ENVIRONMENTAL AUDITING

Choosing Indicators of Natural Resource Condition: A Case Study in Arches National Park, Utah, USA

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ABSTRACT / Heavy visitor use in many areas of the world have necessitated development of ways to assess visitation impacts. Arches National Park recently completed a Visitor Experience and Resource Protection (VERP) plan. Integral to this plan was developing a method to identify biological indicators that would both measure visitor impacts and response to management actions. The process used in Arches for indicator selection is outlined here as a model applicable to many areas facing similar challenges. The steps were: (1) Vegetation types most used by visitors were identified. Impacted and unimpacted areas in these types were sampled, comparing vegetation and soil factors. (2) Variables found to differ significantly between compared sites were used as potential indicators. (3) Site-specific criteria for indicators were developed, and potential indicators evaluated using these criteria. (4) Chosen indicators were further researched for ecological relevancy. (5) Final indicators were chosen, field tested, and monitoring sites designated. In Arches, indicators were chosen for monitoring annually (soil crust index, soil compaction, number of used social trails and soil aggregate stability) and every five years (vegetation cover and frequency; ground cover; soil chemistry; and plant tissue chemistry).

Increasing recreational use of many lands worldwide is resulting in unacceptable deterioration of resource conditions within these areas. Effects of recreation include impacts such as soil compaction, soil loss, vegetation loss, disruption of normal nutrient cycles, changes in hydrologic cycles and changes in animal populations (Belnap 1995, 1996, Grafe and others 1990, Kus and others 1990, Marion 1991, Parsons and MacLeod 1980).

To address impacts associated with this ever-rising use, land management agencies have been actively seeking ways to incorporate resource carrying capacities into the planning process. This idea was popularized by the US Forest Service's Limits of Acceptable Change program (LAC) (Stankey and others 1985) and the National Parks and Conservation Association's Visitor Impact Management program (VIM) (Grafe and others 1990, Kuss and others 1990). Central to both of these programs is the concept that condition of the resource, not visitation levels and infrastructure development, should drive resource management decisions.

Both of these programs use indicators to monitor resource conditions. Many publications list both suggested indicators and the criteria for choosing indicators (Landres 1992, Whittaker and Shelby 1992, Stankey and others 1985, Grafe and others 1990, Kuss and others 1990, Cole 1982, Marion 1984, 1991, Merigliano 1989, Parsons and MacLeod 1980, Shelby and Shindler 1990). However, much less attention has been focused on the process of choosing indicators. Furthermore, most past research has focused on developing indicators for low-use situations such as backcountry and wilderness areas, and most resource indicators have been centered on campsite and trail conditions (Cole 1982, Grafe and others 1990, Marion 1984, 1991, Merigliano 1989, Parsons and MacLeod 1980, Shelby and Shindler 1990). Little research has focused on the large ''front- and mid-country'' areas found in all national parks and many other recreation sites. These areas receive much higher levels of use than backcountry areas, and impacts are often much more severe. In addition, some impacts are unique to front-country areas, such as dust and noise from cars and the presence of roads as a barrier to animal movement.

The National Park Service (NPS) mandate is to ''leave [parks] unimpaired for the enjoyment of future generations'' (USDI 1991). Increased expectations by visitors regarding resource conditions in parks often results in more stringent management goals for national parks when compared to other federal and state lands. NPS Management Policies also require managers ''identify acceptable limits of impacts . . . and take prompt corrective action when unacceptable impacts occur'' (USDI 1991).

This paper describes a process developed for choosing both back- and front-country resource indicators in

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recreational areas. The model presented here is based on the idea that potential indicators can be readily identified by comparing areas with similar resources (such as vegetation and soils) but different use levels. Variables that differ significantly between the areas are assumed to be sensitive to visitor use, and therefore potential indicators. In order to better illustrate this model, data from the recently developed Arches National Park's Visitor Experience and Resource Protection (VERP) (USDI 1993) planning process is used.

Study Area

Arches National Park, comprising 28,340 ha, is located 6 km north of Moab, Utah, USA. This park received almost 900,000 visitors in 1995. Results reported here are from a blackbrush (*Coleogyne ramosissima*) community, the most frequently visited plant community type in Arches. The study site was at the Windows, where approximately 50% of the park's visitors stop. This site is at 1370 m elevation. Rainfall is approximately 250 mm annually. The lack of a defined trail between some of the prominent features and the parking lot has resulted in a 9-ha area being trampled by people walking between these features and their cars. Heavy trampling has only occurred in the last 5–10 years and has resulted in impacts unacceptable to park management and visitors surveyed while visiting the park.

Several factors make Arches National Park especially sensitive to visitor impacts. Arches is located in a semiarid region, and the scarce, unpredictable rainfall results in slow growth and recovery rates for vegetation. Lack of deep freezing and lack of plant litter results in soils that have both low resistance to, and slow recovery from, compressional forces such as foot traffic. Because plants are spaced far apart and plant litter is minimal, the cryptobiotic soil crusts that occur in this region are essential in reducing wind and water erosion, as well as providing carbon and nitrogen inputs to the system (Belnap and Gillette 1997, Belnap and Harper 1995, Beymer and Klopatek 1991, Evans and Ehleringer 1993, McKenna-Neuman and others 1996, Williams and others 1995). Unfortunately, they also have very low resistance to, and slow recovery from, compressional disturbances such as foot and vehicle traffic (Belnap 1993, 1995, 1996, Belnap and Gillette 1997, Garcia-Pichel and Belnap 1996).

Because this study proposed to use comparisons between lightly and heavily used areas to identify potential indicators, two study sites were chosen that represented clear extremes along a visitor impact gradient. One site was located in a heavily impacted area, while the comparison site was an adjacent, relatively unimpacted area approximately 100 m away. Both sites were on Arches loamy fine sand with similar depth, slope, aspect, and exposure.

Methods

Mapped vegetation types (Allen 1977) were combined with visitor use patterns (Arches National Park, unpublished) to identify the vegetation associations most heavily visited in Arches. In these heavily used vegetation types, representative adjacent heavily and lightly used areas were selected for sampling. Given time, money, and expertise constraints, all vegetation and soil variables feasible were measured for each vegetation type. As the purpose of this paper is to illustrate the process of selecting indicators, reported results are from only one of the communities surveyed. The selected community, blackbrush (*Coleogyne ramosissima*), is the most heavily used in Arches.

In both the lightly used and heavily used area, a 50-m^2 plot was established, and all shrubs within the plot mapped. Within each plot, five transects were placed randomly. Along each transect, twenty 0.25-m^2 quadrats were evaluated for vegetation and groundcover composition, frequency, and cover (plants, plant litter, rocks, gravel, mosses, lichens, cyanobacteria, bare ground, blow sand). Animal pellets were collected and counted.

A cryptobiotic soil crust index was developed to reflect time since last disturbance. These ratings were based on previous studies of crustal recovery rates (Belnap 1993, 1995): 0 = loose sand (recent disturbance), 1 = a flat continuous surface (<1 year), 2 = a slightly bumpy, textured surface (1–2 years), 4 = humps heaved >1 cm from the soil plane (2–5 years), 6 = humps, some lichen or moss development (6–9 years), and 10 = well-developed lichens and/or mosses (>10 years). Cover classes were used to estimate the amount of each type present. Cover class was multiplied by the crust index value; resulting numbers were then added to give an overall index value for the quadrat.

For all shrubs intersecting the transect lines, vegetation structure was assessed by recording height classes (0–0.5, 0.5–1, 1–3, 3–5, and >5 m), width, and length of the shrub. Distance to the nearest shrub neighbor was recorded. Shrub hummock height was estimated (defined as the height at which a rod held parallel to the surface from the base of the shrub intersected a rod held vertically at the lowest point in the shrub interspace). Length and number of exposed shrub roots were also recorded. Tissue samples from the dominant shrub (Coleogyne ramosissima), a perennial forb (*Ment-*

zelia multiflora) and the dominant annual (*Festuca octoflora*) were collected, weighed and analyzed for total biomass and tissue elemental content. Soils were collected and analyzed for pH, organic matter, texture and all major cations. Analyses were done by the Brigham Young University Soil Laboratory. Soil aggregate stability was assessed with a slake test. Cubes of soil were placed in distilled water, and time to dissolution recorded.

Soils were also collected and analyzed for biological activity from the shrub interspace. Total and active bacterial and fungal biomass and nematodes, analyzed by functional groups, were assayed along the transects. Analyses were done by the Soil Microbial Biomass Service at Oregon State University.

Water infiltration was measured using a double-ring, drip infiltrometer. Soil compaction was assessed using bulk density measurements. Potential soil nitrogenase activity was determined with the acetylene-reduction method, using 20 samples from each area. Samples were moistened and incubated for 4 h in a 10% acetylene atmosphere. Resultant ethylene levels were measured on a gas chromatograph.

Other variables compared in the two areas included proximity of vegetation to the side of the designated trail and the distance to attractive features, the percent of available shrub interspaces that were trampled, the number of social trails leaving the main trail, the number of trails leaving the main trail used within a 2-h period, and the number of trails found 30 m off the main trail.

All percentile values were arcsine-transformed for statistical analysis. The *t* tests were used to compare the values from the undisturbed and disturbed areas.

Based on a literature search and discussion by the VERP team, criteria for suitable indicators were identified, using previous studies as well as local experience (Landres 1992, Whittaker and Shelby 1992, Stankey and others 1985, Grafe and others 1990, Kuss and others 1990, Cole 1982, Marion 1984, 1991, Merigliano 1989, Parsons and MacLeod 1980, Shelby and Shindler 1990). Criteria were picked according to their ease of application and their relevance to the situation at Arches.

For indicator monitoring, the park was divided into zones that reflected the type and level of visitor use. It was decided to monitor sites within these zones that were more, rather than less, impacted by visitors, with the belief that compliance in these areas would best indicate compliance in the rest of the zone. It was also decided that if visitor use shifted to other areas, monitoring sites would be shifted as well.

Three randomly placed 50-m transects were permanently established in each of the monitoring locations identified, with at least two locations designated per zone. Cryptobiotic soil crust condition and soil aggregate stability was assessed every 5 m along the transect (20 locations), using a 1 × 1-m quadrat. The number of newly used social trails was determined by broom-sweeping 100 m of already present social trails clear of all tracks 200 m before the beginning of the permanent transect. After 2 h, the number of trails newly used were counted.

On an annually rotating basis, three of the 15 sites were evaluated more extensively. This included measurements of cover and frequency of vascular plants by species; cover and frequency of ground cover, including litter, bare ground, cyanobacteria, mosses, and lichens; analysis of plant elemental content; and analysis of soil characteristics, including texture, pH, organic matter, penetration resistance, porosity, major cations, and anions.

Table 1. Soil physical characteristics of disturbed and undisturbed areas at Arches National Park (Belnap 1995)

	Undisturbed (mean ± SD)	Disturbed (mean ± SD)	*P*
pH	8.30 ± 0.00	8.20 ± 0.00	<0.03
Sand (%)	82.23 ± 0.80	85.76 ± 0.70	<0.05
Clay (%)	8.83 ± 0.50	7.24 ± 0.80	
Silt (%)	8.96 ± 0.02	7.00 ± 1.50	
OM (%)	0.55 ± 0.14	0.40 ± 0.30	
P (ppm)	34.04 ± 0.14	44.38 ± 0.08	<0.01
Zn (ppm)	0.40 ± 0.10	0.50 ± 0.14	
Fe (ppm)	19.90 ± 0.26	26.50 ± 0.13	
Mn (ppm)	3.20 ± 0.17	4.30 ± 0.08	
Cu (ppm)	0.20 ± 0.00	0.20 ± 0.00	
N (ppm)	591.70 ± 47.10	558.30 ± 23.60	
K (ppm)	90.00 ± 0.71	110.00 ± 14.10	
Ca (ppm)	4390.00 ± 99.00	3445.00 ± 7.10	<0.02
Mg (ppm)	70.00 ± 0.00	70.00 ± 0.00	
Na (ppm)	90.00 ± 7.10	110.00 ± 14.14	
0–3 cm g/cm^3	104.90 ± 4.40	114.90 ± 10.00	<0.007
3–6 cm g/cm^3	99.50 ± 4.90	108.10 ± 5.60	<0.001

Results

Soil chemical characteristics were very similar between the two sites (Table 1), with the notable exception of phosphorus and calcium values. Soil physical characteristics were significantly different, with soil bulk density greater at both 0–3 cm and 3–6 cm in the disturbed area when compared to the undisturbed area, indicating soils in the disturbed area had been compacted. Most other variables measured were significantly different between the two areas (Tables 2–4). This included plant community composition, fre-

Table 2. Biological characteristics that differed significantly ($P < 0.05$) at Arches National Park between disturbed and undisturbed areas (Belnap 1995)

	Undisturbed (mean ± SD)	Disturbed (mean ± SD)
Percent Cover		
Cyano	45.50 ± 7.20	78.20 ± 14.10
Lichen	2.00 ± 1.20	0.20 ± 0.30
Collema	4.40 ± 2.40	0.60 ± 0.70
Moss	32.70 ± 5.50	4.40 ± 4.00
Litter	31.80 ± 5.00	8.60 ± 3.20
Bare ground	0.06 ± 0.13	8.36 ± 12.20
Exotics	0.06 ± 0.13	1.40 ± 1.30
Frequency		
Lichen	0.36 ± 0.15	0.02 ± 0.02
Collema	0.76 ± 0.05	0.14 ± 0.15
Moss	0.95 ± 0.04	0.31 ± 0.24
Bare ground	0.03 ± 0.05	0.88 ± 0.06
Gravel	0.08 ± 0.15	0.50 ± 0.40
Grass	0.64 ± 0.17	0.39 ± 0.13
Shrubs	0.81 ± 0.25	0.49 ± 0.21
Community		
Shrubs (*N*)	7.20 ± 1.24	3.20 ± 0.58
Festuca weight (g)	0.80 ± 0.16	1.68 ± 0.33
Shrub species (*N*)	2.30 ± 0.50	1.40 ± 0.55
Hummock height (cm)	11.11 ± 1.26	25.19 ± 1.97
Exotics (*N*)	0.30 ± 0.50	1.40 ± 0.55
Plant species (*N*)	8.00 ± 1.20	10.00 ± 1.40
Nitrogenase activity (mol C_2H_2)	13.6 ± 20.84	0.98 ± 3.08

Table 3. Active and total bacterial, fungal biomass, and nematode population at Arches National Park (Belnap 1995)

	Undisturbed (mean ± SD)	Disturbed (mean ± SD)
Active fungi	0.30 ± 0.20	0.40 ± 0.50
Total fungi	14.50 ± 5.50	11.60 ± 4.90
Active bacteria	2.30 ± 1.00[a]	1.20 ± 0.70[a]
Total bacteria	3.78 ± 0.82[a]	5.35 ± 1.60[a]
Total fungi/bacteria	4.00 ± 1.40[a]	2.50 ± 1.70[a]
Bacterial feeders	505.00 ± 287.00[a]	370.00 ± 287.00[a]
Fungal feeders	97.00 ± 142.00[a]	54.00 ± 127.00[a]
Root feeders	35.00 ± 38.00	67.00 ± 54.00
Total individuals	651.00 ± 646.00[a]	493.00 ± 360.00[a]

[a]Statistical differences at $P < 0.05$.

Table 4. Physical characteristics of plant biomass at disturbed and undisturbed areas at Arches National Park

	Undisturbed (mean ± SD)	Disturbed (mean ± SD)	*P*
Mentzelia multiflora			
Zn (ppm)	22.00 ± 6.75	20.00 ± 1.58	
Fe (ppm)	639.80 ± 128.40	465.40 ± 79.45	<0.04
Mn (ppm)	98.20 ± 26.43	82.40 ± 10.38	
Cu (ppm)	8.60 ± 1.81	9.00 ± 1.00	
Na (ppm)	77.20 ± 12.64	63.40 ± 3.21	
N (%)	2.61 ± 0.28	2.18 ± 0.13	<0.02
P (%)	0.20 ± 0.02	0.24 ± 0.01	<0.01
K (%)	3.00 ± 1.15	2.67 ± 0.18	
Ca (%)	2.50 ± 0.69	1.97 ± 0.12	
Mg (%)	0.33 ± 0.92	0.23 ± 0.03	
Coleogyne ramosissima seedlings			
Zn (ppm)	74.50 ± 4.10	51.08 ± 7.90	<0.00
Fe (ppm)	646.88 ± 144.96	765.42 ± 162.04	<0.05
Mn (ppm)	50.38 ± 4.31	32.08 ± 3.68	<0.00
Cu (ppm)	15.00 ± 0.24	13.75 ± 1.22	<0.00
Na (ppm)	69.75 ± 9.92	61.50 ± 25.04	
N (%)	5.83 ± 0.29	5.60 ± 0.24	<0.04
P (%)	0.69 ± 0.03	0.55 ± 0.19	<0.00
K (%)	0.86 ± 0.10	1.19 ± 0.11	<0.00
Ca (%)	0.86 ± 0.08	1.04 ± 0.09	<0.00
Mg (%)	0.46 ± 0.02	0.79 ± 0.07	
Coleogyne ramosissima adult leaves			
Zn (ppm)	11.20 ± 1.48	13.00 ± 4.60	
Fe (ppm)	84.60 ± 17.64	139.60 ± 19.22	<0.00
Mn (ppm)	20.80 ± 3.40	36.60 ± 5.03	<0.00
Cu (ppm)	4.00 ± 0.71	4.00 ± 0.00	
Na (ppm)	9.20 ± 1.92	8.40 ± 2.19	
N (%)	1.07 ± 0.15	0.98 ± 0.11	<0.05
P (%)	0.11 ± 0.03	0.11 ± 0.02	
K (%)	0.78 ± 0.12	0.80 ± 0.13	
Ca (%)	3.13 ± 0.36	3.18 ± 0.50	
Mg (%)	0.43 ± 0.04	0.41 ± 0.14	
Festuca octoflora			
Zn (ppm)	34.40 ± 26.35	33.00 ± 2.55	
Fe (ppm)	240.20 ± 169.55	149.40 ± 45.25	
Mn (ppm)	48.20 ± 28.07	74.00 ± 13.78	
Cu (ppm)	8.80 ± 5.00	10.40 ± 0.89	
Na (ppm)	49.20 ± 33.00	59.80 ± 14.32	
N (%)	2.25 ± 0.08	1.95 ± 0.14	<0.01
P (%)	0.25 ± 0.02	0.14 ± 0.01	<0.00
K (%)	1.50 ± 0.85	1.64 ± 0.03	
Ca (%)	0.52 ± 0.29	0.52 ± 0.03	
Mg (%)	0.12 ± 0.07	0.13 ± 0.01	

quency, and cover; perennial/annual plant ratio; plant community architecture (structure, size, number of shrubs, and hummock height); distance to cover for small animals; all categories of ground cover; nitrogenase activity of the soil surface (Table 2); soil bacterial, fungal, and nematode populations (Table 3); and plant tissue elemental concentrations (Table 4). These were retained as potential indicators. Variables that did not differ significantly were discarded as potential indicators. These included shrub, grass and rock cover; cyanobacteria, litter, rock and forb frequency; and the number of annual, perennial, and grass species.

A matrix was then constructed to evaluate suitability of potential indicators (Table 5). The criteria used included both required and desirable characteristics and were chosen based on site-specific needs. Indicators

Table 5. Evaluation matrix for indicator selection

	Selection criteria: Required				Selection criteria: Desirable								
Variables tested	Low impact to measure	Reliable repeatable measures	Correlates with visitor use	Ecological relevancy	Quick response to impacts	Quick response to mgmt	Ease of measure	Minimal natural variability	Large sampling window	Cost effective	Ease of training	Baseline data[a]	Response over range
Trampled interspace			x	x	x	x			x	x	x		x
Spur social trails used	x	x	x	x	x	x	x	x	x	x	x		x
Non-adjacent trails		x	x	x	x	x	x	x	x	x	x		x
Vegetation composition	x	x	x	x	?			x	x[b]			x	x
Vegetation structure	x	x	x	x	x				x	x	x		?
Vegetation proximity	x	x		x	x	x	x	x	x	x	x		x
Shrub size			?	x					x	x			?
Elements: plant tissue	x	x	x	x	?	?	x	x	x		x		x
Interspace distance		x	x	x			x	x	x	x			?
Distance to cover		x	x	x			x	x	x	x	x		?
Hummock height			x	x					x	x			x
Exposed roots			x	x	?	?	x		x	x			x
Soil crust index	x	x	x	x	x	x	x	x	x	x	x		x
N fix potential		x	x	x	x	x	x	x	x[c]			x	x
Soil compaction	x	x	x	x	x	?	x	x	x	x	x		?
Aggregate stability	x	x	x	x	x	x	x	x	x	x	x		?
Soil surface protection	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil chemistry		x		x	?	?	x	x	x		x		?
Soil food webs	x	x	x	x	?	?	x	x	x[c]		x		?
Animal pellets	x	x		x	x	x	x	x	x	x	x		?
Blow sand	x			x	x	x	x			x			x
Infiltration		x	x	x	x	?	x	x	x	x	x		x
Photo points	x		x	x	x	?	x	x	x	x	x		x
Rock/Gravel	x	x		x			x	x	x	x	x		?

[a]Previous to this project.
[b]Compared to reference site.
[c]Comparable seasonally.

had to meet required criteria first. Required criteria included: (1) directly correlated with visitor use; (2) reliable and measurable response both to visitor impact and management actions; (3) low impact to measure; (4) repeatable with different personnel; and (5) ecologically relevant (impacts have meaning on an ecosystem level or localized impacts are significant enough to warrant concern).

Potential indicators that met all required criteria were then evaluated for desirable characteristics. These were: (1) quick response to visitor impact and management action (so the efficacy of actions can be determined in short time frames); (2) minimal spatial, temporal, and climatic variability (samples can be small and effects seen can be clearly connected to visitor use as opposed to other variables); (3) ease of sampling; (4) can be sampled throughout the year (fewer personnel can be more easily scheduled); (5) cost effectiveness; (6) short training time; (7) baseline data available (effects seen are then known to be visitor-caused and not natural fluctuations); and (8) response over a range of conditions (impacts can be seen while still relatively slight. If indicators show no response to impacts until a large decline in resource condition occurs, impacts may be impossible or difficult to repair).

Retained indicators were then evaluated further for ecological relevancy. A literature search was done to determine what was known about these indicators' role in ecosystems and their response to disturbance. Additional research was then conducted to augment these studies if needed.

Desirability rankings, combined with background information on ecological relevancy, led to the chosen indicators. Based on budgetary considerations, a target of three to five indicators monitored yearly was chosen. Indicators chosen for Arches, along with a discussion of their ecological relevancy, are listed in Table 6. Because of the cost and expertise needed to evaluate some of the most ecologically relevant indicators, a two-tiered system was adopted. Tier 1 includes those indicators that can reasonably be expected to be measured annually. Tier 2 are those indicators with high ecological relevance but that were costly and/or required expertise. Consequently, these indicators would be measured less frequently. In addition, tier 2 indicators are expected to act as a check on the more simplistic tier 1

Table 6. Indicators chosen and their ecological relevance

Tier one (measured every year)	
Social trails	Areas trampled by people had soils that were more compacted than untrampled areas. Increased compaction is detrimental to ecosystems, as it disrupts natural nutrient and hydrologic cycles. It is indicative of lower water infiltration, lower subsurface microfaunal biomass and diversity, and therefore lower plant litter decomposition rates.
Soil crust index	Areas with lower rated soil crusts were compared to areas with higher rated soil crusts. Research in Arches showed areas with higher rated crusts had: (1) higher soil nitrogen concentrations, thus allowing plants and animals to receive more nutrition per unit energy expended to obtain that nutrition; (2) higher soil carbon, thereby increasing microbial activity; (3) increased water infiltration rates, thus increasing local water availability to vascular plants; (4) increased soil microbial biodiversity and biomass, which are associated with increased plant litter decomposition rates; and (5) decreased soil wind and water erosion rates, thus maintaining soil fertility.
Soil compaction	Compacted soils result in: (1) less water infiltration for use by vascular plants, (2) fewer microorganisms and thus slowed plant litter decomposition and less nutrients available for vascular plants, and (3) less root penetration by vascular plants.
Soil aggregate stability	Soils with higher soil aggregate stability have higher resistance to wind and water erosion, thus preserving soil fertility.
Tier two (measured every 5 years)	
Vascular plant community composition	Research at Arches showed trampling changed plant community architecture and composition, resulting in less available wildlife cover and forage, and more exotic plants.
Vascular plant tissue elemental analysis	Research at Arches showed lowered concentrations of elements in plants in trampled areas, resulting in lower quality forage for wildlife.
Soil surface protection	Soils in the trampled areas in Arches had less protection of the soil surface, resulting in greater wind and water soil erosion, thus reducing site fertility.
Soil biological characteristics	Research at Arches showed soil microbial populations were greatly reduced in trampled areas. This results in altered nutrient cycles, including lower plant litter decomposition rates.

indicators, until it is established that tier 1 indicators are sufficiently sensitive to the resource conditions being monitored.

Chosen indicators were then field-tested and adjustments made in indicators used, definition of standards, and measurement techniques. Several adjustments were made in Arches indicators after the first field season. Soil bulk density was originally proposed as the preferred way to measure soil compaction. However, field-testing made it clear that this measurement was too time-consuming and results too variable between different personnel. Consequently, it was decided to use a penetrometer to measure this variable. This gave more consistent results and took minimal training. Another indicator that was originally used was number social trails found 10 m off the trail. Field-testing revealed that measurement of this variable required too much researcher impact. As a result, this indicator was changed to number of social trails leaving the main trail that were used in a 2-h time period. Existing trails were swept clean and then inventoried 2 h later for new footprints.

A new indicator, aggregate stability, was added to tier 1. This indicator is a quick, cheap, and quantitative way to measure soil surface susceptibility to wind and water erosion.

All zones monitored were found to be substantially out of compliance with the standards set for each zone. Upon discussion with park management, it was decided that the standards were representative of desired future condition and should be left as initially defined. Therefore, management actions will be required to reduce the impacts in these areas.

Monitoring teams reported that techniques were easy to use, efficient, representative of conditions in the areas monitored, and sensitive to visitor use levels. Based on this appraisal, no changes were made to the monitoring plan.

Discussion

This approach to indicator selection proved to be both time- and cost-effective. It provided an opportunity to evaluate the specific habitat in question, rather than relying on generic indicators developed for different habitat types, geographical locations, and/or use levels. In addition, indicators chosen were already field-tested, and so their usefulness and applicability for the ecosystem in question was established.

Weaknesses noted in this comparison approach included a need for a lead time of at least 2 years to survey habitats, develop a list of potential indicators, determine ecological relevance, and field-test chosen indicators. In addition, staff research expertise was needed for the assessments. Time and money constraints dictated that, in general, variables measured and compared were those that were clearly visible, cheap, and/or easy to measure. Unfortunately, this meant that many other ecosystem components were not evaluated for their suitability as indicators. This may have resulted in highly suitable indicators being neglected.

One of the major problems faced during this process was finding a way to incorporate variables that were both of high ecological significance and high cost. The tiered approach appears to be a good solution to this, where less costly analyses are done on an annual basis, and more costly analyses are done on a 5-year basis. This solution has yet to be tested over time.

Documenting the ecological relevance of chosen indicators for specific habitat types under investigation should always be an essential part of indicator selection and setting of standards. It is critical that a scientific basis be provided for such management decisions.

Conclusion

It is essential that national parks and other federal lands begin instituting a system for assessing visitor impacts such as VERP. As the demand for recreational experiences increases, resultant impacts will also increase unless appropriate management goals and corrective actions are institutionalized. The process described in this paper was very effective at defining acceptable resource conditions for different levels and types of recreational use and at providing management clear, quantified statements about when and how those goals are achieved. Indispensable to this process is an effective monitoring program to continually compare current conditions with stated resource management goals.

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