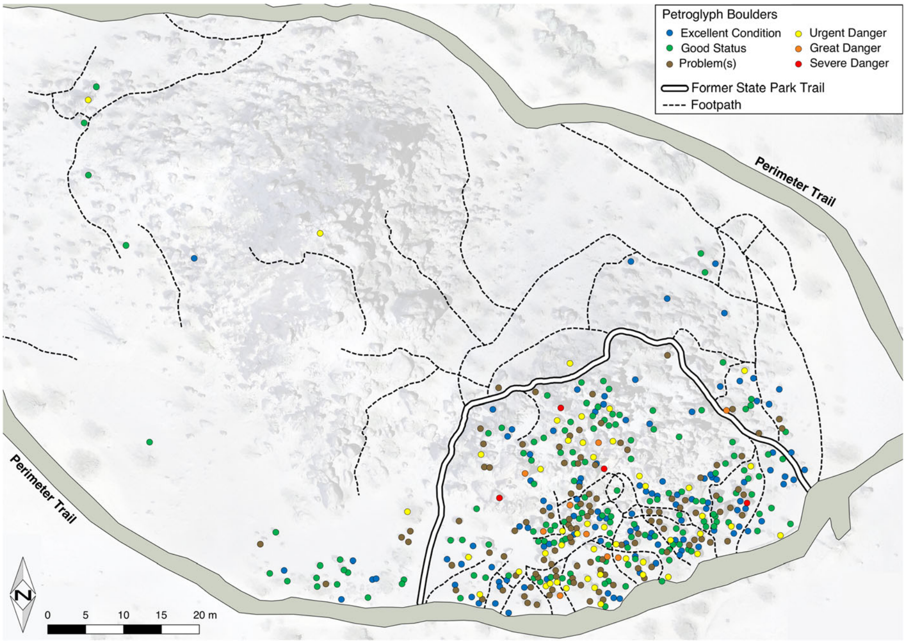

Fig. 13 The spatial distribution of Rock Art Stability Index grades at Painted Rocks

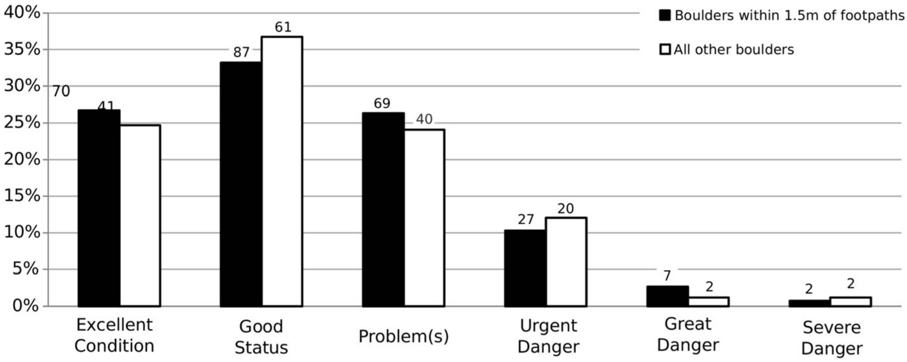

Fig. 14 Bar graph contrasting the Rock Art Stability Index grades between boulders within 1.5 m of trails and footpaths and those further away

clothing rubs against larger boulders, and they are more likely to touch and even sit or climb on boulders closest to trails and footpaths (*e.g.*, Fig. 15). Over time, these actions essentially "erase" the rock art.

The scouring effects of foot traffic and associated visitor impacts are most apparent on the boulders adjacent to the official perimeter trail maintained by the BLM. This trail is composed of imported gravel, and it is elevated and leveled in order to accommodate wheelchairs. As with sands and silts, these gravel are prone to being kicked up and over nearby boulders. Likewise, over time, the elevated gravel have slumped to the point where some of the smaller boulders alongside it are now enveloped within the trail. The right half of Table 3 shows that these boulders have been more prone to visitor-related abrasion, so much so that they consistently exhibit lesser amounts of a protective rock coating (desert varnish) than other petroglyph-adorned boulders at Painted Rocks. While probably exacerbated by the elevated gravel trail, this advanced rate of stone decay precedes BLM management. The most sensitive area of this trail, the southeast arc that closely passes the petroglyph concentration, was part of the original trail established by Arizona State Parks decades prior to BLM management. That trail, too, was lined with gravel, whereas the section passing atop the inselberg, which is no longer maintained but still used by visitors, is paved in asphalt. The current perimeter trail merely perpetuates a long, ongoing process of human-caused weathering that heightens the overall decay of nearby boulders.

Penetrative Vandalism

As briefly touched upon previously, the amount of penetrative vandalism at Painted Rocks is abundant (1023 observed cases and counting) and seemingly rampant. It was documented on 423 boulders, with 207 of those boulders also exhibiting petroglyphs. Figure 8 shows the density of penetrative vandalism across Painted Rocks, with two clear hotspots discernible on the inselberg's right spire. One is centered on the boulders at the eastern edge, and the other is localized to the top center. Each concentration is strongly associated with a particular era and is indicative of management practices at that time. In the few cases where dates were inscribed on the rocks, those in the eastern concentration mostly fall between 1879 and 1927 (*e.g.*, Fig. 16). Interestingly, this era post-dates the decline in the stage line that ran past the boulders and the coming of the

Table 3 RASI indicators pertaining to the stability of boulder surfaces

Stone decay dimensions and indicators	All trails and footpaths							Perimeter trail only						
	Rank scale				Total	K-S test*		Rank scale				Total	K-S test*	
Weaknesses of the Rock Art Boulder	0	1	2	3		D_{max}	*p*	0	1	2	3		D_{max}	*p*
Scaling and flaking														
Near	11	107	127	17	262	0.041	0.995	7	21	24	7	59	0.102	0.637
Away	2	77	83	4	166			6	163	186	14	369		
Evidence of small erosion events on the boulder	0	1	2	3		D_{max}	*p*	0	1	2	3		D_{max}	*p*
Abrasion														
Near	104	135	22	1	262	**0.139**	**0.035**	18	30	10	1	59	*0.169*	*0.097*
Away	89	61	15	1	166			175	166	27	1	369		
Flaking														
Near	29	154	71	8	262	0.050	0.953	13	31	13	2	59	0.150	0.186
Away	10	107	47	2	166			26	230	105	8	369		
Flaking of the weathering rind														
Near	19	178	63	2	262	0.053	0.930	11	35	11	2	59	0.143	0.230
Away	8	108	48	2	166			16	251	100	2	369		
Rock coating detachment														
Near	26	152	76	8	262	0.057	0.882	5	32	17	5	59	0.060	0.991
Away	26	85	49	6	166			47	205	108	9	369		
Rounding of petroglyph edges														
Near	61	122	63	16	262	*0.123*	*0.087*	11	26	14	8	59	0.109	0.558
Away	59	65	36	6	166			109	161	85	13	368		

Table 3 (continued)

Stone decay dimensions and indicators	All trails and footpaths							Perimeter trail only						
	Rank scale				Total	K-S test*		Rank scale				Total	K-S test*	
Scaling														
Near	17	114	120	11	262	0.066	0.658	10	20	24	5	59	0.110	0.547
Away	15	79	65	7	166			22	173	161	13	369		
Rock coatings on the panel	− 3	− 2	− 1	0		D_{max}	p	− 3	− 2	− 1	0		D_{max}	p
Rock coating present														
Near	60	140	60	2	262	0.108	0.173	5	27	27	0	59	**0.282**	**0.000**
Away	56	80	30	0	166			111	193	63	2	369		

*Kolmogorov-Smirnov test; D_{max} is the largest difference between the cumulative proportions for the two distributions (near vs. away). Results in bold are statistically significant at the 95% confidence interval ($p < 0.05$), whereas those in *italic* are highly suggestive but not statistically significant

Fig. 15 Child crawling on the "Pinnacle Rock" at Painted Rocks (photo from The Stone Age Library 1964)

railroad. There was no active management of Painted Rocks at that time, but it was a local tourist attraction (Disturnell 1881).

The other concentration, at the top of the inselberg, follows the former trail established and paved by the Arizona State Parks. Much of the penetrative vandalism in this concentration dates from the 1960s through 1980s, when the trail not only enabled but encouraged people to move up, through, and alongside many of the petroglyph-adorned boulders. Along this segment of the former park trail (within 1.5 m), the 73 boulders exhibiting penetrative vandalism are significantly overrepresented relative to the 28 boulders with petroglyphs (Fisher's exact, $p < 0.0001$, $Q = 0.50$). Likewise, when compared to the entire site, this same area contains a disproportionately higher number of incidents of penetrative vandalism ($n = 228$) relative to the number of petroglyphs ($n = 116$; $\chi^2 = 450.65$, df $= 1$, $p < 0.0001$, $Q = 0.80$), with individual boulders consistently exhibiting more instances of penetrative vandalism here than elsewhere (K–S test: $D_{max} = 0.3046$, $p < 0.0001$). Clearly, and as the measures of Yule's Q affirm, the association between the asphalt trail and penetrative vandalism is quite strong.

The asphalt trail that led visitors atop the Painted Rocks inselberg was decommissioned with the remodeling of the site between 1995 and 2005, and the creation of penetrative vandalism in that section of the site has since abated. Repeat photography between the current project and prior photographic inventories nonetheless shows that new penetrative vandalism remains a serious issue for site management. Between 2006 and 2009, several years after the site's remodeling, a team of avocational rock art recorders attempted a full inventory of the Painted Rock Petroglyph Site (Hasse and Hasse 2009). They documented 3172 petroglyphs and 630 instances of penetrative vandalism on 578 boulders. Comparison of their photographs with the boulders' current state revealed at least 52 cases of new penetrative vandalism over the past decade. Additionally, at least two boulders have been tipped over, presumably through human agency, in that same period. As these figures demonstrate, conservation of the Painted Rock Petroglyph Site could benefit from further refinement to management practices, including a more effective visitor education program regarding the detrimental impact of penetrative vandalism and poor site etiquette on the myriad values attributed to this nationally significant cultural heritage place.

Discussion

With the aid of RASI, this study offers a holistic condition assessment of the Painted Rock Petroglyph Site. The majority of petroglyph boulders are remarkably stable (Figs. 10 and 11), especially with regard to the incredible level of visitation this site has experienced relative to its small size. Although comprehensive data on visitation are unavailable, 500,000 people over the past half century is a conservative estimate based on available information, and more than one million visitors is not an

Fig. 16 Historic names and dates inscribed alongside and overtop of older, pre-colonial petroglyphs

unreasonable approximation. This fortunate posture owes largely to the site's geology, with the hardness of granodiorite and the thick coatings of desert varnish on the boulders either preventing or retarding many weathering forms from adversely affecting the rock art to any great extent. Still, some of the boulders face considerable dangers to their stability, and ongoing monitoring will be dire to their longevity.

In general, accessibility and proximity to foot traffic are not accurate predictors of a boulder's stability at Painted Rocks (Figs. 13 and 14). Rather, a complex and intricate network of weathering agents acts upon the boulders in seemingly unanticipated ways, with each boulder presenting a unique set of conservation challenges. Nonetheless, broad patterns in the stone decay process can be recognized. The natural weathering forms that have most contributed to the overall process of stone decay at Painted Rocks, and which remain an impending threat, are scaling and flaking of the boulders' surfaces, both of which are exacerbated by the development of weathering rinds (Table 1). Interestingly, these weathering forms do not appear to be caused or aggravated by human agency (Table 3).

More technical studies will be needed to determine what is contributing to natural flaking and scaling of the Painted Rocks boulders, though salt fretting is a likely culprit. Albeit still not fully understood (Doehne 2003), salt fretting is a weathering process whereby soluble salts consolidate within the rock, often under the harder weathering rind. Pressure derived from the crystallization of such salt can have deleterious effects on the host rock (Correns 1949). Once deposited, the surface of the host rock is subject to subsequent precipitation- and temperature-dependent actions on the part of those salts, such as cycles of hydration-induced swelling, and differential thermal expansion (Cooke *et al.* 1993, pp. 32–41; Goudie and Viles 1997; Smith 1994). Resultant changes in pressure exerted below the rock's surface can lead to outright loss of the weathering rind through scaling. With the region's high temperatures, it is quite possible that differential thermal expansion among the granodiorite's constituent minerals and between the darker varnished surfaces and the more insulated heart rock is also contributing to the natural flaking and scaling of boulders at Painted Rocks. The culmination of such thermally induced stress can lead to incidents of flaking and scaling through thermal stress fatigue (Griggs 1936; Hall 1999; Jenkins and Smith 1990), a stone decay process suspected to affect rock art in other regions as well (*e.g.*, Hoerlé 2006). Considering the effects of precipitation and temperature on the mechanical breakdown of the stone, the rate of scaling and flaking at Painted Rocks may accelerate in concert with projected rises in global temperatures and changes in precipitation patterns (Giesen *et al.* 2014a, b).

Whereas RASI has informed on the stability and condition of the petroglyph-adorned boulders at Painted Rocks, the status of other aspects of this cultural heritage property is worth considering. The artifacts found around the boulders are an important component of this site because they provide insight on cultural and temporal associations for the petroglyphs, and if vessel form is taken into account, they have the potential to shed light on the activities that took place at the site other than and in conjunction with the rock art (*e.g.*, Wright 2014, pp. 83–102). Because only a thin lens of grus covers the site area, most artifacts lie exposed on the ground surface and are therefore prone to theft and weathering. It is impossible to know to what extent artifacts have been pocketed by visitors over the years, but presumably it has occurred, and likely with a bias toward the easier-to-see larger sherds and those with painted designs (*e.g.*, Dudgeon 2017; Robbins 2013). Similarly, persistent foot traffic across the site area is expected to have taken a toll on surface artifacts, breaking them and grinding their surfaces and edges (Nielsen 1991).

In 1952, over a decade before establishment of the Painted Rock State Park, Al Schroeder (1952) collected 66 ceramic artifacts from the Painted Rock Petroglyph Site as part of a survey by the National Park Service. A comparison between those sherds and ones recorded in the course of this case study permits examination of the toll visitor foot traffic has had on the surface artifacts at Painted Rocks over the past 65 years (Fig. 17). Though there is overlap, it is evident that the sherds collected by Schroeder were, on average, larger than the sherds found at Painted Rocks today (K–S test: $D_{max} = 0.4468$, $p < 0.0001$). This suggests that the cumulative effect of visitors veering off the designated trails has negatively impacted both the petroglyph boulders and the artifacts around them. However, if theft of the larger artifacts is one cause of this, there is no indication that decorated sherds have been preferentially taken. The difference between the ratio of decorated sherds to undecorated ones from Schroeder's survey (3:63) and the current one (4, p. 107) is negligible and insignificant (Fisher's exact, $p < 0.7129$).

Sustainability of the Painted Rock Petroglyph Site

The dilemma with managing Painted Rocks has always been one of sustainability, in particular how to balance tourism and cultural heritage management without sacrificing one set of values for another (McKercher and du Cros 2002; Omar 2013). The struggle for sustainability centers on the tension between the economic, recreational, and educational values of cultural heritage tourism vis-à-vis the preservation, research, aesthetic, and cultural heritage values of conservation management. At least 13

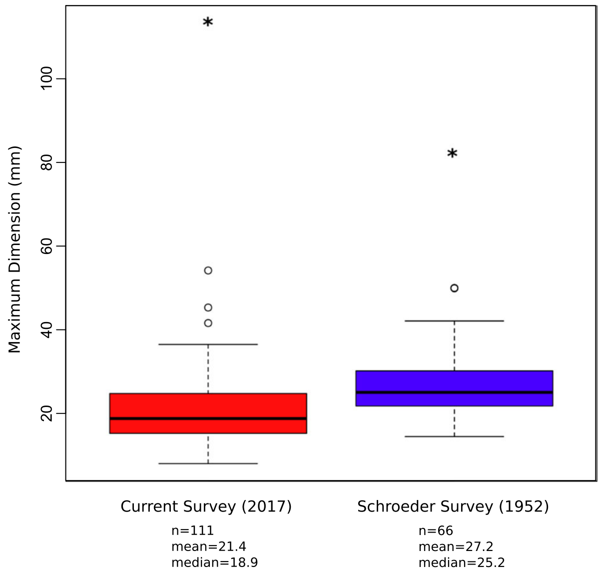

Fig. 17 Boxplots of the maximum dimensions of pottery sherds collected in 1952 and examined in the field in 2017

federally recognized tribes with cultural and historical ties to Painted Rocks have a stake in the site's management, with many considering it a sacred place (Wright and Hopkins 2016). The Tohono O'odham Nation recognizes it as a "place of traditional cultural importance" (BLM 2005, p. 1). Nevertheless, the BLM (1991) considers closure of Painted Rocks to be an unviable option because the place is well known and easy to access. The alternative, then, is to manage the site in a manner that reduces the weight of visitor impact as much as possible while maintaining accessibility and promoting conservation. Accordingly, current management practices on the part of the BLM are aimed at achieving and maintaining site sustainability, and efforts are in line with several of the best practices outlined by Loubser (2001, pp. 98–104) and Whitley (2011, pp. 187–188). These include a designated trail with interpretive signage, a clean setting with maintained facilities, an on-site caretaker and camp host during peak visitor season, a visitor registry book, and fee-based admission with proceeds funding site upkeep.

The effectiveness of current and future management practices at Painted Rocks can be evaluated with the Heritage Asset Sensitivity Gauge (HASG), an audit instrument designed for gauging the degree of balance in management concerns for particular heritage assets. Drawing from contemporary theory and practice regarding sustainable cultural heritage tourism, HASG expands upon an earlier model for evaluating a place's market appeal relative to its robusticity—or its ability to withstand degradation (du Cros 2001; McKercher and du Cros 2002, pp. 185–188)—and focuses it directly on archaeotourism. As with RASI, HASG is a composite index that ranks 10 indicators within each assessment domain (market appeal, cultural significance, and vulnerability), then sums the ranks to render a composite for each domain. With HASG, the higher scores imply higher management obligations for sustainable archaeotourism. HASG was tailored specifically for the cultural heritage tourism industry in South Africa, and while implementation has not yet extended beyond that geopolitical context (SANP 2006; Wurz and van der Merwe 2005), it can be aptly applied in other settings, including to the situation at Painted Rocks.

Tables 4, 5, and 6 provide HASG evaluations for Painted Rocks' market appeal, cultural significance, and vulnerability, respectively. As expected, the overall score of 55 reflects the high level of management attention needed at Painted Rocks (Fig. 18). Not surprisingly, the site scores highest on cultural significance, which was recognized decades ago with its listing on the National Register of Historic Places. The site scores medium or high on all 10 cultural significance indicators, reflecting the diversity of values attributed to this place. The site scores second highest on market appeal, due largely to its accessibility, renown, and the existing degree of development. However, despite the improved management measures implemented to date, the Painted Rock Petroglyph Site remains quite vulnerable. The overall fragility of the landscape, the large number of people who already visit the site, and the self-guided nature of site visitation are driving this evaluation.

Though these results remain heuristic until HASG is implemented at other comparable sites in this general area or under the same type and degree of management, the Painted Rocks' score is remarkably similar to that of rock art sites evaluated in South Africa (Wurz and van der Merwe 2005, p. 15). Such compatibility speaks to the transnational value of rock art as a cultural heritage asset and the need for greater conservation efforts across the globe. However, the Painted Rocks differ from the South

Table 4 Heritage Asset Sensitivity Gauge of market appeal

Site criterion (and explanation)	None (0)	Low (1)	Medium (2)	High (3)	Painted Rocks
1. Scenic ambience and setting appeal (Natural splendor and environmental integrity associated with asset)	Degraded environment lacking any relation to original setting	High degree of modification but not totally degraded	Some degradation detracting from ambience and setting	Outstanding quality retaining ambience of original setting	1
2. Prominence as national icon or symbol (Unique and representative of universal qualities [*e.g.*, Chaco Canyon inspires poets, writers, and archaeologists])	No local or national uniqueness	Local prominence	Some national prominence	Universal uniqueness; true national symbol	2
3. Evocativeness of place—ability to tell a story (History can be brought to life and made relevant for visitors by evoking significant feelings and happenings)	None	Vague notions contributing to evocativeness	Associations with local folklore or traditions	Locally and nationally known folkloric and literary associations	1
4. Potential for tying to other nearby tourism products (Accessibility and setting allow combination with other tourist experiences (*e.g.*, hiking, hunting, festivals, pilgrimages) within 50 km, either combined with different products or bundled in themed packages)	None	Other fixed cultural or natural assets	Other activities or events (*e.g.*, festivals)	Natural or cultural assets, activities, and events	1
5. Appeal for special spiritual needs or uses (Integrity and intactness accommodate tourists' needs for deeper existential connection to spiritual meaning of heritage [*e.g.*, roots, nostalgic experience])	Integrity and intactness do not allow interpretation or connection	Integrity and intactness allow low degree of connection	Integrity and intactness allow medium degree of connection	Integrity and intactness allow high degree of connection	2
6. Tourism profile of region as national magnet (Extent to which region is known for heritage and other tourist activities)	Unknown	Local reputation	Nationally celebrated	Internationally renowned	2
7. Potential to generate new income	None	Uncertain	Limited	Significant new income and stimulation of related	1

Table 4 (continued)

Site criterion (and explanation)	None (0)	Low (1)	Medium (2)	High (3)	Painted Rocks
(Potential for development to generate new income and spin-offs for local community in terms of multiplier effects)				income-generating activi ties	
8. Potential public/private financial support (Potential for development to attract public or private financial support)	None	Official commitment	Application for public funds lodged	Public/private funding approved	3
9. Cost of access (Regional connectivity; road-to-site access and proximity to major tourism market)	Secondary/provincial gravel road; > 50 km to nearest town	Provincial gravel road; < 50 km to nearest town	Paved road; < 50 km to nearest town	Within 100 km of metropolitan hub	2
10. Number of site amenities (Presence of facilities [*e.g.*, parking, paths, signs] on or near the site)	0	1	2	> 2	3
Composite score					18

Table 5 Heritage Asset Sensitivity Gauge of cultural significance

Site criterion (and explanation)	None (0)	Low (1)	Medium (2)	High (3)	Painted Rocks
1. Aesthetic significance of asset (Beauty in terms of attributes such as form, scale, color, texture, design, and technical integrity)	None	Some form and composition attributes	Noteworthy form and composition attributes	Distinctive form or composition attributes; design and technical integrity produce exceptional asset	2
2. Experiential significance of surrounding landscape (Extent to which natural setting enhances visitor experience)	Environmental setting damages experience	Conflict between landscape and asset spoils experience	Proximity of degradation and degree of landscape change detracts from cultural heritage	Pristine environment provides optimum experience	2
3. Historical significance (Extent to which asset demonstrates continuing association with past cultural practices and historic events, phases, periods, or activities regardless of asset intactness)	None	Vague, local historical connections	Strong national significance	Major international and national significance	2
4. Educational value and potential (Potential for interpretation and transformation into educational, easily understandable information, and setting is instrumental to learning experience)	None	Some information relevant to primary and secondary learners; setting does not facilitate learning experience	Information highly important to primary and secondary learners; setting facilitates learning experience	Information highly important to primary, secondary, and tertiary learners; setting facilitates learning experience	3
5. Social significance (Strong/special socio-cultural association with a particular community or cultural group [*e.g.*, importance to community's sense of place or identity; focus of group's spiritual, political, or cultural sentiment; ongoing use for important events])	None	Few members of local community value sense of place or identify with asset	Local community values significance but place not associated with any events	Local community honors place as central to its identity; uses it for important events	2
6. Scientific value (Importance as a reference site, providing evidence of past human cultures unavailable elsewhere with potential to yield substantial information contributing to understanding cultural history)	None or ruined	Some significance but site not intact	Moderate significance and intactness	Universal significance due to high intactness and meaning	2

Table 5 (continued)

Site criterion (and explanation)	None (0)	Low (1)	Medium (2)	High (3)	Painted Rocks
7. Uniqueness (Evidence of artistic or technical achievement, defunct custom, way of life or process, unusually accurate or unique evidence of a significant human activity)	Common (everywhere)	Fair number of similar sites	Few similar sites; moderately uncommon	Unique	3
8. Indigenous spiritual significance (Links with local sacred indigenous awareness and customs)	None	Some but links severed	Spiritual links weakly or inconsistently maintained	Major significance widely maintained through recurrent spiritual practices	2
9. Significance as potential national unifying socio-cultural symbol (Symbolic value that helps build common identities, reinforcing national myths and cultural symbols)	None	Some, but unexploited	Limited, some exploitation	Major, widely exploited	2
10. Representative significance (Exemplifies particular style, technology, high creative/technical achievement, culmination of particular style, principal characteristics of particular class of cultural heritage)	None	Some	Noteworthy	Archetypal; distinctive representation	2
Composite score					22

Table 6 Heritage Asset Sensitivity Gauge of site vulnerability

Site criterion (and explanation)	None (0)	Low (1)	Medium (2)	High (3)	Painted Rocks
1. Number of major natural risks (Vulnerability to physical damage by natural factors [*e.g.*, wild animals, fire, water, atmosphere])	0	1–2	3–4	> 4	1
2. Risk of human damage (Capacity to withstand damage by humans)	Fabric cannot be damaged by human agents	Well protected	Poorly protected	Unprotected; easily damaged by any tourist activity and incidental visits	2
3. Current level of irreversible damage (Amount of natural and human damage already sustained)	Irreparable damage	Some repairable, some irreparable damage	Limited, repairable damage	Original pristine condition	1
4. Potential negative impact of high visitation on fabric of asset (Potential of high visitation to impact adversely on physical and social environment)	None	Low	Medium	High to extreme	3
5. Potential negative impact of high visitation on social fabric of local communities (Potential of high visitation to introduce new value systems, causing large sections of communities to become dependent on tourism at expense of traditional values, possibly leading to loss of self-reliance and traditional activities)	None	Low	Medium	High	0
6. Level of guidance provision (Trained guide present to guarantee physical protection and experiential authenticity)	Local guide trained and employed	Tour operator or expert guides	Expressed intention to provide guidance	No intention to provide guidance	3
7. Level of site management plan initiation (Degree to which site management plan is initiated)	Impact assessment commissioned or completed	Site formally recorded to contemporary national standards	Limited or incomplete recordation	Site unrecorded; no action taken	2
				No action taken	2

Table 6 (continued)

Site criterion (and explanation)	None (0)	Low (1)	Medium (2)	High (3)	Painted Rocks
8. Implementation level of conservation management plan (Degree to which conservation management plan is implemented)	Conservation management plan implemented	Conservation management plan in development	Informal conservation efforts implemented		
9. Number of exposure monitoring and protection measures in place (Measures may include regular site inspection, site supervisor, fencing, signage, visitor number recording, *etc.*)	> 4	3–4	1–2	None	1
10. Number of stakeholders actually/potentially involved (Stakeholders include landowner/manager, local community, descendent communities, *etc.*)	> 6	5–6	3–4	1–2	0
Composite score					15

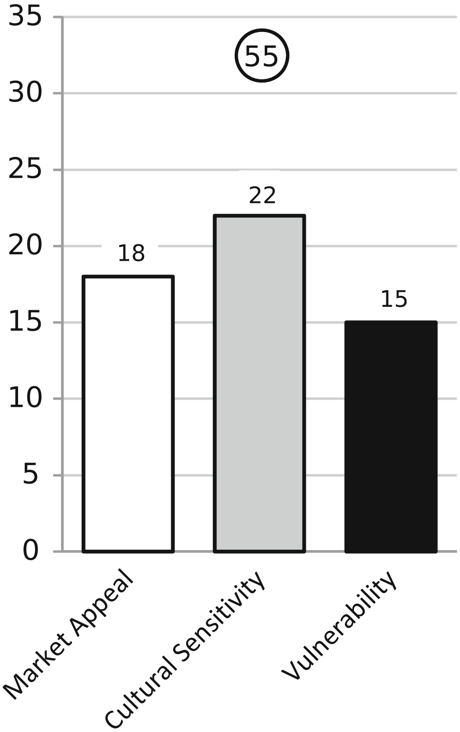

Fig. 18 Bar graph of Heritage Asset Sensitivity Gauge scores for Painted Rocks

African scenario in a compelling way. Painted Rocks scores highest on cultural significance followed secondly by market appeal, suggesting the values tied to conservation currently outweigh those of its tourism potential. This is insightful when considering the potential return on investments directed at protection efforts versus those put toward development and visitor amenities. With the South African cases studied by Wurz and van der Merwe (2005) market appeal outweighs the sites' measured cultural significance. Still, based on recent research at one of the country's World Heritage Sites (Duval and Smith 2013, 2014), the tourism potential for South African rock art remains underappreciated in spite of its perceived economic attractiveness.

Sustainability Forecast

The total HASG score of 55 for Painted Rocks implies a relatively high level of management is required to balance conservation goals and the pressure mounting from the current rate of tourism. Moreover, results of the RASI analysis and observation on the continued creation of penetrative vandalism demonstrate that the site's stability and integrity are under constant and persistent threat, even though the Painted Rocks have so far bore the brunt of these impacts remarkably well. This foreboding conservation forecast is expected to intensify as the population in the adjacent metropolitan centers of Phoenix and Yuma increases, as associated development expands outward from these urban areas, and as the climate changes toward more challenging conditions

(Hambrecht and Rockman 2017; Rockman *et al.* 2016). In the event that Painted Rocks becomes part of a national monument, tourism to the region is projected to more than double in the first five years (BBC Research and Consulting 2014).

Considering the relatively good status of the stability of the Painted Rocks—coupled with the amount of infrastructure already in place, ongoing monitoring and stewardship by volunteers, and the conservation interest of the land manager—a sustainable balance between conservation-related values and those of tourism under current and projected conditions is attainable. As noted previously, the BLM has implemented a number of best practices that have helped thwart overall degradation of Painted Rocks. There is room for improvement nonetheless, and proactive measures are needed to counteract forecasted increases in stressors on the stability and integrity of the site, especially those that are anthropogenic in origin. As detailed above, penetrative vandalism, proximity of the perimeter trail to the petroglyph boulders, and the ability to roam freely across the site area have adversely affected the Painted Rocks to a considerable extent, and while the damage is irreversible, ongoing degradation can be curtailed through more effective visitor control practices. This condition assessment informed a number of recommendations (Wright 2018), including erection of boardwalk around the site area to limit impact from foot traffic, installation of a remote surveillance system, placement of site etiquette signage near the rock art rather than near the parking lot, and the removal of creosote (*Larrea tridentata*) bushes enveloping rock art boulders.

Conclusions

Rock art is one of the most intellectually accessible, visually engaging, and all-around popular types of cultural heritage asset for the public. A report commissioned by the Society for American Archaeology indicated that 84 (±3) % of adult US citizens support action and legislation aimed at protecting rock art (Ramos and Duganne 2000, p. 27), with the general popularity of rock art publications attesting to a similarly high level of public interest. If left unmanaged, this wide appeal can be a double-edged sword, as increased tourism to unprotected or inadequately managed rock art sites has the potential to exacerbate stone decay processes and aggravate conservation efforts. Effective and flexible conservation management practices are sorely needed in order to preserve what remains of the world's quickly disappearing rock art. Initial steps in conservation planning and action include inventorying a site's assets and evaluating their condition (Fig. 1), which has now been accomplished for the Painted Rock Petroglyph Site.

This asset inventory and appraisal of the stability of the Painted Rock Petroglyph Site has demonstrated the applicability of the Rock Art Stability Index (RASI) to inform on particular weathering forces acting upon the site, the extent to which they have damaged the rock art, and their projected impacts in the future. Facilitated by GIS-enabled spatial analysis and augmented with petroglyph-level observations, RASI has permitted evaluation of stone decay processes in relation to place-specific weathering agents. Coupled with an appraisal of penetrative vandalism at the site, a contrast between current condition and that witnessed in older photographs, and a comparison of surface artifact sizes through time, this holistic condition assessment has shown that the Painted Rock Petroglyph Site faces considerable conservation challenges from natural and human forces. Indeed, according to the Heritage Asset Sensitivity Gauge (HASG), the Painted Rock Petroglyph Site requires a relatively high degree of management in order to conserve the rock art, which implies this same management is needed to protect the various values ascribed to the petroglyphs as well as any economic and educational benefit generated through tourism.

Albeit each example of rock art faces a unique conservation challenge, case-specific treatments are incredibly inefficient when considering the thousands of petroglyphs spread across hundreds of boulders at the Painted Rock Petroglyph Site. Accordingly, mitigating impacts that affect a sizeable proportion of the site's rock art, or which affect the general site area, will have the greatest return on conservation investment. The most pronounced natural weathering processes acting upon the rock art at Painted Rocks concern surficial scaling and flaking due to case hardening and the development of weathering rinds on the boulders. Anthropogenic forces are equally pervasive, if not more so, in the weathering of rock art at the site. The spatial analysis of RASI data revealed that unrestricted foot traffic across the site area has led to deleterious impacts to the rock art along designated trails as well as informal footpaths. In these areas, the boulders exhibit significantly more abrasion and less desert varnish, and usually the edges of petroglyphs are more rounded that in other settings. These erosive impacts are due to the dust and sand that are kicked up and over the boulders as well as the friction of feet, hands, and other items that come into direct contact with the rock art. Unfettered foot traffic has also adversely affected the artifacts at the site, resulting in the breaking, grinding, and edge-rounding of pottery sherds. Likewise, the location of penetrative vandalism is strongly associated with proximity to designated trails. Additional information and infrastructure to guide visitors around the site and educate them in appropriate site etiquette are highly needed (Wright 2018).

Although the Painted Rock Petroglyph Site has weathered the agents of stone decay remarkably well, the impacts of natural and anthropogenic weathering forces have accrued to the point where they alter visitors' experiences at the site. The penetrative vandalism cannot go unnoticed, and several boulders along the perimeter trail have eroded to the point where the petroglyphs are no longer discernible. Moreover, the ongoing weathering of rock art and other impacts to the site detract from the overall research potential of this unique cultural heritage property. With regard to the sustainability of the Painted Rock Petroglyph Site, anthropogenic weathering is expected to magnify as population levels increase, urban areas expand, and cultural heritage tourism intensifies, especially if the Painted Rocks gain even more prominence in the event of national monument designation. Likewise, natural weathering processes are expected to aggravate in concert with increasing temperatures and changes in precipitation regimes. Rather than focus on managing the site under current visitation rates or reacting to threats after they have already impacted the site, an effective, proactive conservation plan must take these forecasted changes into account. Holistic condition assessments, such as the one presented here, are an essential early step in conservation management planning, but they are not an end in and of themselves. This study of the Painted Rock Petroglyph Site should inform preparation of a formal conservation plan, and whether or not the recommendations are implemented, periodic condition assessments will be needed to monitor natural and human impacts and gauge rates of change in site stability and integrity.

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