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RECREATION IMPACTS TO CLIFF RESOURCES IN THE POTOMAC GORGE

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George Washington Memorial Parkway

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Managers of the National Park Service (NPS) are directed by law to accommodate appropriate types and amounts of visitation while ensuring that: "any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS 2006). The increasing popularity of the national park system presents substantial management challenges. High visitatation may cause unacceptable impacts to fragile natural and cultural resources, and may also cause crowding and other social impacts, which can also degrade the quality of visitor experiences.

Responding to these concerns, NPS managers at Chesapeake & Ohio Canal National Historical Park (CHOH) and George Washington Memorial Parkway (GWMP) sponsored this research within the upper Potomac Gorge portions of these parks to investigate visitation-related impacts to the park's cliff resources. The cliffs and non-cliff rocky areas within the Great Falls and Mather Gorge areas provide important habitats for numerous sensitive rare plants and plant communities. A recent General Management Planning process for Great Falls Park (GFP), a portion of GWMP, highlighted the potential impacts of cliff-associated recreational activities, including hiking, climbing, and fishing, on sensitive cliff resources. The planning process identified the need for development of a Climbing Management Plan and a Trail Plan to more specifically address site and visitor management actions needed to protect rare and sensitive natural and cultural resources. Good science to assess cliff-associated rare plants and communities and to determine the existing and potential effects of cliff-related recreational activities is required for these new planning efforts. This research is designed to specifically address these informational needs and to assist park managers on both sides of the river with current and future cliff and recreation management decisions.

This program of research has the following specific objectives:

1) assess and document recreation-associated vegetation and soil impacts to cliff-top, -face, and -base habitats;
2) assess recreation impacts to rare vascular plant species;
3) conduct a comprehensive survey of cliff-associated rare plant species,

4) develop, test, and apply protocols for assessing and monitoring recreation impacts to cliff communities that can be adopted for long-term monitoring by NPS staff, and
5) provide guidance to park managers on site and visitor management practices for minimizing visitor impacts to cliff resources.

This research reports on the results of this program of research, though portions are also covered in companion studies, including a sub-component of this study to address objective 3 (Davis 2011), surveys of formal and informal (visitor-created) trails (Wimpey & Marion 2011), and a study designed to evaluate options for deterring off-trail hiking (Hockett *et al.* 2010). This report presents findings related to the Potomac Gorge cliffs and adjacent rocky areas, including a survey of cliff-top and cliff-base recreation sites and research designed to evaluate factors influencing vascular plant presence.

Park management decision-making always benefits when baseline data on park resource conditions are available. Literature reviews and analyses of resource data can also provide insights about factors that influence resource conditions. Resource monitoring programs can characterize long-term trends and evaluate the efficacy of corrective actions and progress in achieving park management objectives. This research was specifically designed to assist in each of these topic areas. The most relevant scientific literature on recreation impacts is reviewed, including the role of influential factors. Park legislative mandates and management policies related to the protection of park resources are described, along with planning and decision-making frameworks for responding to visitor impact and carrying capacity concerns. Agency guidance on resource monitoring and its capabilities and roles in management decision-making are also reviewed.

Study methods, including our field manuals in Appendices 1 & 2, are fully described for possible use in future monitoring programs. The recreation site survey was conducted in GFP and the adjacent areas of CHOH. Field staff sought to locate and assess all cliff and rocky area recreation sites based on the presence of visible trampling disturbance to vegetation, organic litter, and soils. Site locations were recorded with accurate GPS devices and resource conditions were documented through permanently referenced photos and quantitative measurements for a variety of inventory and impact indicators.

Within GFP, a stratified-random sampling design with 16 vertical transects and 95 quadrats was employed to assess resource conditions and factors affecting the occurrence of vascular plants on the cliff-face and adjacent rocky areas. The study area extended from the Falls Overlook #3 downstream to Sandy Landing, and from the river's edge, up the cliffs, to 10 meters beyond the cliff edge. A comprehensive array of bio-physical measurements were recorded for each quadrat, including the presence and cover of vascular plant species and bryophytes (mosses, liverworts, and hornworts) and lichens. Physical measurements included the types and dimensions of geofeatures, such as cracks, ledges, and depressions in the rock necessary to support the growth of vascular plants, availability of water, insolation (sunlight/shading), flooding, and substrates. Extensive regression modeling was conducted to explore and document correlations and relationships concerning factors that influence vascular plant occurrence within the rocky area zone.

Study Results

The cliff-associated recreation site survey located and assessed 122 sites at cliff-top and cliff-based locations, including 60 sites in CHOH and 62 sites in GWMP, with an aggregate area of disturbance of 86,782 ft^2 (2 acres). Loss of vegetation cover and organic litter has left some portions of the recreation sites with exposed soil that is susceptible to subsequent erosion, including 9,432 ft^2 at CHOH and 8,155 ft^2 at GWMP. Other impacts included damaged trees (47), trees with exposed roots (184), tree stumps (84), and off-site trampling impacts associated with numerous site access trails (323). Though not quantitatively documented, observations by field staff during several weeks of field work suggest that the majority of the recreation sites are predominantly used by hikers (e.g., seeking cliff-top vistas of the river gorge), though some are used primarily by climbers, and a smaller number by visitors involved in fishing, photography, and nature study. The majority of these sites are located at cliff-tops (84 (69%) and account for 83% of the total area of trampling disturbance.

In the cliff research, only 33 of 74 cliff and rocky area quadrats (45%) located within the non-forested cliff and rocky areas have vascular plants. Even within the 33 vegetated quadrats, vascular plants were found growing in only 72 of 148 geofeatures present (49%). The relative rarity of vascular plants within the cliff and rocky areas is the result of many factors, including a challenging bio-physical environment with periodic flooding and droughts, limited soil substrates, and disturbance associated with recreational visitation. Vascular plants were only found growing within geofeatures, with cracks accounting for 78% of the geofeatures. The most common vascular plant found was *Solidago racemosa*, a rare plant not found outside the Potomac Gorge elsewhere in Virginia and Maryland.

The results of extensive regression modeling identified a number of variables that are significantly correlated with the occurrence of vascular plants in the cliff and rocky areas. Regressions were conducted using quadrat data and at the finer geofeature scale. Highly correlated variables included elevation above the river, overhanging woody plant cover, proximity to recreation sites, water flow/availability, and geofeature characteristics (e.g., number of features and their dimensions). Regression results at the quadrat and geofeature scales include the recreation proximity variable with a negative correlation to vascular plant numbers, a correlation that could mean that recreational activity is reducing plant numbers within the cliff and rocky areas of Mather Gorge. As previously noted, such analyses are based on mathematical correlations that cannot demonstrate causality.

While it is reasonable to expect causality, we also note the importance of other explanatory factors. Our analyses revealed that the cliff and rocky areas sought out for recreational activity have only 2.0 geofeatures/quadrat, whereas the quadrats without recreational activity have 4.1 geofeatures/quadrat. Since plants require geofeatures to grow, this finding means that the areas with recreational uses must have started out with fewer plants than the areas without recreation, possibly by a factor of two. The regression modeling also points to the influence of other physical and environmental factors that determine plant presence. Our interpretation of these modeling exercises is that recreational activities are likely contributing to a slight reduction in the number of vascular plants within the cliff and rocky areas but that it is just one of many influential factors.

It is clear from this research that recreational activity *can* pose a threat to the rare plants growing within the cliff and rocky areas. To address this potential threat, we describe a comprehensive array of alternative recreation and site management options for consideration by park planners and managers. These include actions to promote low impact outdoor practices, close and restore duplicative and/or unnecessary recreation sites and informal trails, and reduce rates of off-trail hiking and informal trail impact. We also include suggestions for improving management of formal trails, recreation sites, and climbing to reduce impacts. Finally, we describe the need for a more focused effort to evaluate the mapped locations of rare plants and respond to potential impacts from recreational activities. We describe planning and management decision-making models that incorporate feedback from long-term monitoring programs and recommend their adoption as a framework for selecting, implementing, and evaluating specific management actions. Our research benefited from volunteer assistance offered by members of local hiking and climbing organizations and we recommend their continued involvement in planning and management decision-making, and in the selection, implementation and monitoring of corrective actions.

INTRODUCTION

The National Park Service (NPS) accommodates nearly 300 million visitors per year, visitation that presents managers with substantial challenges at some 394 park units across some 83.6 million acres of protected lands. An increasing number of visitors inevitably contributes negative effects to fragile natural and cultural resources. Such visitation-related resource impacts can degrade natural conditions and processes and the quality of recreation experiences. According to the NPS *Management Policies*: "The fundamental purpose of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values…The fundamental purpose of all parks also includes providing for the enjoyment of park resources and values by the people of the United States." (NPS 2006, Section 1.4.3). However, what might appear to be dual mandates - visitation and resource protection - are clarified to reveal the primacy of resource protection. The *Management Policies* acknowledge that some resource degradation is an inevitable consequence of visitation, but directs managers to "ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS 2006).

The increasing popularity of the national park system presents substantial management challenges. Too many visitors may cause unacceptable impacts to fragile natural and cultural resources, and may also cause crowding and other social impacts, which can also degrade the quality of visitor experiences. How many visitors can ultimately be accommodated in a park or related area? How much resource and social impact should be allowed? These and related questions are commonly referred to as carrying capacity (Manning 1999, Stankey & Manning 1986, Shelby & Heberlein 1986, Graefe *et al.* 1984).

Responding to these concerns, NPS managers at Chesapeake & Ohio Canal National Historical Park (CHOH) and George Washington Memorial Parkway (GWMP) sponsored this research within the upper Potomac Gorge portions of these parks to investigate visitation-related impacts to the park's cliff resources. The cliffs and rocky areas within the Great Falls and Mather Gorge areas provide important habitats for numerous sensitive rare plants and plant communities. A recent General Management Planning process for Great Falls Park (VA) highlighted the potential impacts of cliff-associated recreational activities, including hiking, climbing, and fishing, on sensitive cliff resources. The planning process identified the need for development of a Climbing Management Plan and a Trail Plan to more specifically address site and visitor management actions needed to protect rare and sensitive natural and cultural resources. Good science to assess cliff-associated rare plants and communities and to determine the existing and potential effects of cliff-related recreational activities are required for these new planning efforts. This research is designed to specifically address these informational needs and to assist park managers on both sides of the river with current and future cliff and recreation management decisions.

The potential environmental impacts from recreational activities includes the trampling and loss of vegetation, including rare plants and plant communities, alteration in vegetation composition, possible introduction and spread of non-native plants, compaction and loss of soil, and disturbance or displacement of wildlife. At popular cliff sites, the creation and proliferation of informal trails and recreation sites can be a significant management problem that can directly impact sensitive plant communities, rare or endangered flora and fauna, and wildlife habitats

(Leung *et al.* 2002, Wood *et al.* 2006). Even limited trampling has the potential to significantly affect populations of plants that are small in areal extent and number. Resource impacts on informal trails and sites can be severe, partially because of the absence of professional design, construction, and maintenance practices. While some degree of visitor impact is unavoidable, excessive trampling impacts can threaten natural resource conditions and processes, visitor safety, and the quality of recreational experiences (Leung *et al.* 2002). These potential impacts are reviewed more fully in the Literature Review section of this report, found in Appendix 4.

This program of research has the following specific objectives:

1) assess and document recreation-associated vegetation and soil impacts to cliff-top, -face, and -base habitats;
2) assess recreation impacts to rare vascular plant species;
3) conduct a comprehensive survey of cliff-associated rare plant species,
4) develop, test, and apply protocols for assessing and monitoring recreation impacts to cliff communities that can be adopted for long-term monitoring by NPS staff, and
5) provide suggestions to park managers on site and visitor management practices for minimizing visitor impacts to cliff resources.

In summary, this research is designed to document the type, distribution, and extent of cliff-associated recreation impacts to the upper Potomac Gorge's cliff resources to enhance management planning and decision-making. This includes developing and applying objective methods for assessing recreation-related impacts at cliff-top and cliff-base vistas and recreation sites, and from climbers on the cliff-face. Resource impacts associated with formal and informal trails were assessed and reported in a companion study by Wimpey and Marion (2011). Rare vascular plants and many non-vascular plants (e.g., lichens, mosses, liverworts) were also comprehensively surveyed in the vicinity of cliffs, as these areas have been omitted in most previous surveys. These findings are reported separately by Botanist Charlie Davis (2011).

This report contains Study Area, Methods, Results, and Discussion sections, with the following sections included in a Report Addendum section as Appendix 4: Justification for Monitoring, Legislative Mandates, Carrying Capacity Decision-Making, Visitor Perceptions of Resource Conditions, Monitoring Program Capabilities, Literature Review, and Management Considerations. This Addendum was created to shorten the body of report. The Management Considerations information is useful in selecting and implementing effective site or visitor management actions. If park staff implement procedures developed from this research as part of a long-term monitoring program then comparisons to the baseline dataset provided by this study will allow the detection of trends and evaluation of the effectiveness of management interventions. Finally, these data support the selection of indicators and standards as part of Cliff and Trail Management Plans, or other carrying capacity planning based on the NPS Visitor Experience and Resource Protection (VERP) framework (described in the Carrying Capacity section).

STUDY AREA

This research examined the effects of recreational visitation on Potomac Gorge cliff resources at portions of two NPS units: Great Falls Park (GFP), managed by the George Washington Memorial Parkway (GWMP), and the upper Potomac Gorge and Carderock portions of the Chesapeake & Ohio Canal National Historical Park (CHOH). GFP is located in northeastern Virginia along the Potomac River outside of Washington, D.C. (Figure 1). CHOH is located immediately across the river in Maryland (Figure 2). Together, these parks provide a rugged oasis of protected natural lands near the crowded urban Capital area.

Natural and Cultural Resources

Potomac Gorge is situated within the Piedmont physiographic province on harder metamorphic rocks. During the Pleistocene epoch continental glaciations lowered the sea level while the Piedmont Plateau slowly uplifted. A difference in the more rapid erosion of softer downstream sedimentary rocks, and the slower erosion of hard metamorphic rocks, created a waterfall that cut and exposed the Mather Gorge cliffs as it retreated upstream to the current location of Great Falls (Reed *et al.* 1980, Reusser *et al.* 2004). The primary types of rock exposed within Mather Gorge are the metamorphic rocks mica schist and metagraywacke (a slate-like metamorphosed sandstone), along with some intruded igneous rocks. These approximately 600 million year old rocks were originally deposited as sand, silt, and mud in an ancient sea (Reed *et al.* 1980).

The study area has a long and rich cultural history centered most notably on the construction of the Patowmack Canal (1786-1802) on the Virginia side and the Chesapeake & Ohio Canal (1828-1850) on the Maryland side. The Patowmack Canal was operated until the C&O Canal was completed in 1850, and the C&O Canal continued operation until 1924. The town of Matildaville, VA, was developed adjacent to the Patowmack Canal in the late 1790's; a number of foundations remain visible as do many portions of the canal walls and locks. Petroglyphs and other evidence of prehistoric Native American Indian occupation have also found in both parks.

The Potomac Gorge is biologically significant natural area supporting rare plant communities within the lower portions of the bedrock terrace, the gorge rim, and river channel (NPS 2007). For example, 28 plant species found within GFP are on the State list of rare, threatened or endangered species, including the sticky goldenrod (*Solidago racemosa*), Nantucket shadbush (*Amelanchier nantucketensis*), sterile sedge, (*Carex straminea*), and western sunflower (*Helianthus occidentalis*). Sticky goldenrod is extremely common on Potomac Gorge cliffs but is not known outside the Potomac Gorge in Virginia or Maryland, though it is found in many other states. Plant communities living on the cliffs and adjacent rocky areas support a large and unique regional flora because of their unique combination of geology, a flood-scour disturbance regime, and mist from the falls. Most rare species occur within the rocky flood-prone areas, occupying rock crevices, scour sites, sheltered crevices, cliff ledges, and narrow floodplains at bases of cliffs. Although biologists have surveyed this vicinity for rare vascular plants (Fleming 2007, Lee 2000), the extensive rock faces have not been included in these surveys because of the logistical and safety difficulties of accessing the cliff faces. This was a primary objective for a concurrent study conducted by our third author, whose results will appear in a separate report.

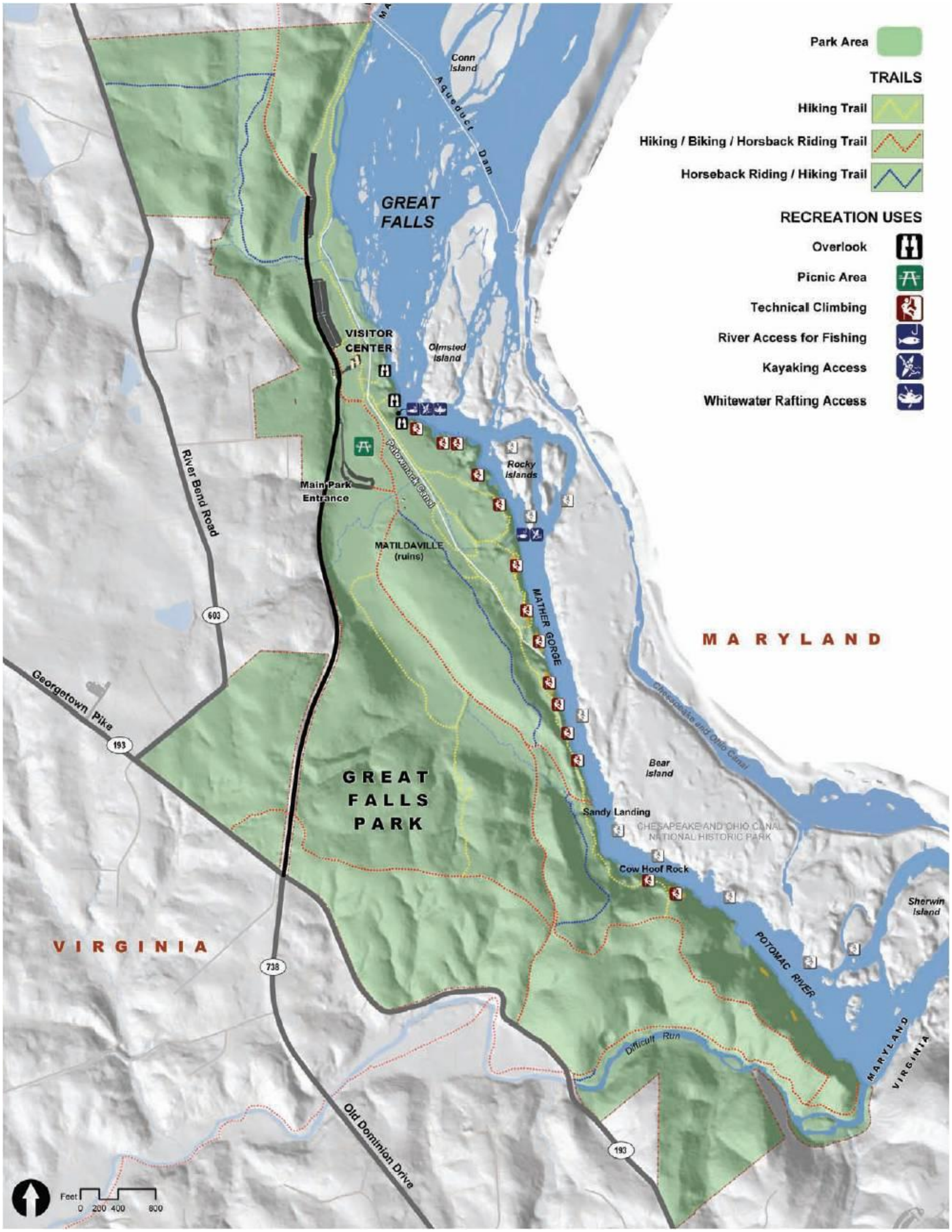

Figure 1. Great Falls Park, managed by the National Park Service, George Washington Memorial Parkway, in northern Virginia.

Figure 2. Upper Potomac Gorge and Carderock portions of the Chesapeake & Ohio Canal National Historical Park, managed by the National Park Service in southern Maryland.

Fleming's (2007) "Ecological Communities of the Potomac Gorge of Virginia" defines three ecological community types prevalent in our study area. Fleming's Riverside Outcrop Woodland community corresponds to the cliff-top forested areas. His Riverside Outcrop Barren community type includes the steeper cliffs and is considered globally rare and endemic to the Potomac Gorge. His Riverside Outcrop Prairie includes steeply sloped terrain and river benches – both zones are generally quite rocky and subject to frequent flooding. Fleming states that the Prairie community type is "extremely rare globally" and that: "Although locally common in Mather Gorge, this community is unquestionably one of the study area's most important and conservation-worthy vegetation types because of its range-wide rarity." (Fleming 2007: 237). Fleming also notes that these riparian plant communities "are very susceptible to degradation by over-visitation and trampling." Other pervasive threats include excessive herbivory by deer and invasive introduced plants – though these threats are more prevalent outside of these two riparian plant communities.

A key factor influencing the plant communities of the Potomac River Gorge is the flood regime (Lee 2000, Fleming 2007). More recent investigations by the third author indicate that the composition of these plant communities is also influenced by the high calcium levels in flood-deposited soils, derived from the crushed shells of native mussels and exotic clams. The large watershed and the confined nature of the river in the Mather Gorge lead to dramatic changes in the river level in the gorge from upstream rainfall. Major flood events raise water levels above the cliff-tops and the energy from floods scours all rock faces, with the greatest disturbance to upstream-facing rocks.

Recreational Uses

Located in a densely populated urban landscape, the Potomac Gorge is also highly regarded for its exceptional natural, cultural, recreational, and scenic features. More than four million people live within the Washington metro region and the Potomac Gorge is a noted tourist attraction that receives exceptionally heavy local, national, and even international visitation. The Potomac Gorge received nearly two million visitors recorded in 2000, primarily sightseers and hikers, with smaller numbers of boaters, climbers, and anglers. The cliffs and rocky areas are a year-round attraction feature for thousands of visitors seeking views of the Great Falls of the Potomac and the upper cliff-lined Gorge. Most visitors engage in sightseeing, recreational hiking, nature-study, and photography, and generally use the River Trail (VA side), or one of the Billy Goat Trails (MD side), to access numerous cliff-top vistas or shorelines (Figure 3). From cliff-top trails, anglers work their way down the cliffs to and along the river's edge, along with other adventurous hikers who scramble along the rocky shoreline and lower angle cliffs. Rock climbing is a recreational pursuit on the taller vertical sections of cliff, including both non-commercial and commercial groups. A considerable amount of hiking from all recreational activities occurs off the formal trail system, which has created a large network of informal (visitor-created) trails within both parks, particularly in cliff-top areas.

A companion trails study of the Potomac Gorge sought to locate and map all informal trails, though we note that these trails generally disappear when they enter rocky areas (Wimpey & Marion 2011). This survey identified 8.37 miles of informal trails within GFP, including 3.44 miles within the cliff-top proximate Mather Gorge zone. Within the CHOH study area, the survey identified 19.29 miles of informal trails, including 15.87 miles located between the C&O Canal and the Potomac River. The spatial distribution of the mapped informal trails is consistent with visitor traffic focused towards exploring and accessing the cliff-top areas for the scenic vistas that they afford. The majority of hiking impacts are focused along the cliff-tops, with very limited traffic through cliff-face and cliff-base areas due to limitations in access and safety.

Visitation at Great Falls Park was 424,290 in 2004 (NPS 2004), and a 1996 study described the most common visitor activities as viewing the Great Falls (73%), walking/hiking (56 %), viewing wildlife (41 %), and visiting the Patowmack Canal (31%), picnicking (19%), climbing (16%), … and fishing (4%) (NPS 1996). Similarly, CHOH received 285,579,941 visits in 2009 (though the park includes considerable land outside the Potomac Gorge study area), and the most common visitor activities in 2003 were jogging/walking/hiking (64%), viewing Great Falls (28%), bicycling (22%), picnicking (43%), … and climbing (2%) (NPS 2003, 2010). These data suggest that hiking and walking are the predominant recreational activities within Potomac

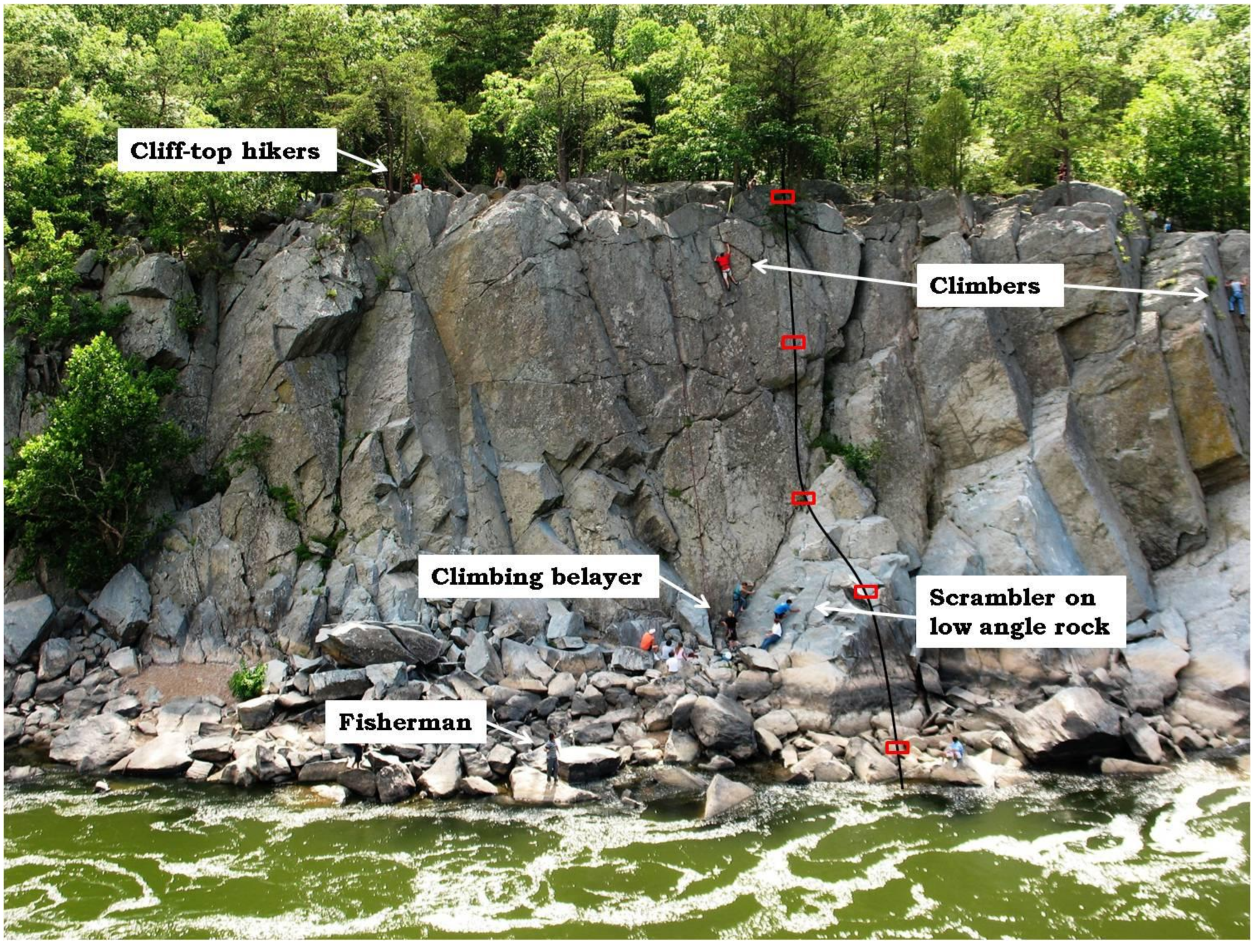

Figure 3. A typical scene of cliff-associated recreationists within the study area.

Note the different types of recreational activity: hikers along the cliff-top, rock climbers on the cliff-face, the climber's belayer at the cliff-base, several observers watching the climbers "scramblers" working their way across low-angle rocks, and fisherman at the river's edge. Also note the depiction of study transect T-11 running down the cliff-face showing quadrats 2-6.

Gorge, with the majority of visitors seeking to access cliff-top views of the Great Falls and Mather Gorge.

The Potomac Gorge and Carderock cliffs have long been the premier climbing areas in the DC-Metro region, offering a wide variety of climbs from novice to expert. The cliffs range up to 70 feet in height, some rising from a rocky shoreline, others directly from the river (depending on water levels). About 410 documented climbing routes occur on vertical cliff faces along this 4-mile stretch of the Potomac River in both states, comprising over 17,210 feet of climbing routes (Hanel 1990, Hörst 2001, Tait 2001). Though many of these climbs are not commonly accessed, climbing is a popular activity within the Gorge.

The earliest records of the Potomac Appalachian Trail Club (PATC) cite Paul Bradt as among the first climbers in the late 1920's (Tait 2001). Bradt was a member of the PATC's Board of Advisors in the 1930's, where he met and began climbing with others. The first recorded listings of Potomac Gorge climbing trips from the PATC Bulletin occurred in 1940 (John Christian, 2009, personal communication). Don Hubbard, another early climber, compiled and published the first guide to climbing in the Potomac Gorge in 1943.

While a few old bolts and pitons remain, current local climbing traditions dictate the use of removable protection and natural anchors, generally trees, as the majority of climbing is top-roped. Climbers hike to the vicinity of their climb site using cliff-top trails, and set their anchors before either walking down a descent trail or rappelling down. Thus, there is some climbing-associated activity and impact at cliff-top sites, which in some areas coincides with hiker-created vista sites. Climbers generally set their anchors at the cliff-top, with ropes attached to trees, boulders, or removable protection. However, belayers stand at the cliff-base, with their rope running up to a pulley arrangement (generally two or more locking carabineers), and back down to the climbers. Climbs in Potomac Gorge are rarely led - the rock is considered too brittle to safely hold lead protection. With this type of setup, climbers never “summit,” stopping just below the cliff edge and then lowered back down to the base. Thus, climbers spend limited time at the cliff-top and our informal observations indicate that hikers seeking vistas of the gorge and river are the primarily users of the cliff-top recreation sites. Rappelling, where visitors use ropes to descend the cliff-face, is a less frequent activity at Potomac Gorge, but one where participants can spend more time at the cliff-top.

METHODS

This section describes the research design and methods applied to assess cliff-associated recreation impacts at cliff-top and cliff-base recreation sites and on the cliff-face. Field staff sought to locate and assess all recreation sites based on the presence of visible trampling disturbance to vegetation, organic litter, and soils. A sampling approach was employed to assess visitor impacts to the cliffs and adjacent rocky areas. Detailed procedural manuals are included in Appendices.

Recreation Site Procedures

Standardized procedures were developed, field tested and refined for assessing cliff-associated visitor impacts at cliff-top and cliff-base recreation sites within the larger study area for both parks and sides of the river. These procedures, similar to those applied in Marion and Carr (2007), emphasize measurements with incorporated condition class assessments and photographs from permanently referenced photo points. Photographs provide for visual comparisons of changes on individual sites over time. The field assessment manual containing detailed assessment procedures for all recreation site indicators is included as Appendix 1.

The tops and bases of all cliffs were searched to locate and assess all cliff-associated recreation sites. Generally these sites were located by looking for recreational trampling disturbance-associated boundaries to vegetation (including vegetation height, cover, and/or composition), organic litter (pulverization and/or cover loss), or substrates (scuffing and/or footprints). Reference photographs depicting these different boundary types (Marion 1991) were consulted as needed to maintain consistency. Judgments based on site configurations and observed or likely use areas were sometimes required to determine when contiguous areas of exposed rock should be included within recreation site boundaries. Some recreation sites showed no obvious disturbance to these vegetation or substrate attributes (i.e., no clear disturbance-associated boundaries) but were identified by their clear cliff-top location at the end of a commonly used trail (e.g., a cliff-top vista site on bedrock).

Impact indicators were selected based on earlier recreation ecology studies (see Literature Review section), indicator selection criteria, and discussions with park staff. Recreation site sizes were measured using a Variable Radial Transect method based on measurements of transect lengths and compass bearings radiating from a permanent reference point to points selected along site boundaries (Marion 1995). Reference points were described, accurately located using a Trimble GeoXT GPS device, and referenced by compass bearings and distances to recognizable permanent features (see Appendix 1). Where necessary, multiple radial transects that shared common points were used to accurately measure area of disturbance for long linear recreation sites. Site sizes were calculated arithmetically from transect data using Excel spreadsheet formulas. Use of trade, product, or firm names does not imply endorsement by the U.S. Government.

The tops of the climbs were located for us by volunteers from the Mountaineering Section of the Potomac Appalachian Trail Club and by a local climbing guide. We verified the locations and the climb names using the local climbing guidebooks (Tait 2001, Hörst 2001, Brinkworth 1998).

We used the GPS to measure the location of a reference point in the vicinity of each group of climbs. We then used a Suunto KB-14 precision sighting compass and a Sonin Multi-measure Combo Pro to measure the direction and distance from the permanent reference point to the climb tops. We then calculated the location of the climb top from the reference point location and the offset from the compass and range finder. Our climb numbers follow Tait (2001).

Conditions for most other indicators were assessed within the trampling disturbance boundaries for each site, with additional procedures allowing assessments of any "satellite" use areas (Marion 1991). Fixing the area of interest within site boundaries increases the efficiency and precision of assessments; but, this approach could slightly reduce measurement accuracy if damaged trees occur just outside of site boundaries.

Ground vegetation on recreation sites and in paired environmentally similar but undisturbed control sites, was assessed using six cover classes (Marion & Cole 1996). Vegetation loss was calculated by subtracting the onsite coverage class midpoint value from its paired control site coverage class midpoint value, resulting in a percentage of vegetation loss. This percentage value was multiplied by the corresponding site size to obtain an estimate of the area over which vegetation cover has been lost. The area of exposed soil was also assessed by multiplying the onsite coverage class midpoint value for exposed soil by the corresponding site size.

Tree damage and root exposure were recorded by category (none/slight, moderate, and severe) for each onsite tree and tree stumps were counted (Marion & Cole 1996). But, data are reported by summing trees assessed in the moderate and severe categories as “damaged trees” or “trees with exposed roots.” These indicators were assessed to evaluate potential damage to trees from climbing ropes being tied around them, limb breakage or cutting, and from intensive foot traffic and associated soil loss around tree roots. Informal trails that connected with each site were counted, regardless of length. Site expansion potential was assessed for each site based on the extent to which expansion appeared to be inhibited by topography, rockiness, or dense woody vegetation.

Cliff-Face/Rocky Area Assessment Procedures

The study area for this portion of the research is the Virginia side of Mather Gorge, Great Falls Park. The study area extends along the Potomac River from the lower Great Falls observation deck downstream to Sandy Landing – a distance of approximately 1.5 km. The study area extends from the river’s edge, up the cliffs, to the forest edge. The study area includes vertical cliffs, rock outcrops at the cliff-top and cliff-base, and more heavily vegetated non-cliff areas that we call “gardens” (see Figure 4).

Due to the large study area and difficulties with safe data collection on cliffs, we elected to sample, rather than census, the area. Based on a review of prior cliff research studies, we sampled using a quadrat as our basic unit of analysis. Much of our sampling was on vertical cliffs where rappel ropes were needed for safe access. The straight-line nature of the rappel lines made it natural to arrange the quadrats along 16 transect lines aligned perpendicular to the direction of the river. We measured plant cover and physical parameters in 95 quadrats randomly distributed throughout this study area.

Figure 4. Illustration of cliff sampling plan with three transects showing placement of example quadrats, running from the cliff-top to the river.

Note the patchy vegetation; cliff trees and shrubs appear to be crack associated. Exposed rock resumes to the left of the "garden." A descent trail (dashed line) of second-class difficulty descends through the garden. Shoreline areas were either bedrock or rocky areas with boulders. The center transect crosses climbs 119, 118 and 117, indicated by dotted lines (Tait 2001).

We note that this study sought to examine the influence of all types of cliff-associated recreation, not just climbing. Thus, study transects started 10 m back from the cliff-top and ran down the cliff-face and across the cliff-base to the river's edge. Transect locations were randomly placed; they were not purposively located to capture climbing routes, informal trails, or recreation sites. The physical measurements and subsequent statistical modeling analyses could then better represent relationships between recreational impacts and plant presence and cover.

We note here a concurrent companion study by co-author Charles Davis (2011), providing a more comprehensive census-oriented survey to document the presence and distribution of rare plants within the study area. The specific management concern for assessing potential impacts to rare plants at specific locations for future management and monitoring required this more comprehensive extensive approach. In this study, Davis directly inspected the cliff-top to river's edge areas through walking and rappelling surveys to map locations of rare vascular plant species. This work produced a photographic record of the cliff faces showing the locations of rare plants and a comprehensive listing of vascular plant species. In Virginia, this survey covered upstream portions of Echo Rock, Cow Hoof Rock, the continuous rock zone from Sandy Landing to Sandbox climb sites, vicinities of climb sites Flat Iron, Microdome, and Gorky Park, and the cliffs between the 2nd and 3rd Falls Overlooks.

To minimize the possibility of observer bias and to allow for statistical modeling, we developed a sampling plan with several levels of randomization. The first level of randomization was in the transect spacing. We used a systematic sampling plan for both transects and quadrats, which were spaced at a regular interval following a random start. Based on an estimate of the time needed to measure each transect and the length of our field season, we decided to measure sixteen transects (Figure 5). Based on the distance from Sandy Landing to the Lower Overlook, the sixteen transects were spaced 100 m apart. A random number between 0 and 99 was picked and used as the distance upstream from Sandy Landing to transect one. The remaining transects were spaced at 100 m intervals in the upstream direction. We used a GIS system to position the transects on a map of the study area. We then measured the cliff-top starting point of each transect, entered the values into a GPS, and used it and a compass to position the transects on the ground. A tape measure draped along the ground, down the cliffs and out to the river was used to locate the quadrat positions. Figures 6 and 7 illustrate field staff conducing quadrat assessments.

The second level of randomization was for positioning quadrats along transect lines. We selected a 7 m quadrat spacing based on the number of quadrats we thought we could measure in the time allowed. To insure we had at least one quadrat on each transect in the cliff-top forest portion of the study area, we started the transect 10 m back from the cliff edge. We selected a random number between 0 and 6 and used this number as the distance from the transect start point to our first quadrat. The quadrats were then positioned every 7 m along the transect down the cliffs to the cliff base and out to the river (Figure 4).

The third level randomization was the order we measured the transects. By randomizing the order, we did not introduce any spatial bias as we gained experience with the procedures. On the days we were able to measure more than one transect, we flipped a coin to determine if we would measure the transect to the left or right of the current transect, rather than taking the time to move to a possibly distant transect on the randomization list.

The field data were recorded on four data sheets and in several sets of photographs (Appendix 2). The data sheets are conceptually arranged as shown in Figure 8. Each transect contains multiple quadrats and each quadrat may contain multiple geofeatures, which were assessed on the quadrat data sheets. Each geofeature has multiple physical measurements and may, or may not, contain vascular plants.

An important key to the data organization, which may be unique to this project, is the “Quadrat map” (Figure 9). The map is a numbered sketch of the geofeatures in the quadrat. The Physical data sheet (Appendix 2) records the physical dimensions of the geofeatures by the geofeature ID number. Similarly, the botanical data sheet records the plants in the geofeatures by the same geofeature ID number. By establishing this link between the physical dimensions and the botanical data we can analyze plant presence on a geofeature level (in addition to the more traditional quadrat level). This was done through the development of a relational database using Access software. The database contains 24 tables with more than 13,000 data entries, including physical attribute data for quads and geofeatures, recreation attributes, and vascular plant species names and cover data. The cover of non-vascular plants was assessed by life form. Queries performed on this database allowed the construction of data files exported to SPSS for the statistical modeling work described in a following section.

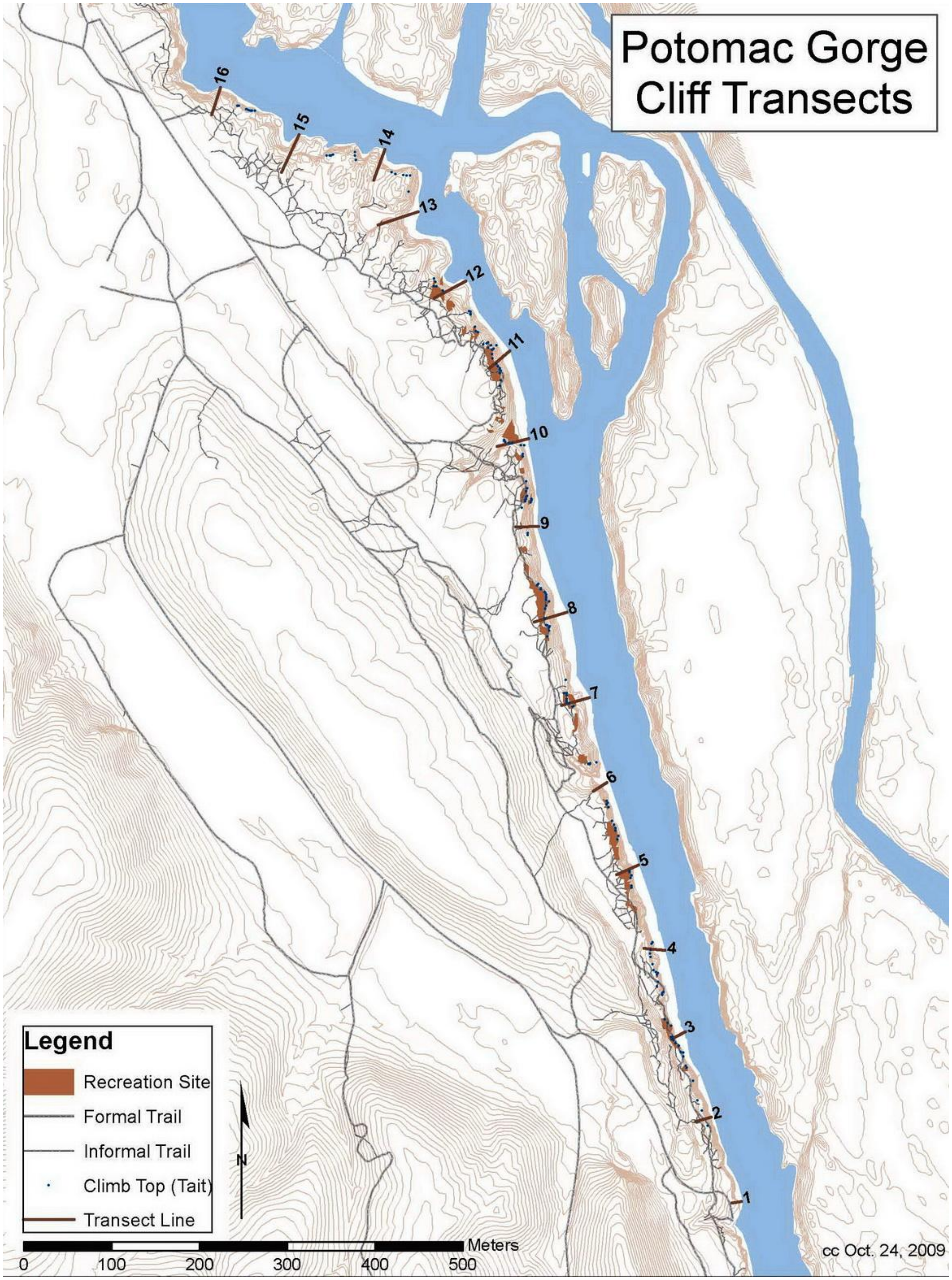

Figure 5. The study area showing the 16 transects used to sample vegetation in cliff and rocky areas along Potomac Gorge (VA side). The Potomac River flows from north (top) to south. Transect lines were oriented perpendicular to the river flow at the transect. Cliff-associated recreation sites, trails, and individual climbs are also shown.

Figure 6. The quadrat frame in place on transect 11 at quad position 2. Chris Carr (top) is recording physical measures while Charlie Davis records vegetation species and cover. A shared coding scheme was used to identify geofeatures so physical and plant data can be linked.

Figure 7. Recording the data for transect 6, quad 3. The central yellow line is a tape measure used to locate the quad along the transect; the white rectangle is the quad frame.

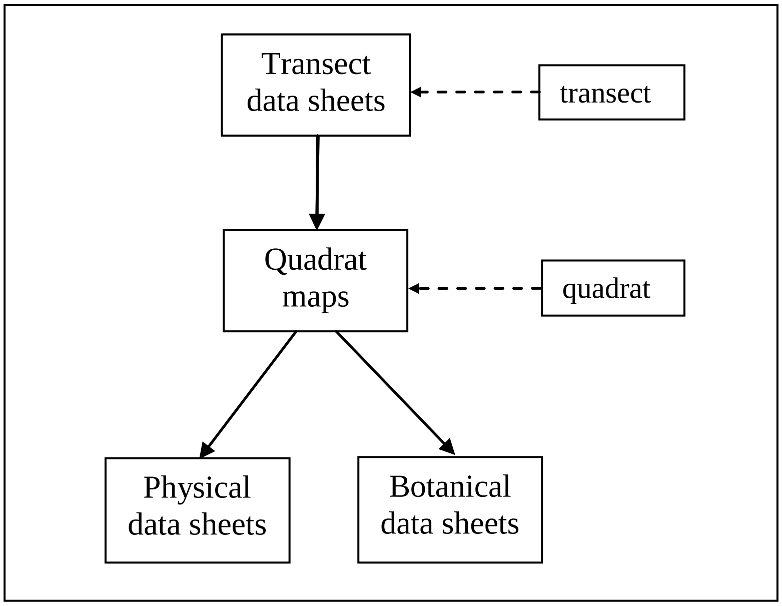

Figure 8. Conceptual arrangement of the study area data sheets.

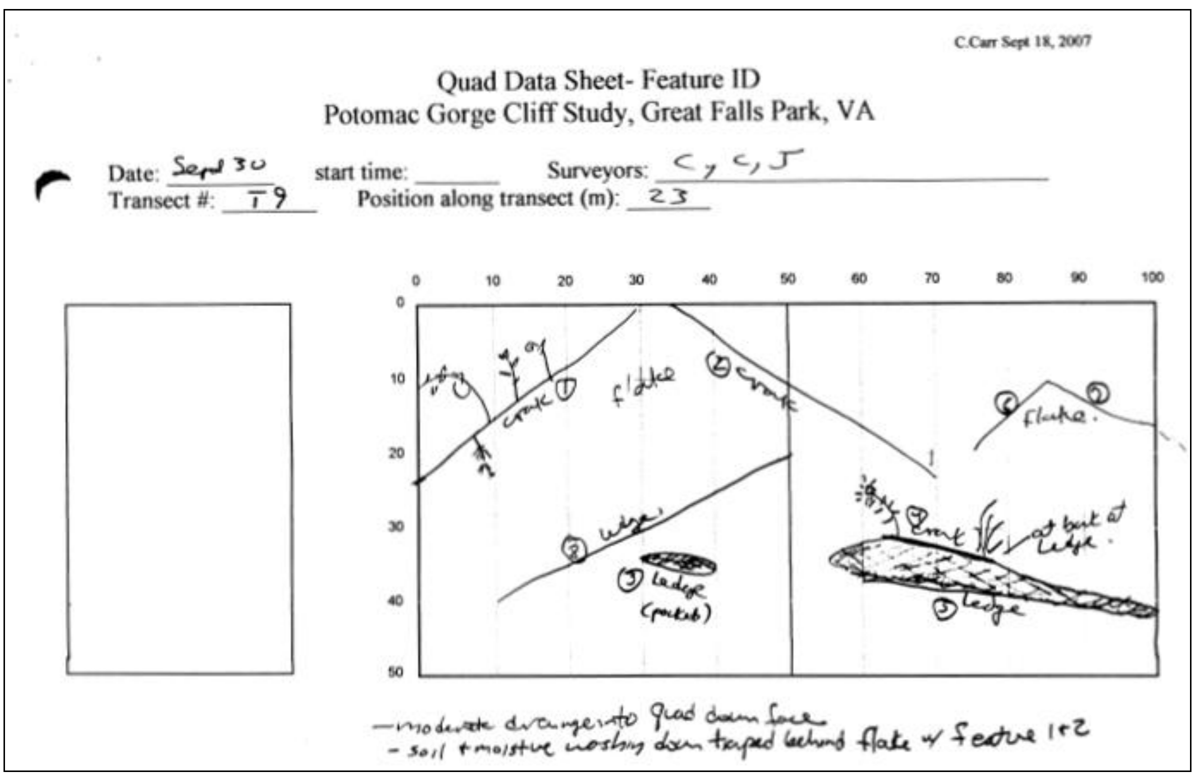

Figure 9. Quadrat map. Each geofeature is given an ID number, which is also recorded on the physical and botanical data sheets.

Variables Measured: For each quadrat we recorded the genus, species and percent cover for all vascular plants (Elzinga *et al.* 1998). Identification for bryophytes and lichens was limited to general forms or types (crustose, foliose, and fruticose for lichens). Physical parameters for each quadrat were also assessed or derived from our data. Physical parameters relate to large scale, local scale, and fine scale physical features (see Table 1. The primary variables measured for each quadrat.). Large-scale features include quadrat latitude/longitude, distance downstream from the falls and elevation (to be related to river flood stage). Local scale features include quadrat slope, aspect and distance to recreational uses (e.g. climbing routes, trails, recreation sites). Fine scale features include microtopography within the quadrat—the number and size of ledges and crevices, and the amount of soil accumulation.

Table 1. The primary variables measured for each quadrat.

Scale	Variable	Description
Large scale	latitude/longitude	quad position
	distance downstream from falls	humidity effect, particularly on bryophytes
	Elevation	to calculate river stage and flood return interval of quad
	cliff overhang	above quad: length and depth
Local scale	Slope	the angle of the quad to the horizontal
	Aspect	the angle of the quad to north
	cover up	standard canopy cover measure
	cover out	canopy cover in direction away from cliff
	dist to cliff-top trail	a source of runoff of water and soil to cliff-face
	distance to river	a source of humidity and sediment
	distance to nearest recreation impact	climb route, stage area, trail, fishing spot
	quad position on cliff	general position on cliff
	angle to current	a measure of local modification of flood current
	water drainage into quad	seeps and water funneled down the rock
	surface roughness	max minus min height of surface
	recreation type	hiking, scrambling, technical (w/ropes)
Fine scale	crack and crevice features	length, depth and width , angle and slope (into rock)
	ledge features	length and depth, angle and slope
	solution pocket features	volume, orientation
	soil volume in features	volume of soil in features
	Vegetation	the vegetation list will be linked to the individual features

The data collection procedures were guided by previous cliff work of others. Of particular relevance to this project are the recent publications from the Cliff Ecology Research Group at University of Guelph: Kuntz and Larson (2006a) "Microtopographic control of vascular plant, bryophyte and lichen communities on cliff faces" and Kuntz and Larson (2006b) "Influences of microhabitat constraints and rock-climbing disturbance on cliff-vegetation communities." Of particular site-specific relevance was the master's thesis by Chris Lee (2000) "Plant communities of the Potomac Gorge and their relationship to fluvial factors" and the Fleming (2007) report on the vegetation communities of the Virginia side of the Potomac Gorge. We also incorporated data recording procedures employed by the VA Heritage Program (DCR/VANHP 2005). We added specific measures related to the physical parameters of the rock (e.g. crack and crevice size), and adjusted the cover class sizes to the sparse vascular and abundant lichen cover of the rocks. Appendix 2 contains additional detail for measurement procedures, additional information can be obtained directly from the authors.

Quad Zones – Forest and Rocky Area

Our study area is divided into two zones - the cliff-top "forested area" and the cliff and non-cliff "rocky areas." We divide the study area into these two zones for ecological and recreation reasons. We expect the ecological controls that predict plant abundance to be different in the two zones. The cliff/rocky area zone has little soil and much of it is frequently scoured by floods. The cliff-top forest zone is at a higher elevation and rarely sees floods; it also generally has good soil cover and an extensive tree canopy. The forested areas are easily accessible to the general visitor; rated at mountaineering difficulty classes of one and two (walking and walking with use of hands). Our transects and data included the first 10m of the cliff-top forest zone.

Terrain in the cliff and rocky area zone ranges from horizontal to vertical, with little or no soil and very patchy vegetation. Access to this area is more difficult: scrambling (class three and low class four) or by rope (upper class four, class five and six). Recreation in the cliff and rocky area zone includes hiking, fishing, the technical activities of rappelling and rock climbing, and scrambling. These areas have several descent gullies that can be used by non-climbers. The focus of our analyses is in the impact of recreation to the cliff and rocky area zone, so most of the modeling analyses are limited to quads in this zone. The total study area encompasses 95 quads, with 74 located in the cliff and rocky area zone.

Assessing the Influence of Recreation

A core focus of this research is determining the extent of visitor impact to cliff-associated natural resources, particularly vegetation. For assessing cliff-associated recreation sites, we applied protocols originally developed for campsites and other recreation sites adapted from those employed by Marion and Carr (2007). Those protocols make comparisons between measures taken on recreation sites with adjacent undisturbed areas used as "controls." These protocols have worked well in both Shenandoah NP and in this Potomac Gorge study - finding adequate representative controls was not a problem. But, studies that have sought to apply similar research designs for assessing cliff-face climbing impacts have encountered significant difficulties in finding adequate control areas. Climbing routes often follow crack systems, ledges, or other pronounced geofeatures that allow climbers to place protection or use as holds. On a cliff commonly accessed by climbers, all such possible routes are likely to have been climbed and exhibit some degree of impact. Finding pristine cracks and ledges for comparable "control" measures is not possible, unless a nearby cliff closed to climbing is available with comparable geology, microtopography, and flooding regime. This was not possible.

Allard (2008) notes that studies employing paired on- and off-climb measures are more feasible when applied to sport climbing cliffs, where climbers substitute bolts for the placement of protection in geofeatures. This allows climbers to use more homogeneous and featureless cliff faces, for which controls can often be found, though such areas generally support few to no vascular plants.

In consideration of these objectives and challenges in Potomac Gorge, we opted for the fully randomized research design as previously described, with statistical regression modeling to infer the potential influence of recreational activity on plants. The location of transects and quadrats is completely random, so while this approach will yield representative data, it runs the risk of including relatively few sites that are proximate (close) to recreational activity in areas with low use. Given the intensive visitation within Potomac Gorge, we were reasonably confident that this would not present a problem and our dataset fortunately does include a sufficient number of quadrats on or very close to climbs, trails, and recreation sites to support analyses.

Statistical models were developed using regression modeling analyses to characterize the abundance of vascular plants based on the physical and recreational properties of the cliff environment. The Virginia Tech Statistical Consulting Clinic recommended regression modeling for conducting our analyses and clinic staff provided guidance in the selection and application of regression models. Through modeling, we avoided the difficulty of purposively selecting climbing routes and the challenging selection of comparable environmentally "similar" control sites. Data collected for the abundance model are used to describe the distribution of vascular plants within these rocky environments. Model development and associated statistical analyses were performed to evaluate relationships between various environmental attributes (e.g., cliff morphology, microtopography, soil volume) and recreation site attributes (proximity to trails, recreation sites, and climbing routes).

This research design is not without limitations. Regression modeling produces quantitatively defined statistical relationships (correlations), but such relationships may or may not reflect causality. An experimental design where different types and amounts of recreational activity are "applied" to pristine settings would be required to demonstrate causal relationships. Application of an experimental design was judged to be impractical and we found no instances of its application within the cliff impact literature, though such designs have been used to assess trail impacts (Cole 1995, Leung & Marion 2000). When experimental designs cannot be applied, scientists commonly use multivariate analyses like regression modeling to evaluate real-world processes, generally to "infer" the nature and strength of causal relationships. However, it's important to note that correlations derived from regression modeling, even highly significant correlations, may reflect causal relationships, or spurious non-causal relationships. Regression equations are simple quantitative models of more complex real-world relationships. Such models may omit influential factors that could not be measured, or were measured using methods that failed to reflect their true influence. Alternately, such models may include non-influential factors that merely co-vary with influential factors. Readers are thus cautioned to consider these limitations when examining the results and implications of the regression modeling presented in this report.

We also point out differences between using regression modeling to identify and evaluate influential factors versus their use for prediction. As an example, consider the variable “height above river” which was included in our regression models as a predictor of vascular plant occurrence. We note that this variable does not directly influence plant occurrence, rather it is “surrogate variable” correlated with variables that likely do influence plant occurrence, for example flood interval of occurrence and intensity. Regression modeling can help to identify causal factors and assess their relative influence but such analyses must be conducted by individuals who understand the relevant ecology of the setting and who are building from pre-existing knowledge. Informed judgment is required in the development and interpretation of such models. In contrast, when regression models are used for prediction, representations of causality are less important than the ability of an included variable to capture and represent a significant amount of variation in the dependent variable. A primary focus of this study was on predicting the influence of recreational activity on cliff-associated vascular plants, particularly rare plants.

The independent variables in the regression modeling were the large scale, local scale, and fine scale physical parameters assessed for each quadrat (Table 1). The dependent variable was the number of vascular plants in each quad or geofeature; analyses were run separately for quadrats and geofeatures. Even when the suitable physical parameters are present, any particular species will be present only some of the time (depending on chance, position in the succession cycle, recreation impact, etc.) and, when present, its cover will vary. We used the statistical software package SPSS to create the regression models using the “Generalized linear model” procedure. Specifically, we employed a Poisson log-linear regression model for quadrat analyses and logistic regression for the geofeature analyses. The influence of outlier values (those substantially outside the range of most other values) were investigated and removed based on their studentized residual values. For logistic regression, model quality was tracked with the Hosmer and Lemeshow Test and the Omnibus Test of Model Coefficients. Model quality was also tracked with the classification table of prediction accuracy.

Count data is characterized by non-negative integers, which in cliff studies such as this one, include numerous zeros. This characteristic leads to a highly skewed (non-normal) distribution for which Ordinary Least Squares (OLS) Regression is inappropriate. Poisson Regression and Negative Binomial Regression are well suited for this kind of distribution. These two regression methods are non-parametric so the normality requirements of OLS regression are relaxed.

Poisson Regression is a log-linear method. The regression equation is of the form: “Ln(count) = intercept + B_1(independent variable$_1$) + B_2(independent varaiable$_2$) + …” The intercept and the coefficients ($B_{1\text{-}n}$) are estimated by the model.

The literature on plant growth on cliffs and in rocky areas, particularly studies related to rock climbing, was consulted to identify potential explanatory variables. Twenty-two independent variables were selected to explain the abundance of vascular plants (the dependent variable). During initial model development, independent variables were added and removed from the regression models based on the variable’s statistical significance using a Backward Stepwise (Likelihood Ratio) process with the probability of F-to-enter of 0.05 (PIN) and the probability of F-to-remove of 0.10 (POUT). This method can minimize the “suppressor” effect. “In some cases, a variable may appear to have a statistically significant effect only when another variable is controlled or held constant… backward elimination may uncover relationships missed by forward inclusion” (Menard 2002).

A core objective was to assess the characteristics of the vegetation communities at cliff-associated recreational sites to determine how much they differ from those predicted by the physical parameters of the model. The difference between the vegetation abundance predicted by the model and actual abundance at the quadrats close to recreational activity will infer or approximate the loss or gain associated with recreation activity sites. We caution readers once again that the regression modeling is based on correlations that do not demonstrate causal use-impact relationships.

Recreation attributes were incorporated into the analyses with several indicators. For recreation sites, we assessed "Type of Use" as mostly climbing, mixed uses, and mostly hiking, and "Site Use Level" as high, medium and low. Assessments are subjective, as they were based on discussions with local climbers who assisted us, proximity to named climbs, and our observations of recreational activity during several weeks of fieldwork. For cliff-face assessments, we examined the proximity of each quadrat to trails, recreation sites, and climbs listed in the guidebooks. Quadrats were classified as Yes/No for recreation presence based on a quadrat being on or within one meter from a trail, recreation site, or climb, defined as "proximate" to recreation activity. A "Type of Use" category was also developed, including four categories: None (no apparent recreation impact), RecTop (<1m to a cliff-top recreation site), TrailTop (<1m to a cliff-top trail), RockRec (<1.5 m to a rocky area recreation site, trail, climb, or commonly used rappel or scrambling area). Recreation activities that take place in rocky areas, which leave a less distinct "footprint," are grouped separately.

Geofeature Classification

Plant ecology literature on cliffs and rocky areas emphasize the importance of geofeatures to the growth and distribution of vascular plants. Geofeatures are formed by the micro-topography of exposed rock surfaces. Thus, a key part of our data collection was to identify and characterize geomorphological features within each quadrat. We initially grouped geofeatures into crack, ledge and pocket categories (revised during analyses). Along with the categories we photographed each quadrat, measured the dimensions of the features and made sketches and notes. The species and cover of plants in the geofeatures was recorded and linked to each geofeature so that analyses could be performed at the geofeature unit of observation. Smooth rock without these features was not characterized, but non-vascular plants growing directly on the rock were recorded.

Following our fieldwork we realized a further division of the ledge category was needed. During data collection, ledge-like features were recorded as ledges, even when there was a crack at its back edge (which was sometimes covered and hidden by soil). But, from the perspective of a plant, ledges with cracks, which may retain or allow access to water, are ecologically quite different from ledges without cracks. Following a comprehensive review of the literature (Coats & Kirkpatrick 1992, Davis 1951, Farris 1998, Kuntz & Larson 2006a, Matthes-Sears & Larson 1995), we used quadrat photographs and our field notes and sketches to reclassify the ledge category as shown in Table 2 and Figure 10.

Table 2. Geofeature classification categories and descriptions as applied during fieldwork and later refined.

Field Classification	Refined Classification	Geofeature Description
Crevice/crack	**Crack**	- result from rock fracturing and jointing - narrow, usually linear features extending into the rock - includes "closed" cracks - may or may not contain soil - plants can root in the crack (for support, moisture, nutrients) - slope can be horizontal, vertical or anything in between
Ledge	**Step-crevice**	- a crack with a horizontal ledge (≤10°) - plants can root in the crack (for support, moisture, nutrients) - plants can get additional support from the (horizontal) ledge - may or may not contain soil
	Ledge-pure	- a substantially flat and level surface - slope ≤10° from horizontal - no obvious crevice development - plant development depends solely on superficial soil development
	Concave depression	- protected area where soil can accumulate and be held in place against the force of gravity - contains sand or soil - plants can root much as they do on level ground - below the soil are cracks, generally, converging from multiple directions
	Not a feature	- an item not classified as a feature (e.g., slope >10^{o})
Pocket	**Pocket**	- a solution feature characteristic of limestone rock

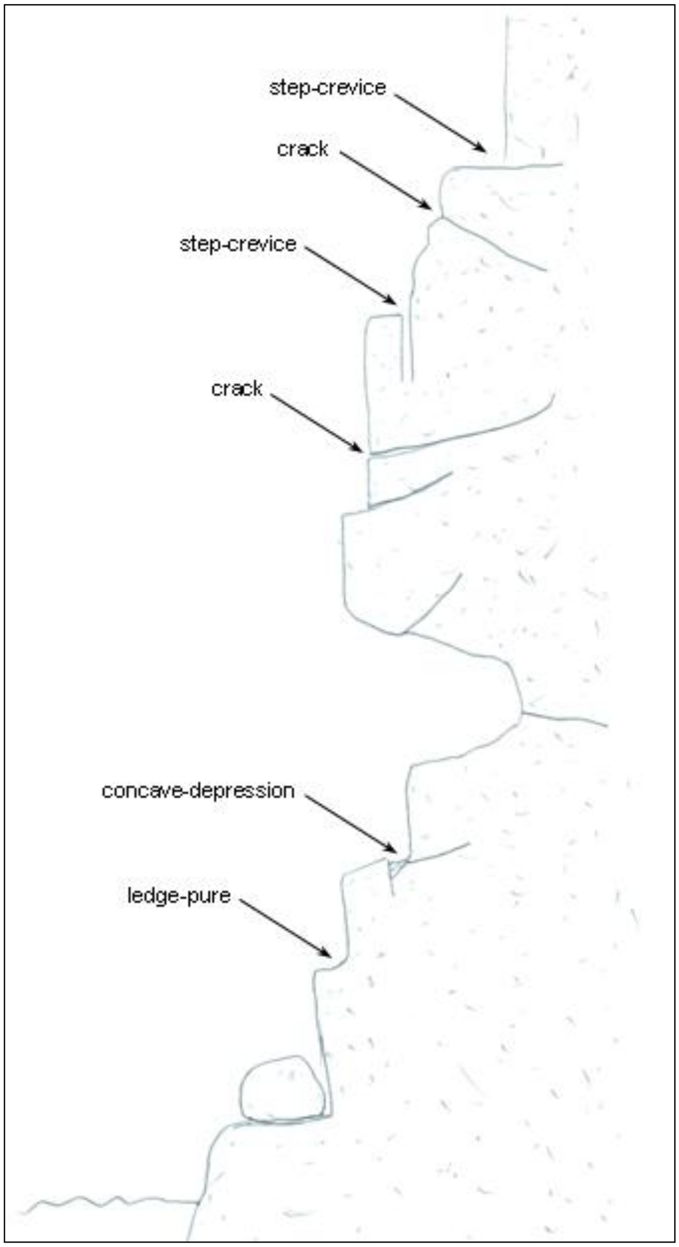

Figure 10. Cliff cross-section with examples of typical geofeature types (after Davis 1951:67)

RESULTS

Cliff-Associated Recreation Sites

Survey staff found and assessed 122 cliff-top or cliff-base recreation sites (CHOH: 60 sites, GWMP: 62 sites) with an aggregate area of disturbance of 86,782 ft^2 for an average area of 711 ft^2/site (Table 3). Figure 11 is a GIS map illustrating recreation-related features in the vicinity of two representative cliff transects within GWMP. A full set of these transect maps is included in Appendix 3 depicting the locations of all recreation sites within GWMP, including climb site locations, formal and informal trails, and cliff transects.

Results indicate that most recreation sites (84, 69%) are located at cliff-top positions and that these sites account for the majority of the total area of trampling disturbance (71,980 ft^2, 83%). At CHOH, 13 sites lacked definable boundaries and no area of disturbance was recorded; 23 sites lacked definable boundaries at GWMP. These sites were generally on rock surfaces that lacked vegetation due to the absence of soil or occurred on barren soil exposed along frequently flooded and scoured shorelines. For those sites with discernable boundaries, staff estimated the area over which vegetation cover had been lost within the boundaries. Similar to site size, the majority of vegetation cover loss has occurred on the cliff-top sites, with 22,852 ft^2 of estimated vegetation loss at CHOH (74%) and 22,232 ft^2 of vegetation loss at GWMP (91%) (Table 3).

Table 3. Cliff-associated recreation site size and estimated area of vegetation loss by park and cliff location. Aggregate values (sums) are reported.

Park	Cliff Location	N	Recreation Site Area (ft^2)	Estimated Area of Vegetation Loss (ft^2)
CHOH	Top	43	36,520	22,852
	Bottom	17	9,989	7,887
	Total	60	46,509	30,739
GWMP	Top	41	35,460	22,232
	Bottom	21	4,813	2,211
	Total	62	40,273	24,443
	Grand Totals	122	86,782	55,183

Recreation sites not located near named climbs were labeled as “mostly hiking” for type of use, including 24 sites (40%) at CHOH and 16 sites (26%) at GWMP (Table 4). Recreation sites located close to popular climbs, and including many cliff-base sites and some isolated cliff-top sites, were labeled “mostly climbing,” including 17 sites (28%) at CHOH and 21 sites (34%) at GWMP. The remaining sites were assigned as mixed use. At GWMP, site use levels were high (26), medium (20), and low (16), while at CHOH use levels were more evenly distributed (Table 4). Finally, the expansion potential for a majority of CHOH sites was assessed as moderate

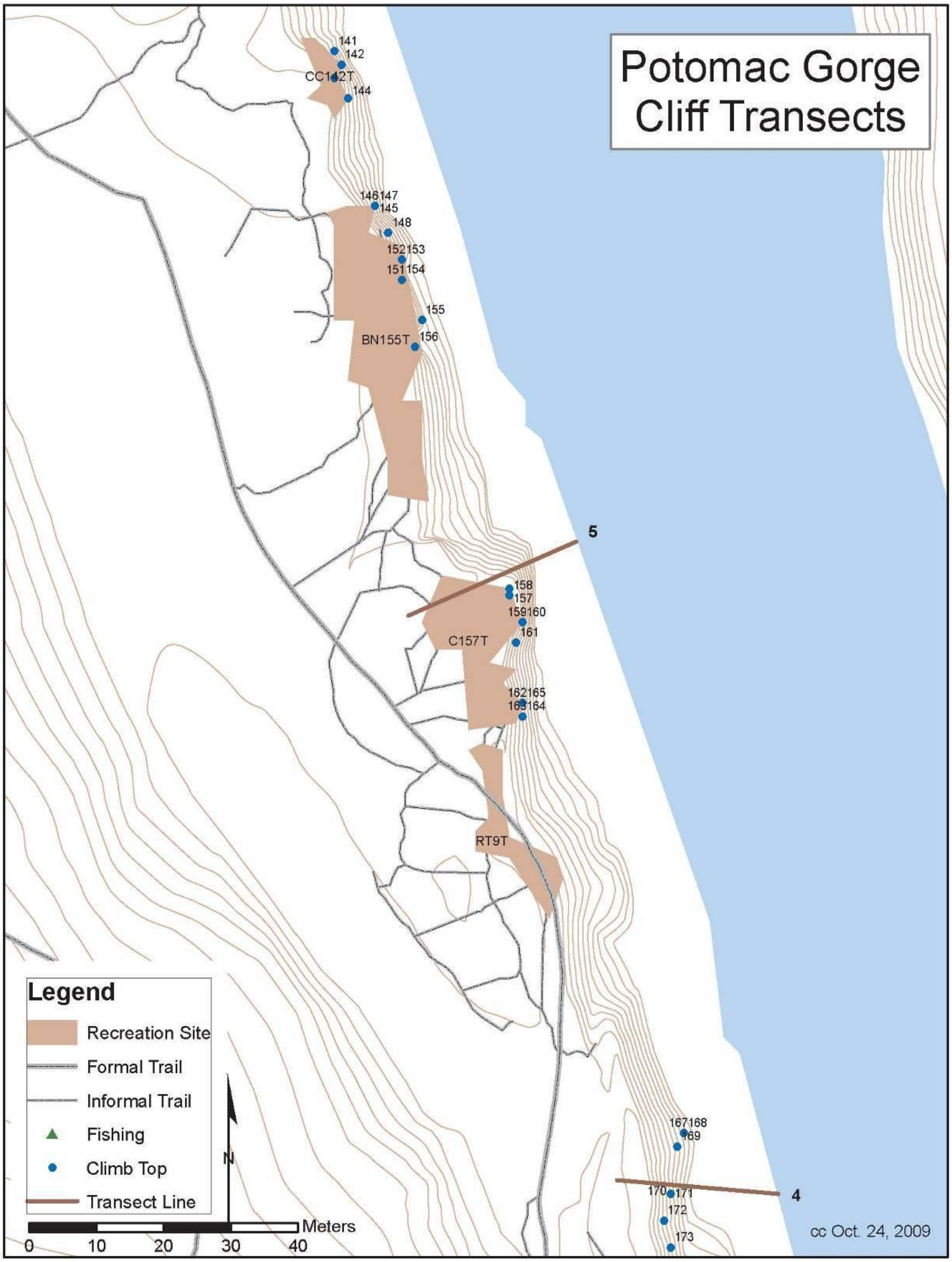

Figure 11. Transects 4 and 5 in relation to the river, topography, and recreation impacts. Impacts include recreation sites (typically scenic vistas and cliff-top or cliff-base climbing sites), fishing areas, and formal and informal trails. The tops of climbing routes, labeled with their numbers from Tait (2001) are also shown. Contour interval = 5 ft.

(52%) or poor (37%), reflecting the influence of steep topography and the presence of dense adjacent woody vegetation in constricting recreation site sizes. Expansion potential was generally lower at GWMP, where 34 of the sites (55%) were judged to have poor expansion potential (Table 4). Only 13 sites at GWMP and 7 sites at CHOH were rated as having good site expansion potential.

Table 4. Summary of cliff-associated recreation site inventory indicators by park.

Inventory Indicators		**CHOH Recreation Sites**		**GWMP Recreation Sites**	
		N	%	N	%
Type of Use	Mostly Climbing	17	28	21	34
	Mixed Uses	19	32	25	40
	Mostly Hiking	24	40	16	26
Site Use Level	High	21	35	26	42
	Medium	17	28	20	32
	Low	22	37	16	26
Expansion Potential	Good	7	12	13	21
	Moderate	31	52	15	24
	Poor	22	37	34	55

Recreation sites at CHOH ranged in size from 0-2938 ft^2 with a mean of 775 ft^2 and an aggregate area of disturbance of 46,509 ft^2 (Table 5). Recreation sites at GWMP ranged in size from 0-4476 ft^2 with a mean of 650 ft^2 and an aggregate area of disturbance of 40,273 ft^2. Estimated mean vegetation cover loss on CHOH and GWMP sites was 46% and 33%, respectively, with vegetation cover lost over estimated mean areas of 512 ft^2 and 394 ft^2 (Table 5). Trampling induced exposure of soil occupied smaller percentages of recreation site areas, with mean soil exposure of 20% and 14% at CHOH and GWMP (Table 5).

Table 5. Summary of cliff-associated recreation site size, vegetation cover, and exposed soil impact indicators by park.

Park		**Site Area (ft^2)**	**Vegetation Loss (%)**	**Vegetation Loss (ft^2)**	**Exposed Soil Onsite (%)**	**Exposed Soil Area (ft^2)**
CHOH	Mean	775	46	512	20	157
	Sum	46,509	-	30,740	-	9,432
GWMP	Mean	650	33	394	14	132
	Sum	40,273	-	24,443	-	8,155

Assessments of moderate to severe tree damage (from all recreational uses) found between 0-2 damaged trees/site at CHOH with a mean of 0.2/site and sum of 14 (Table 6). At GWMP tree damage ranged from 0-11 trees/site with a mean of 0.5/site and sum of 33. Recreational traffic from all uses can remove vegetation, organic litter, and soil from the bases of trees, exposing tree roots to physical damage or the drying influence of the sun. Moderate to severe tree root exposure occurred on 0-8 trees/site at CHOH with a mean of 1.5 trees/site and sum of 87 (Table 6). At GWMP, root exposure ranged from 0-18 trees/site with a mean of 1.6/site and sum of 97. Tree stumps (> 1 in diameter), cut by park staff or recreationists were counted, ranging from 0-6/site with a mean of 0.6/site and sum of 35 at CHOH (Table 6). At GWMP, the number of stumps ranged from 0-12/site with a mean of 0.8/site and sum of 49. Finally, the number of formal or informal (visitor-created) trails intersecting recreation site boundaries was assessed. The number of these site access trails at CHOH ranged from 0-10/site with a mean of 2.6/site and sum of 168. At GWMP, the number of trails ranged from 0-11/site with a mean of 2.5/site and sum of 155.

Table 6. Summary of cliff-associated tree damage, root exposure, and informal trail impact indicators by park.

Park		**Damaged Trees (#)**	**Trees w/Exposed Roots (#)**	**Tree Stumps (#)**	**Site Trails (#)**
CHOH	Mean	0.2	1.5	0.6	2.8
	Sum	14	87	35	168
GWMP	Mean	0.5	1.6	0.8	2.5
	Sum	33	97	49	155

A six-category qualitative Condition Class (CC) assessment scale was developed and applied to all recreation sites to provide a rapid-assessment protocol that managers may find useful for monitoring recreation site conditions over time (Table 7). The class descriptions depict increasing levels of disturbance to vegetation cover, organic litter, and soil exposure. These class descriptions were both evaluated and characterized using quantitative data from three indicators: site size, onsite vegetation cover, and onsite exposed soil (Tables 8 & 9). A number of the recreation sites were located predominantly on rock such that a CC rating could not be applied: CHOH, 17 sites (28%), and GWMP, 25 sites (40%). At CHOH, CC ratings were strongly skewed to the higher or more impacted categories, including 13 (22%) rated a 4 and 18 (30%) rated a 5 (

Table 8). As expected, vegetation cover diminishes and exposed soil increases with increasing CC ratings, and site size, though not considered in rating descriptors, also increased. GWMP recreation sites were somewhat less skewed toward the higher CC ratings, with a total of 25 sites (40%) rated as CC 4 or 5 (Table 9).

Table 7. Cliff-associated recreation site Condition Class rating descriptions.

Rock:	Site is predominantly on rock surfaces. Clear boundaries based on trampling disturbance cannot be easily discerned.
Class 0:	Site barely distinguishable; no or minimal disturbance of vegetation and /or organic litter. Often an old site that has not seen recent use.
Class 1:	Site barely distinguishable; slight loss of vegetation cover and /or minimal disturbance of organic litter.
Class 2:	Site obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3:	Vegetation cover lost and/or organic litter pulverized on much of the site, some bare soil exposed in primary use areas.
Class 4:	Nearly complete or total loss of vegetation cover and organic litter, bare soil widespread.
Class 5:	Soil erosion obvious, as indicated by exposed tree roots and rocks and/or gullying.

Table 8. Number, percent, size, vegetation cover, and exposed soil of cliff-associated recreation sites by condition class for CHOH.

Condition Class	**Sites** #	%	**Avg. Site Size** (ft^2)	**Avg. Vegetation Cover** (%)	**Avg. Exposed Soil** (%)
Rock	17	28	291	27	3
0	1	2	-	-	-
1	0	0	-	-	-
2	1	2	75	63	16
3	10	16	435	48	18
4	13	22	1071	15	29
5	18	30	1290	11	34
All Sites	60	100	775	25	20

Table 9. Number, percent, size, vegetation cover, and exposed soil of cliff-associated recreation sites by condition class for GWMP.

Condition Class	**Sites** #	%	**Avg. Site Size** (ft^2)	**Avg. Vegetation Cover** (%)	**Avg. Exposed Soil** (%)
Rock	25	40	86	12	3
0	-	-	-	-	-
1	4	7	8	33	3
2	3	5	223	35	3
3	5	8	312	22	34
4	13	21	953	9	26
5	12	19	1956	9	23
All Sites	62	100	650	14	14

Cliff and Rocky Area Research Results

Quadrats

Of the 95 quadrats arrayed along the 16 study transects, 74 were classified in the Rocky Area Zone and 21 in the Forest Zone. Of the 74 Rocky Area Zone quadrats, only 33 (45%) had vascular plants rooted within them. These vegetated quadrats contained 148 geofeatures and 72 (49%) had plants. The 41 quadrats without plants had 84 geofeatures. Thus, while vascular plants require geofeatures to root in, there are large numbers of geofeatures (157 of 229, 69%) that do not have plants.

The number of vascular plants within each quadrat by transect is depicted in Figure 12. This figure illustrates the large number of quadrats that lack plants and two apparent but relatively weak trends: 1) that plant numbers increase in an upstream (left to right) direction, and 2) that plant numbers increase with elevation above the river (from front to back).

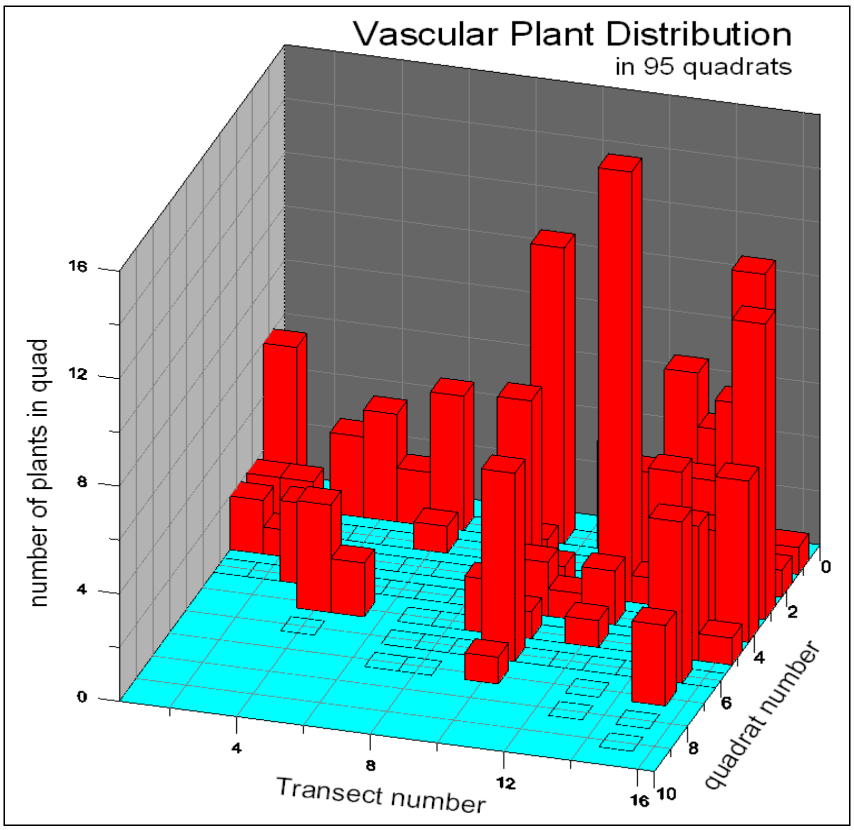

Figure 12. Number of vascular plants by transect and quadrat .

Mean plant cover for nine life-form categories and for plant litter, soil and bare rock within the Rocky Area Zone is presented in Figure 13. Bare rock and crustose lichen are the dominant cover categories, followed by foliose lichen and vascular plants. Note that vascular plants (7% cover) can overlap the cover of other categories, such as lichens – assessments were not mutually exclusive. Plants of any type were present in 69 of the 74 quads, with an average cover of 58%.

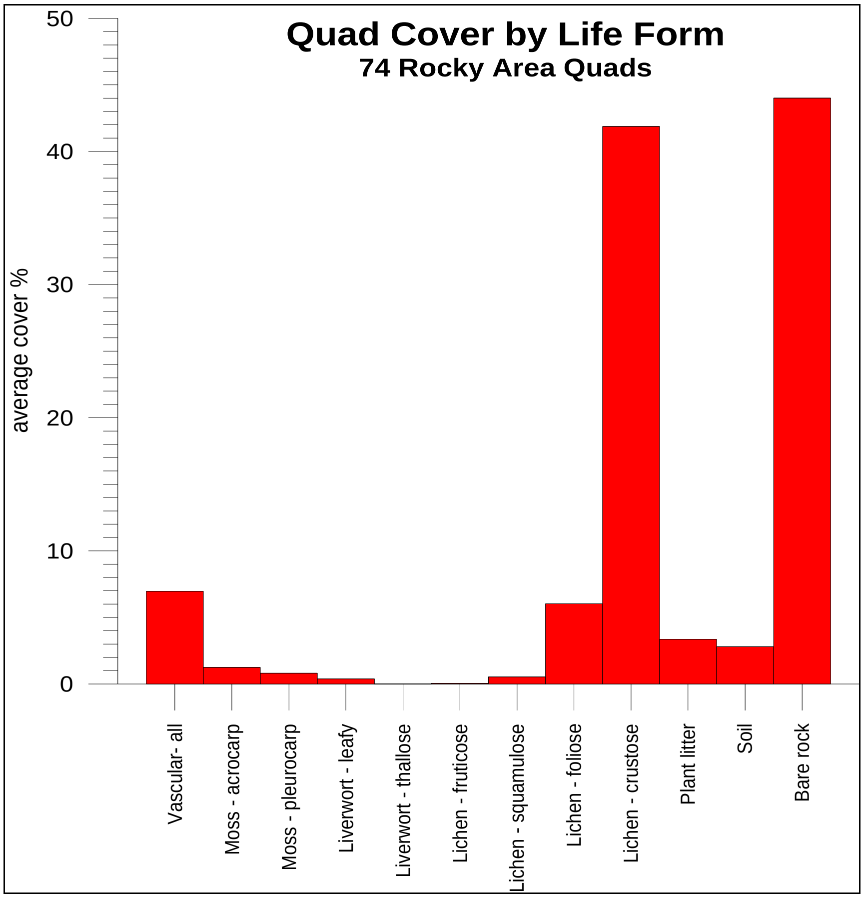

Figure 13. Vascular, non-vascular, and lichen cover within quadrats for the Rocky Area Zone.

A number of comparisons for examining the possible influence of recreation are presented in this section. To begin, we caution readers that the more simplistic comparisons can be misleading due to the influence of multiple factors on the presence and cover of vascular plants. For example, *no* vascular plants were found in quadrats that lacked geofeatures within which they could root, regardless of their proximity to recreation activity sites. Numerous environmental factors (e.g., geofeature type, soil volume, proximity to river/flooding) are also likely to influence plant presence and cover. Later in this section, we present results from regression modeling aimed at improving our understanding of factors that may be influencing the presence of vascular plants in the cliffs and rocky areas of Mather Gorge.

First, we note that the number of quadrats (33) in the rocky area proximate to recreation activity sites (within one meter from a trail, recreation site, or climb) is comparable to the number of quadrats (41) where recreational activity is more distant. Vascular plants were present in 61% (25 of 41) of quadrats that lacked evidence of recreation activity, and 24% (8 of 33) of quadrats proximate to locations with evidence of recreation activity. Table 10 lists the mean plant cover with and without recreation activity. As might be expected, when recreation is present there is less cover, on average, for each life form, except for the trampling resistant lichen-crustose. But, these differences are statistically significant only for vascular plants (p=.002), with mean vascular plant cover of 1.5% on quadrats proximate to recreational traffic and cover of 11.4% on quadrats without traffic (Table 10). As other cliff impact investigators have noted, it is unclear if the reduced frequency and cover of vascular plants is a result of recreational activity or if recreationists are simply selecting areas that have less vascular plant cover. We might expect recreationists to avoid vegetation when possible, particularly when it is easy to do so if vegetation is sparse and/or if poison ivy is present.

Table 10. Plant cover by life form within the Rocky Area Zone quadrats, with comparison for quadrats with and without recreational activity.

Life Form	**Quadrats with Life Form (#)**	**Mean Cover (%)**	**Mean Cover, No Recreation (%)**	**Mean Cover, Recreation (%)**	**Mann-Whitney test (p-value)**
Plants - all	69	57.9	65.8	48.1	.153
Vascular Plants - all	33	7.0	11.4	1.5	.002
Moss - Acrocarp	22	1.3	1.9	0.4	.678
Moss - Pleurocarp	10	0.8	1.3	0.2	.092
Liverwort - Leafy	9	0.4	0.6	0.1	.468
Liverwort - Thallose	1	0.0	0.0	0.0	.366
Lichen - Fruticose	2	0.0	0.1	0.0	.198
Lichen - Squamulose	14	0.5	0.8	0.2	.180
Lichen - Foliose	47	6.0	8.5	2.9	.060
Lichen - Crustose	67	41.9	41.2	42.7	.815
Plant Litter	74	3.4	3.9	2.7	.440
Soil	74	2.8	3.1	2.5	.100
Bare Rock	74	44.0	40.4	48.5	.242

Geofeatures

A total of 317 geofeatures were identified within the 95 quadrats, including 217 with vascular plants and 100 with no plants present. Within the rocky area zone, 232 geofeatures occurred within the 74 quadrats (Table 11). Cracks were the most common type of geofeature (see Figure 10), accounting for 181 (78%) of the 232 geofeatures in the rocky area zone. No pockets were found. Vascular plants were found in less than one-third of these geofeatures (72, 31%), with cracks accounting for 62 of these (86%) (Table 11). It is interesting to note that no plants grew in the absence of geofeatures or on pure ledges, those without an associated crack that could provide water. Many plants were found in step-crevices (ledges with cracks) and in concave depressions, both of which can provide water for plants. As illustrated in Figure 14, geofeatures that do host vascular plants, most frequently have only one or two species. Fifty vascular plant species were found within geofeatures in the rocky area zone (Figure 15). Davis (2011) found at least 300 species in his more comprehensive census of vascular plants around and on cliffs within the same study area. The majority of vascular plants (33, 69%) were found in only one geofeature. Of particular interest is that *Solidago racemosa*, a rare plant not found outside the

Potomac Gorge elsewhere in Virginia or Maryland, was substantially more common than any other vascular plant in the rock area zone. This ubiquitous plant is extremely well adapted to growing in narrow cracks, often with little to no soil present. This plant is most prevalent in cracks, with only single occurrences in step-crevices and concave depressions. It exhibited a preference for mid- to upper-cliff positions, bounded below by the spring high flow mark and above by maximum flood limits.

Table 11. Rocky area zone geofeatures by type, including number and percent of geofeatures with vascular plants.

Indicator	Crack	Step-crevice	Ledge-Pure	Concave Depression	Pocket	Totals
Geofeatures (#)	181	6	20	25	0	232
Geofeatures with plants (# [column %])	62 [35]	3 [50]	0	7 [28]	-	72 [31]

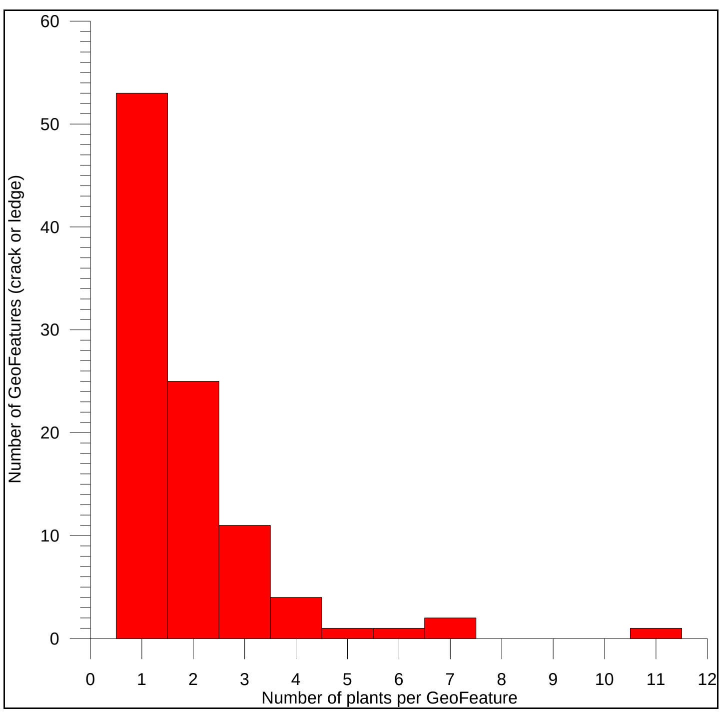

Figure 14. Number of vascular plant species found in geofeatures for all quadrats (N=74).

Forbs (broad-leafed herbs) were the most common vascular plant growth form found growing in geofeatures in the rocky area, occurring in 50 geofeatures (Table 12). Grasses were also common (30 geofeatures), with the remaining growth forms far less common (≤ 8 geofeatures). But, by total cover, trees accounted for the majority of total cover (252%), followed by shrubs (83%) and grasses (80%) (Table 12).

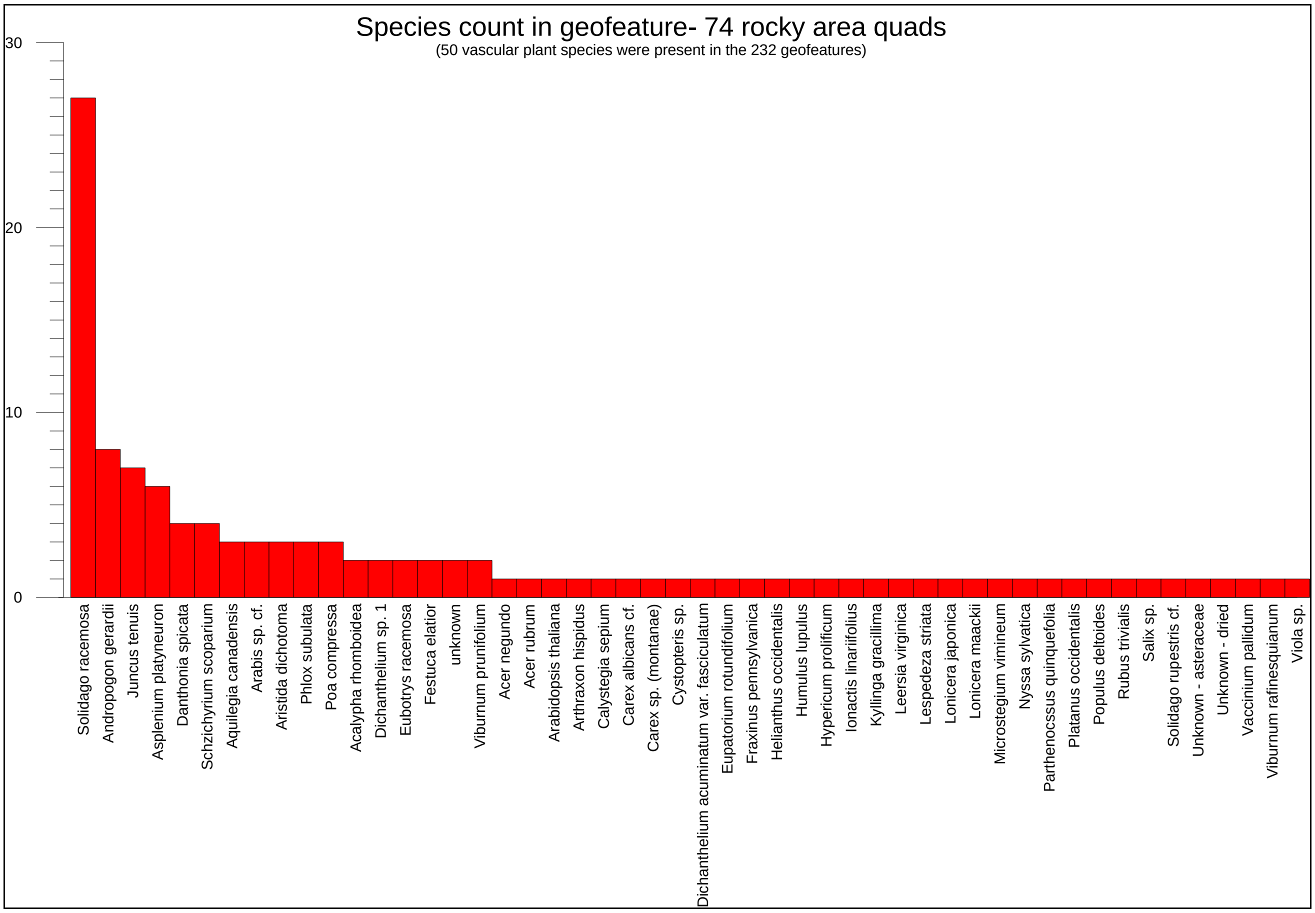

Figure 15. Number of geofeatures that contain plants of each species for quadrats in the rocky area zone. (Note: These were the initial species names from fieldwork; they will be revised within the final report).

Examining the possible influence of recreational activity at the geofeature level, Table 13 presents data on the number of geofeatures with and without plants by proximity to recreation activity sites. Eighty-six percent of the geofeatures proximate to recreational activity (within one meter from a trail, recreation site, or climb) lack vascular plants or ferns, compared to sixty-two percent of the geofeatures that are more distant from recreation activity sites. As previously noted, this should not be taken to imply causation due to the possible confounding influence of other factors.

The influence of crack size and soil volume were also examined for geofeatures located within the rocky area zone. All of the crack sizes had vascular plants, including those assessed as “closed.” The percent of cracks with vascular plants ranged from 27% for cracks 1-3 cm in width (n=78), to 50% for cracks 0.2-0.9 cm in width (n=34). Interestingly, 29 cracks (44%) that lacked soil had plants present while 27 cracks with soil (22%) had no plants. Plots of vascular plant cover against soil volume revealed a weak positive relationship, confounded by the absence of plants in some larger cracks with soil (presumably due to recreational activity) and to the presence of plants in the 29 cracks that lacked soil. Interestingly, an evaluation of recreational activity found substantially greater mean soil volumes in cracks located in areas with recreational activity than those without such activity (310 vs. 39 cm^3), though differences were not statistically significant (Mann-Whitney U test, p-value = .609).

Table 12. Vascular plants and ferns, incidence and cover in geofeatures within the rocky area zone.

Plant Growth Form	Incidence in Geofeature (#)	Total Cover (%)
Forbs	50	38.8
Grasses	30	80.1
Sedges	2	1.5
Rushes	7	3.1
Ferns and allies	7	3.1
Herbaceous vines	2	32
Woody vines	3	22
Shrubs	7	83.1
Trees	8	251.5

Table 13. Number and percent of geofeatures with and without vascular plants by proximity to recreational activity within the rocky area zone.

Recreational Activity	Geofeatures w/out Plants	Geofeatures with Plants	Totals
	------------- (#, row %) -------------		
Not Proximate	104 (62%)	63 (38%)	167
Proximate[1]	56 (86%)	9 (15%)	65
Totals	160 (69%)	72 (31%)	232

1 - within one meter from a trail, recreation site, or climb.

Regression Modeling - Quadrats

Multivariate analyses allow investigators to evaluate the *relative influence* of many different independent variables on a dependent variable of interest. Influence is “implied” through statistically significant correlations, but correlations may not be based on the assumed causal relationships so readers are again cautioned when interpreting these results. Nevertheless, these statistical models provide the best available depiction of the possible influence of the factors included in a model.

The following sections report results from regression modeling focused on predicting the number of small vascular plants in a quadrat or geofeature within the rocky area zone quadrats, our primary dependent variable. This section presents data on quadrat-level modeling; a following section presents data on geofeature-level modeling. Large vascular plants like trees and shrubs are not considered as they are less easily affected by recreational trampling.

We used a “Generalized Linear Model” with Poisson log-linear regression modeling for quadrat analyses. The dependent variable in the model is the count of small vascular plants in the quad. The count is defined as the sum of the number of species in each crack or on each ledge within the quad. Count data is characterized by non-negative integers (frequently with many zeros). This characteristic leads to a highly non-normal distribution, making Poisson Regression a more appropriate procedure than Ordinary Least Squares Regression. This regression method is non-parametric so the normality requirements of OLS regression are relaxed.

Poisson Regression is a log-linear method. The regression equation is of the form:

$$\text{Ln(count)} = \text{intercept} + B_1(\text{independent variable}_1) + B_2(\text{independent varaiable}_2) + \ldots$$

The intercept and the B_ns are the coefficients to be estimated by the model.

Independent variables evaluated in the regression modeling are listed and described in Table 1 and Appendix 3, and include large-scale variables (e.g., elevation), local scale variables (e.g., aspect, proximity to recreation activity sites), and fine scale variables (e.g., physical measurements of geofeature, soil volume). Twenty-two independent variables were selected to explain the abundance of plants. These variables were added or removed from the models based on the variable’s statistical significance and judgments based on their underlying ecological and physical relationships.

Features of the quadrats determine which would be useful for prediction modeling. To be useful the quadrats should have vascular plants and various geofeatures (see Table 14). Of the 95 quadrats, 89 have some type of geofeature (N=317) and 49 (or 55%) of these have vascular plants. The small vascular plants occur in 55% of quadrats (N=62) with cracks and 35% of those (N=63) with ledges. By modeling the various types of geofeatures separately, we can determine their associated relationships with vascular plant occurrences.

Table 14. Number of geofeatures and quadrats with and without small vascular plants for cracks and ledges. Data are included for all quadrats with small vascular plants (N=89).

Quadrat Geofeature	Geofeatures (#)	Quadrats (#)	Quadrats (#)	
			w/Small Vascular Plants	w/out Small Vascular Plants
Cracks	190	62	34	28
Ledges	127	63	22	41

Table 15 provides a summary of three regression models—plants in cracks, plants on ledges, and for the rare plant *Solidago racemosa*, the most common small vascular plant found in this study. All three models are statistically significant (<.001) but they contain different sets of independent variables. The first model examined factors that may influence the number of small vascular plants in cracks, with six highly significant variables. The number of small plants increased with increasing elevation above the river, number of cracks, and crack area. Plant numbers decreased with increasing woody plant cover above the quadrat, proximity to recreation activity sites, and decreasing crack length. The second model examined factors that may influence the number of small plants growing on ledges, with four significant variables (Table 15). The number of small plants increased with increasing number of cracks, and ledge lengths and soil volume. Plant numbers decreased with increasing proximity to recreation activity sites. The third model examined factors that may influence the number of *S. racemosa* plants, with three significant variables (Table 15). Number of *S. racemosa* plants increased with increasing numbers of cracks and decreased with increasing proximity to recreation activity sites and crack length. Additional variables that were tested and not found to be highly correlated are listed below the table.

Table 15. Poisson log-linear regression modeling results for predicting the number of small vascular plants (species), and the rare plant *Solidago racemosa*, within quadrats located in the rocky area zone.

Rocky Area Zone	**Small Vascular Plants (#)**				***Solidago racemosa (#)***	
	In Cracks		**On Ledges**		**In cracks**	
Quadrats (#)	54		46		54	
Deviance / df	1.344		0.625		0.813	
Pearson χ^2 / df	1.309		0.871		1.012	
Likelihood ratio χ^2	106.0		34.2		42.1	
Model significance	<.001		<.001		<.001	
Independent Variables[1]	**B**[2]	**sig**	**B**	**Sig**	**B**	**sig**
Intercept	-.304	.324	-3.684	.000	-1.248	.007
Elevation above river (m)	.097	.001	--	--	--	--
Cover above quad (%)	-.029	.003	--	--	--	--
Recreation proximity (y/n)	-1.267	.002	-2.034	.022	-2.000	.057
Crack count (#)[3]	.346	.000	.457	.000	.632	.000
Crack length (cm)[3]	-.013	.003	--	--	-.019	.001
Crack area (cm^2)[3]	.0022	.002	--	--	--	--
Ledge length (cm)[3]	--	--	.022	.025	--	--
Ledge soil volume (cm^3)[3]	--	--	.00006	.000	--	--

1 – Other variables considered in the modeling: distance from falls, surface water flow into quad, slope of quad, aspect of quad, quad angle to river, cliff overhang above quad, general surface roughness, crack soil volume, ledge count, ledge surface area.
2 – Unstandardized B coefficients.
3 – Sum of the variable for each quadrat.

Based on these models, two equations predicting number of small vascular plants can be developed:

Ln(count in cracks) = -.304 + .097(elevation) -.029(cover) -1.267(recreation proximity)
+ .346(crack count) -.013(crack length) + .0022(crack area)

Ln(count on ledges) = -3.684 -2.034(recreation proximity) + .457(crack count)
+.022(ledge length) + .00006(ledge soil volume)

For any particular quad, the assumed or expected effect of being near a recreation site can be calculated by changing the recreation proximity variable from one (indicating close proximity) to zero (distant from a recreation activity site).

Predicted Effects of Proximity of Recreation Sites on Plants

For each of the 33 rocky area quadrats proximate to recreational activity (within one meter from a trail, recreation site, or climb), regression models can be used to roughly predict the increase in plant count from removing the recreation proximity variable. Predictions are made by changing the Recreation Proximity code from "1" to "0" in the regression equations. The sum of small vascular plant counts for the 74 quadrats is given in Table 16. According to the model, eliminating the recreation proximity variable changes the plant count from a measured 106 plants to a "predicted" 128 plants. We emphasize that this predication also includes the limitations of regression modeling previously noted. The true determinants of plant number could be an inherent condition of the rocky environment or an attribute not properly assessed or included in our measurements, the choice of recreation location made by visitors, or some other unknown factor that may correlate or co-vary with our recreation variable. Nonetheless, the model provides an estimate of the magnitude of differential abundance of plants within close proximity to existing recreational sites at Mather Gorge compared to sites that are more distant—regardless of the cause of the difference. This is helpful information for resource management because: 1) it provides a baseline statistic of current plant populations at current levels of recreation use and other unknown factors, 2) it provides an estimate of worst case impact from recreation if all the difference is assumed to be attributed to recreational activity, and 3) it quantifies a plant population management target to judge whether increases in population would even be feasible or unusual based on the inherent 'natural' edaphic constraints of these specific recreation sites.

Table 16. Actual and predicted numbers of small vascular plants in cracks and on ledges with and without recreation activity variable within 74 quadrats, cliff and rocky area zone.

Geofeature	Small Vascular Plants (#)		
	Actual: Current Recreation Uses	**Predicted: Recreation Eliminated**	**Difference**
In Cracks	81	99	18
On Ledges	25	29	4
Totals	106	128	22

Three types of recreational activity were assessed for study quadrats, including Hiking (14 quadrats), Scrambling (requiring use of hands) (3 quadrats), and Technical (rock climbing and rappelling with ropes) (16 quadrats), plus 42 quadrats not considered proximate to recreational activity. Based on an assessment of the potential for these types of recreation to access and affect vegetation in each quadrat, Table 17 provides an extrapolated breakdown to estimate plant losses by recreation type. This prediction suggests that technical recreation is associated with the greatest loss, estimated at 16 plants. Readers are again cautioned that these estimates are based on a number of qualitative assessments and assumed causal relationships that may not be valid. Various recreational activity types are associated with different inherent site conditions. The predicted counts can aid judgments about the possible relative contribution of recreation vs. background natural constraints in limiting plant population size.

Table 17. Predicted total change in number of small vascular plants in cracks and on ledges by recreation type within 74 quadrats, rocky area zone.

Geofeature	Change in Small Vascular Plants (#)			
	Hiking	**Scrambling**	**Technical[1]**	**Totals**
In Cracks	4	0	14	18
On Ledges	2	0	2	4
Totals	6	0	16	22

1 – rock climbing and rappelling

Regression Modeling - Geofeatures

As previously noted, vascular plants were found only in geofeatures within the rocky area zone in this study, only lichens and bryophytes are able to colonize featureless rock. We expect that vascular plants in different kinds of geofeatures likely require physically and ecologically similar controls. If so, then modeling at the finer geofeature scale, rather than at a quadrat scale, should yield models that more accurately describe the relative influence of factors and provide greater predictive power. This section uses data from the 74 rocky area quadrats with Logistic Regression modeling based on the geofeature as the unit of analysis, as opposed to the quadrat in the preceding section. Cracks and concave depressions are the only geofeatures sufficiently numerous to support modeling. Within the 74 rocky area quadrats there are 168 cracks, 59 of which contain one or more vascular plants, and 25 concave depressions, 7 of which contain one or more small vascular plants.

Logistic regression modeling for the cracks geofeature evaluated twenty-seven variables for their significance in predicting plant presence, with five variables included in the final model (Table 18). Logistic regression does not have an acceptable significance test so model quality was tracked with the Hosmer and Lemeshow Test and the Omnibus Test of Model Coefficients. Model quality was also tracked with the classification table of prediction accuracy.

The number of cracks with vascular plants increased with increasing water flow into the quadrat and elevation above the river. Plant numbers decreased with increasing woody plant cover above the quadrat, proximity to recreational activity, and crack opening size. Regression modeling for the concave depression geofeature also evaluated twenty-seven variables, with three included in the final model (Table 18). The number of concave depressions with plants increased with increasing soil volume. Numbers decreased with increasing woody plant cover above the quadrat and proximity to recreation activity sites.

Table 18. Logistic regression modeling results for predicting the number of small vascular plants (species) within geofeatures in the rocky area zone.

Rocky Area Zone	**Geofeatures with Vascular Plants (#)**			
	In Cracks		**Concave Depressions**	
Geofeatures (#)	168		25	
Independent Variables[1]	**B[2]**	**sig**	**B**	**Sig**
Intercept	-0.804	.078	-0.734	.462
Water flow into quadrat (y/n)	2.988	<.001	--	--
Elevation above river (m)	0.142	.005	--	--
Cover above quad (%)	-0.026	.008	- 0.0698	.243
Recreation proximity (y/n)	-1.633	.005	- 2.286	.128
Crack opening size (cm)	-1.793	<.001	--	--
Soil volume (cm^3)	--	--	0.00027	.064

Classification Table	*Predicted Presence of Vascular Plants*			
		0	1	Correct (%)
	0	91	17	84.3
	1	19	40	78.4

1 – Other variables considered in the modeling: distance downstream from falls, surface water flow into the quad (2, 3 & 4 categories), elevation above river, quad slope, quad easterly aspect, quad northerly aspect, quad angle to river flow, vegetation cover, length of rock overhanging quad, width of rock overhanging quad, quad surface roughness, recreation type, crack slope, crack length, crack opening size (metric, 2 & 5 categories), crack opening area, moss/liverwort/fern cover as indicator of ground water (metric, 2 & 3 categories).
2 – Unstandardized B coefficients.

Based on these models, two equations predicting number of geofeatures with vascular plants can be developed. The key equations are:

$z = b_0 + b_1X_1 + b_2X_2 + ... + b_iX_i$

where z = “logit” = log odds

b_i = the coefficients, the B values

X_i = the explanatory variables

P(event) = Exp(z)/(1 + Exp(z))

Where P(event) = the probability of the event (a plant)

From the output, we can assemble prediction equations:

Cracks: z = logit = -0.804 + 2.988(Water flow) + 0.142(Elevation above river) -0.026(Cover above quad) -1.633(Recreation proximity) – 1.793(Crack opening size)

Concave depressions: z = logit = -0.734 - 0.0698(Cover above quad) - 2.286(Recreation proximity) + 0.00027(Soil volume)

From the z-values, we can calculate the probability of each crack or concave depression containing a plant using the equations above. The probabilities range from zero to one, with probabilities greater than 0.5 indicating the presence of a plant.

Predicted Effects of Proximity of Recreation Sites on Plants

For each of the 168 rocky area cracks and 25 concave depressions proximate to recreational activity (within one meter from a trail, recreation site, or climb), regression models can be used to roughly predict the increase in plant count from removing recreation use. The prediction is made by changing the Recreation Proximity code from "1" to "0" in the prediction equations. The sum of cracks with plants for these geofeatures is given in Table 19. According to the model, eliminating recreation (as inferred by the recreation proximity variable) changes the plant count from a measured 59 geofeatures with vascular plants to a "predicted" 68 geofeatures with plants. For concave depressions, eliminating recreation changes the count from a 7 to 10.6. We emphasize that this predication also includes the limitations of regression modeling previously noted. The true determinants of plant number could be an inherent condition of the rocky environment or an attribute not properly assessed or included in our measurements, the choice of recreation location made by visitors, or some other unknown factor that may correlate or co-vary with our recreation variable.

Table 19. Actual and predicted numbers of cracks with vascular plants and concave depressions with and without recreation proximity variable within 168 cracks and 25 concave depressions, rocky area zone.

Geofeature	Geofeatures with Vascular Plants (#)		
	Actual: Current Recreation Uses	Predicted: Recreation Eliminated	Difference
Cracks w/plants (#, %)[1]	59, 35%	68, 40%	9
Depressions w/plants (#, %)[2]	7, 28%	10.6, 42%	3.6

1 – Analyses based on 168 cracks, 41 of which were proximate to recreation.
2 – Analyses based on 25 depressions, 16 of which were proximate to recreation.

Further investigation led to the discovery that recreation occurs in areas with a lower density of geofeatures. Our quadrat placements were randomly located so we would expect to find no differences in the number of geofeatures for those quadrats with recreation vs. those without recreation. However, this was not the case:

Quadrats w/out recreation: 167 geofeatures/41 quads = 4.1 geofeatures/quad
Quadrats w/recreation: 65 geofeatures/33 quads = 2.0 geofeatures/quad

While recreation activities can undoubtedly reduce plant abundance, having just half as many geofeatures per quad means the quadrats with recreation must start with far fewer plants than the quadrats without recreation (plants require geofeatures to grow). Further, the extensive non-vegetated areas and large number of geofeatures without plants allow recreationists the relatively easy option of avoiding plants entirely when hiking or climbing in the cliff and rocky areas. The regression correlations suggesting fewer plants when proximate to recreation may not mean that recreation *caused* a reduction in plants. Microtopography differences and recreationist preferences must also be a factor.

DISCUSSION

This section reviews and summarizes principal research findings and discusses implications for managers. Site and visitor management suggestions are offered in the Appendix 4 Report Addendum for improving the protection of cliff-associated resources and increasing the sustainability of recreational activities. As previously noted, this report is restricted to cliff-associated recreation sites and climbing routes. Formal and informal trail impacts and management are addressed in a separate report (Wimpey & Marion 1011).

Research Summary and Management Implications

Park managers are continually challenged to protect the natural and cultural resources under their stewardship while also providing for appropriate types and levels of visitation. Potomac Gorge cliffs and associated rocky uplands and shorelines support unique and rare communities of flora and fauna, and in places, heavy recreational use. Hiking, rock climbing, fishing, nature study, and photography have been traditional recreational activities in the Gorge and park managers are striving to preserve opportunities for these pursuits in the future. To some degree, resource impacts associated with recreational activities are inevitable. The principal challenge for park managers is to avoid impacts where possible, particularly within areas of sensitive natural and cultural resources, and to reduce unavoidable impacts to minimal and acceptable levels.

NPS resource protection decisions are generally made during a planning process and the Great Falls Park General Management Plan specifies the need to develop separate Climbing and Trail Management Plans. Carrying capacity based decision frameworks, such as the NPS Visitor Experience and Resource Protection (VERP) framework (Figure 17), are recommended as a framework for these planning and decision-making efforts. These frameworks provide a formal process and forum within which managers and recreation group representatives can consider the need for such practices, select preferred practices, and evaluate their success and need for modifications over time.

This research and report was developed to assist NPS managers in cliff-associated visitor impact management decision-making and plan development. It provides a comprehensive source of information on quantitatively described indicators related to visitor impacts, including protocols found in the Appendices that can be adapted for monitoring programs required by these decision-making frameworks. This report also contains a review of other studies and publications that may be beneficial to managers as they proceed with planning and decision-making. Specifically, we highlight a publication that is particularly relevant and contains high quality guidance and information. This publication, compiled by Aram Attarian and Jason Keith (2008), is titled: "Climbing Management: A Guide to Climbing Issues and the Production of a Climbing Management Plan," and was published by the Access Fund, a non-profit organization dedicated to keeping climbing areas open and conserving the climbing environment. It is available online at: http://www.accessfund.org/atf/cf/%7B1F5726D5-6646-4050-AA6E-C275DF6CA8E3%7D/CM-web.pdf.

Given the prevalence of rare and sensitive plant communities and plants occurring within Potomac Gorge, we also investigated decision-making models focused on rare plant management as part of our literature review. Based on these reviews we recommend management consideration of the Population Viability Management (PVM) model (Figure 16) (Bakker and

Doak 2009), and believe that it could be incorporated into the VERP process (see Figure 17, Appendix 4). The PVM model incorporates a traditional Population Viability Analysis (PVA) process that performs risk assessments on a species to forecast population health and extinction risk. While PVA is commonly applied as a one-time analysis, PVM includes PVA within a cyclical Adaptive Management decision process. In a combined PVM-VERP process, information from this report and from a PVA process would be considered in the selection of indicators and standards of quality. Resource monitoring would periodically assess these indicators for comparison against quantitatively defined standards, permitting an evaluation of management success in achieving its objectives. If sub-standard (unacceptable) conditions exist, an evaluation would identify influential factors, followed by selection and implementation of management actions and further monitoring in the ongoing adaptive management cycle.

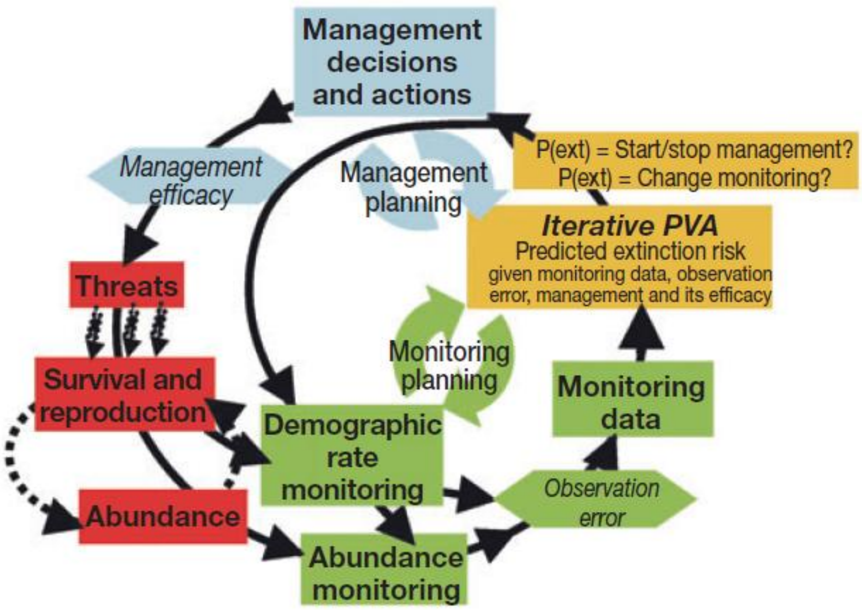

Figure 16. The Population Viability Management (PVM) model integrates a Population Viability Analysis (PVA) process (yellow) to evaluate threats to rare plants (red) using an adaptive management decision-making cycle (blue). The efficacy of management actions are evaluated based on feedback from monitoring (green), and used to guide the selection of rare plant protection actions. Illustration from Bakker & Doak (2009).

We engaged in correspondence with Victoria Bakker, the principal author of the PVM model, to describe the VERP model and discuss how the PVM model might be integrated within it. Here is a portion of her response:

> "The key to PVM is developing a population model so that monitoring data can be linked more directly to viability. In making this link, acceptable change can then be defined, at least in part, by a viability criterion -- acceptable change is that which ensures extinction risk remains below some target. Estimates on the efficacy with which corrective actions reduce recreational impacts should be incorporated (and refined through monitoring) to help define acceptable change. That is, if none of the corrective actions are particularly effective, one would want to respond more quickly to recreation

impacts to ensure viability targets are maintained. And, as you mention, other, non-recreational threats should be accounted for in modeling as well. (Bakker, personal communication, 2009).

Common indicators in VERP models have included attributes such as recreation site size (individual and aggregate) or soil loss on trails. Bakker suggests that a PVA process could yield additional indicators that reflect the viability of rare plants. Assuming these can be quantitatively defined and are responsive to management actions, they could be included in the VERP decision-making framework. She adds that the model can also account for influential non-recreational factors that affect rare plant viability. These factors could also be manipulated to maintain viable rare plant populations, separate from the management of park visitation.

Finally, we recommend formation of a Cliff Resources Oversight Committee comprised of representatives from local hiking, climbing, and fishing clubs, organizations, and commercial groups. Such a committee could work with NPS planners and managers in deliberations about planning and management actions.

Recreation Site Survey Summary

A field survey of cliff-associated recreation sites located and assessed 122 sites, including 60 sites in CHOH and 62 sites in GWMP, with an aggregate area of disturbance of 86,782 ft^2 (2 acres). Informal observations by field staff during several weeks of field work indicate that the majority of the recreation sites are predominantly used by hikers, who are far more numerous than climbers or fishermen. The majority of these sites are located at cliff-tops (84 (69%) and account for 83% of the total area of trampling disturbance. Cliff-base sites, with the exception of the Carderock area, are generally rocky and lack substantial soil and vegetation cover due to the scouring effects of frequent flooding. For example, the estimated area of vegetation loss for cliff-base sites was 10,098 ft^2, 18% of the total.

The loss of vegetation cover and organic litter has also left some portions of recreation sites with exposed soil that is susceptible to subsequent erosion, including 9,432 ft^2 at CHOH and 8,155 ft^2 at GWMP. Other impacts included damaged trees (47), trees with exposed roots (184), tree stumps (84), and off-site trampling impacts associated with numerous site access trails (323). These findings reveal greater disturbance than those reported from a similar cliff-associated recreation impact study at Shenandoah National Park (Marion & Carr 2007). The Shenandoah study assessed 16 of the most accessible cliffs and found 44 recreation sites, 36 (82%) with cliff-top locations, and a combined area of disturbance of 37,738 ft^2. Using comparable protocols, this study reported 23 damaged trees, 15 trees with exposed roots, 9 tree stumps, and 111 access trails. Based largely on fieldwork observations, the Potomac Gorge cliffs are subject to substantially greater numbers of visitors of all types, but as in the Shenandoah study, we ascribe the majority of cliff-top trampling impacts to hikers, the predominant visitor activity.

The Shenandoah study included an observational component conducted at the top of the most intensively visited park cliff, known as Little Stony Man (Wood *et al.* 2006). This study provides some insights into factors that may be driving visitor-caused impacts at similar cliff-top sites within Potomac Gorge. First, observers found that day hiking constituted the majority of recreational trampling and that hikers walked on soil and vegetation more frequently than rock climbers, whose activity was more restricted to rock surfaces. Second, observations revealed that hikers are predominantly drawn to cliff-top locations for the vistas they provide, while climbers spent most of their time at cliff-base sites. Also of importance was the finding that day hikers were more likely to disperse along the cliff edge during crowded periods to get a good view and/or find personal space. In contrast, climbers tend to cluster at the top and base of specific climbing routes, which limits the areal extent of their trampling impact. Such motives and patterns of use are also likely applicable to the cliffs in Potomac Gorge, where hikers and photographers are drawn to the cliff-tops for vistas of the scenic river gorge. As reported for Shenandoah NP, a principal management implication of these findings is that hikers are the probable primary contributors to the development and expansion of cliff-top recreational sites and associated cliff-top informal trails.

These findings have described the number, location, and spatial extent of cliff-associated recreation activity in the development of cliff-top and cliff-base recreation sites. They also provide quantitative data on several types of recreation impacts occurring at these locations (e.g., area of trampling disturbance, soil exposure, tree damage) – indicators that managers could incorporate into a VERP process with standards of quality. The significance and acceptability of these documented impacts requires a subjective value judgment by managers, with appropriate public input. No scientific procedure can make such determinations, though guidance is provided in a following section.

But, the results do clearly demonstrate that these recreation sites are numerous and account for sizable areas of trampling disturbance that have significant departures from natural conditions. Some rare plants do grow in these cliff-top and cliff-base settings. A companion study by Charlie Davis (2011) provides additional information on rare plants growing in the vicinity of these recreation sites. Though not demonstrated by this study, we suspect that most of these recreation sites are developed and used predominantly by hikers, primarily as vista sites overlooking the highly scenic Potomac Gorge. Climbers do contribute some trampling impacts at cliff-top locations when installing and removing anchor systems but spend the majority of their time on resistant rock surfaces at the cliff-base and on the cliff-face.

A case example pertaining to CHOH’s Bear Island included in a following section (Appendix 4) will illustrate a management decision-making process for reducing recreation site impacts. In particular, we note that many of vista sites had either poor vistas or vistas that closely resembled those provided by adjacent sites. Clearly many vista sites could be removed, with limited reductions in the quality of recreation experiences. Those that aren’t removed can likely be reduced in size; techniques and guidance are provided in following sections.

Rocky Area/Cliff-Face Survey Summary

Field research in Great Falls Park employed 16 transects and 95 quadrats in a random-stratified sampling design to provide a representative sample of the rocky and cliff-face areas of Mather Gorge within Great Falls Park, Virginia. Measurements and analyses were focused on understanding and predicting the presence of vascular plants, and the potential negative effects of recreational activities. Results show that only 33 of 74 quadrats (45%) located within the non-forested cliff and rocky areas have vascular plants. Even within the 33 vegetated quadrats, vascular plants were found growing in only 72 of 148 geofeatures present (49%). The relative rarity of vascular plants within the cliff and rocky areas is the result of many factors, including a challenging bio-physical environment with periodic flooding and droughts, limited soil substrates, and disturbance associated with recreational visitation. Recreational use is common and is comprised of a diverse array of activities, including sightseeing, hiking, nature study, photography, climbing, exploration, and fishing. Park managers are challenged in accommodating this visitation, and seek to avoid or minimize the negative impacts of such activities on rare and sensitive plant communities, species, and cultural resources.

Our research employed a comprehensive array of bio-physical measurements and extensive regression modeling to explore and document correlations and relationships to improve our understanding of factors that influence vascular plant presence within the rocky area zone. While regression modeling represents the "best-available" statistical method for analyzing our data to accomplish these objectives, it is not without limitations. In particular, we note that correlations derived from regression modeling, even when statistically significant, can infer but do not demonstrate causality. With respect to recreational impacts, a carefully controlled experimental design that applies known types and amounts of visitor activity to pristine settings would be necessary to demonstrate causal relationships. Nonetheless, regression modeling is frequently employed in studies to identify potential factors that may be influencing an attribute of concern and to improve insights regarding the relative influence of such factors.

In summarizing the results of our analyses, we begin by noting the importance of microtopography, including geofeatures such as cracks, ledges, and depressions in the rock that are essential to support vascular plant growth. While non-vascular lichen and mosses may grow on relatively featureless rock substrates, vascular plants require geofeatures – no vascular plants were found in rocky area quadrats that lacked geofeatures. While numerous previous studies have reported the negative effects of recreational activities on cliff and rocky area vegetation (Camp & Knight 1998a, McMillan *et al.* 2003, Parikesit *et al.* 1995), few have applied extensive multivariate analyses or have properly accounted for the influence of microtopography (Farris 1998, Kuntz & Larson 2006a, Nuzzo 1996). This study sought to further the development of assessment protocols and multivariate analytical methodologies emphasized by Kuntz and Larson (2006a) to more fully explore the potential influence of numerous factors, including microtopography.

As suggested in earlier studies, trampling and disturbance from recreational activities appears to reduce vegetation cover. For example, a simplistic (univariate) analysis of our data reveals that vascular plants are present in 61% of quadrats that lacked recreational activity (were more than 1 meter away from a trail, recreation site or climb) (mean cover: 11.4%) and 25% of quadrats proximate to recreational activity (mean cover 1.5%). Similarly, for geofeatures, 86% of geofeatures proximate to recreational activity lack vascular plants, compared to 62% of geofeatures more distant to recreational activity. These results may not describe a causal relationship, for example, visitors may simply be favoring non-vegetated areas.

Our analyses also revealed that the cliff and rocky areas sought out for recreational activity have only 2.0 geofeatures/quadrat, whereas the quadrats without recreational activity have 4.1 geofeatures/quadrat. Since plants require geofeatures to grow, this finding means that the areas with recreational uses must have started out with fewer plants than the areas without recreation, possibly by a factor of two.

Our results reinforce the conclusions of Kuntz and Larson (2006a) regarding the importance of microtopography and geofeatures. Cracks were the most common type of geofeature, accounting for 181 (78%) of the 232 geofeatures in the rocky area quadrats. Vascular plants (48 species) were found in less than one-third of these geofeatures (72, 31%). Vascular plants were only found in geofeatures able to supply water, including cracks, ledges with cracks, and depressions. *Solidago racemosa*, a rare plant not found anywhere else in Virginia and Maryland, was substantially more common than many other vascular plants in the cliff and rocky areas. This species is well-adapted to growing in narrow cracks, often with little to no soil present.

Multivariate analyses, including multiple regression, can compute correlations with many different independent factors and document the relative contribution of each in explaining variation in a dependent factor of interest. For example, vascular plant presence in our study area is likely to be influenced by factors such as the physical types and dimensions of geofeatures, availability of water, insolation (sunlight/shading), flooding, substrates, and recreational activity. Therefore, in addition to recreational variables, our analyses captured and evaluated the possible influence of more than 25 biophysical variables operating at large, local, and fine scales (see Table 1). These variables were simultaneously input into the regression modeling exercises to investigate their possible influence on vascular plants.

Regression modeling at the quadrat scale are presented in Table 15. For the more prevalent plants in cracks model, these analyses indicate that the number of vascular plants increase with increasing elevation above the river, number of cracks, and crack area. Plant numbers decreased with increasing woody plant cover above the quadrat, proximity to recreation activity sites, and decreasing crack length. Numerous other biophysical factors, listed below the Table, were evaluated and found not to be significantly correlated with the presence of vascular plants. The resulting regression model was also used to “predict” the effect of eliminating recreational use (as inferred by the recreation proximity variable) on vascular plant numbers. Recreational activity is estimated to have reduced vascular plant numbers within the 74 rocky area quadrats from 128 plants to 106 plants, a loss of 22 plants. This estimate assumes a causal relationship between recreational activity and plant loss (likely), and that recreationists do not preferentially avoid vegetated areas (which we believe is unlikely).

Regression modeling at the geofeature scale are presented in Table 18. We believe that this finer scale is more appropriate and more accurately reflects important influences on vascular plant presence. For the more prevalent plants in cracks model, these analyses indicate that the number of vascular plants increased with increasing water flow into the quadrat and elevation above the river. Plant numbers decreased with increasing woody plant cover above the quadrat, proximity to recreation sites, and crack opening size. Regression equations were developed separately for cracks and depressions, and used to predict the effect of eliminating recreational use on vascular plant presence. For cracks, recreational activity is estimated to have reduced the incidence of vascular plants within the 74 rocky area quadrats from 68 cracks with plants to 59 cracks with plants. For depressions, recreational activity is estimated to have reduced the incidence of vascular plants from 10.6 to 7.

Results from regression modeling at the quadrat and geofeature scales include the recreation proximity variable with a negative correlation to vascular plant numbers, a correlation that could mean that recreational activity is reducing plant numbers within the cliff and rocky areas of Mather Gorge. As previously noted, such analyses are based on mathematical correlations that cannot demonstrate causality. However, while it is reasonable to expect causality, it is also reasonable to expect that visitors naturally avoid harming vegetation when it is easy or convenient to do so. If true, then the regression modeling overestimates the negative effects of recreation activities on the occurrence of vascular plants. We also note that the quadrats proximate to recreation have 2.0 geofeatures/quad while those more distant from recreation have 4.1 geofeatures/quad. Since plants require geofeatures to grow, this finding suggests that the recreation proximate quadrats started out with fewer plants, up to half as many, in comparison to quadrats located at greater distances from recreational activity. Our interpretation of these modeling exercises is that recreational activities are likely contributing to a reduction in the number of vascular plants within the cliff and rocky areas but that it is just one of many influential factors.

All forms of recreational activity contribute to the trampling and disturbance of vegetation. Visitors interested in sightseeing, photography, exploration, nature study, and exercise (collectively identified as hikers), are likely responsible for the majority of off-trail trampling impacts within the cliff-top and cliff-base areas. Our observations revealed that climbing activity at the cliff-top and base is largely focused on barren rock surfaces, though there is some tree damage and trampling around the bases of trees associated with the installation and removal of anchors. Climbing is the principal recreation activity causing impacts to vascular plants on the cliff-face, though some is related to rappelling and scrambling. Fishermen also contribute some impacts, particularly to informal trail creation and litter (trash), but their numbers are also relatively low.

Recreation ecology studies consistently demonstrate an asymptotic use-impact relationship whereby the majority of resource impact occurs with initial and low levels of use (Hammitt & Cole 1998, Leung and Marion 2000). Once initial impacts occur, further visitation results in diminishing levels of impact. For example, hikers who “walk-in” a new informal trail are responsible for considerable damage and loss of plant cover but impacts from the 500th or 1000th hiker may not even be measurable if they stay on the trail. This use-impact relationship has been well documented with respect to the creation of trails and recreation sites and we believe it is applicable to climbing routes. The climbers who pioneer and initially use a new climbing route may purposefully or unintentionally “clean” the route of plants in those places that offer the best available hand or footholds. We observed numerous plants growing on and near well-used climbing routes, but they invariably occupied protected niches or geofeatures that were less useful to climbers than others nearby. Unlike hikers, climbers move more slowly and use careful judgment in the placement of their feet and hands. The selected foot and handholds must occur on geofeatures that provide purchase and support their body weight as they climb. They can and presumably do avoid soil and plant-filled crevices in favor of barren rock geofeatures that provide more secure holds. Further, in contrast to most other climbing areas, at Potomac Gorge flooding periodically *returns* soil to the cliff cracks and depressions, negating some of these impacts.

An important implication of the asymptotic use-impact relationship is that on well-established climbs, continuing climbing activity is unlikely to be contributing much additional impact over time. Climbing activity has likely reached a roughly static equilibrium with the amount of resource impact, and continued climbing activities, unless the amount or type of climbing changes appreciably, are unlikely to cause additional resource impacts. This is less true on trails and recreation sites, where use occurs primarily on plants and soils that can be trampled and lost, particularly, when these features are not sustainably designed or actively maintained. For example, a steep trail that directly ascends a slope or crosses wet soils, or informal trail networks that receive no maintenance. In contrast, climbing is an activity restricted to solid rock, the most resistant surface we find in nature.

However, recreational activity can pose a direct threat to rare plants. For example, there is no question that the number of *S. racemosa* plants has been reduced by recreational activity, particularly by climbing, as this rare plant prefers small cracks in mid- to upper cliff-face positions. However, because this plant is locally ubiquitous and prefers narrow cracks that generally make poor climbing features, we don't expect recreational activity poses a threat to its long-term viability. For example, in his comprehensive survey of plants within the study area, Charlie Davis (2011) recorded 6,619 *S. racemosa* plants, and 2,198 on nearby cliffs. In his judgment, this population is particularly resistant to both natural and recreation-related disturbances, including catastrophic flooding. Of greater concern, are rare plants that are globally and locally rare. A good example is *Amelanchier nantucketensis*, a G3 globally rare species. Charlie mapped 68 occurrences (clumps) of this rare species within the cliff and rocky areas on the Virginia side and 21 on the Maryland side. Within our Virginia study area, 14 mapped occurrences occurred on or within one foot of a climbing route described in Tait (2001). While their current presence in these locations proves some degree of tolerance to recreational disturbance, management actions to enhance their protection should nonetheless be considered. His report will document the occurrence of approximately 13 other rare plants at 54 cliff and rocky area locations within the larger Virginia and Maryland study area.

We recommend careful consideration of the mapped locations of rare plants to evaluate potential impacts from formal and informal trails, recreation sites, and climbing routes. This could be integrated within a program of long term monitoring to track rare plant locations, assess their numbers and conditions, evaluate recreation-related threats, provide suggestions for alternative management actions, and evaluate the efficacy of any implemented actions. Case-specific evaluations can assess the degree of threat posed by park visitors based on the proximity, type, amount, and intensity of recreational activity. Plant-related factors must also be considered. Most of the rare plant species are perennials, which are less mobile over time than annuals, increasing the efficacy of site-specific management actions. Consideration of existing population sizes and whether they have been increasing or decreasing are important considerations. Management actions may be able to identify suitable adjacent habitats for population expansion and develop a protection strategy. For example, *A. nantucketensis* may have occurred in additional cliff-top locations and could be restored to them. The City of New York Parks and Recreation Department successfully propagated cuttings and fruits from a Staten Island population of *A. nantuckentensis* for relocation (Natural Resources Group 2001).

In Appendix 4 we provide additional discussion and guidance on evaluating the acceptability of visitation-related impacts and on a range of alternative management actions that can help sustain appropriate types and amounts of recreational activity while avoiding or minimizing associated resource impacts. This information is intended to assist managers in development of climbing and trail management plans. Attarian and Keith (2008) provide additional guidance and steps for developing such plans, and numerous agency climbing plans are available for download at the Access Fund's climbing management website: http://www.climbingmanagement.org/.

CONCLUSION

The National Park Service initiated this research study at GWMP and CHOH in response to concerns regarding the resource impacts of cliff-associated recreational activities and their need for information to inform park planning and management decision-making. This was accomplished by measuring visitor impacts to cliff-related trails, recreation sites, and to the cliff-faces, and in a companion study on trail impacts. Documentation of these recreation resource impacts provides an objective quantitative characterization of current conditions and provides useful baseline information for management planning and decision-making, and comparison with future assessments and monitoring.

This study revealed that recreational visitation does result in documented impacts to the natural resources of both parks. Park managers will consider these results when making determinations of their acceptability, developing management plans, and making decisions about management strategies and actions. Research implications and guidance are offered within the Discussion sections on alternative management planning frameworks and actions that can assist managers in avoiding or minimizing these impacts. For planning, we recommend consideration of the NPS VERP carrying capacity framework, possibly with an incorporation of the PVM process to provide an enhanced focus on the management of rare plants common to Potomac Gorge. For visitor impact management, we offer an array of site and visitor management options for cliff-associated recreation sites and the cliff-face. Furthermore, we offer the services of our research team for consulting on future planning and decision-making related to our work.

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APPENDIX 1: CLIFF RECREATION SITE MONITORING MANUAL

Great Falls & C&O Canal Parks[1,2]

(*version 7/2/06*)

This manual describes procedures for conducting inventories and resource condition assessments of recreation sites at the bases or tops of cliffs within Great Falls and C&O Parks. Procedures are also described for future reassessments to allow monitoring of site conditions over time. Three general approaches are used for assessing cliff site conditions: 1) photographs from permanently referenced photo points, 2) a condition class assessment determined by visual comparison with described levels of trampling impact, and 3) predominantly measurement-based assessments of several impact indicators.

The tops and bases of all cliffs were searched to locate and assess all cliff-associated recreation sites. Generally these sites were located by looking for recreational trampling disturbance-associated boundaries to vegetation (including vegetation height, cover, and/or composition), organic litter (pulverization and/or cover loss), or substrates (scuffing and/or footprints). Judgments based on site configurations and observed or likely use areas were sometimes required to determine when contiguous areas of exposed rock should be included within recreation site boundaries. Some recreation sites showed no obvious disturbance to these vegetation or substrate attributes (i.e., no clear disturbance-associated boundaries) but were identified by their clear cliff-top location at the end of a commonly used trail (e.g., a cliff-top vista site on bedrock).

Monitoring measurements should be taken near the middle or end of the visitor use season but before leaf fall. Site conditions generally recover during the fall/winter/spring periods of lower visitation and reflect rapid impact during early season use. Site conditions are more stable during the mid- to late-use season and reflect the resource impacts of that year's visitation. Subsequent assessments, if conducted, should be completed as close in timing to the original year's measures as possible. Generally monitoring should be replicated at about five-year intervals, unless conditions are changing rapidly.

Materials

❏ Topographic maps (1/24,000) with copier enlargements of areas with dense concentrations of sites (cut out and copy scale bars with enlargements)
❏ Compass, peephole type (not corrected for declination)
❏ Tape measure (100 ft. in tenths) and/or Sonin Combo Pro distance measuring device
❏ Field forms, maps, and photographs from previous surveys
❏ Flagged wire pins (25 minimum w/additional set of different color for remeasurement)
❏ Large reference point stake for attaching tape measure
❏ Digital camera, w/fully charged batteries, extra memory cards, computer/cords to download images
❏ Aluminum numbered tags, 4 in. galvanized steel nails
❏ Clipboard, monitoring manual, blank field forms (some on waterproof paper), pencils
❏ Backpacking trowel
❏ Magnetic pin locator (site remeasurement only)

1 - Developed by Dr. Jeff Marion, USGS Patuxent Wildlife Research Center, Field Station at Virginia Tech/ Department of Forestry (0324), Blacksburg, VA 24061 (540/231-6603) email: jmarion@vt.edu.

2 - Photographs illustrating site boundaries, boundary flag placement, vegetative ground cover classes, soil exposure, tree damage, and root exposure are part of this manual. High quality reproductions of these photographs, some of which are in color, may be found in: Marion, Jeffrey L. 1991. Developing a natural resource inventory and monitoring program for visitor impacts on recreation sites: A procedural manual. USDI, National Park Service, Natural Resources Report NPS/NRVT/NRR-91/06, pages 46-51.

General Cliff Site Information

1) **Site Number**: Each site must have a unique number. Refer to site maps and forms from earlier surveys to identify if the site has been previously surveyed. If it has, follow the site remeasurement procedures below. If the site has not been previously surveyed then assign a new number and record it on the form. For climb sites use initials for the name, followed by the climb number nearest the reference point, followed by T for top or B for bottom. For non-climb sites use the initials of the nearest formal trail. Criteria for locating the permanent reference point are provided in the Variable Radial Transect section of the manual. Reference points will typically be keyed to unique rock features, with a tag/nail combination used on sites with only soil substrates.

   Site remeasurement **-** Examine mapped site locations and field forms to determine if each site was present during the previous survey. Relocate permanent reference points with information from the form and use the magnetic pin locator if a tag and nail were buried. If the site has been previously surveyed but you are unable to locate the nail and tag then record the old number (if positively known) with a note that the nail and tag could not be found. If the reference point can be accurately identified from the previous survey form information and photo then do so, noting this on the new form. Use a new site tag and number, however, and record both old and new numbers on the form. If the reference point cannot be identified then proceed as if the site had never been surveyed before, recording new reference site information and the old and new tag numbers.

   Note – Guidance for odd/rare situations: 1) A satellite use area has become the main site and the previous site is now a satellite site or has recovered. Use the same site number from the earlier survey. Relocate and dig up the nail and tag from the old site. Rebury the nail in the original location, moving the tag along with a new nail to a permanent reference point location on the current site (which was formerly a satellite site). Complete all procedures on the current site. Describe the situation in the comments section. 2) The site was rehabilitated by park staff or has recovered on its own. Complete a new form to allow an evaluation of site recovery for any sites that you can find. Take a photo from previous survey photo points.

2) **Site Type**: Record the most specific applicable code: **L -** current site, also present in last survey; **N -** new site; **S -** current site, satellite in last survey; **RL -** rehabilitated, present in last survey; **RN -** rehabilitated, new site; **SRE -** site is recovered, rehab work evident; **SRN -** site is recovered, no rehab.

3) **Inventoried by**: Identify the initials of field personnel assessing the site.

4) **GPS**: Use a GPS device to obtain the position of the permanent reference point and place a check in space to verify it was done. Label the point feature with the site number. If necessary, do an offset to get an accurate site location. Later fill in the UTM Coordinate information.

5) **Date**: Month, day, and year the site was evaluated (e.g. July 1, 2006 = 07/01/06).

   Site remeasurement **-** Due to phenological and site use changes which occur over the use season, it is critical that sites be re-measured as close to the initial assessment month and day as possible, preferably within 1 to 2 weeks if early in the use season, 3 to 4 weeks if later.

6) **Location**: Record the cliff or climb area name from the PATC climbing guidebook: Tait, Alex, editor. 2001. Climbers' Guide to the Great Falls of the Potomac, second edition. Vienna, VA: Mountaineering Section, Potomac Appalachian Trial Club.

Comments: Comments concerning the site and its location: note any assessments that were particularly difficult or subjective, problems with monitoring procedures or their application, suggestions for clarifying monitoring procedures, descriptions of particularly significant impacts beyond site boundaries (quantify if possible), or any other comments you feel may be useful.

Inventory Indicators

7) **Site Expansion Potential**: P = Poor expansion potential - off-site areas are completely unsuitable for any expansion due to steep slopes, rockiness, dense vegetation, and/or poor drainage, M = Moderate expansion potential - off-site areas moderately unsuitable for expansion due to the factors listed above, and G = Good expansion potential - off-site areas are suitable for site expansion, features listed above provide no effective resistance to site expansion.

8) **Tree Canopy Cover**: Imagine that the sun is directly overhead and estimate the percentage of the site that is shaded by the tree canopy cover; record the mid-point value. Note: use "85.5" for nearly full to full tree canopy cover over the site; use "98" only if the cover is fairly dense or thick.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

9) **Rock Substrate**: Estimate the percentage of rock substrate within recreation site boundaries (see below). The rock may be bedrock, boulders, or cobble and barren or covered with lichens or moss. This category, plus soil substrates should equal 100%.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

10) **Use Type**: Mixed Climbing/Hiking = MCH, Mostly Climbing = MC, Mostly Hiking = MH Based on observations during field work and consultations with local recreationists and managers knowledgeable with the site. This can be revised at a later date if a more accurate estimate can be provided.

11) **Use Level**: Low = L, Moderate = M, Heavy = H Based on guidebooks and consultations with local rock climbers.

12) **Cliff Location**: Top = T, Base = B

13) **Climbs**: Record the number of climbs that begin or end along the recreation site's borders.

14) **Climb #'s**: Record the climb numbers from the PATC guidebook that begin/end along the site's borders.

Impact Indicators

The first step is to establish the sites' boundaries and measure its size. The following procedures describe the use of the **Variable Radial Transect Method** for determining the sizes of sites. This is accomplished by measuring the lengths of linear transects radiating from a permanently defined reference point to the site boundary. **If the site has previously been assessed with the Variable Radial Transect Method, then skip to the Site Remeasurement procedures below.**

Step 1. Identify Site Boundaries and Flag Transect Endpoints. Walk the site boundary and place flagged wire pins at locations which, when connected with straight lines, will define a polygon whose area approximates the site area. Use as few pins as necessary, typical sites can be adequately flagged with 10-15 pins. Look both directions along site boundaries as you place the flags and try to balance areas of the site that fall outside the lines with off-site (undisturbed) areas which fall inside the lines. Pins do not have to be placed on site boundaries, as demonstrated in the diagram in Figure 1. Project site boundaries straight across areas where trails enter the site. Identify site boundaries by pronounced human trampling-related changes in vegetation cover, vegetation height/disturbance, vegetation composition, surface organic litter, and topography (refer to photographs following these procedures). Many sites with dense forest overstories will have very little vegetation and it will be necessary to identify boundaries by examining changes in organic litter, i.e. leaves which are untrampled and intact vs. leaves which are pulverized or absent. In defining the site boundaries be careful to include only those areas that appear to have been disturbed from human trampling. Natural factors such as dense shade can create areas lacking vegetative cover. Do not include these areas if they appear "natural" to you. When in doubt, it may also be helpful to speculate on which areas typical visitors might use based on factors such as slope or rockiness. If you cannot discern trampling-related disturbance boundaries for most of the site then skip this procedure and record a 0 for site area (#27).

Step 2. **Establish Site Reference Point.** Select a site reference point which is preferably: a) visible from all the site boundary pins, and b) a distinctive location on bedrock or on a large immovable boulder. If no bedrock features are available then select a location that is near a tree in soil sufficiently deep to bury a numbered aluminum tag and galvanized nail. Reference this point to at least two relatively permanent and distinctive features. If trees are used select ones that are healthy and unique to the site area, such as an uncommon species or with unique physical characteristics (forked trunk or large size). Try to select reference features in three opposing directions, as this will enable future workers to triangulate the reference point location. Also take the reference point and site photograph(s) as described at the end of this manual.

For each reference feature, take a compass bearing (nearest degree) and measure the distance (nearest 1/10th foot) from the feature (center of trees or the highest point of boulders) to the site reference point. Also measure the approximate diameter of reference trees at 4.5 ft above ground (dbh). Be extremely careful in taking these bearings and measurements as they are critical to relocating the reference point in the future. Record this information on the back of the form.

Examples:
1) Red Maple, 2.9 ft. dbh, 8.9 ft. at 195^o (largest tree on site)

2) Boulder, 7.9 ft. at 312^o, (distance and bearing to highest point)

3) Sycamore, 1.8 ft. dbh, 8.4 ft. at 78^o, (only Sycamore in the area)

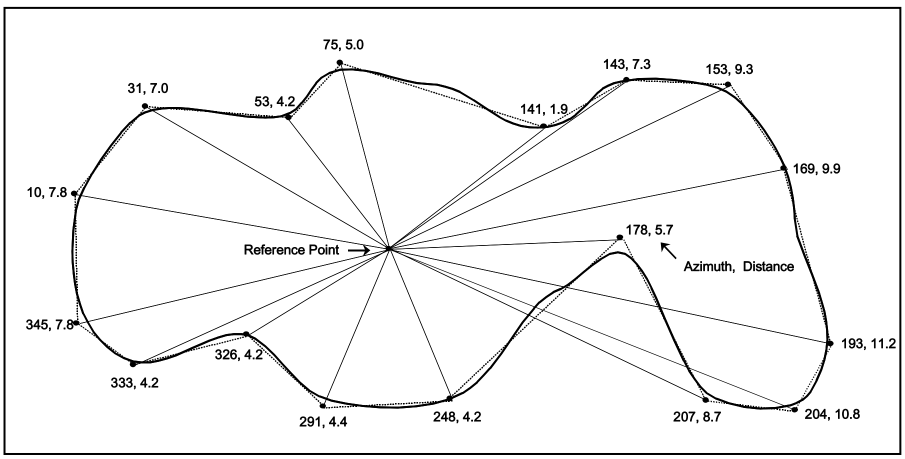


Figure 1. Variable radial transect method.

Step 3. **Record Transect Azimuths and Lengths.** Standing directly over the reference point, identify and record the compass bearing (azimuth) and distance to each site boundary pin working in a clockwise fashion (in the exact order you would encounter them if you were walking the site boundary). Be careful not to miss any pins hidden behind vegetation or trees. Be extremely careful in identifying the correct compass bearings to these pins as error in these bearings will bias current and future measurements of site size. If a tape measure is used, anchor the end to the large reference point stake and route it via the shortest distance around trees or other obstructions. Record the length of each transect (nearest 1/10th foot), starting with the same boundary pin and in the same clockwise order as before. Be absolutely certain that the appropriate pin distances are recorded adjacent to their respective compass bearings. Leave boundary pins in place until you finish all other site measurements.

Step 4. **Measure Island and Satellite Areas.** Identify any undisturbed "islands" of vegetation (≥ 3x3 feet) inside site boundaries (often due to clumps of trees or shrubs) and disturbed "satellite" use areas (≥ 3x3 feet) outside site boundaries (often due to tent sites or cooking sites). Use site boundary definitions for determining the boundaries of these areas. Use the **Geographic Figure Method** to determine the areas of these islands and satellites (refer to the Figure 3 diagrams at the end of the manual). This method involves superimposing one or more imaginary geometric figures (rectangles, circles, or right triangles) on island or satellite boundaries and measuring appropriate dimensions to calculate their areas. Record the types of figures used and their dimensions on the back of the form; the sizes of these areas should be computed in the office with a calculator. Also, record the compass bearing and distance from the center of each island or satellite site to the site reference point. Remove the reference point stake. Place a 4 inch long galvanized steel nail through the hole in the site number tag and bury at the reference point so that the tag is 3 inches deep.

Site Remeasurement - Relocate the reference point using point references, photos, and a magnetic pin locator. Typically the photo will get you in the right area and the pin locator will allow you to pinpoint the buried nail and tag. If you cannot find it then search for the three reference features, go to each and shoot the back azimuth (small number scale in the peep hole compass viewfinder). Use the tape measure to determine the correct distance and draw an arc on the ground. If the pin locator still does not register then repeat procedure from the other reference features and reestablish the reference point with a new tag and nail (note new site number on form and in database). Insert the large steel stake at the reference point location and reestablish all former site boundary pins using the previous transect data compass bearings and distances. Place wire flags on a single color at each the transect endpoints. Next, reassess these previous boundary locations using the following procedures (illustrated in Figure 2). Place wire flags of a different color at the end of each reassessed transect, both pre-existing and new (including transects whose length has not changed).

a) Keep the same transect length if that length still seems appropriate, i.e. there is no compelling reason to alter the initial boundary determination.

b) Record a new transect length if the prior length is inappropriate, i.e. there is compelling evidence that the present boundary does not coincide with the pin and the pin should be relocated either closer to or further from the reference point along the prescribed compass bearing.

c) Repeat earlier Steps 1 and 3 to establish additional transects where necessary to accommodate changes in the shape of site boundaries. Also repeat Step 4 to account for changes in island and satellite sites. If satellite areas are no longer disturbed, i.e. condition class 0, then note this in the Comments and do not remeasure their size.

d) Take and record new distances and compass bearings for transects that have changed in length and for new transects using the flags denoting current site boundaries. For transects that have not changed in length, copy the old transect data to the new forms (reassessing these would introduce measurement error). Record all transect data on the new form in the exact order you would encounter each transect if you walked the site boundary in a clockwise direction.

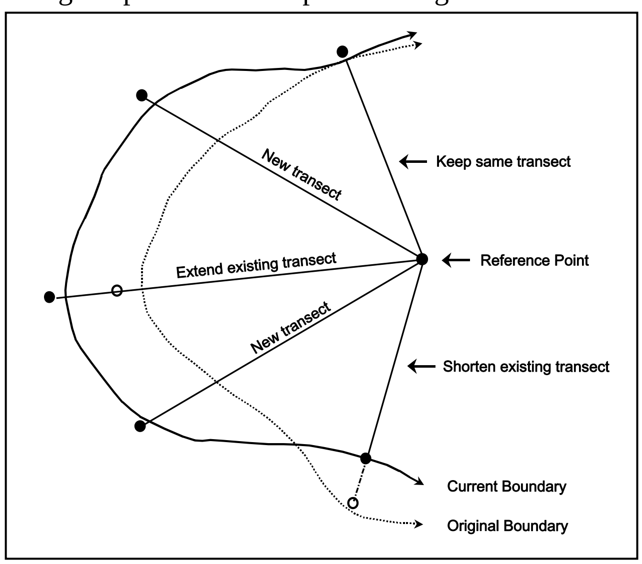


Figure2. Transect site remeasurement procedures.

These procedures are designed to eliminate much of the measurement error associated with different individuals making subjective judgments on those sites or portions of sites where boundaries are not pronounced. These procedures may only be used for sites whose reference points can be relocated.

15) **<u>Condition Class</u>**: Record a site Condition Class using the descriptions below.

Rock: Site is predominantly on rock surfaces. Clear boundaries based on trampling disturbance cannot be easily discerned.
Class 0: Site barely distinguishable; no or minimal disturbance of vegetation and /or organic litter. Often an old site that has not seen recent use.
Class 1: Site barely distinguishable; slight loss of vegetation cover and /or minimal disturbance of organic litter.
Class 2: Site obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3: Vegetation cover lost and/or organic litter pulverized on much of the site, some bare soil exposed in primary use areas.
Class 4: Nearly complete or total loss of vegetation cover and organic litter, bare soil widespread.
Class 5: Soil erosion obvious, as indicated by exposed tree roots and rocks and/or gullying.

16) **<u>Vegetative Ground Cover On-Site</u>**: An estimate of the percentage of live vegetative ground cover < 2 ft tall (including herbs, grasses, tree seedlings, shrubs, mosses, and folios (leaf-like) lichens) within the flagged site boundaries using the coded categories listed below (refer to photographs following these procedures). <u>Include any disturbed "satellite" use areas and exclude undisturbed "islands" of vegetation.</u> For this and the following two indicators, it is often helpful to narrow your decision to two categories and concentrate on the boundary that separates them. For example, if the vegetation cover is either category (6-25%) or category (26-50%), you can simplify your decision by focusing on whether vegetative cover is greater than 25%.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

<u>Site remeasurement</u> - Also evaluate vegetative ground cover within the site boundaries identified during the last measurement period.

17) **<u>Vegetative Ground Cover Off-Site</u>**: An estimate of the percentage of live vegetative ground cover < 2 ft tall (including herbs, grasses, tree seedlings, shrubs, mosses, and folios (leaf-like) lichens) in an adjacent "control" area that lacks human disturbance. Exclude crustose lichens, those that closely adhere to rock, as these are difficult to discern and are considerably less susceptible to trampling impacts. Use the categories listed above. The control site should be similar to the site in slope, tree canopy cover (extent of sunlight penetration), and other relevant environmental conditions. <u>The intent is to locate an area which would closely resemble the site area had the site never been used.</u> In instances where you cannot decide between two categories, select the category with less vegetative cover. The rationale for this is simply that the first visitors would tend to select a site with the least amount of vegetation. Note that if some of the substrates on the recreation site would likely be barren due to river flooding or exposed bedrock then the control substrates, or at a minimum, the control vegetation estimates, must reflect that.

<u>Site remeasurement</u> - Start by reexamining the off-site vegetative cover estimate from the last measurement period. Use this value only if it remains an appropriate estimate.

18) **<u>Exposed Soil</u>**: An estimate of the percentage of exposed soil, defined as ground with very little or no organic litter (partially decomposed leaf, needle, or twig litter) or vegetation cover, within the site boundaries <u>and satellite use areas</u> (refer to the photographs following these procedures). Dark organic soil, the decomposed product of organic litter, should be assessed as bare soil when its consistency resembles peat moss. Assessments of exposed soil may be difficult when organic litter forms a patchwork with areas of bare soil. If patches of organic material are relatively thin and few in number, the entire area should be assessed as bare soil. Otherwise, the patches of organic litter should be mentally combined and excluded from assessments. Code as for vegetative cover above.

Site remeasurement - Also evaluate exposed soil within the site boundaries identified during the last measurement period.

19-21) **Tree Damage**: Tally each live tree (>1 in. diameter at 4.5 ft.) within or on site boundaries to one of the tree damage rating classes described below (refer to the photographs following these procedures). **Include** trees within undisturbed "islands" and **exclude** trees in disturbed "satellite" areas. Assessments are restricted to all trees within the flagged site boundaries in order to ensure consistency with future measurements. Multiple tree stems from the same species that are joined at or above ground level should be counted as one tree when assessing damage to any of its stems. Assess a cut stem on a multiple-stemmed tree as tree damage, not as a stump. Do not count tree stumps as tree damage. Take into account tree size. For example, damage for a small tree would be considerably less in size than damage for a large tree. Where obvious, assess trees with scars from natural causes (e.g., lightning strikes) as None/Slight.

None/Slight..... No or slight damage such as broken or cut smaller branches, one nail, or a few superficial trunk scars or worn bark.

Moderate......... Numerous small trunk scars and/or nails or one moderate-sized scar. Abraded bark exposing the inner wood.

Severe............. Trunk scars numerous with many that are large and have penetrated to the inner wood; any complete girdling of tree (cutting through tree bark all the way around tree).

Site remeasurement - begin by assessing tree damage on all trees within the site boundaries identified in the last measurement period. Place boxes around each tally for trees in areas where boundaries have moved closer to the reference point, i.e., former site areas which are not currently judged to be part of the site. Next, assess tree damage in areas where boundaries have moved further from the reference point, i.e., expanded site areas that are newly impacted since the last measurement period. Circle these tallies. These additional procedures are necessary in order to accurately analyze changes in tree damage over time.

22-24) **Root Exposure**: Tally each live tree (>1 in. diameter at 4.5 ft.) within or on site boundaries to one of the root exposure rating classes described below. **Include** trees within undisturbed "islands" and **exclude** trees in disturbed "satellite" areas. Assessments are restricted to all trees within the flagged site boundaries in order to ensure consistency with future measurements. Where obvious, assess trees with roots exposed by natural causes (e.g., stream/river flooding) as None/Slight.

None/Slight..... No or slight root exposure such as is typical in adjacent offsite areas.

Moderate......... Top half of many major roots exposed more than one foot from base of tree. Generally indicative of soil loss of 2-4 inches.

Severe............. Three-quarters or more of major roots exposed more than one foot from base of tree; soil erosion obvious. Generally indicative of soil loss of >4 inches

Site remeasurement - Begin by assessing root exposure on all trees within the site boundaries identified in the last measurement period. Place boxes around each tally for trees in areas where boundaries have moved closer to the reference point, i.e., former site areas which are not currently judged to be part of the site. Next, assess root exposure in areas where boundaries have moved further from the reference point, i.e., expanded site areas that are newly impacted since the last measurement period. Circle these tallies. These procedures are necessary in order to accurately analyze changes in root exposure over time.

25) **Number of Tree Stumps**: A count of the number of tree stumps (> 1 in. diameter at ground and less than 4.5 feet tall) within or on site boundaries. **Include** trees within undisturbed "islands" and **exclude** trees in disturbed "satellite" areas. Do not include windthrown trees with their trunks still attached or cut stems from a multiple stemmed tree.

Site remeasurement - begin by assessing stumps within the site boundaries identified in the last measurement period. Place boxes around each tally for stumps in areas where boundaries have moved closer to the reference point, i.e., former site areas which are not currently judged to be part of the site. Next, assess stumps in areas where boundaries have moved further from the reference point, i.e., expanded site areas that are newly impacted since the last measurement period. Circle these tallies. These additional procedures are necessary in order to accurately analyze changes in stumps over time.

26) **Access Trails**: A count of all trails leading away from the outer site boundaries. For trails that branch apart or merge together just beyond site boundaries, count the number of separate trails at a distance of 10 ft. from site boundaries. Do not count extremely faint trails that have untrampled tall herbs in their tread.

27) **Total Site Area**: Using a computer program (contact Jeff Marion), compute the site size using the transect data. Using a calculator, compute and sum the area of each island and satellite site (see the *Geometric Figure Method* sheet for procedures and formulas). Record these values in the spaces provided on the back of the form and calculate the Total Site Area. Record this value on the front of the form to facilitate computer data entry.

Recommendations: Describe any site management recommendations or comments related to avoiding/minimizing resource impacts.

Site/Reference Point Photographs: If the site has not been previously surveyed, select a vantage point that provides the best view of the site and reference point location. Try to select a location that clearly shows the reference point location in relation to nearby trees or boulders. It is best to have a person stand at the reference point and point directly at the reference point. Take additional site photos where necessary to capture other parts of the site. Also take a separate reference point photograph from a closer position that clearly identifies this point in relation to permanent site features. Place the tape measure or some other object against the reference point stake so that it is clearly visible in the camera viewfinder. Take photos with the camera pointed down to include as much of the site groundcover as possible. The intent of these photos is to positively identify the site, record a visual image of its condition, and to assist in relocating the permanent reference point.

If the site has been previously surveyed, relocate the photo points by looking through the viewfinder and positioning yourself to replicate each earlier site photograph. Frame your photo and adjust the zoom lens if necessary to include the same area depicted in the earlier photo(s). If the site has expanded to areas that are not visible in the viewfinder then turn the camera to capture these areas or move back if necessary. ***Photo description procedures***: Use the photo description space to record the photo numbers and to write something unique about each photo that will allow someone to recognize and label the photo for this site.

* **Bury reference point nail and tag (if used) about 3 inches deep, compact soil with foot. Collect all site boundary pins, the reference point stake, and all other equipment.**

Equipment Use Procedures

Use of Peep Hole Compasses: Hold the compass level with the viewfinder close to your eye and away from any metal objects. The top of the white floating scale should be centered in the viewfinder. With your chin over the reference point, align the object with the vertical black line in the viewfinder. Hold the compass very steady, allowing the compass scale to come to a rest. Read and record the bearing to the nearest degree. Be careful in reading the bearing from the scale, use large numbers (small numbers are the back azimuth) and note that scale values decrease from left to right. Large-scale interval is 5 degrees, smallest interval is 1 degree. Practice and periodically compare compass readings with your partner to verify their accuracy. (Cost: $42)

Use of Sonin Combo Pro: Read the Sonin manual. We will only use it in the target or dual unit mode. Turn main receiver unit on by pressing switch up to the double icons, turn target unit on and slide the protector shield up. The units power down automatically after 4 minutes of inactivity. Position units at opposite ends of segment to be measured, pointing the receiver sensors in a perpendicular orientation towards the target sensors. **Note:** The measurement is calculated from the base of the receiver and the back of the target, position units accordingly so that you measure precisely the distance your intended. Press and hold down the button with the line over the triangle symbol. The receiver will continue to take and display measurements as long as you depress the button. Wait until you achieve a consistent measurement, then release the button to freeze the measurement. Measures initially appear in feet/inches. To obtain conversions, press and hold the "C" button until the measure is converted to the units you want (tenths of a foot). Turn both devices off and store in protective case following use. Unit range is supposed to be 250 ft; be careful and take multiple measures for distances over 100 ft. Under optimal conditions accuracy is within 4 in. at 60 ft. Device can be affected by temperature, altitude and barometric pressure, and noise (even strong wind). The units are not waterproof. **Batteries**: Carry spare batteries (2 9-volt alkaline). (Cost: $185)

Geometric Figure Method

This method for determining the area of sites, disturbed "satellite" sites, and interior undisturbed "island" sites is relatively rapid and can be quite accurate if applied with good judgment. Begin by carefully studying the site's shape, as if you were looking down from above. Mentally superimpose and arrange one or more simple geometric figures to closely match the site boundaries. Any combination and orientation of these figures is permissible, see the examples below. Measure (nearest 1/10th foot) the dimensions necessary for computing the area of each geometric figure. It is best to complete area computations in the office with a calculator to reduce field time and minimize errors.

Good judgment is required in making the necessary measurements of each geometric figure. As boundaries will never perfectly match the shapes of geometric figures, you will have to mentally balance disturbed and undisturbed areas included and excluded from the geometric figures used. For example, in measuring an oval site with a rectangular figure, you would have to exclude some of the disturbed area along each side in order to balance out some of the undisturbed area included at each of the four corners. It may help, at least initially, to place plastic tape or wire flags at the corners of each geometric figure used. In addition, be sure that the opposite sides of rectangles or squares are the same length.

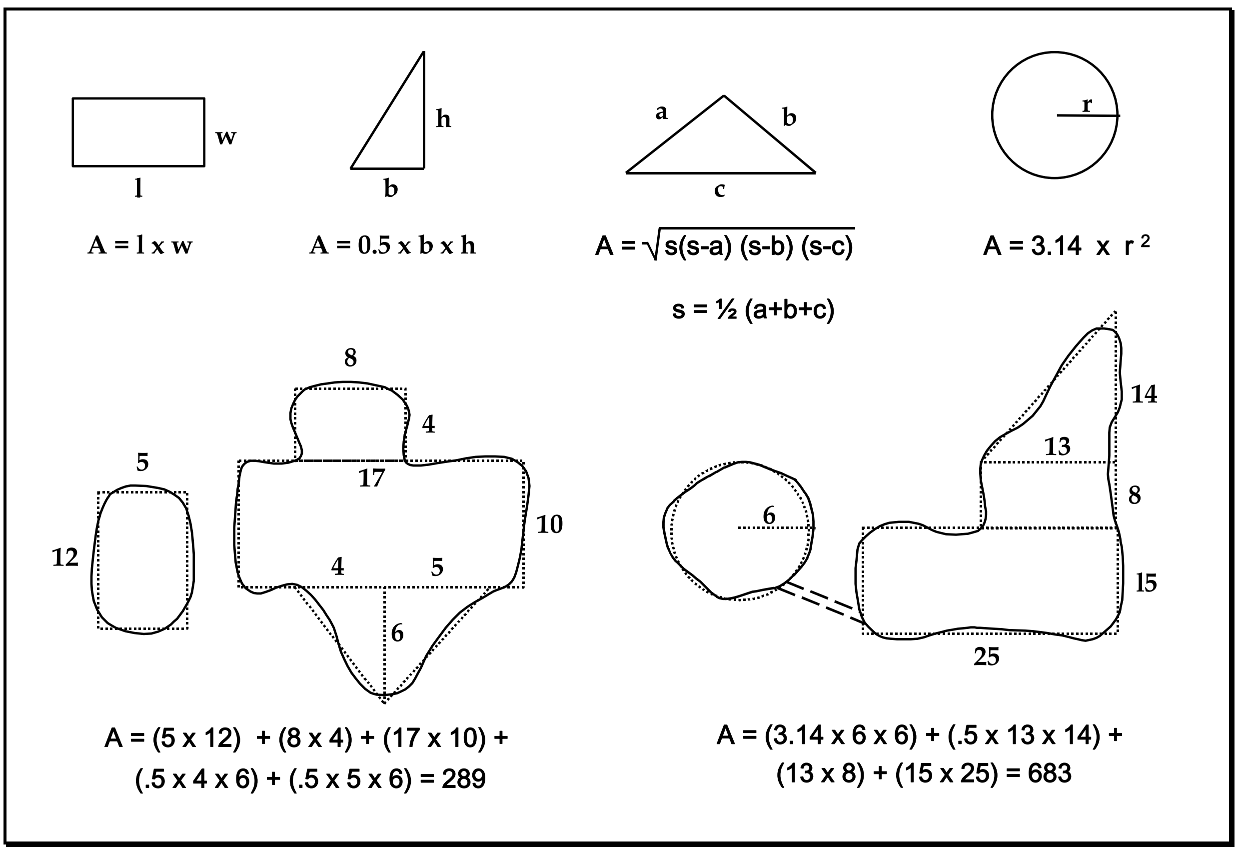


Figure 3. Geometric figure method for assessing site sizes.

Cliff Site Visitor Impact Monitoring Form, Great Falls & C&O Canal Parks

ver. 7/2/06

General Site Information

1) Site Tag No. ____________ 2) Site Type ______ 3) Inventoried by: _______________________

4) GPS: ____ UTM Coordinates: _____________________________

5) Date _ _ / _ _ / _ _ 6) Location: ____________________________

Comments: ____

____

____

Inventory Indicators

7) Site Expansion Potential: P M G _____

8) Tree Canopy Cover: (%, use item 16 midpoint categories below) _____

9) Rock Substrate: (%, use item 16 midpoint categories below) _____

10) Use Type: Mixed Climbing/Hiking = MCH, Mostly Climbing = MC, Mostly Hiking = MH _____

11) Use Level: Low = L, Moderate = M, Heavy = H _____

12) Cliff Location: Top = T, Base = B _____

13) Climbs: (#) _____

14) Climbs #'s that begin/end at site: ____

Impact Indicators

-- Apply Variable Radial Transect Method --

15) Condition Class (0 to 5) _____ ***Previous B.***

16) Vegetative Ground Cover On-Site (Use categories below) _____ _____

	(0-5%	6-25%	26-50%	51-75%	76-95%	96-100%)
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

17) Vegetative Ground Cover Off-Site (Use categories above) _____ _____

18) Exposed Soil (Use categories above) _____ _____

19-21) Tree Damage None/Slight ____________________ Moderate ______________________ Severe _________

22-24) Root Exposure None/Slight ____________________ Moderate ______________________ Severe _________

25) Tree Stumps (#)______________________ _____

26) Access Trails (#) _____

27) Total Site Area (Office) _____ft^2

Cliff Site Visitor Impact Monitoring Form, Great Falls & C&O Canal Parks

ver. 7/2/06

Recommendations:____

____

____

____

Site Photo: Photo: ____

____

Ref. Pt. Photo: ____

<u>Site Reference Point Information</u> <u>Bearing Distance dbh</u>

1)

2)

3)

Bury Nail/Tag ___

<u>Satellite Site Dimensions</u> <u>Bearing Distance</u>

<u>Island Site Dimensions</u> <u>Bearing Distance</u>

Area from computer program ________

\+ Satellite Area ________

~ Island Area ________

= Total Site Area ________ ft^2

Transect Data

	Bearing	Distance (ft)	Climb #'s
1)			
2)			
3)			
4)			
5)			
6)			
7)			
8)			
9)			
10)			
11)			
12)			
13)			
14)			
15)			
16)			
17)			
18)			
19)			
20)			
21)			
22)			
23)			
24)			
25)			

APPENDIX 2: CLIFF-FACE ASSESSMENT PROTOCOLS

Quad Data Sheet- Physical
Potomac Gorge Cliff Study, Great Falls, VA

Date: __________ Start time: ________ Data recorder: ___________ Others: ________________

Transect #: _________ Position along transect (m): ________

Slope (°): _________ Aspect (°M): __________

Distance to top of cliff (m): _____ Distance to base of cliff (m): ____

Overhang above quad - Length: _____ Depth: ____

Nearest climb route - name/#: _________________ Distance (m): ______ Direction: _________

Nearest other disturbance: _____________________ Distance (m): ______ Direction: _________

Evidence of human use/impact: _________ *(P= Pristine, S=Slight, I=Intermediate, H=Heavy)*

Rock types: __________________________

Angle of river current (°M): __________ Comments: ______________________________________

Surface roughness (cm) - Vertical: ____________________ horizontal: ___________________

Water drainage into quad: ____

F #	Type	Slope Angle (°)		Feature Size (cm)			Soil Volume (cm)			Vasc. Plants (#)	Comments
		cross quad	in /out	length	depth	width	length	depth	width		
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											

Photos - camera: __________ Photo number(s): __________________

Overall comments: ____

Transect Data Sheet

Potomac Gorge Cliff Study, Great Falls, VA

Date: __________ Start time: ________ Data recorder: ___________ Others: ________________

Transect #: ________ bearing (°M): _______ length (m): _______ # quads: ________

	Garmin wpt #	Trimble wpt #	Camera	Reference photo #	reference photo °M	Comments on end points / overview
Start pt						
End pt						
Overview						

Transect profile view (looking upstream)

View towards rock

Item #	Dist (m)	Feature description (climbs, quads, other veg, trail….)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Item #	Dist (m)	Feature description (…, cliff high pt, river edge…)
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

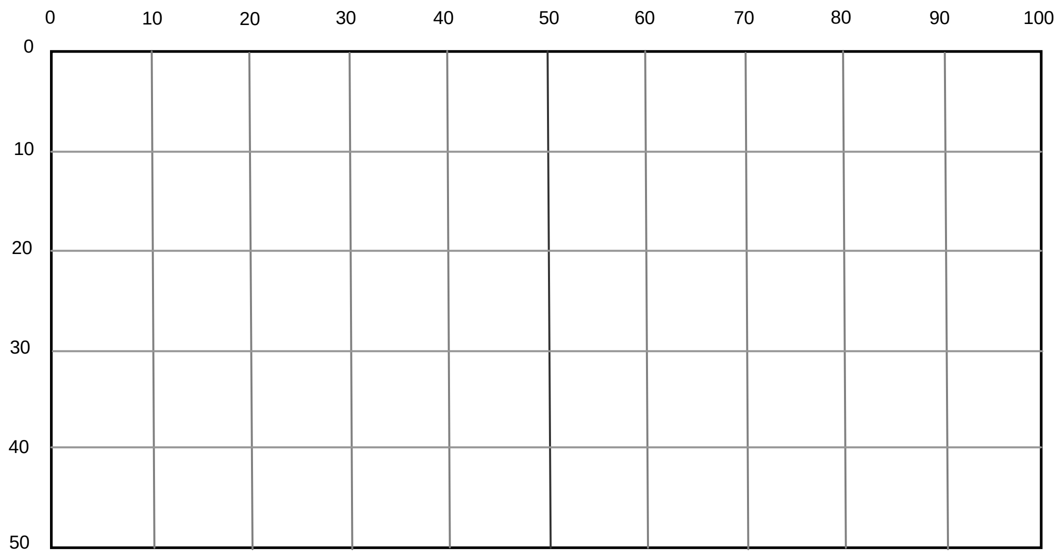
Comments:

Quad Data Sheet- Feature ID

Potomac Gorge Cliff Study, Great Falls Park, VA

Date: __________ start time: ________ Surveyors: __________________________________

Transect #: _________ Position along transect (m): ________



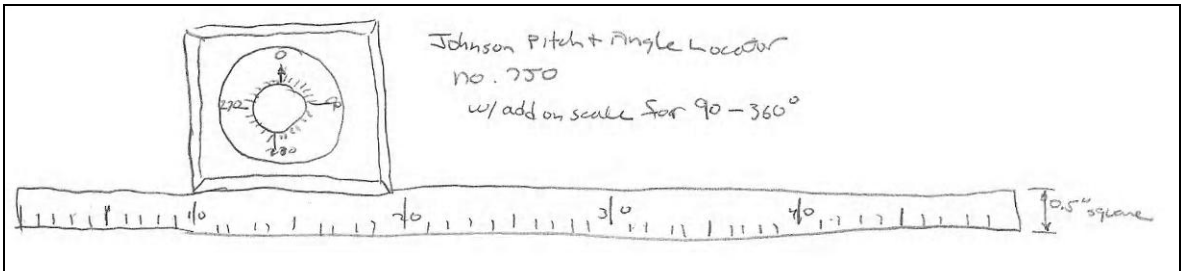
Measuring Tools: Cliff Geometry

This section summarizes tools used to measure the physical features of the cliff.

I. Quadrat frame:

The quadrat frame is 0.5 m tall by 1.0 m wide. The frame was fabricated from 1.5 by 0.5 inch thick wood. The dimension lines around the quad frame (and the center reference string) divide the quad frame into a measurement grid. The grid was used to accurately sketch the geofeatures on the data sheet. The grid divides the quad into 50 squares of 2% each to guide estimates of plant cover. All physical measurements of rock features in the quad were made by one person, as were all plant cover estimates. The quad position along the transect line is measured from the top inside edge of the quad. The quad frame is bolted at the corners to fold for easy transport.

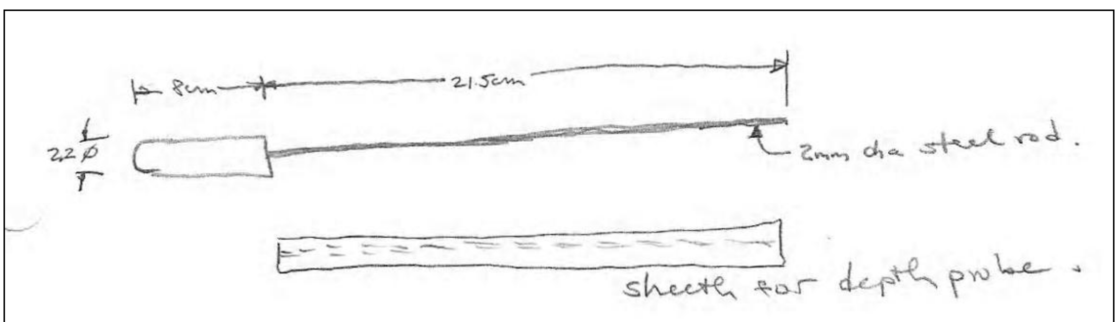
II. Angle and length measurement:



The angle and length measuring tool was made by attaching a “Johnson Pitch and Angle Locator, model 750 to a 0.5 inch square piece of wood. The wood was marked with a scale from 0 to 50 cm. The tool was used to measure the dimensions of the geofeatures, the cross slope angle of the geofeatures, and the slope of the quad.

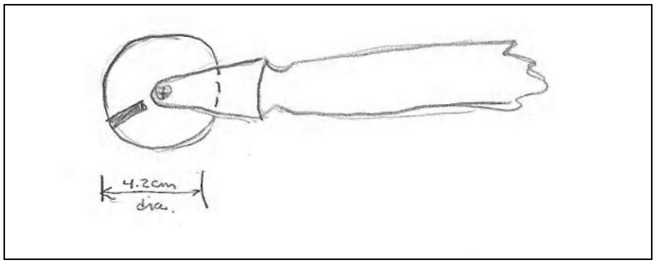
The Johnson Pitch and Angle Locator displays the angle by means of a floating needle. The needle uses gravity to indicate the vertical direction. The scale around the device indicates the orientation of the device. The device comes with a 0 to 90° scale. We added a 0 to 360° scale.

III. Crack and crevice depth probe:



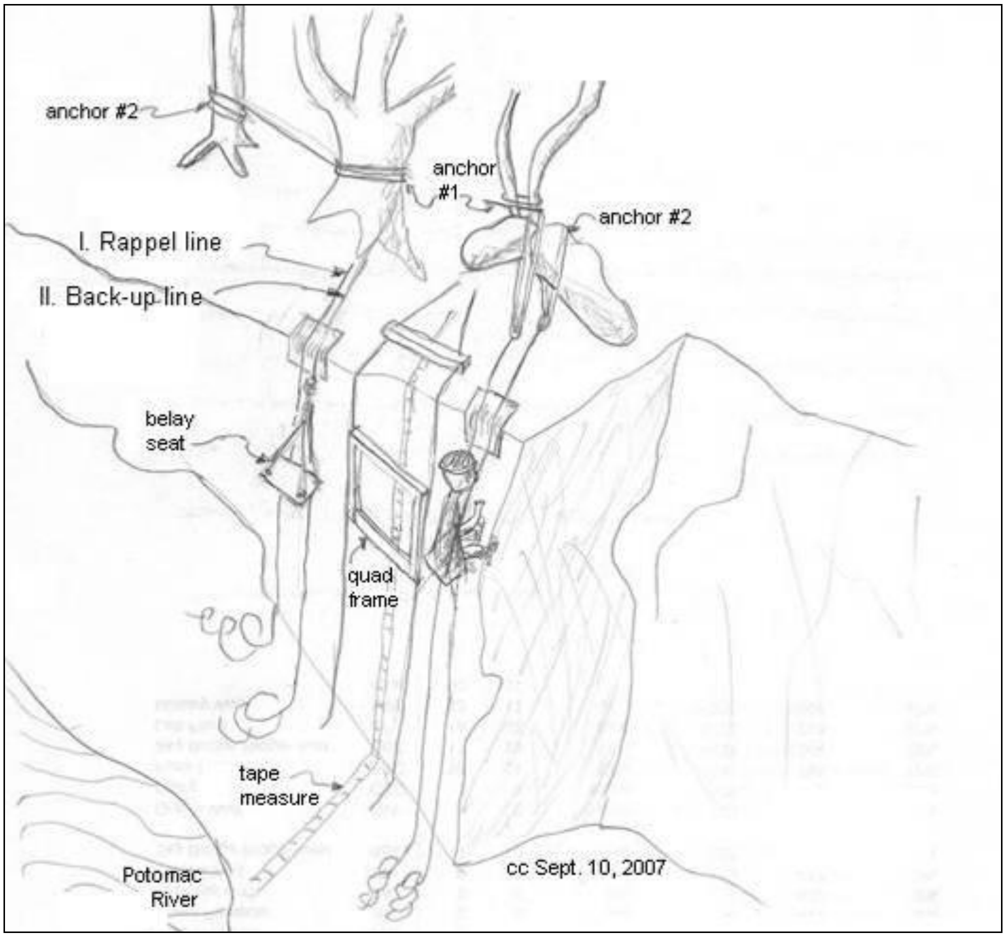
The probe can measure cracks up to 21.5 cm deep—assuming the crack is not curving. The probe can measure cracks larger than 0.2 cm in width.

IV. Surface roughness wheel:



This tool measures surface roughness by measuring the number of revolutions of the wheel necessary to follow the rock surface from one side of the quad frame to the other. The wheel is 4.2 cm in diameter. If the rock surface is flat the wheel will turn 7.6 revolutions when covering the 1.0 m width of the quad frame. Surface roughness increases the number of revolutions. The ratio between the actual number of revolutions and 7.6 revolutions is an indication of roughness. The wheel diameter sets the lower limit on the roughness that can be measured.

Rappel Rigging



The sketch above illustrates the safety procedures for rappelling down cliffs to collect data. The key is multiple safety systems. If there is a failure or error in one system, there is a backup to reduce the risk of injury. Two complete systems were built. One system is for the person collecting physical data and one for the person collecting botanical data. Each system consists of a rappel line and a back-up line. Each of the lines is connected to two anchors. On the cliff-face, each line is connected to the researcher in two ways (a total of four connections for the two lines). The rappel line is connected to a belay device (e.g. Black Diamond ATC) followed by an autoblock knot connected to the leg loop of the climb harness. The back-up line connects to the climb harness and the belay seat with a Petzl Grigri followed by a prussic knot.

Since it is very uncomfortable and potentially dangerous to sit in a climb harness for long periods of time, we used wooden “belay seats” (Bosun’s Seat). When the researcher rappels to the proper level on the cliff, they transfer their weight from the climb harness to the belay seat. The lines to the climb harness are left a little slack. Once in position, an overhand knot is put in the ropes below the autoblock or prussic knots (as an additional backup). As an additional safety measure for anyone below the researchers, all the tools and gear used by the field staff on rappel are “leashed” to the person (e.g., cameras tape measures, clipboards, and other measurement gear). Photos below illustrate the safety lines and field gear in use during the cliff-face assessments.

Plant Cover Assessment Methods

We identified all vascular plants originating within each quadrat, noted their co-occurrence with a particular geofeature, and estimated their relative coverage within the quadrat perspective. In addition, we noted coverage in each quadrat from plants originating outside of the quadrat. Since plots occurred on surfaces that varied from generally level (cliff-tops, cliff-bottoms) to perpendicular (cliff-faces), cover by vascular plants was estimated in two separate tiers. First, estimates were made for plants originating in the plot and were judged by a perpendicular perspective through the quadrat frame at the perpendicular projection of the quadrat frame to the substrate. Consequently, quadrats frames did not sample equal surface areas, but rather the perpendicular vector of cover occurring within the view. These features were judged from head height looking down at the quadrat (or on the cliff-face a body distance away from the cliff-face). The purpose of these cover estimates was to estimate the occurrence and relative dominance of each species originating in a geofeature and combined to give a estimate of the coverage conditions in the near vicinity of the herbaceous plants occurring within a quadrat.

Category	Cover Type
Bryophyte	Acrocarp/cleistocarp Pleurocarp Leafy liverwort Thallose liverwort
Lichen	Fruticose/umbilicate Crustose Foliose Squamulose
Other Surface Cover Types	Soil Bare rock Plant litter Water
Vascular Plant	Tree Shrub Woody vine Herbaceous vine Forb Grass Sedge Rush Fern and allies

Cover Types

Resistance to and recovery from natural and anthropogenic disturbances depend on the structural form of the cover, so we emphasized quantifying the various forms of vascular plants, bryophytes, and lichens present within the quadrats based on their life forms (see text box).

Estimating Quadrat Cover

The typical sequence of estimating coverage proceeded by first making estimates at the surface/air interface. This surface is comprised of lichen forms, bryophyte forms, or other surface cover types; generally these cover types summed to 100 percent. Coverage estimates were facilitated by marks at 10 cm intervals on the entire quadrat frame. Secondly, coverage for each vascular plant originating within the quadrat was estimated separately; then estimates of coverage for vascular plants originating outside of the quadrat.

A separate aspect of cover was judged for each quadrat, namely, overhead cover and lateral cover. Since transects included quadrats in level forested cliff-tops, vertical cliff-faces, and rolling rocky bottoms, the quadrats could have very different orientations depending on their position along the transects. Overhead and lateral cover are estimates of the contextual exposure of the quadrat. For overhead cover we conceptually projected a horizontal quadrat frame vertically above the center of the quadrat site and estimated the cover by shrub/tree canopy on cliff-top sites or rock overhang on cliff faces. Lateral cover is most relevant as a measure on vertical cliff faces where the greatest exposure is usually from a lateral direction. Here, lateral cover was an estimate of the openness toward the river. We conceptually projected a vertical quadrat frame horizontally centered on the quadrat site and estimated the cover by the amount of vegetation/rock/soil or rock that intervened between the quadrat site and the open river.

Plant Identification

Plants of Great Falls Park are well documented, including a recent revision of the flora of the Park (Steury *et al.* 2008), a "bio blitz" survey in 2007 (Evans 2008), and vegetation research by the Virginia Natural Heritage Program (http://www.dcr.virginia.gov/natural_heritage/ncPIj.shtml; http://www.dcr.virginia.gov/natural_heritage/ncPIk.shtml). Most vascular plants were identified in the field and were not vouchered. In several instances though, vouchers were collected where plants were immature or senescent, which made field identification difficult. Voucher specimens were taken from adjacent occurrences.

We photographed each plot for later general visual reference, but photographs were not controlled for distance and angle because the rock surface defined by the rigid plot frame was 3-dimensional and the perspective distortion by the camera lens means that portions viewed around the interior edge of the quadrat frame of the images are often outside of the plot.

Database Notes

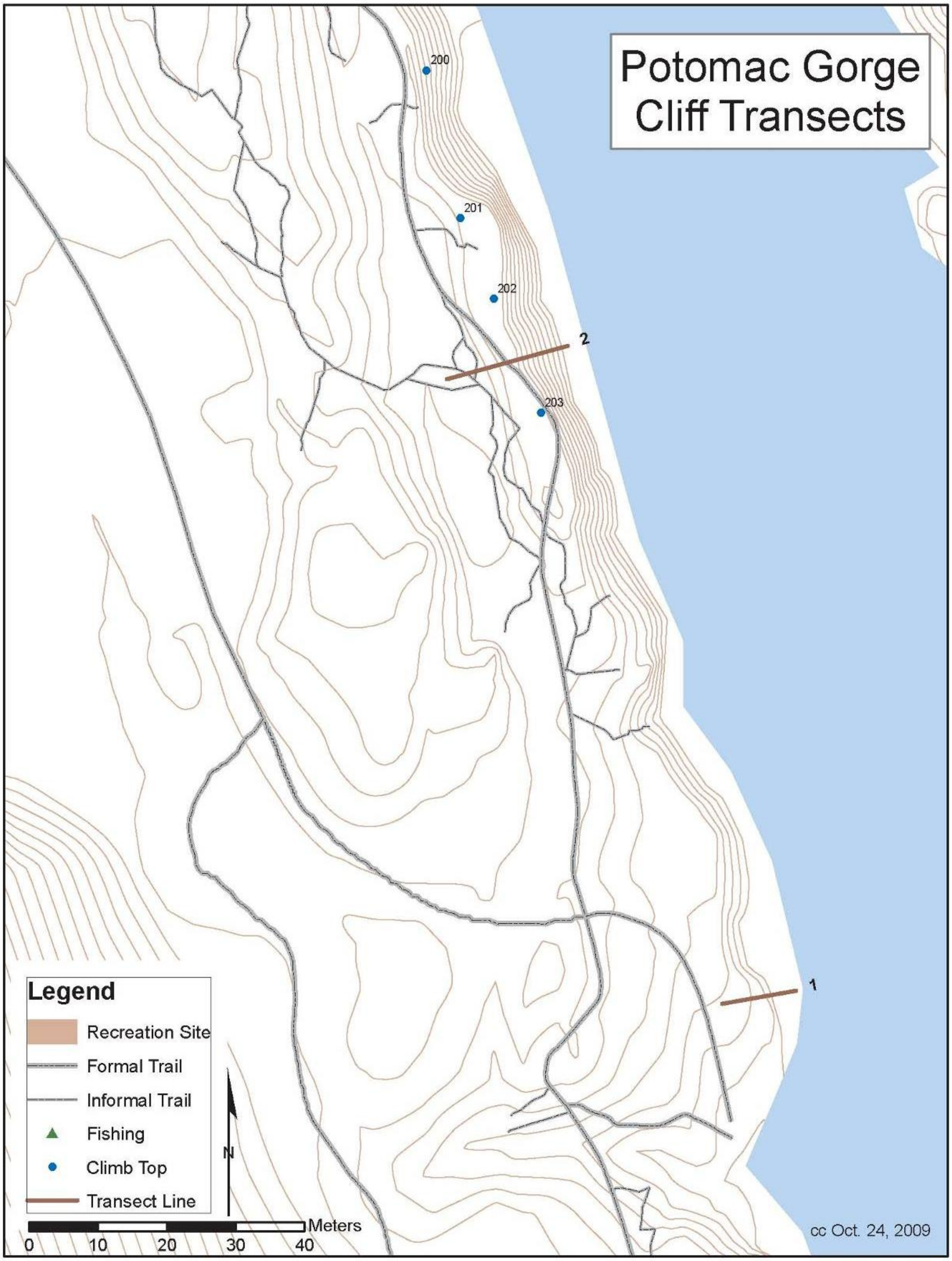
The ***Plant and Lichen Cover*** portion of the database contains three tables: Quadrat Cover, Plants in Features, and Cover Characters.

Quadrat Cover: This box contains the cover estimates for vascular plants, lichen growth forms, bryophyte growth forms, soil, plant litter, and rock, as well as, the horizontal and vertical total cover estimates. All coverages are assigned a Cover Type and analyses using whole quadrat measures rely on this table. Coverage by individual 'plants in features' are entered here as a cumulative value for each species. Plants originating outside of the quadrat but contributing to overhead cover are also listed. Note that the cover of a tree seedling may be summed with the cover of that same species estimated as overhead cover. Also that in early fieldwork we only estimated overhead coverage without noting the species, consequently some overhead cover estimates in this table indicate 'Vascular Plant – Tree' with no species name indicated.

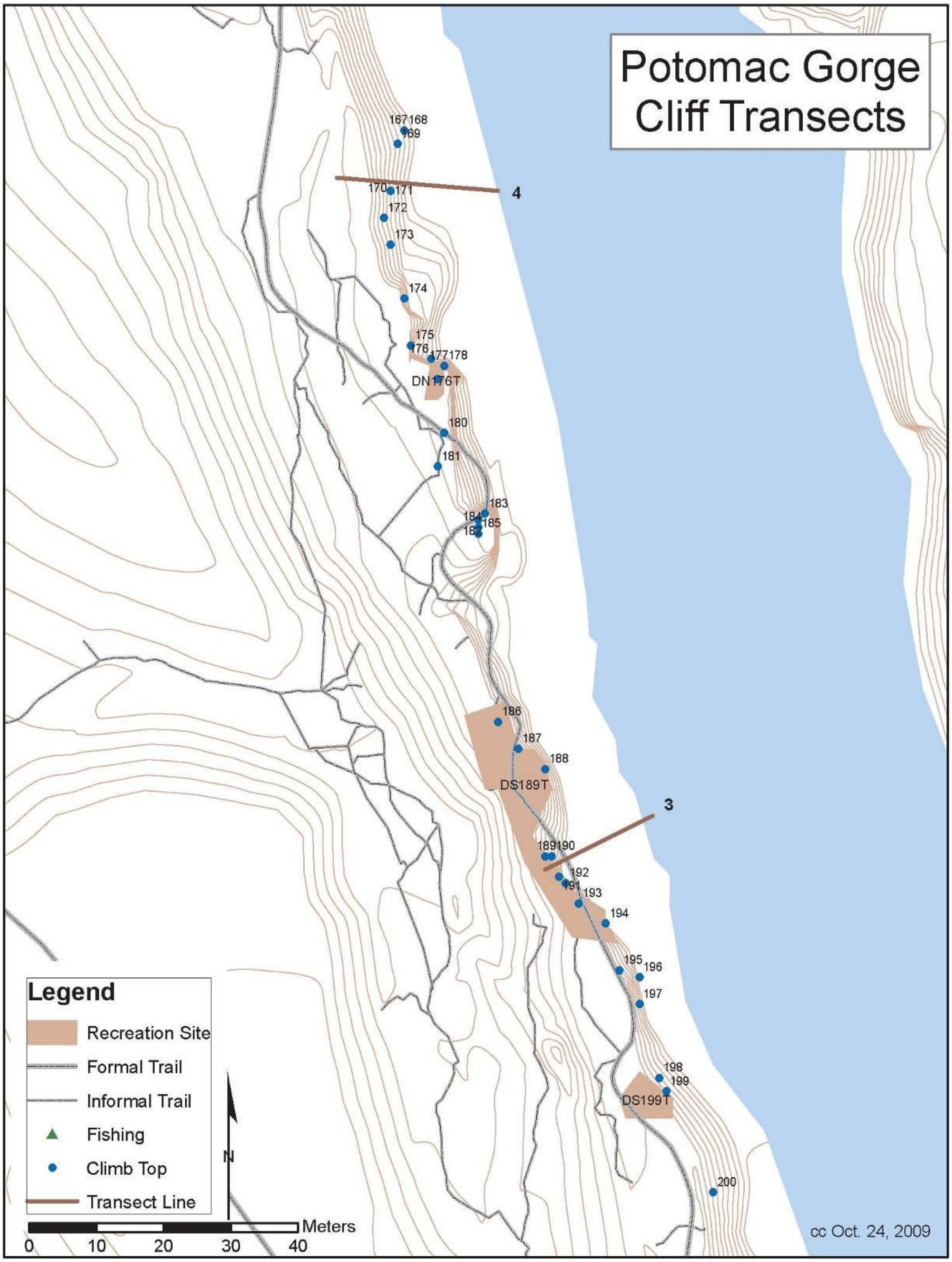
Plants in Features: This box contains estimates of vascular plant species coverage by Geo-Feature. Vascular plants originating outside of the quadrat are assigned '97' as a Geo-Feature code so they can be filtered from this table for analyses. Overhead cover trees are also listed here and assigned a code of '97'.

Cover Characters: Since lichens and bryophytes were not identified to species during this study, this table contains some further descriptors of the various lichens (primarily described by color); some notes on bryophytes are also included. This information may be most useful for follow-up surveys to identify potential unique occurrences of particular lichens and bryophytes.

APPENDIX 3: MAPS OF CLIFF-ASSOCIATED RECREATION SITES, CLIMBS, TRANSECTS, AND TRAILS



Contour interval = 5 ft.


Potomac Gorge
Cliff Transects
167168
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172
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174
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177178
DN176T
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183
184
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188
DS189T
3
189190
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191
193
194
195
196
197
198
199
DS199T
200
Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
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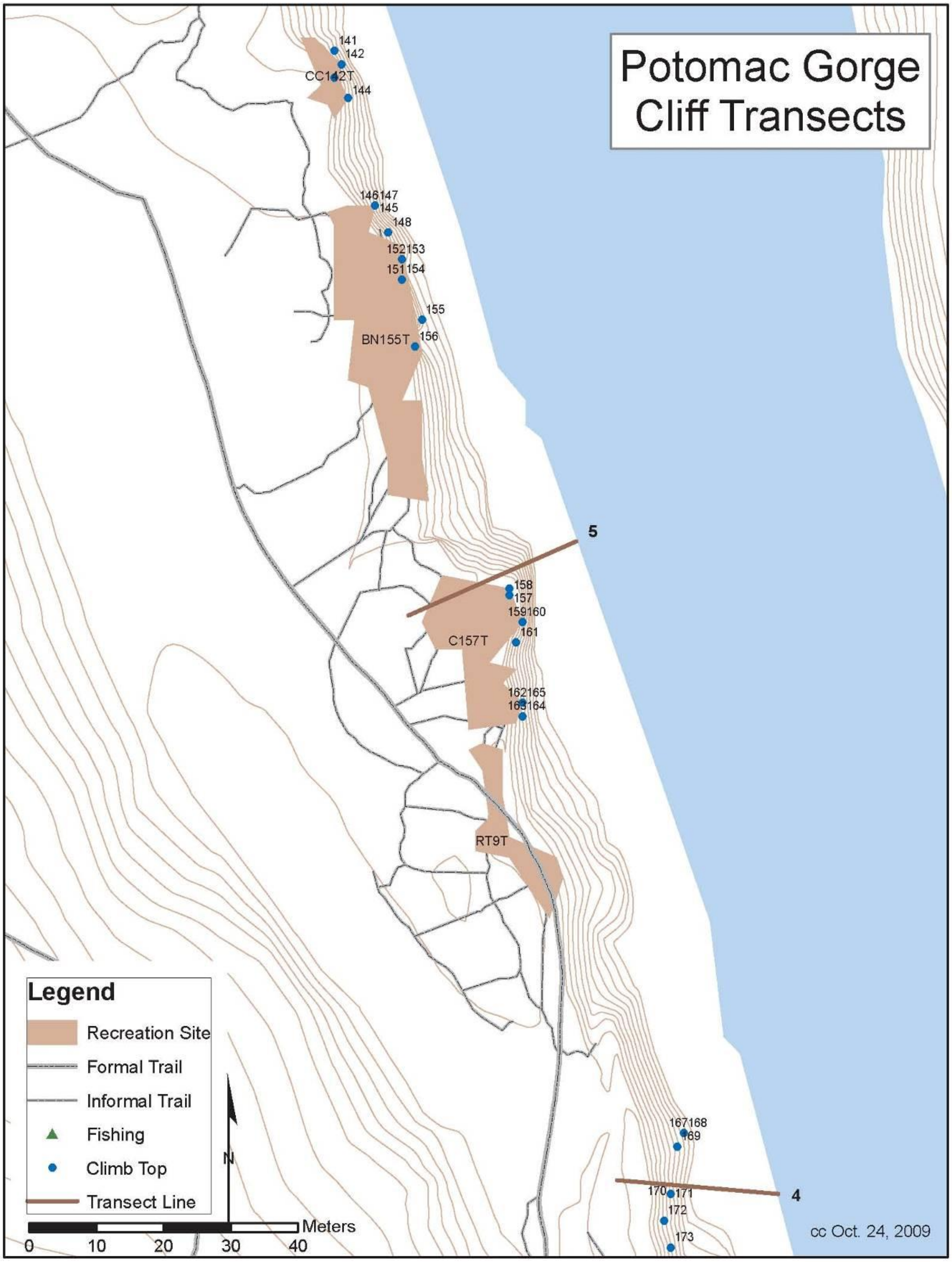
40
Meters
cc Oct. 24, 2009


Potomac Gorge
Cliff Transects
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148
152153
151154
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BN155T
156
5
158
157
159160
161
C157T
162165
163164
RT9T
167168
169
170
171
4
172
173
Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
N
Meters
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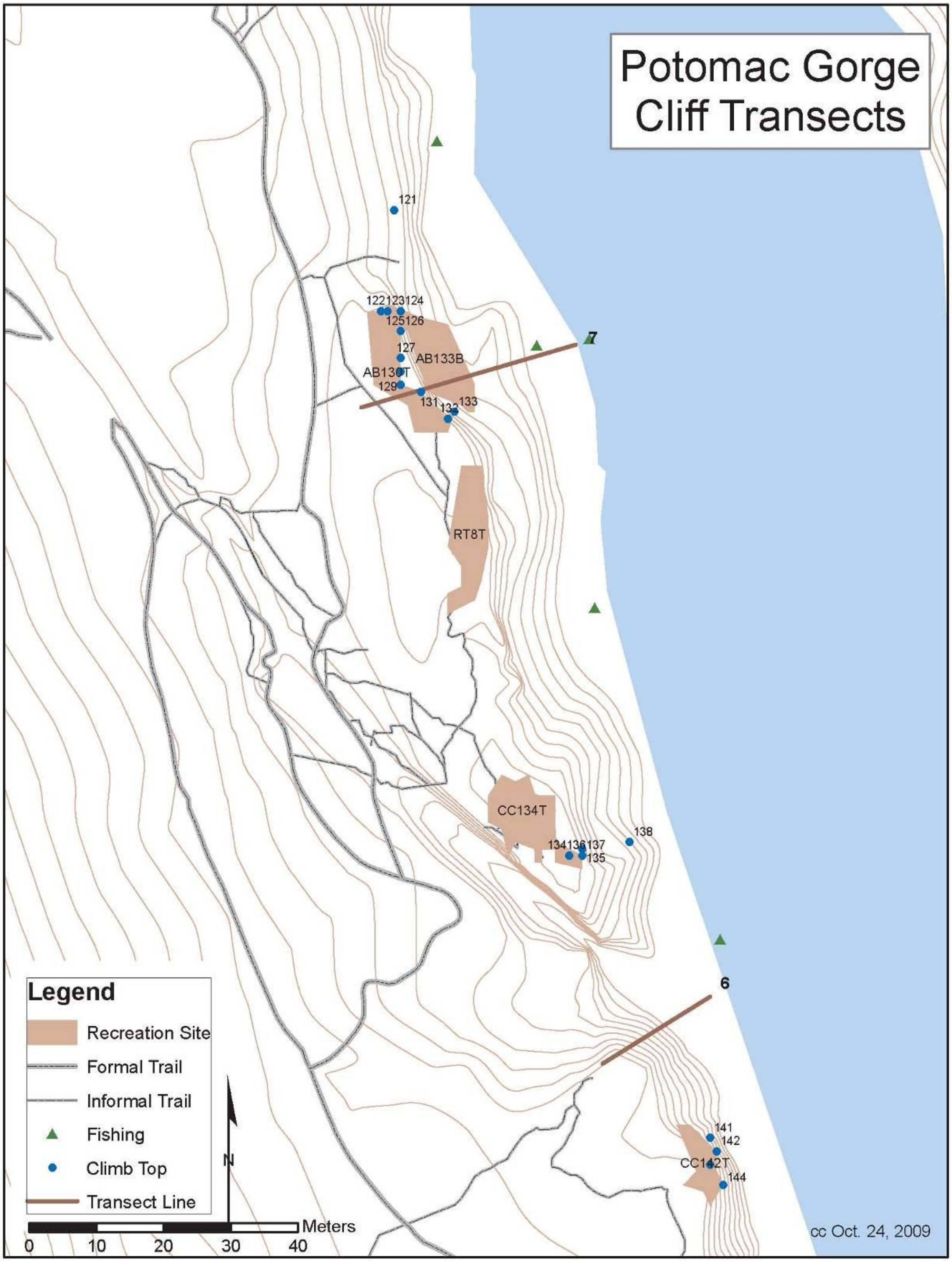
cc Oct. 24, 2009


Potomac Gorge
Cliff Transects
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AB133B
AB130T
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RT8T
CC134T
134136137
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142
CC142T
144
Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
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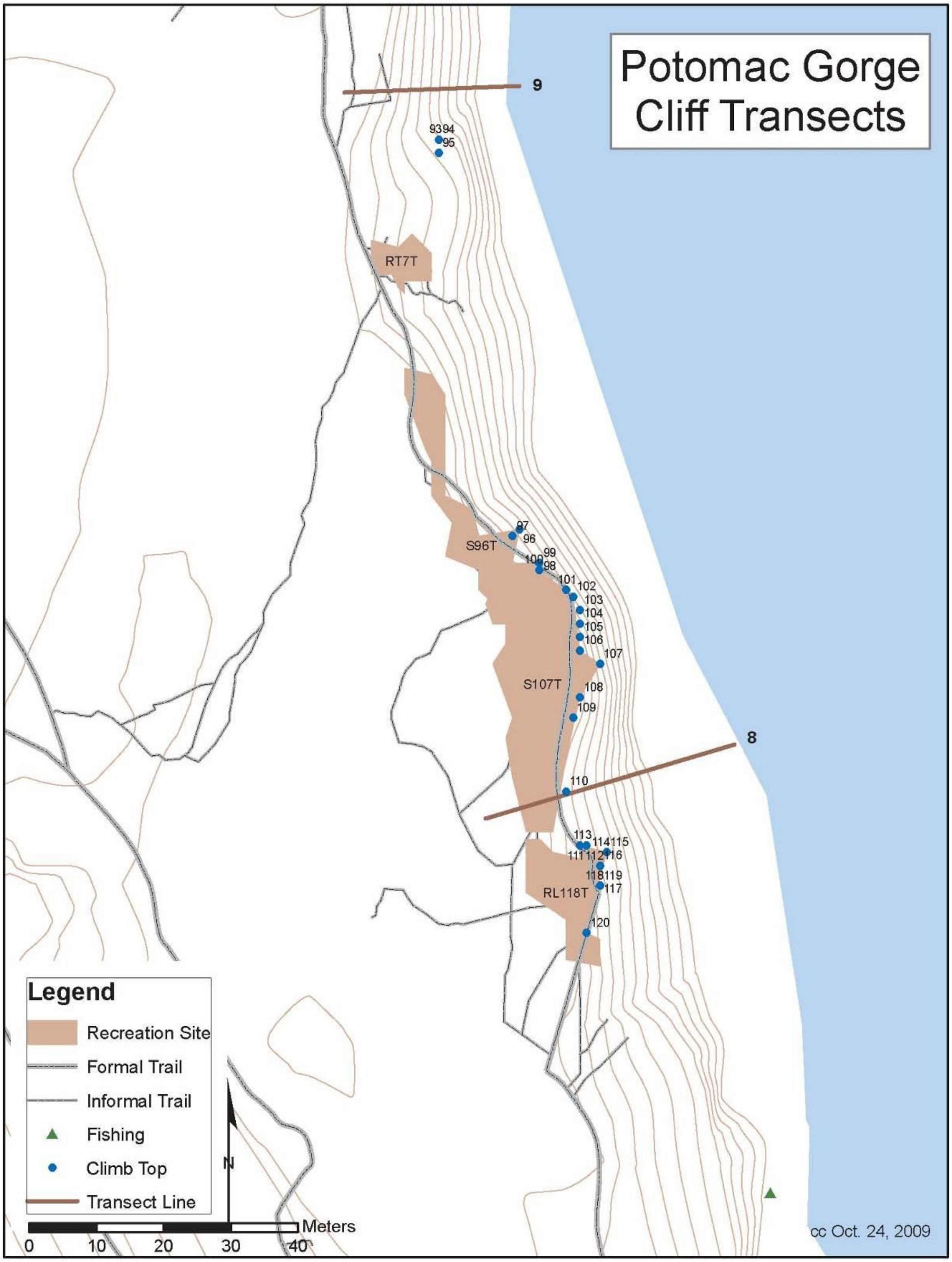
Meters
0 10 20 30 40
cc Oct. 24, 2009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Cliff Transects
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8
RT7T
S96T
S107T
RL118T
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Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
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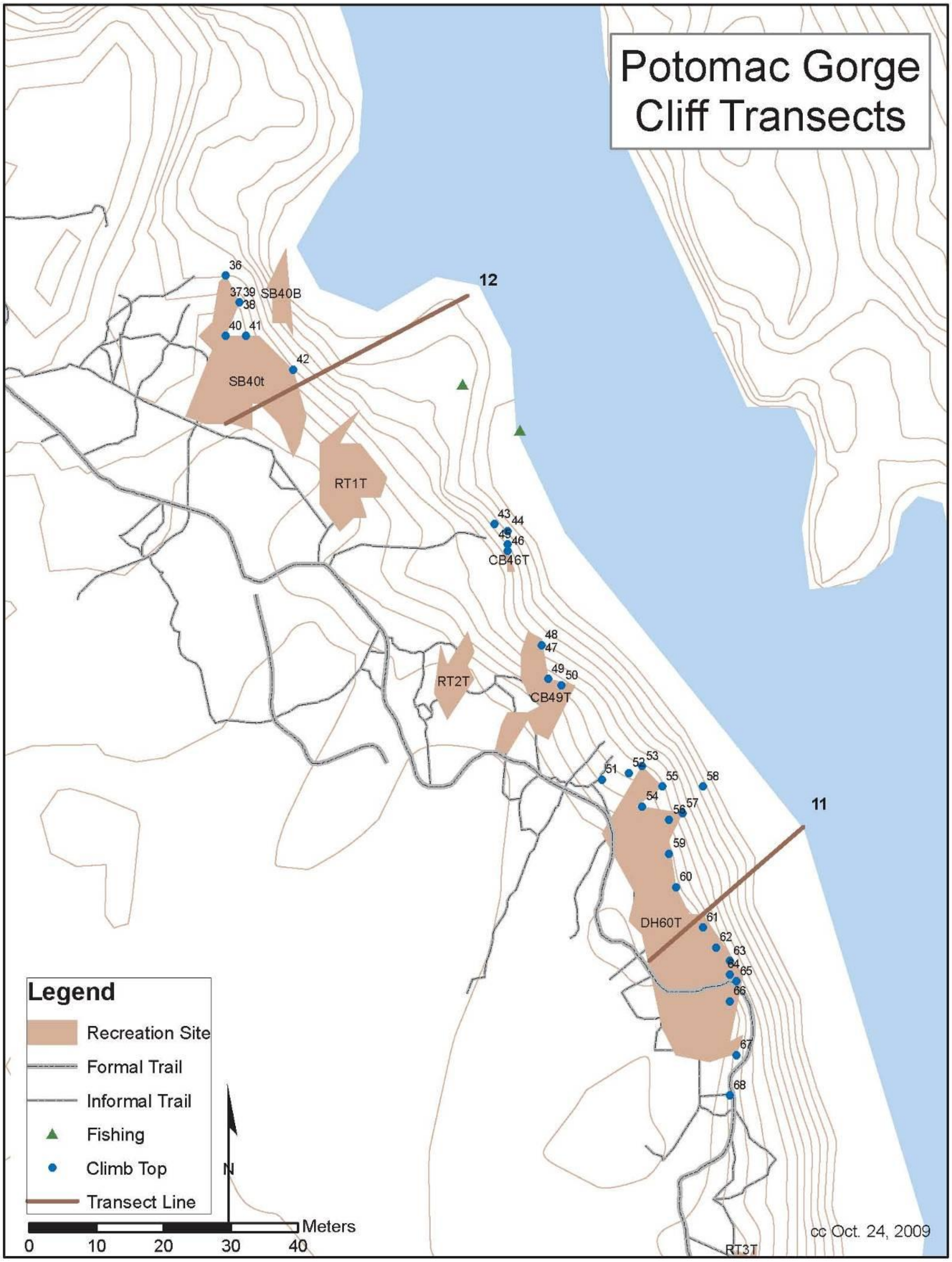
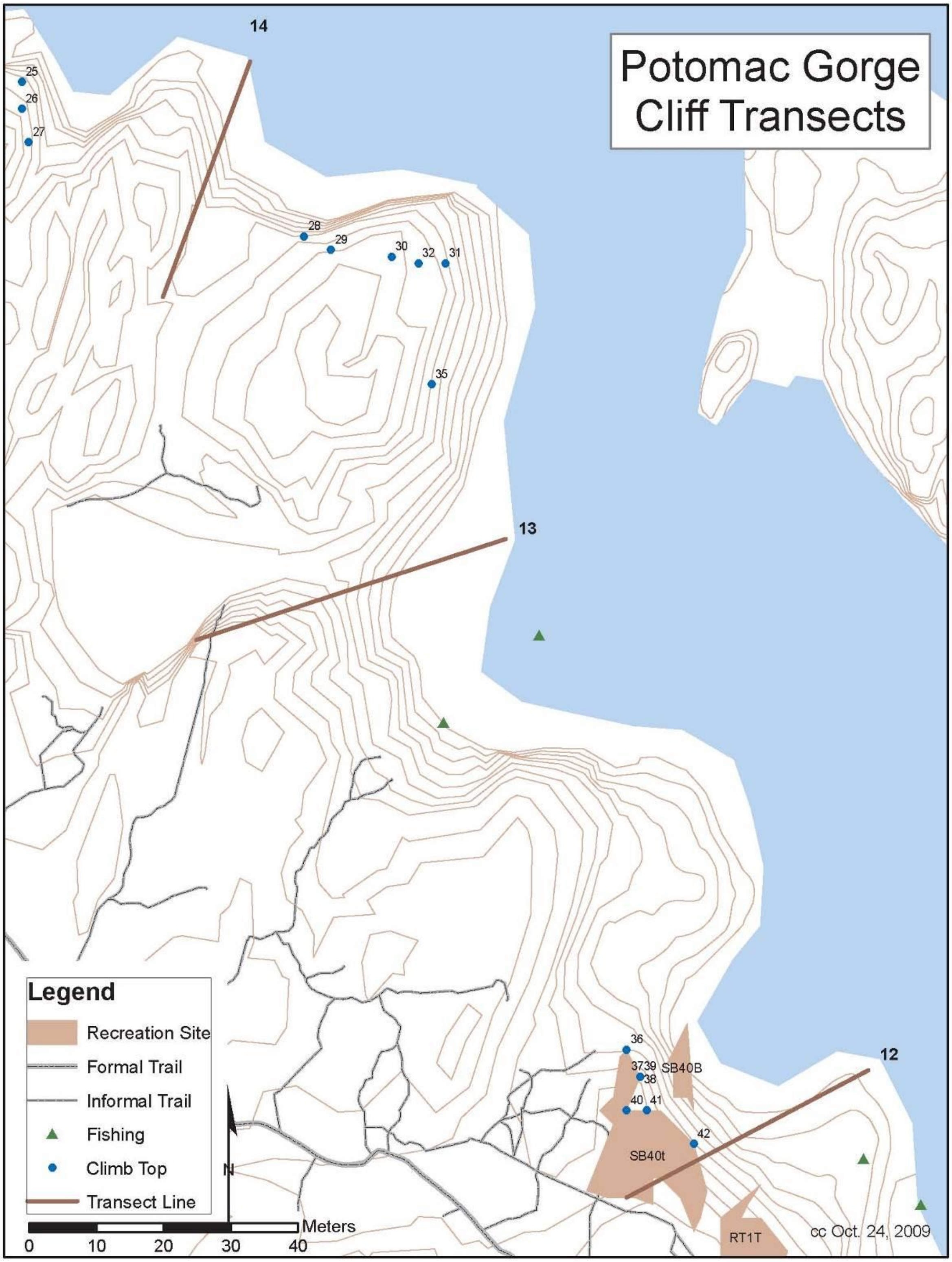
Meters
cc Oct. 24, 2009


Potomac Gorge
Cliff Transects
12
11
SB40B
SB40t
RT1T
CB46T
RT2T
CB49T
DH60T
RT3T
Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
N
Meters
0 10 20 30 40
cc Oct. 24, 2009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Cliff Transects
14
13
12
25
26
27
28
29
30
32
31
35
36
3739
38
40
41
42
SB40B
SB40t
RT1T
Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
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Meters
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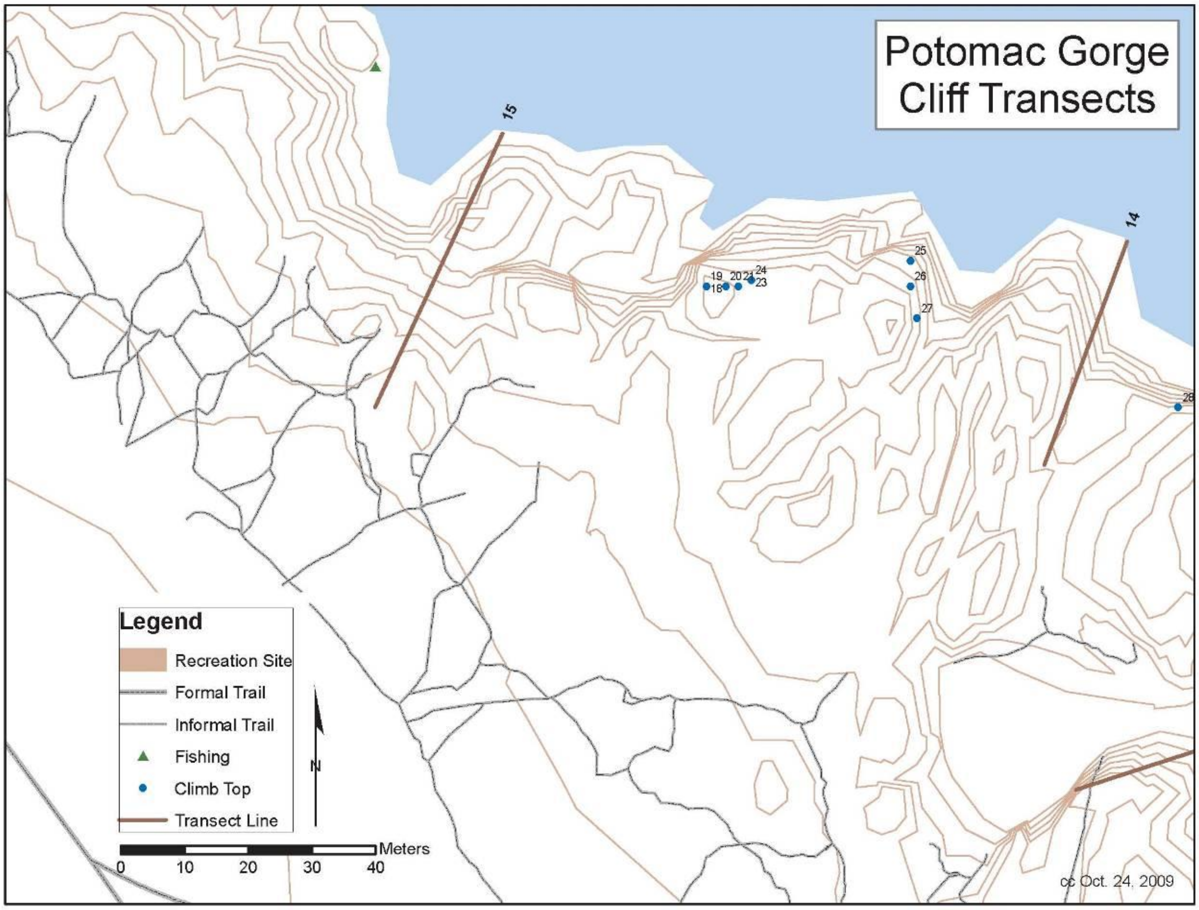
Potomac Gorge
Cliff Transects
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Legend
Recreation Site
Formal Trail
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Fishing
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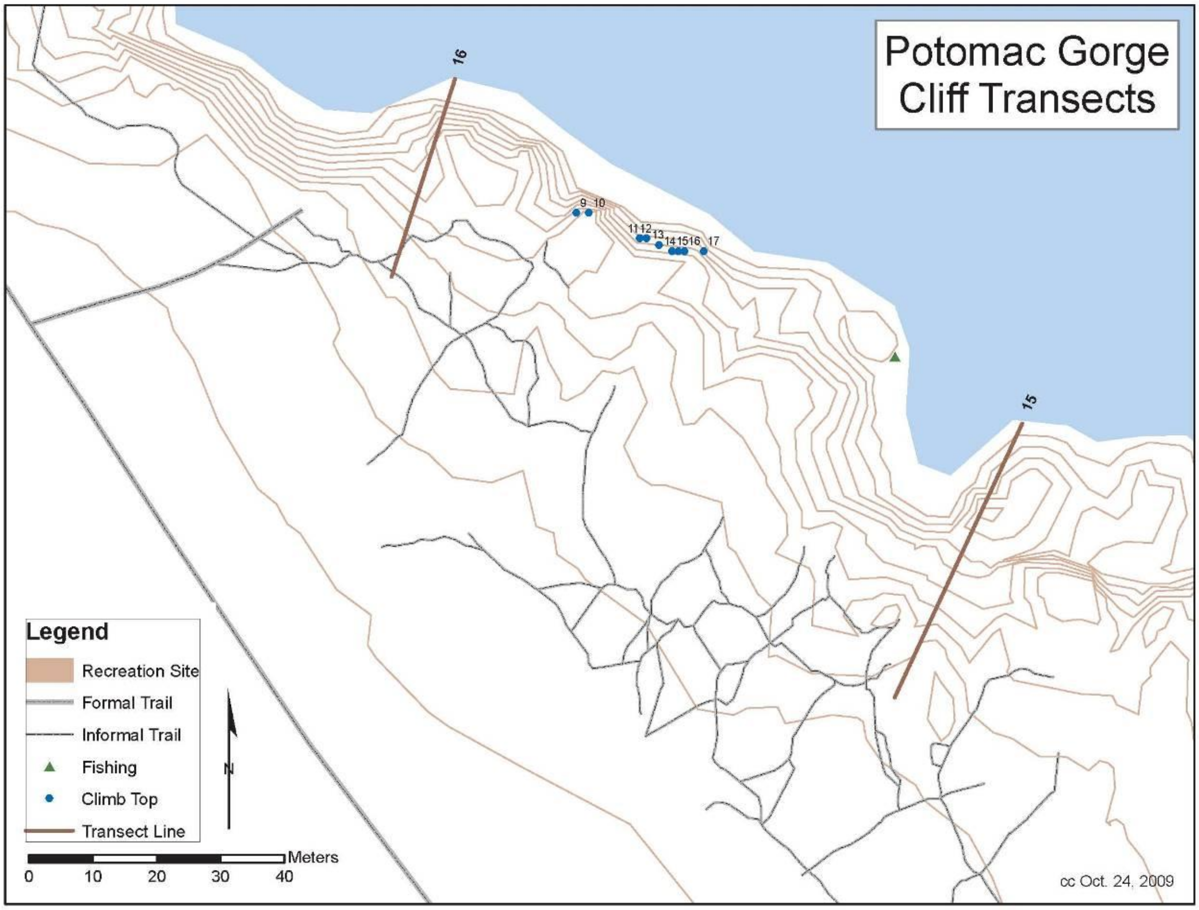
Potomac Gorge
Cliff Transects
16
15
9 10
11 12 13 14 15 16 17
Legend
Recreation Site
Formal Trail
Informal Trail
Fishing
Climb Top
Transect Line
N
Meters
0 10 20 30 40
cc Oct. 24, 2009

APPENDIX 4: MISCELLANEOUS TABLES

This table presents some of the key indicators to provide a sense of the data for the 74 rocky area quadrats.

Variable	Description
Transect	Study transect number (1-16)
Quadrat	Quad #'s increase with increasing distance from the cliff-top to the cliff base
Small Vascular In Cracks	Sum of the plant species #'s in all quad cracks
Small Vascular On Ledges	Sum of the plant species #'s on all quad ledges
Recreation Type	Coded: 0-not proximate to recreation, 1-rappel/climb, 2-scramble, 3-hiker/fishermen
Quad Elevation	Elevation above reference river level at transect base
Slope	Level=0°, vertical=90°, overhang=135°
Crack Count	# of cracks in the quad
Ledge Count	# of ledges in the quad

Transect	Quadrat	Small Vascular In Cracks (#)	Small Vascular On Ledges (#)	Recreation Type	Quad Elevation (m)	Quad Slope (°)	Crack Count (#)	Ledge Count (#)
1	3	2	0	0	27.0	18	2	
1	4	0	0	0	20.0	85	1	
2	2	2	0	0	37.0	55	4	1
2	3	1	0	0	30.5	105	3	
2	4	0	0	0	24.5	65	4	
3	2	0	0	1	33.0	95	2	3
3	3	0	0	1	27.5	70		
3	4	0	0	2	22.0	5		1
4	2	0	0	1	40.0	90	2	2
4	3	0	0	1	34.0	80		2
4	4	0	0	1	27.5	80	1	
4	5	0	1	0	24.5	25		1
4	6	0	0	0	22.5	30		
5	3	0	0	1	40.0	60	1	1
5	4	0	0	1	34.0	100	2	
5	5	0	2	0	27.5	70	1	2
6	2	1	0	0	39.0	70	2	
6	3	0	0	0	33.5	70	5	
6	4	0	0	0	27.0	115	4	
7	2	0	0	1	37.0	87	2	1
7	3	0	0	1	30.0	95	3	
7	4	0	0	3	29.0	55	1	1
7	5	0	0	3	27.0	0		1
7	6	0	0	3	25.0	0	2	
7	7	0	0	3	21.0	25		1
8	2	0	0	0	40.0	42		5
8	3	0	0	1	36.0	45	1	2
8	4	0	0	1	30.5	52		3
8	5	0	0	3	26.0	0		2
8	6	0	0	3	24.0			1
8	7	0	0	3	21.5	25		2

9	3	0	4	0	35.5	35		1
9	4	4	0	0	30.0	65	5	3
9	5	1	1	0	25.0	60	2	3
9	6	0	0	0	22.0	50	2	1
10	2	0	0	2	30.0	60	1	1
10	3	1	0	1	33.0	80	2	
10	4	2	0	1	34.0	70	5	1
10	5	1	0	1	32.0	65	2	
10	6	6	0	0	27.0	80	3	2
10	7	0	0	3	23.0	45	3	1
11	2	0	0	0	40.0	50	8	
11	3	0	0	1	34.0	68		
11	4	0	0	1	29.5	60	2	4
11	5	0	0	0	26.0	14	4	
11	6	0	0	2	22.0	0		
12	2	4	0	0	39.0		3	1
12	3	10	3	0	34.0		7	2
12	4	2	0	3	29.0	14	2	2
12	5	1	0	3	28.0	20	1	2
12	6	0	0	3	27.0		4	
13	3	0	0	0	39.0	25		3
13	4	0	0	0	35.0	60		
13	5	0	0	0	30.0	85		3
13	6	0	0	3	25.0	35		2
13	7	0	0	3	24.0	45	2	
13	8	0	0	3	23.0	18		6
14	2	1	0	0	37.0	10	1	1
14	3	0	0	0	36.0	15	1	2
14	4	4	2	0	32.0	65	4	2
14	5	0	0	0	28.0	0	3	
14	6	0	0	0	26.0	40	2	1
15	3	3	0	0	41.0		4	3
15	4	4	0	0	38.0		4	2
15	5	5	0	0	34.0	30	7	3
15	6	6	0	0	35.0		12	
15	7	3	0	0	31.0	70	3	1
15	8	0	0	0	29.0		1	2
15	9	0	0	0	26.0	75	1	
16	2	1	0	0	39.0	60	3	
16	3	9	2	0	36.0	10	9	5
16	4	6	0	0	37.0	0	6	
16	5	1	0	0	32.0	72	4	
16	6	0	0	0	26.0	70	3	

Data for all quadrats listing distances to nearest recreation activity.

Recreation Type Codes: 0-not proximate to recreation, 1-rappel/climb, 2-scramble, 3-hiker/fishermen

Tran sect	Area	Quad	Access	Cliff/ Rock Area	Dist to rec (m)	Dist to trail (m)	Nearest climb #	Dist to climb (m)	RecType Code
1	Sandy L	1	hike	☒	13.0	2.5	203	92.0	0
1	Sandy L	2	hike	☒	6.0	0.5	203	92.0	3
1	Sandy L	3	scrmbl	✓	1.0	7.0	203	92.0	0
1	Sandy L	4	climb	✓	8.0	14.0	203	92.0	0
2	Downst	1	hike	☒	58.0	1.5	203	11.0	0
2	Downst	2	climb	✓	58.0	4.0	203	5.0	0
2	Downst	3	climb	✓	58.0	11.0	203	6.0	0
2	Downst	4	climb	✓	58.0	18.0	203	5.0	0
3	Downst	1	hike	☒	0.0	0.0	190	7.0	3
3	Downst	2	climb	✓	3.0	7.0	190	0.0	1
3	Downst	3	climb	✓	4.0	14.0	190	0.0	1
3	Downst	4	scrmbl	✓	0.0	21.0	190	3.0	2
4	Dr. Ndl	1	hike	☒	6.0	1.0	170	9.0	0
4	Dr. Ndl	2	climb	✓	0.3	8.0	170	0.0	1
4	Dr. Ndl	3	climb	✓	7.0	10.0	170	1.0	1
4	Dr. Ndl	4	climb	✓	14.0	3.0	170	0.0	1
4	Dr. Ndl	5	scrmbl	✓	21.0	4.0	170	4.0	0
4	Dr. Ndl	6	scrmbl	✓	28.0	11.0	170	11.0	0
5	Cornice	1	hike	☒	0.0	0.3	157	14.0	3
5	Cornice	2	hike	☒	0.0	1.0	157	7.0	3
5	Cornice	3	climb	✓	0.3	8.0	157	0.0	1
5	Cornice	4	climb	✓	5.0	15.0	157	1.0	1
5	Cornice	5	climb	✓	7.0	22.0	157	3.0	0
6	Canal C	1	hike	☒	16.0	1.0	140	6.0	0
6	Canal C	2	climb	✓	14.0	6.0	140	0.0	0
6	Canal C	3	climb	✓	14.0	10.0	140	0.0	0
6	Canal C	4	climb	✓	7.0	13.0	140	0.0	0
7	Aid Box	1	hike	☒	1.0	0.3	130	5.0	0
7	Aid Box	2	climb	✓	2.0	3.0	130	0.3	1
7	Aid Box	3	climb	✓	2.0	3.0	131	0.2	1
7	Aid Box	4	hike	✓	0.0	3.0	131	6.0	3
7	Aid Box	5	hike	✓	0.0	10.0	131	13.0	3
7	Aid Box	6	hike	✓	0.0	17.0	131	20.0	3
7	Aid Box	7	hike	✓	0.0	23.0	131	27.0	3
8	Romeo	1	hike	☒	0.0	1.0	110	9.0	3
8	Romeo	2	climb	✓	0.3	1.0	110	2.0	0
8	Romeo	3	climb	✓	4.0	1.0	110	0.0	1
8	Romeo	4	climb	✓	9.0	3.0	110	0.0	1
8	Romeo	5	hike	✓	0.0	5.0	110	1.0	3
8	Romeo	6	hike	✓	0.0	7.0	110	8.0	3
8	Romeo	7	hike	✓	0.0	14.0	110	15.0	3
9	Juliet	1	hike	☒	5.5	0.0	93	10.0	3
9	Juliet	2	scrmbl	✓	1.5	1.5	93	8.0	0
9	Juliet	3	hike	✓	9.0	0.7	93	8.0	0
9	Juliet	4	climb	✓	16.0	8.0	93	8.0	0

9	Juliet	5	scrmbl	✓	23.0	15.0	93	8.0	0
9	Juliet	6	scrmbl	✓	30.0	22.0	93	8.0	0
10	Dike Cr	1	hike	☒	25.0	3.0	70	13.0	0
10	Dike Cr	2	scrmbl	✓	19.0	0.7	70	8.0	2
10	Dike Cr	3	climb	✓	14.0	7.0	72	0.5	1
10	Dike Cr	4	climb	✓	9.0	4.0	74	0.0	1
10	Dike Cr	5	climb	✓	2.0	7.0	74	0.0	1
10	Dike Cr	6	climb	✓	6.0	1.0	75	5.0	0
10	Dike Cr	7	hike	✓	0.0	1.0	75	2.0	3
11	Dihed	1	hike	☒	0.0	0.5	61	6.0	3
11	Dihed	2	climb	✓	1.0	8.0	61	1.5	0
11	Dihed	3	climb	✓	4.0	15.0	61	1.0	1
11	Dihed	4	climb	✓	8.0	14.0	61	0.0	1
11	Dihed	5	climb	✓	7.0	7.0	61	7.0	0
11	Dihed	6	scrmbl	✓	0.0	0.0	61	14.0	2
12	Sand B	1	hike	☒	0.0	1.0	42	10.0	3
12	Sand B	2	climb	✓	1.0	8.0	42	3.0	0
12	Sand B	3	climb	✓	6.0	8.0	42	7.0	0
12	Sand B	4	hike	✓	0.0	1.0	42	11.0	3
12	Sand B	5	hike	✓	0.0	6.0	42	18.0	3
12	Sand B	6	hike	✓	0.0	13.0	42	25.0	3
13	S Eddy	1	hike	☒	7.0	2.0	35	51.0	0
13	S Eddy	2	hike	☒	0.0	0.0	35	45.0	3
13	S Eddy	3	scrmbl	✓	7.0	7.0	35	40.0	0
13	S Eddy	4	climb	✓	14.0	14.0	35	35.0	0
13	S Eddy	5	hike	✓	21.0	2.5	35	30.0	0
13	S Eddy	6	hike	✓	0.0	0.0	35	27.0	3
13	S Eddy	7	hike	✓	0.0	3.0	35	25.0	3
13	S Eddy	8	hike	✓	0.0	10.0	35	27.0	3
14	Fish L	1	hike	☒	59.0	20.0	28	22.0	0
14	Fish L	2	hike	✓	62.0	28.0	28	17.0	0
14	Fish L	3	scrmbl	✓	64.0	34.0	28	16.0	0
14	Fish L	4	scrmbl	✓	66.0	40.0	28	16.0	0
14	Fish L	5	scrmbl	✓	69.0	47.0	28	16.0	0
14	Fish L	6	scrmbl	✓	73.0	53.0	28	19.0	0
15	Beaver	1	hike	☒	35.0	1.0	18	65.0	0
15	Beaver	2	hike	☒	28.0	0.0	18	58.0	3
15	Beaver	3	hike	✓	21.0	4.0	18	50.0	0
15	Beaver	4	hike	✓	14.0	7.0	18	46.0	0
15	Beaver	5	scrmbl	✓	7.0	14.0	18	42.0	0
15	Beaver	6	scrmbl	✓	0.0	21.0	18	40.0	0
15	Beaver	7	climb	✓	0.0	28.0	18	40.0	0
15	Beaver	8	scrmbl	✓	0.0	35.0	18	41.0	0
15	Beaver	9	climb	✓	7.0	42.0	18	43.0	0
16	"O" Dk	1	hike	☒	13.0	0.0	9	30.0	3
16	"O" Dk	2	hike	✓	10.0	7.0	9	26.0	0
16	"O" Dk	3	scrmbl	✓	11.0	0.0	9	25.0	0
16	"O" Dk	4	scrmbl	✓	15.0	7.0	9	25.0	0
16	"O" Dk	5	climb	✓	20.0	14.0	9	26.0	0
16	"O" Dk	6	climb	✓	26.0	21.0	9	29.0	0

The sixteen transects, ninety-five quads, and the means of access:

Transect: / Quad	T-1 Sandy L	T-2 Downst	T-3 Downst	T-4 Dr. Ndl	T-5 Cornice	T-6 Canal C	T-7 Aid Box	T-8 Romeo	T-9 Juliet	T-10 Dike Cr	T-11 Dihedral	T-12 Sand B	T-13 S Eddy	T-14 Fish L	T-15 Beaver	T-16 "O" Deck
1	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike	hike
2	hike	rope	rope	rope	hike	rope	rope	rope	hike	scrmbl	rope	rope	hike	hike	hike	rope
3	scrmbl	rope	rope	rope	rope	rope	rope	rope	scrmbl	scrmbl	rope	rope	scrmbl	scrmbl	hike	scrmbl
4	rope	rope	scrmbl	rope	rope	rope	scrmbl	rope	rope	rope	rope	hike	rope	rope	scrmbl	scrmbl
5				rope	rope		hike	hike	rope	rope	rope	hike	rope	scrmbl	scrmbl	rope
6				rope			hike	hike	rope	rope	scrmbl	hike	scrmbl	rope	scrmbl	rope
7							hike	hike		rope			scrmbl		rope	
8													hike		scrmbl	
9															rope	
10																

The 74 quads in the cliff and rocky areas can be accessed by three types of recreation activity, plus a "no recreation" type on vertical cliffs away from climbing routes. The counts of quadrats for these classes are presented below:

Recreation (Yes/No)	**Recreation Type**	**Mountaineering Class[1]**	**Quads (#)**
1	Hike	1^{st} , 2^{nd}	14
1	Scramble	3^{rd} , - 4^{th}	3
1	Technical	+ 4^{th}, 5^{th}	16
0	No recreation	n/a	42

1 - Mountaineering difficulty classes (Yosemite system): 1 = walking, 2 = walking with use of hands, 3 = scrambling and low angle climbing with hands, 4 = easier climbing, rope may or may not be needed, 5 = technical climbing with ropes on vertical cliffs.

Data for 232 geofeatures in the 74 cliff/rocky area. The majority of geofeatures (69%) do not contain vascular plants; 38% of geofeatures without recreation and 14% of geofeatures with recreation contain vascular plants. These findings may be attributable to a reduction in plant cover due to recreational activity, or to visitors choosing less vegetated areas or avoiding vegetation when hiking or climbing.

Recreation Presence	Geofeatures (#)		
	No Vascular Plants in Geofeatures (#)	Vascular Plants in Geofeature (#)	Totals
No Recreation	104	63	167
With Recreation	56	9	65
Totals	160	72	232

Recreation Presence and Plant Presence

The interaction of recreation presence and plant presence.

Recreation Presence	Quadrats (#)	Geofeatures (#)	Number of Geofeatures w/this Number of Plants							
			0	1	2	3	4	5	6	7
No Recreation	41	167	104	37	18	4	3	0	0	1
With Recreation	33	65	56	7	1	1	0	0	0	0
Totals	74	232	160	44	19	5	3	0	0	1

In terms of micro topography (number of geofeatures) our random sample of quadrats without recreation presence and quadrats with recreation presence are very different on the most basic level—number of geofeatures/quadrat:

Quads w/out recreation: 167 geofeatures/41 quads = 4.1 geofeatures/quad
Quads w/recreation: 65 geofeatures/33 quads = 2.0 geofeatures/quad

While recreation activities undoubtedly reduce plant abundance, having just half as many geofeatures per quad means the quads with recreation must start with far fewer plants than the quads without recreation. Further, the large number of geofeatures without plants give recreationists the easy option to avoid plants entirely. It is clear that the correlation between fewer plants and recreation does not mean recreation caused a reduction in plants. Micro topography differences and recreationist preferences must also be a factor.

Examination of regression modeling prediction equations

For each of the 33 quads in the cliff and rocky areas with recreation, the increase in plant count from removing recreation can be predicted by the model. The prediction is made by changing the Recreation code from "1" to "0" in the prediction equation. The sum of plant counts for the 74 quads is given in the table below.

	Small vascular plants in quads (#)		
	Measured w/current recreation mix	Predicted w/recreation eliminated	Delta
In cracks	81	99	18
On ledges	25	29	4
Totals	106	128	22

By eliminating recreation in the 33 quads with recreation (of 74 quads) the plant count changes from a measured 106 plants to a predicted 128 plants. Put another way, recreation (hiking, fishing, scrambling, climbing, rappelling) in the 74 quads in the rocky area is predicted to have caused a loss of 22 plants.

Detailed examination of model predictions

We can break up the summary table above into crack results and ledge results. We can break up the results by quads without recreation impacts and quads with recreation impact.

For the 74 cliff and rocky area quads, some have cracks or ledges, some don't. If the quad does not have any cracks, plant cover is not modeled to prevent a modeling problem with too many "zeros".

	Quads in rocky area (#)	
	w/cracks	w/ledges
Geofeatures	54	46
No geofeatures	20	28

Cracks Model	Quads in the rocky area (#)		
	w/cracks	w/out cracks	Totals
No recreation	34	7	41
With recreation	20	13	33
Totals	54	20	74

The regression model is used to predict pre-recreation plant abundance in cracks.

Cracks Model	Small vascular plants in cracks (#)		
	Measured w/current recreation mix	Predicted w/recreation eliminated	Plants/quad pre-recreation
No recreation	74	74	74/41 = 1.8
With recreation	7	25	25/33 = 0.8
Totals	81	99	99/74 = 1.3

Ledges Model	Number quads in the rocky area		
	With ledges	Without ledges	TOTAL
No recreation	24	17	41
With recreation	22	11	33
Totals	46	28	74

The regression model is used to predict pre-recreation plant abundance on ledges.

Ledges Model	Small vascular plants on ledges (#)		
	Measured w/current recreation mix	Predicted w/recreation eliminated	Plants/quad pre-recreation
No recreation	24	24	24/41 = 0.59
With recreation	1	5	5/33 = 0.15
Totals	25	29	29/74 = 0.39

This table combines crack and ledge results to examine plant counts with and without recreation:

Combined Model	Small vascular plants in cracks and on ledges (#)		
	Measured w/current recreation mix	Predicted w/recreation eliminated	Plants/quad pre-recreation
No recreation	74+24= 98	74+24= 98	98/41 = 2.4
With recreation	7+ 1= 8	25+ 5= 30	30/33 = 0.9
Totals	106	128	

Overall, this modeling predicts that the areas accessible to recreationists had 2.4/0.9 = 2.6 times fewer plants pre-recreation than other parts of the cliff and rocky areas.

Plant Cover by Life Form and Recreation

The table below lists the average percent cover for each life form along with the number of quads where the life form was present. Plants of any type were present in 69 of the 74 quads, with an average cover of 57.9%. Vascular plants were present in about half the quads (33 of 74). The other life forms, except crustose and foliose lichen, are even more sparsely distributed.

Life Form	Quads w/Lifeform (#)	Average Cover (%)	Avg Cover w/out Recreation (%)	Avg Cover w/Recreation (%)	Significance: Mann-Whitney test	Significant difference with & w/out Recreation
Plants- all	69	57.9	65.8	48.1	.153	no
Vascular- all	33	7.0	11.4	1.5	.002	yes
Moss - acrocarp	22	1.3	1.9	0.4	.678	no
Moss - pleurocarp	10	0.8	1.3	0.2	.092	no
Liverwort - leafy	9	0.4	0.6	0.1	.468	no
Lichen - fruticose	2	0.0	0.1	0.0	.198	no
Lichen - squamulose	14	0.5	0.8	0.2	.180	no
Lichen - foliose	47	6.0	8.5	2.9	.060	no
Lichen - crustose	67	41.9	41.2	42.7	.815	no
Plant litter	74	3.4	3.9	2.7	.440	no
Soil	74	2.8	3.1	2.5	.100	no
Bare rock	74	44.0	40.4	48.5	.242	no

Of the plant life forms and physical indicators assessed, all have reduced cover on quadrats proximate to recreation, except crustose lichen and bare rock, which increased. However, the only difference that was statistically significant was the reduction in overall vascular plant cover ($p < 0.05$), all other differences could be due to chance. We note that crustose lichen adhere tightly to the rock and is the most trampling resistant lichen life form. Also note that these changes could also be attributed to recreationists choosing to avoid vegetated areas, which is generally easy to due in the largely non-vegetated cliff and rocky areas common to the study area.

The following electronic files are also considered products of this research and have transferred to the National Park Service on a DVD:

- Electronic copy of this report
- Electronic copy of PowerPoint presentations
- Field data sheets
    - Physical (transect, quad map, quad physical)
    - Botanical
- Field photographs
    - Cliff overview photographs
        - Overview photographs with quad locations
    - Transect overview photographs
    - Quadrat detail photographs (left and right sides)
- Access data base of field data
    - Front end with queries
    - Back end with the raw data
- GIS layers
    - Base layers from other sources
        - Topographic contours (clip)
        - Hydrology (clip)
        - Natural communities (clip)
        - Aerial photographs (orthorectified)
    - Layers generated by this project
        - Transect sample lines- v2
        - Transect line actual
        - Study end points
        - Quad location
        - VA recreation sites
        - VA formal trails
        - VA informal trails
        - Descent trails
        - Climb top VA side
    - ArcMap .mxd files
- Study area maps
    - Overview map of the 16 transects
    - Detail maps of each transect
- Bibliography (in End Note format)
    - Copies of key articles
        - Davis (1951)
        - Flemming
        - Kuntz
        - Kuntz and Larson

APPENDIX 5: REPORT ADDENDUM

This Report Addendum includes the following report sections that NPS staff requested be moved to this Appendix to shorten the main body of the report: Justification for Monitoring, Legislative Mandates, Carrying Capacity Decision-Making, Visitor Perceptions of Resource Conditions, Monitoring Program Capabilities, Literature Review, and Management Considerations.

JUSTIFICATION FOR MONITORING

Sustaining any type of long-term natural resource monitoring program over time can be exceptionally challenging for agencies due to changing personnel, management priorities, and budgets. This section reviews legislative mandates, management policies and guidelines, carrying capacity, visitor perceptions of recreation resource conditions, and monitoring program capabilities. The purpose of this review is to describe legislative and management intent regarding visitor impact monitoring and its role in balancing visitor use and resource protection objectives. This section is included to assist in justifying implementation of a visitor impact monitoring program and to describe its utility to enlist organizational support for sustaining such a program over time.

Legislative mandates challenge managers to develop and implement management policies, strategies, and actions that permit recreation without compromising ecological and aesthetic integrity. Furthermore, managers are frequently forced to engage in this balancing act under the close scrutiny of the public, competing interest groups, and the courts. Managers can no longer afford a wait-and-see attitude or rely on subjective impressions of deterioration in resource conditions. Professional land management increasingly requires the collection and use of scientifically valid research and monitoring data. Such data should describe the nature and severity of visitor impacts and the relationships between controlling visitor use and biophysical factors. These relationships are complex and not always intuitive. A reliable information base is therefore essential to managers seeking to develop, implement, and gauge the success of visitor and resource management programs.

Although numerous reasons for implementing a visitor impact monitoring program are described in the following sections, the actual value of these programs is entirely dependent upon the park staff who manage them. Programs developed with little regard to data quality assurance or operated in isolation from resource protection decision-making will be short-lived. In contrast, programs that provide managers with relevant and reliable information necessary for developing and evaluating resource protection actions can be of significant value. Only through the development and implementation of professionally managed and scientifically defensible monitoring programs can we hope to provide legitimate answers to the question, "Are we loving our parks to death?"

Legislative Mandates

Current legislation and agency documents establish mandates for monitoring (Marion 1991). Recent legislative mandates allow managers more latitude to make proactive decisions that can be defended in court if necessary. Managers who make proactive decisions should be prepared to prove the viability of their strategies, or risk public disapproval or even legal action against the agency. Survey and monitoring programs provide the means for such demonstrations.

Agency Organic Act

The National Park Service Organic Act of 1916 (16 *United States Code* (USC) 1) established the Service, directing it to:

> …promote and regulate the use…[of parks]…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

These provisions were supplemented and clarified by the Congress through enactment of the General Authorities Act in 1970, and through a 1978 amendment expanding Redwood National Park (16 USC 1a-1):

> …the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…

Congress intended park visitation to be contingent upon the National Park Service's ability to preserve park environments in an unimpaired condition. However, unimpaired does not mean unaltered or unchanged. Any recreational activity, no matter how infrequent, will cause changes or impacts lasting for some period of time. What constitutes an impaired resource is ultimately a management decision, a judgment. The Organic Act's mandate presents the agency with a management challenge since research demonstrates that resources are inevitably changed by recreational activities, even with infrequent recreation by conscientious visitors (Cole 1982 1995, Leung & Marion 2000). If interpreted overly strictly, the legal mandate of unimpaired preservation may not be achievable, yet it provides a useful goal for managers in reconciling these two competing objectives.

More recently, the National Parks Omnibus Management Act of 1998 established a framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. The Act charges the Secretary of the Interior to:

> …develop a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources.

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill:

> A major part of protecting [park] resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with

> other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data.

Management Policies and Guidelines

Authority to implement congressional legislation is delegated to agencies, which identify and interpret all relevant laws and formulate administrative policies to guide their implementation. A document titled *Management Policies* (NPS 2006) describes these policies to provide more specific direction to management decision-making. For example, relative to the need for balancing visitor use and resource impacts, the NPS *Management Policies* state that:

> The "fundamental purpose" of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values. This mandate is independent of the separate prohibition on impairment, and so applies all the time, with respect to all park resources and values, even when there is no risk that any park resources or values may be impaired. NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values.
>
> Congress, recognizing that the enjoyment by future generations of the national parks can be ensured only if the superb quality of park resources and values is left unimpaired, has provided that when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant. This is how courts have consistently interpreted the Organic Act, in decisions that variously describe it as making "resource protection the primary goal" or "resource protection the overarching concern"… (*Section 1.4.3*)
>
> The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgment of the responsible NPS manager, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts. (*Section 1.4.5*)
>
> Impacts may affect park resources or values and still be within the limits of the discretionary authority conferred by the Organic Act. In these situations, the Service will ensure that the impacts are unavoidable and cannot be further mitigated. Even when they fall far short of impairment, unacceptable impacts can rapidly lead to impairment and must be avoided. When a use is mandated by law but causes unacceptable impacts on park resources or values, the Service will take appropriate management actions to avoid or mitigate the adverse effects. (*Section 8.1.1*)

Thus, relative to visitor use, park managers must evaluate the types and extents of resource impacts associated with recreational activities, and determine to what extent they are unacceptable and constitute impairment. Further, managers must seek to avoid or limit any form of resource impact, including those judged to fall short of impairment. Visitor impact monitoring programs can assist managers in making objective evaluations of impact acceptability and impairment and in selecting effective impact management practices by providing quantitative documentation of the types and extent of recreation-related impacts to natural resources. Monitoring programs are also explicitly authorized in Section 4.1 of the Management Policies:

Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions". (*Section 4.1*)

Further, The Service will:

- Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.
- Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.
- Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.
- Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.
- Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems (*Section 4.2.1*).

The National Park Service has implemented a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. A service-wide Inventory & Monitoring Program has been implemented to ensure that park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. A key component of this effort, known as the NPS Inventory & Monitoring Program, is the organization of park units into 32 ecoregional networks to conduct long-term monitoring for key indicators of change, or "vital signs." Vital signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems. Early detection of potential problems allows park managers to take steps to restore ecological health of park resources before serious damage can happen.

Carrying Capacity Decision-Making

Decisions regarding impact acceptability and the selection of actions needed to prevent resource impairment frequently fall into the domain of carrying capacity decision-making. The 1978 National Parks and Recreation Act (P.L. 95-625) requires the NPS to determine carrying capacities for each park as part of the process of developing a general management plan. Specifically, amendments to Public Law 91-383 (84 Stat. 824, 1970) require general management plans developed for national park units to include "identification of and implementation commitments for visitor carrying capacities for all areas of the unit" and determination of whether park visitation patterns are consistent with social and ecological carrying capacities.

The NPS employs the Visitor Experience and Resource Protection (VERP) planning and decision-making framework for formal evaluations of the acceptability of visitor impacts and for establishing carrying capacity limits on visitation (NPS 1997; NPS 2006, Section 8.2.1) (Figure 17). Visitor impact monitoring programs provide an essential component of such efforts. VERP and other similar frameworks (e.g., Limits of Acceptable Change), evolved from, and have largely replaced, management approaches based on the more traditional carrying capacity model

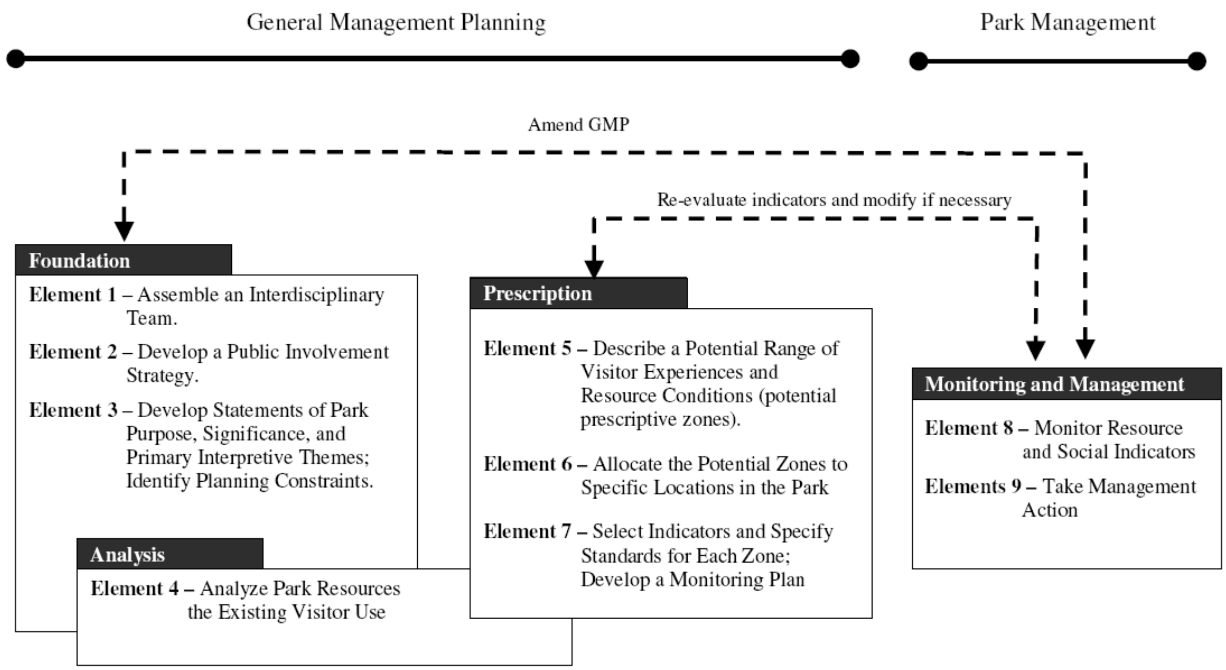

Figure 17. The NPS Visitor Experience and Resource Protection framework used to address carrying capacity decision making.

(Stankey et al. 1985). Under these newer frameworks, numerical standards are set for individual biophysical or social condition indicators. These limits define the critical boundary between acceptable and unacceptable change in resource or social conditions, and against which future conditions can be compared through periodic monitoring. VERP is an adaptive management process wherein periodic monitoring is conducted to compare actual conditions to quantitatively defined standards of quality. If standards are exceeded, an evaluation is conducted to identify those factors that managers can effectively manipulate to improve conditions for the indicators with sub-standard (unacceptable) conditions. For example, if a standard for the individual or aggregate size of recreation sites was exceeded, managers might consider implementing one or more site management or educational actions. If the next cycle of monitoring also found sub-standard conditions, more restrictive actions like fencing or area closures would be considered.

Additional guidance on visitor carrying capacity decision-making is provided in the NPS Management Policies (2006):

> Visitor carrying capacity is the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park. By identifying and staying within carrying capacities, superintendents can prevent park uses that may unacceptably impact the resources and values for which the parks were established. For all zones, districts, or other logical management divisions within a park, superintendents will identify visitor carrying capacities for managing public use. Superintendents will also identify ways to monitor for, and address, unacceptable impacts to park resources and visitor experiences.
>
> When making decisions about carrying capacity, superintendents must utilize the best available natural and social science and other information, and maintain a comprehensive administrative record relating to their decisions. The decision-making process should be based on desired

> resource conditions and visitor experiences for the area; quality indicators and standards that define the desired resource conditions and visitor experiences; and other factors that will lead to logical conclusions and the protection of park resources and values…
>
> The general management planning process will determine the desired resource and visitor experience conditions that are the foundation for carrying capacity analysis and decision-making. If a general management plan is not current or complete, or if more detailed decision-making is required, a carrying capacity planning process, such as the Visitor Experience and Resource Protection (VERP) framework, should be applied in an implementation plan or an amendment to an existing plan.
>
> As use changes over time, superintendents must continue to decide if management actions are needed to keep use at acceptable and sustainable levels. If indicators and standards have been prescribed for an impact, the acceptable level is the prescribed standard. If indicators and standards do not exist, the superintendent must determine how much impact can be tolerated before management intervention is required (*Section 8.2.1*).

Visitor Perceptions of Resource Conditions

Visitors to protected areas are aware of resource conditions along trails and at recreation sites, just as are managers (Lucas 1979, Marion & Lime 1986, Vaske *et al.* 1982). Legislative mandates set high standards when they direct managers to keep protected natural areas "unimpaired" and human impacts "substantially unnoticeable." Seeing trails and recreation sites, particularly those in degraded condition, reminds visitors that others have preceded them. In remote areas even the presence of trails and recreation sites reduce perceived naturalness and can diminish opportunities for solitude. In accessible and popular areas, the proliferation and deterioration of trails and recreation sites present a "soiled" or "used" appearance, in contrast to the ideal of a pristine natural environment (Leung & Marion 2000).

Degraded resource conditions on trails and recreation sites can have significant utilitarian, safety, and experiential consequences for visitors (Leung & Marion 2000). Trails serve a vital transportation function in protected natural areas and their degradation greatly diminishes their utility for visitors and land managers. For example, excessive tread erosion or muddiness can render trails difficult and unpleasant to use. Such conditions can also threaten visitor or pack stock safety and prevent or slow rescues, possibly increasing agency liability. Impacts associated with certain types of uses, such as linear rutting from bikes or vehicles or muddy hoof prints from horses, can also exacerbate conflicts between recreationists.

Visitors spend most of their time within protected natural areas on trails and recreation sites, so their perceptions of the area and its naturalness are strongly influenced by trail and site conditions. Visitors are sensitive to overt effects of other visitors (such as the occurrence of litter, horse manure, malicious damage to vegetation) and to visually obtrusive examples of impacts such as tree root exposure, tree felling, and soil erosion. A survey of visitors to four wilderness areas, three in southeastern states and another in Montana, found that littering and human damage to recreation site trees were among the most highly rated indicators affecting the quality of recreational experiences (Roggenbuck *et al.* 1993). Amount of vegetation loss and exposed soil around a recreation site was rated as more important than many social indicators, including number of people seen while hiking and encounters with other groups at recreation sites. Hollenhorst and Gardner (1994) also found vegetation loss and bare ground on recreation sites to be important determinants of satisfaction by wilderness visitors. These views contrast with those reported in White *et al.* (2008) that some impacts, such as bare soil at a campsite, may be viewed from a "functional" perspective as a desirable amenity, though their study found that more experienced visitors exhibited greater sensitivity to deteriorating site conditions.

Monitoring Program Capabilities

Visitor impact monitoring programs can be of significant value when providing managers with reliable information necessary for establishing and evaluating resource protection policies, strategies, and actions. When implemented properly and with periodic reassessments, these programs produce a database with significant benefits to protected area managers (Figure 18). Data from the first application of impact assessment methods developed for a long-term monitoring program can objectively document the types and extent of recreation-related resource impacts. Such work also provides information needed to select appropriate biophysical indicators and formulate realistic standards, as required in VERP or LAC planning and decision-making frameworks.

Reapplication of impact assessment protocols as part of a monitoring program provides an essential mechanism for periodically evaluating resource conditions in relation to standards. Visitor impact monitoring programs provide an objective record of impacts, even though individual managers come and go. A monitoring program can identify and evaluate trends when data are compared between present and past resource assessments. It may detect deteriorating conditions before severe or irreversible changes occur, allowing time to implement corrective actions. Analysis of monitoring data can reveal insights into relationships with causal or non-causal yet influential factors. For example, the trampling and loss of vegetation or soils may be greatly reduced by shifting trails to more resistant and resilient vegetation types or topographic alignments, instead of more contentious limitations on use. Following the implementation of corrective actions, monitoring programs can evaluate their efficacy.

- Identify and quantify site-specific resource impacts.
- Summarize impacts by environmental or use-related factors to evaluate relationships.
- Aid in setting and monitoring resource conditions standards of quality.
- Evaluate deterioration to suggest potential causes and effective management actions.
- Evaluate the effectiveness of resource protection measures.
- Identify and assign priorities to maintenance needs.

Figure 18. Capabilities of visitor impact monitoring programs.

LITERATURE REVIEW

Visitation-Related Resource Impacts

Visitors participating in a diverse array of recreation activities, including hiking, camping, climbing, fishing, and wildlife viewing, contribute to an equally diverse array of effects on protected natural areas resources, including vegetation, soils, water, and wildlife. The term *impact* is commonly used to denote any undesirable visitor-related change in these resources. This study was restricted to assessments of trampling-related impacts to vegetation and soil along trails and at recreation sites.

Resource impacts associated with recreation-related trampling include an array of direct and indirect problems (Table 20). Even light traffic can remove protective layers of vegetation cover and organic litter (Cole 2004, Leung & Marion 1996). Trampling disturbance can alter the appearance and composition of trailside vegetation by reducing vegetation height and favoring trampling resistant species. The loss of tree and shrub cover can increase sunlight exposure, which promotes further changes in composition by favoring shade-intolerant plant species (Hammitt & Cole 1998, Leung & Marion 2000). Visitors can also introduce and transport non-native plant species along trail corridors, some of which may out-compete undisturbed native vegetation and migrate away from trails (Cole 1987).

Table 20. Direct and indirect effects of recreational trampling on soils and vegetation.

	Vegetation	Soil
Direct Effects	Reduced height/vigor	Loss of organic litter
	Loss of ground vegetation, shrubs and trees	Soil exposure and compaction
	Introduction of non-native vegetation	Soil erosion
Indirect Effects	Altered composition – shift to trampling resistant or non-native species	Reduced soil pore space and moisture, increased soil temperature
	Altered microclimate	Increased water runoff
		Reduced soil fauna

The exposure of soil on unsurfaced trails and recreation sites can lead to soil compaction, muddiness, erosion, trail widening and site expansion (Hammitt & Cole 1998, Leung & Marion 1996, Tyser & Worley 1992). The compaction of soils decreases soil pore space and water infiltration, which in turn increases muddiness, water runoff and soil erosion. The erosion of soil exposes rocks and plant roots, creating a rutted, uneven surface. Eroded soils may smother vegetation or find their way into water bodies, increasing water turbidity and sedimentation impacts to aquatic organisms (Fritz 1993). Visitors seeking to circumvent muddy or badly eroded sections of trail contribute to tread widening and creation of parallel secondary treads, which expand vegetation loss and the aggregate area of trampling disturbance (Marion 1994, Liddle & Greig-Smith 1975).

The creation and use of trails and recreation sites can also directly degrade and fragment wildlife habitats, and the presence of visitors may disrupt essential wildlife activities such as feeding, reproduction and the raising of young (Knight & Cole 1995). While most trampling-related resource impacts are limited to narrow linear corridors (trails) or nodes (recreation sites) of disturbance, impacts like altered surface water flow, invasive plants, and wildlife disturbance, can extend considerably further into natural landscapes (Kasworm & Monley 1990, Tyser & Worley 1992). But, even localized disturbance can harm rare or endangered species or damage sensitive plant communities, particularly in environments with slow recovery rates.

Cliff Resource Impacts

Cliffs often support distinctly different plant communities than surrounding environments because their vertical orientation, exposure, and heterogeneity of limited microhabitats result in unique habitat characteristics of insolation, wind, moisture, and temperature (Larson *et al*. 2000). Cliff plants must be well-adapted to the challenging physical and environmental conditions on cliff-faces, but their resistance to human forms of disturbance (e.g., trampling) may be limited (Farris 1998). Concerns regarding the environmental impacts of rock climbing are expanding as its popularity increases, along with the advent of sport climbing that is opening up new locations and the continuing emphasis on pioneering new climbing routes – all have increased the spatial extent of climbing activity and impact (Camp & Knight 1998a, Kelly & Larson 1997, Krajick 1999). The growing popularity of rock climbing means that more people are accessing and using cliff sites, which may negatively affect cliff flora and fauna (Camp & Knight 1998b, Farris 1998, McMillan *et al.* 2003). The increasing potential for resource degradation have led to growing resource protection concerns among land managers, who are expanding educational and regulatory efforts designed to avoid or minimize the associated impacts to sensitive flora and fauna (Merrill & Graefe 1997).

We note that climbing impacts are generally restricted to the immediate vicinity of well-used climbs, which can essentially be considered as “vertical trails” (Starkman 2003). Furthermore, though climbing guidebooks can list dozens, even hundreds of climbs for a particular area, many of these climbs may be rarely visited. Climbing use is frequently concentrated on a smaller number of popular climbs and these are likely to exhibit greater resource impacts if plants are present. Easier climbs may have larger or more numerous geofeatures that could support plants and allow greater flexibility in lateral movement. In contrast, some difficult climbs on steep or overhanging rock faces have the potential for more limited impact due to their greatly reduced micro-topography, which supports fewer plants and have limited options for hand and foot-holds (Kuntz & Larson 2006a, 2006b). User behavior, ranging from climbers who may purposefully remove vegetation and soil to expose handholds, to climbers who may actively avoid vegetation and soil disturbance, can also be an important factor.

Despite the fact that over nine million individuals are estimated to participate in rock climbing annually, the effects of rock climbing on cliff site environments have received limited attention in the scientific literature (Cordell 2004, Farris 1998, McMillan & Larson 2002). Compared to most forms of visitor impact, few studies have been published in academic journals on the environmental impacts of climbing, and variation in methodologies and results suggest a limited development of climbing impact research theory and methodology (McMillan & Larson 2002). Consequently, the findings presented in this review should be treated as providing an initial understanding of the resource impacts associated with climbing – results are incomplete and many relationships to potentially influential environmental and use-related factors require greater clarification through further research.

The Access Fund (Attarian & Keith 2008) describes six zones that have the potential to be impacted by rock climbing activities: the approach (access trail), staging area (cliff-bottom), climb (cliff-face), summit (cliff-top), descent (descent trail or rappel route), and campsite. Existing cliff research has generally focused on studying rock climbing-related impacts to vegetation in the cliff-top, cliff-bottom, and cliff-face zones. Climbing impacts to the cliff-face include damage and loss of vegetation cover, including rooted vascular species, bryophytes (mosses, liverworts, and hornworts), and lichens attached to rock (Larson *et al.* 2000, McMillan 2000). Several studies have documented negative effects of rock climbing on vascular plant density and/or species richness on cliff-faces (Camp & Knight 1998a, Kelly & Larson 1997, Nuzzo 1995), on cliff-tops (Kelly & Larson 1997, McMillan & Larson 2002) and cliff-bottoms (Camp & Knight 1998a). Results of other studies have not found significant relationships between climbing and cliff vegetation impacts (Kuntz & Larson 2006b, McMillan & Larson 2002), thus a conclusive relationship between rock climbing activities and cliff site impacts has not been achieved.

When comparing cliff areas to the forest, a difference that is immediately apparent is a sharp contrast in vegetation structure and cover. Forests generally have several vertical strata of vegetation cover. In contrast, cliffs frequently have large patches almost completely devoid of vegetation cover. Vascular plants are generally rare on cliffs because they need cracks, ledges, or pockets to provide rooting opportunities (Matthessears & Larson 1995, Larson *et al.* 2000). In contrast with vascular plants, lichens are able to colonize nearly all rock surfaces. Some lichens (e.g., crustose forms) attach so firmly that they appear to be rock itself.

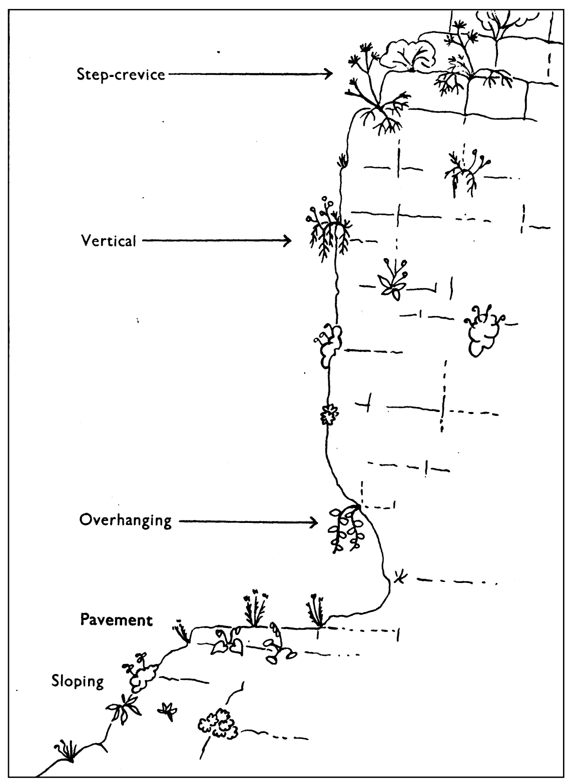

Figure 19. Rock area divided into six habitat areas for plants (ledge not indicated) (Davis 1951).

The group of vascular plants that grow on rocks and cliff-faces have three classifications: 1) chasmophytes grow in cracks with accumulated sediment, 2) chomophytes grow on accumulated detritus, and lithophytes grow directly on rock surfaces. Davis (1951) divides cliffs and rocky areas into six habitat areas for plants (Figure 19). The six areas are pavement, sloping rock, vertical rock, overhanging rock, step crevice and ledge. In addition to these areas, largely defined by slope angle, plant presence is also influenced by aspect and the amount of water and nutrients that can wash down from above, and the amount of soil that can collect in the cracks, ledges, and pockets. An important factor in understanding plants on cliffs is the pronounced effect of gravity (Larson *et al.* 2000), and in Potomac Gorge, the additional effect of flood scouring, sediment deposition, and sediment chemistry. An important interaction is between the plant roots, and cracks and ledges, which hold the plant in place (Matthessears & Larson 1995).

The following section provides a more in-depth review of cliff resource impacts associated with recreational uses. It follows a roughly chronological order, beginning with cliff-face impacts from climbing and progressing to cliff-top and cliff-base impacts associated with non-climbing recreational activities.

Nuzzo (1995) examined the effects of rock climbing on cliff goldenrod (*Solidago sciaphila* Steele) growing on cliff-faces at a rock climbing site in northwest Illinois. Belt transects were established on climbed and unclimbed sections of three cliffs. Initial results at all three study sites suggest that position on the cliff-face is the most significant factor in affecting growth of cliff goldenrod, with 70% of all plants located in the upper three meters of each cliff (Nuzzo 1995). Furthermore, within the upper three meters, rock climbing use was found to have a statistically significant impact on cliff goldenrod, as the density of cliff goldenrod was 75% lower on climbed cliffs than on unclimbed cliffs. The lower portion (i.e., greater than three meters below the cliff-top) of all cliffs was found to have consistently lower cliff goldenrod density than the upper portion of cliffs, and plant density did not vary between climbed and unclimbed cliffs.

In a follow-up study, Nuzzo (1996) examined rock climbing effects on vascular vegetation and lichen on climbed and unclimbed cliff-faces at a climbing area in northwest Illinois. Similar to cliff goldenrod findings (Nuzzo 1995), 70% of all vegetation was found to grow within three meters of the cliff-top. Lichen density and cover was significantly lower on climbed cliff-faces but no differences were found in vascular vegetation cover between climbed and unclimbed cliff-faces. Instead, vascular vegetation cover was predominantly influenced by the amount of fracturing in the rock and position on the cliff-face.

The effects of environmental gradient (position) and trampling on vegetation structure were studied by Parikesit *et al.* (1995) on cliff-edge trails located on the Niagara Escarpment, Ontario, Canada. To examine trampling effects on vegetation structure, transects with quadrats located adjacent to and on active and abandoned trails were examined. Plant species richness was significantly lower along high-use trails. Lower frequencies of phanerogams (seed producing plants) were found on quadrats positioned on the center of high-use trails compared to trailside quadrats, while cryptogams (mosses, lichens, etc.) were not found to differ according to quadrat position. Abandoned trails, in contrast, exhibited higher frequencies of both phanerogams and cryptogams on trails than on trailside quadrats (Parikesit *et al.* 1995). Soil characteristics affected by trampling, including soil depth and litter cover, had the most significant influence on vegetation structure. Thus, trampling impacts to soils may be the most influential factor in determining cliff-edge vegetation conditions in the study area, regardless of quadrat position or level of use.

Kelly and Larson (1997) examined the effects of rock climbing on tree density and age structure among populations of eastern white cedar (*Thuja occidentalis*) located on the cliff-face and cliff-top on the Niagara Escarpment in Ontario, Canada. In addition, trees were examined for damage caused by rock climbers, such as sawn off branches or rope abrasion. On each of four climbed and three unclimbed cliffs, five transects were extended from the base of the cliff, up the cliff-face, to three meters beyond the top cliff-edge. Tree density was found to be significantly lower on climbed cliff-faces, although no differences were found with regard to tree density on the cliff-top. The presence of rock climbing was found to coincide with higher rates of moderate to severe tree damage on both the cliff-face and cliff-top.

Eighteen cliff sites in Joshua Tree National Park, differing in level of climbing use (classified as intensive, moderate, and none), were examined by Camp and Knight (1998a) for effects of rock climbing on plant communities located at the cliff-base and on the cliff-face. Rock climbing intensity was determined using a combination of onsite assessments (i.e., looking for evidence of rock climbing use such as bolts, slings, chalk) and information from a rock climbing guidebook. Vegetative cover and species were recorded in transects established at 10 meter intervals along the base of each cliff. Sampling of vegetation on the cliff-face was limited to randomly selecting cracks ascending the face vertically, as preliminary analysis found little to no evidence of vegetation on unfractured rock. Results of the study suggest a negative vegetation response to increased climbing intensities on both the cliff-base and cliff-face. The number of plant species per meter, for example, was found to be lower for more intensively used rock climbing sites. Vegetative cover was not found to differ significantly among sites with different intensities of rock climbing use, although evidence of trampling (e.g., matted or crushed vegetation) was greater at higher use sites. Vegetation cover on the cliff-face was found to be significantly lower on more intensively used rock climbing sites.

A study by Farris (1998) examined the effects of rock climbing on cliff-face vegetative cover at three different Minnesota rock climbing sites. Building on conclusions from previous research citing the important influence of cliff physical characteristics (e.g., cracks and ledges) in affecting the presence and cover of cliff vegetation (Nuzzo 1996), this study examined three cliff systems varying in geological, physical, and vegetation characteristics (Farris 1998). Using a modified point-frame analysis (Bonham 1989), vegetative cover was estimated for plots on climbed and unclimbed sections of cliff a minimum of one meter below the cliff-edge and two meters above the cliff-base to limit the influence of non-climbing recreationists. In addition to vegetation cover, microtopographic features (e.g., crack, face, ledge, overhang), slope, and aspect of each plot was documented. Study results found vegetative cover to be significantly lower on climbed than unclimbed sections on two of the cliffs. Vegetative cover was also significantly related to microtopographic features, slope, and aspect. Based on the analyses, the authors suggested that the intervening effects of microtopography, slope, and aspect help explain the lack of a consistent relationship between rock climbing use and vegetation conditions. These findings call into question the results of earlier studies which did not account for differences in physical and topographic features of cliffs at macro and micro scales. Such physical factors may be as or more important than rock climbing use alone in explaining cliff-face vegetation attributes.

Smith (1998) conducted a study of cliff-face plant and lichen communities in Linville Gorge Wilderness Area, North Carolina. This study found that climbing disturbance removed foliose lichens, which are most susceptible to disturbance, but that crustose lichens, which closely adhere to rocks, increased in cover.

McMillan and Larson (2002) examined rock climbing effects on cliff vegetation within cliff-top, cliff-base, and cliff-face zones of climbed and unclimbed cliffs on the Niagara Escarpment, Ontario, Canada. Statistically significant reduction in vascular plant density on the cliff-top, cliff-base, and cliff-face of climbed transects was found, while vascular plant cover was only significantly lower on the cliff-top and the cliff-base of climbed sites. Bryophyte cover was found to be significantly lower in climbed transects than unclimbed transects in all three cliff zones. Lichen cover was found to be similar among climbed and unclimbed cliffs, while species richness was significantly lower on climbed cliffs for all three zones. The study also examined, but did not draw any definitive conclusions about the relative effect of different types of recreational use on vegetation impacts. The authors suggested that hikers were contributing to some cliff-top impacts in the study area but attributed most of the observed impacts to rock climbing.

Walker *et. al.* (2004) surveyed vascular plants, bryophytes, and lichens on cliff faces in the Obed River Gorge, Tennessee. This study conducted quadrat assessments placed at 3m intervals along 16 climbs, with "control" quadrat assessments made in quadrats placed 1-2 meters to the side. No effort was made to match geofeatures found along the climbs to control quadrats. Cliff-base and cliff-top areas were also sampled; comparing cliff-base and cliff-top quadrats to control quadrats placed 4-5m away from the cliff base or top. The variables for climbing status and visual climbing disturbance were significantly related to cliff-associated vegetation, though they were the "least influential of the [11] significant variables" examined (Walker *et. al.* 2004). Further, the variables for climbing status and climbing disturbance were insignificant for cliff-face vegetation, disturbance was highest for the cliff-base quadrats. They conclude that "variation among sample plots is not correlated to the climbing status (climbed or unclimbed) or the observed level of disturbance in those plots."

Consistent with the findings of Nuzzo (1996) and Farris (1998), and in what is perhaps the most comprehensive and sophisticated study of rock climbing effects on cliff-face vegetation, Kuntz and Larson (2006a, 2006b) found that microtopographic features of cliffs are important determinants of cliff-face vegetation conditions. Kuntz and Larson suggest that most previous studies of rock climbing effects on cliff-face vegetation have either ignored or have not properly controlled for microsite (microtopography) characteristics, and as a consequence, the results of these studies concerning the relationship between rock climbing use and vegetation impacts may not be valid.

To address these concerns, Kuntz and Larson (2006a, 2006b) conducted a study in the Niagara Escarpment that examined cliff-face microtopography and vegetation conditions between pristine and sport climbed cliffs. When microtopography differences were not accounted for in analyses, results showed greater vegetation impacts on climbed cliffs. But, when analyses examined the influence of climbing disturbance *and* microtopography, results showed that species richness and abundance of vascular plants, bryophytes, and lichens were related primarily to microsite attributes and did not decrease in the presence of climbing. In particular, vascular plant richness and abundance increased with increasing soil volume in cracks and on ledges while bryophyte richness and lichen abundance increased with decreasing volumes of soil. An examination of 2971 microtopographic features identified within study quadrats revealed greater numbers and densities of these features on pristine cliff faces than on cliffs selected for sport climbing. These findings also suggest the importance of differentiating between types of climbing – sport climbing does not require cracks for inserting protective gear like chocks and cams, which are required for traditional (trad) climbing.

Visitors to cliffs can also disturb and potentially displace wildlife that live or nest in cliff habitats. Cliff-related recreational activities can disrupt raptor foraging, nesting activities, and cause abandonment of nests and breeding territories (Cymerys & Walton 1988, Camp & Knight 1998b). Climbing management options to avoid or minimize impacts to raptors are described in Pyke (1997).

McMillan *et al.* (2003) examined the effects of rock climbing on land snails inhabiting the Niagara Escarpment in Ontario, Canada. Snail density and species richness were surveyed using transects located across cliff-base, cliff-face, and cliff-top zones of climbed and unclimbed cliffs. The study found snail density and species richness to be significantly lower in all three zones of climbed cliffs compared to unclimbed cliffs for 14 of 40 species of snails identified. Furthermore, snail species diversity was found to be lower in climbed cliff sites surveyed than in unclimbed sites. Removal and/or compaction of soils caused by rock climbing use were cited as primary factors affecting snail density, species, richness, and species diversity.

Climbing and rappelling impacts also include the use of fixed and removable anchors for protection, and chalk (carbonate of magnesia) used to reduce sweat on hands and provide greater friction on the rock. Potential impacts from chalk use include its visibility, dissolution of carbonate rock minerals, and increase in pH that could adversely affect cliff vegetation (Jones 2004, Swineford 1994). Chalk could raise the solubility of carbonate minerals in rocks such as dolomite and limestone, though this effect is likely negligible given the small amounts of chalk used. Similarly, the extent to which small amounts of chalk alters the pH of water runoff or affects cliff vegetation are likely minor, though this topic has not been investigated.

Installation of fixed anchors has been a particularly controversial issue for managers of federal wilderness areas, due to their permanency (Jones & Hollenhorst 2002). Anchors generally take the form of expansion bolts placed into holes drilled in the rock. Climbers attach their ropes to the anchors, which can arrest a fall of belayed climbers, or for anchor points in rappelling to descend the cliff. Most management agencies have policies governing their installation. When placed properly and responsibly, their use does little ecological damage to the cliff-face and may avoid resource impacts associated with tying ropes to trees or boulders, including damage to tree limbs, bark, or the associated trampling of plants and soil (Attarian & Keith 2008). Their use is also a subject of some debate between different types of climbers. Traditional climbers generally shun their use, preferring the challenge of placing removable protection devices in natural rock features. In contrast, sport climbers, who generally make face climbs that do not follow crack systems, require the use of bolts.

We note that the impacts from rappelling have generally been overlooked in cliff impact studies. Our observations suggest the need for greater research attention and management concern. Rappellers can anchor from trees to descend or reach any point on the cliff-face, whereas climbing routes are generally more restrictive. Furthermore, rappellers have the freedom to move in lateral directions during the rappel and the rope above them under tension can damage cliff-face vegetation.

Whereas cliff-face impacts are generally associated with rock climbers and rappellers due to technical skill and equipment requirements, the remaining zones are subject to impact by other recreationists such as hikers, backpackers, fishermen, photographers, birders, and campers. Cliff-associated trails are frequently visitor-created and lack the benefit of professional design or management. Such "informal" trails tend to directly ascend steep grades, alignments that are highly prone to erosion. For example, a study at Pinnacles National Monument in California (Genetti & Zenone 1987) documented erosion up to four feet in depth on some climber's trails. Similarly, cliff-top and cliff-base recreation sites are also often visitor-created, such as for belaying climbs, as vista sites, or even campsites. Cliff-associated recreation sites receive concentrated foot traffic and impacts similar to other recreation sites and campsites (Genetti & Zenone 1987, Carr 2007).

A study by Carr (2007) assessed cliff-base recreation site impacts at 16 climb areas (241 climbs) in the Red River Gorge, Kentucky. Mapping and assessments of visitor impacts showed the impact at the base of the cliff is composed of access trails and recreation sites that form at the base of climbs. Regression modeling was used to evaluate factors that could affect the size and locations of the cliff-base recreation sites. Sport climbing sites had nearly three times more impact than traditional climbing sites. Though not evaluated, this could be attributed to greater use intensity and more time spent on the ground. For sport climbs, predictive variables included the trail quality, number of similarly rated climbs at the area, and presence of overhanging rock. For traditional climbs, factors included the climb difficulty rating, climb quality, access trail length, and the presence of overhanging rock. Conversely, many variables were tested and found not to be important. For example, climb difficulty rating is not a predictor of impact at sport climbs. In contrast, for traditional climbs, as climbs get harder, impact decreases, presumably because they receive fewer climbers. Overall, climbing impacted 0.01% of the Gorge area and 0.4% of the cliffline of the study area.

Few studies have examined the relative effect of alternative types of recreational use on cliff resources (Parikesit *et al.* 1995). It is often inferred that cliff-top and cliff-bottom trampling impacts are caused primarily by rock climbers (Camp & Knight 1998a, Kelly & Larson 1997, McMillan & Larson 2002). For example, a letter from Virginia's Division of Natural Heritage describing the trampling and loss of globally significant cliff-top plant communities at Shenandoah National Park largely attributed the worst damage to "increased heavy use … by large rock-climbing groups" at Little Stony Man Cliff.

Marion and Carr (2007) investigated visitation and recreation-related impacts to cliffs in Shenandoah National Park to address management concerns related to rare and sensitive cliff-associated flora and fauna. In contrast to other studies, assessments omitted cliff-face assessments and focused on the development of protocols for assessing the condition of cliff-associated trails and cliff-top and cliff-base recreation sites. Staff located and assessed 44 recreation sites at 15 study sites; 32 were judged as predominantly hiking-related - all cliff-top vista sites easily accessed from park trails. Only six sites were judged as primarily climbing-related, with the six remaining sites assessed as mixed use. Mean recreation site size was 868 ft^2 with mean vegetation cover loss of 44% and base soil exposure of 28%. Impacts to woody vegetation included 17 trees assessed as damaged, 11 with erosion-related root exposure, and 7 tree stumps. Condition at 10 cliff-associated campsites were also assessed, 7 were predominantly hiking-related and 3 as climbing-related; 9 were located at cliff-tops.

This study included a comprehensive inventory and assessment of informal (visitor-created) trails located in proximity to the park's cliffs (Marion & Carr 2007). This included assessments of 58 informal trail segments totaling 7,532 lineal feet and 14,214 ft^2. The majority of informal trails were short off-shoots from a formal park trail or road to cliff-top vista sites. Only five informal trails were judged to be climbing-associated; these were cited in a climbing guide and provided climbers with access to the base climb routes. Mean soil loss from erosion, displacement and compaction, was 2.8 in with total estimated soil loss of 3250 ft^3 (2293 ft^3/mi). Suggestions to redesign, manage, and close/restore cliff-associated trails, recreation sites, and campsites, and to encourage low impact hiking and climbing practices are offered for consideration by cliff resource managers.

Wood *et al.* (2006) report additional results from this study from Little Stony Man Cliff, the most highly visited and impacted cliff in Shenandoah National Park, popular with hikers, backpackers, and climbers. Unobtrusive visitor observation of the primary cliff-top vista and climbing site was applied to investigate contributory factors of cliff-related recreation impacts. Day-hikers (particularly on weekends) and backpackers significantly outnumbered climbers within the cliff-top observation zone, though climbers spent more time on average (24 minutes), than hikers (9 minutes) or backpackers (5 minutes). A greater percentage of day hikers were observed to walk off-trail onto vegetation and soil (39%), compared with 29% of rock climbers and 16% of backpackers. Of particular importance to managers is the observation that climbers concentrated their traffic at the tops of climbs while hikers dispersed their traffic along the cliff-top, particularly during crowded, peak use periods. Thus, day-hikers were the most likely use type to expand the site and contribute trampling damage to the rare plant community. Site management and educational interventions are offered for minimizing visitor impacts to the cliff-top site and from adjacent campsites and informal trails.

MANAGEMENT CONSIDERATIONS

Evaluating Impact Acceptability

An important first step in management decision-making is evaluating and determining the acceptability of existing cliff-associated recreation impacts. Such judgments can be made by examining the results of this and other scientific studies, data collected by Charlie Davis (2011) documenting the presence and locations of rare flora, agency planning and management guidance documents, and with appropriate public input.

Managers might first consider the management zone and associated objectives where visitor impacts are occurring. Impacts occurring in pristine areas where preservation values are paramount are less acceptable than when located in areas that are intensively developed and managed for heavy recreation use. Secondly, managers might consider environmental and cultural factors. Visitor impacts occurring within rare, sensitive, or fragile communities of flora or cultural resources are less acceptable than when located in areas that lack such attributes. Within such sensitive areas, managers may also consider the specific locations where recreational activity is concentrated, their proximity to rare plants or cultural resources, and actual threat potentials. For example, the regionally rare but locally common *S. racemosa* was seen during fieldwork growing on and within trail and recreation site boundaries. Another rare plant was seen growing on an informal trail in recently deposited soils eroded from a poorly aligned upslope tread. This species only colonizes such disturbed substrates, which recreational activity occasionally provides.

Finally, managers should consider use-related factors. Impacts that can be easily avoided are less acceptable – such as when three informal trails in close proximity to each other access a recreation site that could be accessed by a single trail. Similarly, are three vistas present when one could suffice, or could a 2000 ft^2 vista be reduced to 500 ft^2 and serve the same purpose? Is visitor behavior a factor? Could low impact *Leave No Trace* practices be communicated and adopted by visitors to reduce their per capita impacts? Some impacts are desirable to visitors and facilitate visitor use. For example, the lack of vegetation on trails and recreation sites attracts and spatially concentrates visitor use and trampling, and facilitates their use by visitors. A trail or climb that lacks vegetation is simply easier to use.

A careful consideration of these and other relevant factors (e.g., visitor safety) can assist managers in making inherently value-laden decisions regarding the acceptability of visitor impacts. The acceptability of visitor impacts, in turn, guides decisions about the need for and selection of appropriate and effective management interventions.

For visitor impacts found to be within acceptable limits, managers may continue existing management actions and monitoring. As previously noted, visitation to parks is an important mandate and some degree of degradation is an inevitable consequence. Formal trails and recreation sites are never sufficient by themselves for sustaining all forms of park visitation. Dispersed off-trail traffic that can lead to the development of informal trails and recreation sites are necessary for accessing and using less visited locations, like rock climbing or fishing sites. Some degree of visitor impact associated with dispersed use activities is inevitable. The challenge is to avoid those visitor-associated impacts that can be avoided, and minimize those that can't. Defining, monitoring, and managing resources and visitors to avoid exceeding "acceptable limits of change" is a key challenge for park planning and management activities.

Managers should also consider the "costs" to visitors in reduced opportunities or experiential quality associated with alternative management actions under consideration. Frequent dialogue with recreation representatives can aid in the selection of the most effective practices that have the least cost to visitors. Fortunately, managers have some powerful site and visitor impact management strategies and actions available for avoiding or minimizing such impacts. The following sections review site and visitor management options, and provide specific suggestions relevant to cliff-associated recreational activities.

Site Management

Recreation Sites

Recreation site management actions fall into three general categories: close and restore sites, redesign sites, and install facilities. The following suggestions largely exclude reference to formal and informal trails, as these are more comprehensively addressed in a separate management report from a related study (Wimpey & Marion 2011).

<u>Close and Restore Recreation Sites</u>

Recreation sites that represent avoidable impacts, result from illegal uses, are poorly designed, or threaten rare or sensitive resources should be considered for closure and restoration. Give consideration to how closures will affect recreational opportunities, including what alternative sites are available, if visitors will find them acceptable, and how information about closures and alternatives will be communicated. Consider that visitors will migrate from a closed area to other areas; closures are only effective when the shift visitation from high-value/sensitive areas to lower-value/resistant areas. Working directly with the affected recreational groups to evaluate problems and alternatives, and implement appropriate solutions, is always preferable and provides the most effective outcome. Such groups can also provide volunteers to assist with site closure and restoration work.

Communication: Begin by evaluating existing communication, including printed literature, signs, and personal communication.

- Clearly communicate that rare or sensitive resources exist in the area and that they are being adversely affected by recreational activities.
- Explicitly ask visitors to remain on the formal trails and sites whenever possible to protect sensitive resources from damage. The objective is to reduce casual or unnecessary off-trail traffic, recognizing that off-trail activity may be essential for visitors engaged in activities such as nature study, climbing, and fishing.
- Ensure that visitors easily distinguish between formal trails/vistas and informal trails/vistas. Clear marking with paint blazes or signs can help visitors make distinctions.
- Include maps in printed materials and on trailhead signs showing the presence and locations of formal recreation sites (e.g., designated vistas) along trails. Otherwise, visitors may venture off-trail in search of vistas before they encounter the formal sites.

Actions to Close Sites: Consider a variety of options for closing sites, following an incremental approach and combines and adds actions as needed to improve success. Consider vegetative restoration actions only after sites have been effectively closed to visitor traffic.

- Consider the need for relocating formal trails well-away from sites that may otherwise be difficult to close.
- Close all recreation site access trails. Actions found to be effective in companion studies conducted within Potomac Gorge (Hockett *et al.* 2010, Wimpey & Marion 2011) include the placement of logs across informal trails at their junctions with formal trails, use of symbolic “No-hiking” prompter signs, and dispersal of organic leaf litter, rocks and light brushing to naturalize and hide informal trails.
- Apply these same actions to the closed recreation sites.
- If needed, post a sign indicating the direction and distance to the closest formal vista site.
- Consider installing low symbolic fencing or high barrier fencing to block site access.
- Move large felled trees or rocks onto the site to deter use.
- Restore soils to pre-use conditions.
- Restore vegetation through plantings of native trees, shrubs, and herbs/grasses.

Barren well-used informal trails and recreation sites serve as a “releasor cue” for visitors, attracting visitors to explore them for the reward of an interesting view (Hockett *et al.* 2010). Eliminate their attraction by keeping closed trails and sites covered with naturally appearing organic litter and materials. These actions seek to “hide” or make the trails and sites less visually obvious and appealing while they additionally reduce soil erosion and speed natural recovery. Note that heavy brushing with materials that a single person cannot easily remove can be effective, but may also shift traffic around them. A Blue Ridge Parkway study evaluating the effectiveness of heavy brushing work to close informal trails in rare plant communities reported that visitors dismantled twelve of fourteen brushings within two months (Johnson *et al.* 1987). The two successful brushings also failed to stop hikers, instead diverting them into rare plant habitats and creating new trails. The investigators stressed that managers need to focus on addressing the causes for the off-trail traffic, i.e., a visitor's desire to access a particular location. Contributing factors included:

- Visitor lack of knowledge about the rare plant habitat, its fragility, and visitor impacts,
- Lack of adequate signing to direct visitors to official trails and sites,
- Confusion about formal trail locations and destinations,
- Desire to explore or pick blueberries.

Sometimes physical barriers are necessary to prevent visitor access. Low borders of rocks or logs can sometimes communicate management intent to deter access and are less visually obtrusive than high barriers. Higher barriers include scree walls of native rock and low or high fencing that physically block access and provide indisputable evidence of management intent. A study at Acadia NP found low symbolic post and rope fencing to be substantially more effective than signs alone and deterred nearly all off-trail traffic (Park *et al*. 2006). Fencing can include rope or chain strung through wooden or steel posts and various types of manufactured fencing (Figure 20). Tall fencing is a highly effective solution, but even these must have clear signage to prevent passage over or around the fence. Terminate fences at locations that prevent informal trails from developing around the ends. High fencing can also present problems to visitors who must venture off-trail to pursue their recreational activities. Finally, barriers of all types can be temporary, altering visitor distribution patterns until vegetative recovery occurs, or permanent. However, it is critical that management actions effectively address the original cause for a recreation site's creation; otherwise, it may simply reappear.

Figure 20. Low symbolic fencing (left) and high fencing (right) provide the most effective deterrence to off-trail traffic.

Deterring continued access and use of recreation sites will initiate natural recovery of recreation sites but even limited or low levels of traffic can prevent or retard recovery (Cole & Spildie 2007, Cole 1992, Leung & Marion 2000). Unassisted recovery rates are extremely slow, particularly when soils are thin and dry, and a recreation site created in a single year can require many years to recover (Cole & Spildie 2007, Therrell *et al*. 2006). Recovery of native vegetation may not even be possible if native soils are not first restored or if non-native species become established on the site. Ecological restoration efforts should begin with evaluations of substrates on the site and comparisons to adjacent off-site substrates. Consult with restoration specialists to ensure the return of appropriate substrates and use of genetically appropriate native plant materials. Factors that affect restoration success include season of year for plantings, use of seed, transplants, or greenhouse stock, and soil type and preparation, fertilization, and watering (Cole & Spildie 2007, Therrell *et al*. 2006). The locations of plantings may also be important; a tree planted in thin soils over bedrock is unlikely to survive droughts unless its roots find deeper crevices that contain water. Don't initiate restoration unless effective actions have been implemented to address the original causes of site use and the site has been effectively closed, otherwise the restored area may receive further damage during or after restoration work.

Bear Island Trail Case Study

A case study is presented to illustrate a process of site evaluation, based on adaptive management research work completed in CHOH for the Billy Goat Trail A (BGT) as part of a companion study (Hockett *et al.* 2010). The BGT is located on Bear Island, a narrow strip of Maryland's Potomac River shoreline home to over 50 of Maryland's R,T &E species (Allen & Flack 2001). The 1.75-mile BGT receives about 122,000 hikers annually, with a large number of hikers venturing off-trail to find scenic vistas of the Potomac Gorge and River. The NPS judged the level of off-trail hiking and perceived impacts to rare plants to be unacceptable, and initiated our companion study to document impacts and investigate effective options for deterring them. As part of this work, 28 cliff-top vista sites were located and evaluated for their suitability based on the sustainability of their access trails, the scenic quality of the vista, durability of site substrates, site expansion potential of the vista site, and proximity of R,T&E species (Figure 21).

Managers selected an option retaining six vista sites (Figure 22) from among three options identified, closing 22 sites, including those with vistas of marginal quality or that duplicate vistas of a selected site, sites that are close to significant rare flora or fauna, and sites that are least resistant to the impacts of visitor traffic. Most of the vista sites retained were entirely located on bedrock, allowing closure of most sites with soil substrates. We note that climbing is quite limited in this area so the locations of climbs were not a factor in decision-making. The option selected represented a consideration of the legitimate need that BGT visitors have for visiting off-trail recreation sites to gain vistas of the Gorge and scenery, while retaining substantial protection of the island's sensitive habitats and species.

Access Trail Design:
1 = Excellent design – highly sustainable (mostly on rock, grades on soil <15%, no seasonally wet soils).
2 = Intermediate design – moderately sustainable.
3 = Poor design – not sustainable.

Site Vista Quality:
1 = High quality vista – highly scenic vantage point for viewing a good portion of the gorge with visibility unobstructed by rocks or vegetation,
2 = Good quality vista – scenic vantage point for viewing the gorge,
3 = Poor quality vista – not particularly scenic and/or a poor vantage point for viewing the gorge.

Site Substrate Durability:
1 = High durability – mostly rock surfaces.
2 = Moderate durability – mixed rock and soil surfaces.
3 = Low durability – mostly soil surfaces.

Site Expansion Potential:
1 = High containment of use – off-site areas are completely unsuitable for any expansion in site size due to steep slopes, rockiness, dense vegetation, and/or poor drainage,
2 = Moderate containment of use – off-site areas moderately unsuitable for expansion due to the factors listed above,
3 = Low containment of use – off-site areas are suitable for site expansion, features listed above provide no effective resistance to site expansion.

Rare/threatened/endangered Species Sensitivity:
1 = Low – site is not located 24 feet or greater from any known rare/threatened/endangered species.
2 = Intermediate – site is located between 12 and 24 feet of any rare/threatened/endangered species.
3 = Poor – site is located within 12 feet of any known rare/threatened/endangered species.

Figure 21. Selection criteria applied to assess the suitability of vista sites along the BGT.

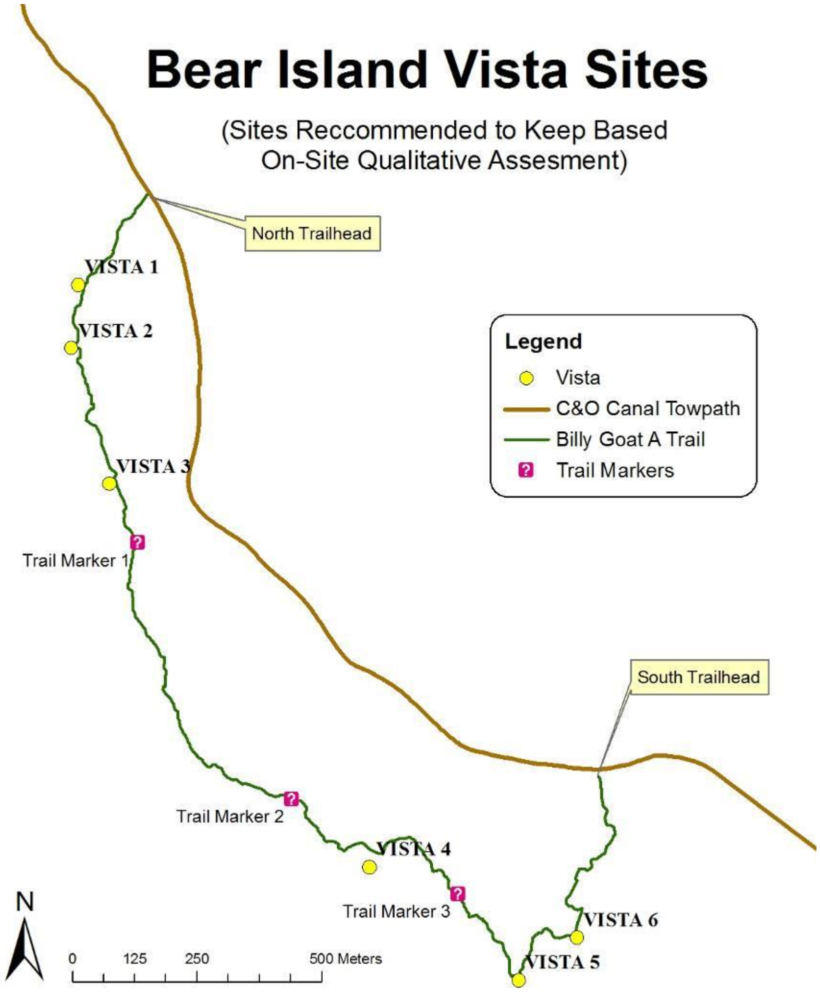

Figure 22. Site map used on trailhead signs to inform hikers of the existence and locations of formal vista sites.

Redesign Recreation Sites

For those sites remaining open to visitor use, several effective site management actions can aid managers in restricting their size and reducing resource impacts. First, consider site access, selecting a single well-designed trail, preferably with durable rocky substrates and low grades. The access trail should enter the site perpendicular to the cliff edge and end, rather than running parallel to the cliff-top. If needed, redesign and reconstruct the access trail to make it sustainable, adding durable substrates and rock borders or even fencing if needed to restrict off-trail hiking.

Second, evaluate the recreation site's uses, size and expansion potential, proximity to sensitive resources, substrates, and safety:

- Whenever possible, separate cliff-top vista sites for hikers, from climbing sites, particularly if climbers use anchors that leaves unattended ropes within reach of hikers. If not, consider installing permanent bolt anchors for climbers just below the cliff-top.
- Where needed, restrict site size and expansion potential with border stones, logs or felled trees, scree walls, or fencing. When possible, retain site portions that have the best vistas

and the most rock and natural constraints to expansion. Post text or symbolic prompter signs as needed to clarify the need for visitors to remain on the site to avoid expanding the site and trampling sensitive resources.

- Some sensitive resources are widespread and difficult to avoid during site selection. If present, consider site designs and actions to protect these resources. For example, the higher level of protection offered by fencing may be justified to protect sensitive resources adjacent to some sites, or rockwork placed to shift traffic patterns around a small patch of plants.
- Improving site substrates by extracting rocks or stumps to provide smoother walking surfaces attracts visitors to a site and keeps them there. Similarly, adding large rocks or logs to adjacent off-site areas can discourage visitor traffic in these areas.
- Where appropriate, adding a gravel/soil mixture to the site can increase its durability to heavy traffic, protecting underlying soils from erosion. The substrates used should have long-term durability and not alter the pH of adjacent native soils. For example, organic mulch may not be preferable as it degrades quickly, forms muck when wet, and could increase the acidity of adjacent soils (limestone gravel should also be avoided). Strategically place border rocks and logs to limit the loss of site substrates to erosion from water or wind.
- Consider that agency liability increases with site development and improvement. Distinguish between barriers placed to limit site expansion (resource protection) and those placed along the cliff-edge for visitor safety. The use of visitor safety barriers substantially increases liability – these must conform to recognized safety standards (e.g., be childproof) and receive frequent evaluation and maintenance.

<u>Construct and Manage Facilities</u>

Visitor impacts can also be avoided or minimized through the construction of facilities to attract and concentrate use to a specific intended location. Actions related to this strategy have already been described but are discussed as a separate strategy here. A new well-designed and constructed formal trail can replace several poorly located and rapidly degrading informal trails. Replacing numerous informal vista sites with a few carefully selected and developed formal vista sites can also greatly reduce the total area of trampling disturbance within sensitive resource areas. Within these features, managers can also construct facilities that increase site durability, attract and concentrate use, and discourage or prevent site expansion and off-site activity.

Consider the appropriateness of relying on facilities in remote areas, though exceptions can be granted when essential to protect sensitive resources. Generally, only primitive and rustic facilities are appropriate in backcountry settings, including rockwork without cement, scree walls, or log borders used to guide and concentrate traffic. For example, the Carderock climbing area photo in Figure 23 illustrates rustic stone steps and rock retaining walls constructed to armor a popular climbing belay site against traffic. Such actions can effectively prevent the soil from eroding away from trees, which are also critical to climbers due to their use as anchors. Such rustic stone steps and retaining walls have long been considered as appropriate facilities for backcountry and even wilderness trails, but are more rarely applied in climbing areas. We recommend expanded use of such facilities as they can improve the ability of these areas to sustain use while substantially limiting associated resource impacts.

Facilities are more appropriate in accessible frontcountry settings, including the use of less rustic materials like dimensional lumber boardwalks, railings, and stonework with cement. A vista site at Shenandoah National Park's Hawksbill Mountain provides one illustration (Figure 23).Similarly, within the Potomac Gorge study area, the highly developed recreation sites constructed at the most accessible Great Falls vista locations effectively accommodate and contain the substantial daily traffic they receive. When planning such facilities care must be taken to match facility sizes to their intended capacities.

Figure 23. Primitive stone steps and retaining walls constructed to protect a popular cliff-base belay site at Carderock Cliffs (left photo); observation platform with cemented stone walls that prohibit site expansion at the Shenandoah NP, Hawksbill Mountain vista (right photo).

Climbing-related facilities, such as permanent bolt anchors, can also be considered as a form of facility. Rock climbers frequently construct climbing anchors using trees, sometimes with ropes stretched across recreation sites commonly access by hikers. Our data in this study and in the Shenandoah NP (Marion & Carr 2007) study found only limited damage to trees, though this contrasts with the more substantial climbing-related damage described by Kelly and Larson (1997). The installation of fixed anchors just below the cliff-top in some locations could avoid problems related to the safety of exposed ropes and trampling impacts to cliff-top soils and vegetation near trees used for anchors (Baker 1999, Attarian & Keith 2008). Due to liability concerns, land managers rely on local climbing organizations to install and maintain fixed protection (bolts) in protected areas. This is generally done through collaborations and after development of guidance documents or climbing plans.

Cliff-Face Environments

This section is restricted to site management practices for cliff-face settings and recreational activity that require ropes, or scrambling that requires the use of hands. Site management practices are presented in this section, with educational and regulatory practices in following sections.

Alter Climbing Routes

In some instances, it may be possible to alter climbing routes to avoid impact to rare plants. The removal or addition of anchor bolts, and/or alteration of climbing guides, which include descriptions and photos or diagrams of each climbing route, can accomplish this. While most climbers own and consult climbing guides, on-site signage may also be necessary to inform all climbers of climb route changes. Attarian and Keith (2008) note that the strategic placement of fixed anchors on the cliff-face can also be used to protect trees or vegetation communities by diverting use away from them. For example, this was done in North Carolina State Parks and at Sunset Rocks, Tennessee in the NPS Chickamauga and Chattanooga National Military Park. They also suggest targeted outreach on species recognition and avoidance practices, and individual climbing route restrictions. Collaborations with climbers and the authors of climbing guides are critical to the successful application of this strategy.

Install Tree Slings or Bolt Anchors

Within Potomac Gorge, climbers have generally used natural anchors rather than fixed protection (permanently installed metal expansion bolts in holes drilled in the cliff-face). However, our survey did reveal the presence of older pitons, top and face bolts, and other mostly historic artifacts. Cliff-top trees are numerous and provide the most commonly used anchor. While abrasions to tree bark and small limb cutting is common, their use as anchors rarely causes damage that is more deleterious. Nevertheless, if trees are used, one recommended low-impact practice is to install webbing slings around trees to avoid trampling damage and impacts from the repeated wrapping and unwrapping of ropes around the base of trees. If used, periodic inspections are necessary to replace webbing that has deteriorated from exposure to the sun.

The trampling and loss of ground vegetation and organic litter cover and soil around trees used as anchors is perhaps a more significant form of visitor impact. Such impacts could affect rare plants, and the removal of vegetation and organic litter substantially increases the rate of soil drying and loss, and may increase tree mortality during severe droughts. The installation of bolt anchors just below the cliff-top is an effective management practice that avoids impacts to trees and adjacent vegetation and soils. According to Attarian and Keith (2008), strategic bolt placement is increasingly being used by land managers “to protect sensitive resources such as cliff-edge vegetation, soils, and specimen cliff trees.” However, it is our understanding that Potomac Gorge climbers may not favor this practice, so discussions with the climbing community and possibly a climb-specific decision-making process is recommended.

Another low impact practice is the placement of permanent bolt anchors at carefully selected “impact resistant” rappel stations, allowing climbers to descend the cliff without using steep descent trails (which often have vegetation and easily eroded substrates). Substituting a rappel station in a location with naturally barren rock at the top, bottom, and along the intervening cliff-face, will result in less environmental damage than the same traffic on a descent trail, which generally have soils and vegetation. One rappel station can generally service a cluster of climbing routes. Such stations have been successfully implemented at the New River Gorge National River, WV, Shiprock, NC, and other areas (Attarian & Keith 2008). Alternately, descent trails can be stabilized by rockwork, which can also channel traffic around vegetation.

The placement of bolts on the cliff-face can also permit climbing in areas where geofeatures and vegetation is rare or non-existent. Known as sport climbing, this type of climbing does not require cracks or other geofeatures that are required by vascular plants. Thus, this type of climbing would likely contribute fewer cliff-face impacts to rare vascular plants. As previously noted, such considerations would necessitate dialogue with the climbing community. A Climbing Oversight Committee is generally used to evaluate and make suggestions to land managers any alterations in climbing routes, placements of permanent webbing and bolt anchors, and other climbing management practices. Delegating the installation, evaluation, and maintenance of permanent bolts to climbing organizations removes any liability for such facilities from landowners and managers.

Close and Restore Climbing Routes

Following an evaluation of impacts and their acceptability, managers may need to consider either temporary or permanent closures of sections of cliffs or specific climbing routes. For example, rare wildlife species, including peregrine and prairie falcons, nest on cliffs and seasonal closures of adjacent trails and climbs are often used to provide protection when the nests are active (Attarian & Keith 2008, Pyke 1997, Richardson & Miller 1997). Peregrine falcons have been released and do nest on the cliffs at Shenandoah NP, where seasonal area closures are established on an “as-needed” basis. An area closure has also been used within the Potomac Gorge to protect cultural resources, specifically the Old Patowmack Canal cut through the cliff-line immediately downstream from the popular Aid Box climbing area. This closure is highlighted in the text and climbing maps of the local climber’s guide (Tait 2001, pg 83) and our observations suggest good compliance. Further information and guidance on the management of climbing relative to the protection of cultural resources is provided by Attarian and Keith (2008).

The protection of rare plants may also necessitate such closures, particularly for high priority plants located directly within climbing routes, descent trails, or other commonly visited sites. Considerations include the proximity of visitor activity and the relative rarity of the plants (global, national, state, and local). We note that the corridor of potential disturbance and impact for a climbing route is wide for easier routes but can be quite narrow for routes that are more difficult. Consultations between botanists and climbers can help to evaluate the need for closures and to gain support for them when essential to achieve adequate resource protection.

This study revealed one state-listed rare plant, *Solidago racemosa*, to be one of the most common vascular plant found on the Potomac Gorge cliffs. While NPS management policies specify the need to protect this and other rare plants, its prevalence both near and distant to climbing routes suggests that closures are likely unnecessary to ensure its protection. But, other species, such as *Amelanchier nantucketensis*, are nationally and locally rare. We suggest greater management attention for these types of species. As previously noted, Charlie Davis (2011) conducted extensive searches throughout the study area for rare plant species and presents his findings in a separate report. As these examples illustrate, a case-by-case evaluation by land managers and affected recreational representatives will generally yield the best solutions that effectively balance resource protection and recreation provision mandates.

Restoration work, if enacted, can be passive or active. Simple closures may be sufficient to allow rare plants to grow and recolonize available geofeatures in areas disturbed by visitor trampling. However, if the rare plant requires substrates that are missing due to recreational activity, managers may want to consider replacing them. Consultations with experts familiar with the rare plants specific physical and environmental requirements are advisable (e.g., geofeature type, substrate type and pH). Active restoration also could include the propagation and planting of rare plants in suitable geofeatures, or the collection and dispersal of seeds. Control of competing species, particularly non-native species, may also be considered.

Visitor Management

Visitor management options avoid or minimize impacts by altering behavior through educational messages or regulations. For example, educational messages on trailhead displays can inform all visitors of the presence of rare plants and need to stay on formal trails and recreation sites to prevent their trampling (Cole *et al*. 1997, Marion & Reid 2007). Alternately, regulations could limit the type or amount of visitation or even prohibit off-trail hiking in certain areas. Unfortunately, studies reveal that education or regulations would need to eliminate nearly all trampling from environments with low trampling resistance or resilience (ability to recover), to achieve any substantial recovery on well-establish recreation sites or trails (Cole 1987, Leung & Marion 2000). This is quite challenging given that education-induced behavior change is voluntary and the effectiveness of regulatory approaches depends on the frequency of patrolling by agency law enforcement officers (Marion & Reid 2007). Integrating visitor management and site management actions provide the best opportunities for achieving success.

Educational Practices

To protect cliff-associated plant communities, the objective of visitor education efforts should be to increase the spatial containment of visitor trampling on a limited number of small, well-defined, and resistant locations (Cole 1992, Leung & Marion 1999b, Marion & Farrell 2002). For example, research has shown that effectively worded and communicated *Leave No Trace* messages can reduce off-trail hiking rates (Marion and Reid 2007). However, compliance can be further enhanced by improving trail blazing and constructing trail borders or fencing. In high use areas, educational messages can ask visitors to concentrate traffic on formal trails and recreation sites. In low use areas, messages can ask visitors to restrict traffic to trampling-resistant natural surfaces (e.g., rock) or on the bare substrates of well-established formal or informal trails and sites. Unnecessary trails and sites can then be closed and restored. Cliff-related visitation is usually tied to specific climbing routes or vistas, so impact-reduction practices based on a visitor dispersal strategy would be ineffective.

Educational messages are generally communicated by signs placed at trailhead or cliff-site locations, through hiking or climbing guides and pamphlets, agency or climbing organization websites, retail stores that sell climbing gear, climbing gyms and guiding/instructional services, climbing clubs and organizations, or by personal communication through park staff or volunteer trail or climbing stewards. Educational signs placed in backcountry settings are generally limited to those deemed critical to resource protection efforts and are generally for short-term use, giving restoration and vegetative recovery a chance to take hold. Financial and experiential “costs” associated with use of signs or artificial site management work (e.g., fenced boardwalks) must be evaluated against the expected “benefits” of enhanced resource protection.

An effective but inexpensive educational method is to install small "prompter" signs, such as a 3x3 inch symbolic sign showing a Vibram boot print with a red slash symbol superimposed (Figure 24, left). These can be screwed onto a log pulled across an informal trail or site, mounted on a short well-anchored stake, or posted in a decal version on a Carsonite post (sources: www.rockartsigns.com, www.vosssigns.com, www.carsonite.com, and www.rhinomarkers.com). For trails or sites that are difficult to close, an effective technique is to cover initial portions with peat moss and/or organic litter and jute netting and install a restoration sign (Figure 24, middle). Visitors who see an earnest attempt to restore a trail or site damaged by foot traffic will be less willing to "ruin" that effort by walking on it. An effectively worded educational sign (Figure 24, right) should clearly define the appropriate behavior, educate visitors about how their personal actions contribute to resource impacts, and provide a compelling rationale (Vande Kamp *et al*. 1994, Winter 2006). For example, a number of studies have demonstrated the efficacy of a sign with message wording like this: "Please Do Not Leave Designated Trails to Preserve Sensitive Vegetation" (Cialdini 1996, Cialdini *et al.* 2006, Johnson & Swearingen 1992).

However, even the most effectively worded signs are ineffective if visitors can't *easily* distinguish between official and visitor-created trails or recreation sites. Clear markings with paint blazes can help visitors distinguish between formal and informal trails. Even a well-blazed trail may be insufficient; what appears clear to managers if often unclear to visitors. Official recreation sites can be identified by blazed trails leading to them, an official sign, or facilities.

Figure 24. Examples of signs designed to discourage off-trail or off-site trampling.

It is worthwhile to consider how some of these visitor management suggestions might be applied to the heavily visited Potomac Gorge cliffs. Educational efforts could employ both trailhead and onsite signs (Figure 24) designed to convey low-impact visitor behaviors to minimize soil and vegetation trampling. Complementary site management work could help restrict visitor traffic to a limited number of formal vistas with educational signs informing visitors of the need to restrict their traffic to intended use areas. Park staff would need to communicate targeted messages to climbers that such guidance does not apply to them – they would need to venture "off-trail" to access their climbs. However, climbers could access climbing sites using a substantially reduced network of informal trails. As noted in Attarian and Keith (2008), informal trail surveys and planning at other climbing areas have led to successful efforts by managers to restrict traffic to a selected subset of informal trails. For example, at Joshua Tree NP, a reduced network of informal trails accessing the climbing areas was identified by placing a climber-specific symbol on stickers attached to Carsonite posts. An image of a climbing carabiner was used, which is recognizable by climbers but not the general public (Joshua Tree NP *et al.* 2000).

The *Leave No Trace* program develops and promotes low impact outdoor practices and ethics designed to make all outdoor activities more sustainable. This national non-profit program has staff and numerous collaborators who develop the best available low impact practices for a diverse array of environments and recreational activities, including materials and messaging that specifically target climbing, hiking, and fishing (see www.LNT.org). We urge park staff to assemble and actively promote these practices, which have been formally adopted by most protected area land managers, including numerous private organizations. For example, the Leave No Trace Center for Outdoor Ethics has developed a comprehensive 25-page Skills & Ethics booklet on rock climbing that could be sold in visitor centers and used as a resource for educational efforts. The ethical component of the *Leave No Trace* program encourages visitors to become more actively involved in planning, management, and stewardship efforts for the areas they visit. Climbers and hikers at both Great Falls Park and Carderock have actively participated in past stewardship projects held at both parks and have been actively involved in current park planning efforts and in our cliff and trail studies.

Including the best available *Leave No Trace* practices in climbing guidebooks for the area is perhaps the best way to inform climbers. While Tait (2001) doesn't specifically mention this program, he does include a section of the book describing the presence of rare plants, visitor impacts to the park, and a plea urging climbers to:

- Use previously established footpaths when possible; do not develop new trails.
- Utilize climbing routes from the bottom as much as possible to reduce impacts on top.
- Avoid pulling, trampling, and stepping on vegetation as much as possible.

While these are excellent low impact practices, much more could be communicated. A one-page version of additional *Leave No Trace* practices for climbers is included in Figure 25. These emphasize learning about and complying with area regulations and low impact practices, accessing climbs using formal or designated informal trails, avoiding plant, wildlife, and cultural resource disturbance, and being considerate of other visitors.

Other effective communication methods for *Leave No Trace* practices include development and free distribution of a climber's pamphlet, an LNT bulletin board panel, and a separate "climbers" page on the park's website. Climbing-related information would include: 1) basic park-wide climbing guidance, 2) information about cliff-associated rare plant communities and species with visitor impact management concerns, 3) low-impact climbing practices, and 4) where necessary, guidance for specific cliffs, climbing areas, or climbs within the park (e.g., how to locate and use a reduced network on climbing area access trails).

Finally, we note that there is good reason to believe that rock climbers will be receptive to such information and compliant with educational messaging. A survey of rock climbers at Shenandoah NP revealed substantial support and receptivity for the provision of information on low impact climbing practices, required use of designated access trails, closing cliffs during critical wildlife seasons, and closing climbing routes with sensitive rare plants (Lawson *et al.* 2006). Interestingly, findings also revealed that climbers were relatively unaware of visitation-related impacts to cliff-associated rare flora and fauna. Such information needs to be communicated more effectively to all cliff visitors, including hikers. All visitors need to become better informed about the resource impacts associated with their recreational activities, for if they are, they can modify their behavior to avoid or minimize these impacts. Doing so will also protect their continued access to the areas they cherish, and avoid future restrictions and regulations that may be imposed on visitors.

Plan Ahead and Prepare

- Develop skill and take responsibility - plan climbing trips that match your ability and be prepared for emergencies.
- Find out and comply with climbing regulations for the area you will visit.
- Learn about and apply the best available low impact practices. Teach these to others in your group.

Travel on Durable Surfaces

- Access your climbs using blazed formal trails or sustainable well-established informal trails, or travel on rock or barren surfaces.
- Avoid trampling or disturbing vegetation – many cliff-associated plants are rare.
- Concentrate all activity on rock or naturally barren substrates.
- Ensure that staging areas large enough for your group and keep these and your belay sites as small as possible.
- Rappel to descend the cliff unless a durable non-vegetated descent trail is available.
- Use permanent anchors when available, or the best available low impact practices for setting anchors on trees.
- Limit bouldering to areas where climbers, spotters or crash pads will not harm vegetation. Avoid removal of rocks or other landscaping to "improve" a bouldering problem or to make it safer.

Dispose of Waste Properly

- Use developed restrooms for human waste disposal or pack out your waste.
- Carry plastic bags to pack out old webbing, climbing tape, and all trash.
- Minimize the use of chalk. Keep your chalk bag closed to prevent spills and clean up any spills that do occur.

Leave What You Find

- Leave natural features undisturbed – do not chip holds or remove vegetation or soil from cliff cracks or features.
- Avoid damaging the rock or trees when installing or retrieving removable protection.
- Bolts may only be established with the approval of park staff.
- Preserve the past - do not disturb historic or archeological sites.
- Avoid spreading non-native plants - clean your gear to remove seeds after each outing.
- Avoid vegetated cracks, rock with easily damaged lichen or moss, and areas that require "cleaning."

Respect Wildlife

- Avoid sensitive times and habitats - observe area closures.
- Observe wildlife from a distance - pay attention to clues that animals are disturbed and retreat from a climb if necessary.
- Never feed animals or allow them to access your food or trash.
- Leave your pet at home.

Be Considerate of Other Visitors

- Keep a low profile - break into smaller groups if you are with a large party, limit your time at any single route, be cordial and polite to others. Let nature's sounds prevail.

Figure 25. Suggested Leave No Trace low impact climbing practices for climbers.

Adapted from: Jefferson County Open Space 2006, Leave No Trace Skills & Ethics Booklet 2003)