Representing, Classifying, and Monitoring In-Cave Features with GIS; Methods Used by the Bigfork High School Cave Club of Northwest Montana

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Abstract

The Bigfork High School Cave Club has completed numerous cave conservation and monitoring projects in partnership with federal land managers. Club members have received considerable recognition for their work, including the 2009 President's Environmental Youth Award. The club typically established three types of in-cave monitoring: (1) temperature and humidity measurements, (2) photo monitoring, and (3) visitor impact point and area monitoring (VIP and VIA). The club represents and analyzes their monitoring using Geographic Information Systems (GIS). Inputting monitoring into GIS begins with georeferencing cave maps onto a base layer. Next, monitoring points are drawn relative to features represented on the georeferenced cave map using the pencil tool in editor. For each point a description and feature classes are included in the attribute table. Feature classes have been developed for feature type, significance, fragility, and condition. GIS facilitates organization of the club's copious monitoring data. Examples of how the club uses GIS to represent and analyze data include graphical representation of resource conditions, evaluation of the extent and distribution of feature types, calculating and comparing areas of polygons that represent expansive features, and deriving statistics for classified features. The club has developed a procedure that links monitoring to management. The procedure involves: (1) assigning a LAC management class to each feature, (2) setting a LAC threshold for each class of feature and having managers commit to a predetermined management action should the threshold be exceeded, and (3) implementing predetermined management.

Background

The Bigfork High School Cave Club of northwest Montana was created in 2005 to provide high school students with opportunities to participate in wholesome recreational activities and conduct cave conservation projects through partnerships with local land managing agencies such as the US Forest Service and National Park Service. The club maintains an active membership of about 15 students. Each school-year club members participate in at least three recreational trips and three conservation projects. Conservation projects include removing graffiti and trash from heavily vandalized caves, mapping passage, and inventory and monitoring of sensitive cave resources using Geographic Information Systems (GIS).

In 2010, the club was awarded the President's Environmental Youth Award (PEYA) for their work in the conservation of caves in Glacier National Park (Bodenhamer, 2010a). They were only one of ten groups in the nation to receive the award and as part of the award ceremony two club members were flown to Washington DC to present their project to the director of the EPA and meet President Obama. In 2010 they were also invited to present at the opening ceremony of the International GIS Users Conference in San Diego (Bodenhamer, 2010b). At the conference they spoke to a gathering of over 10,000 people!

In 2011 the club finished an aquatic invertebrate study for Glacier National Park (see Cottle, within these proceedings) and worked in caves on the Flathead National Forest to establish monitoring of mineral resources, macroscopic biology, bat sign and bat hibernacula. The club's bat work is being done in coordination with Montana Fish, Wildlife, and Parks in preparation for the potential spread of White Nose Syndrome to Montana. Also in 2011, the club completed monitoring for 11 caves in Grand Canyon National Park (Baker et al. 2011). This work was completed in one week of field work followed by two months of GIS input and report preparation.

At the 2011 National Cave Management Symposium in Midway, Utah the club presented highlights of the work in Glacier and Grand Canyon National Park. During questions and answers, there was much interest in methods the club uses to represent, classify and monitor in-cave features with GIS. This article overviews these methods. Those interested in learning more about the club's monitoring, GIS use, or other aspects of their work are encouraged to contact the club sponsor.

Monitoring Methods

Club members typically conduct three types of in-cave monitoring: (1) temperature and humidity measurement, (2) photo monitoring, and (3) visitor impact monitoring.

Temperature and Humidity

Temperature and humidity are measured using an Extech model HD500 psychrometer with IR thermometer. Temperatures are measured at the ceiling, floor, and mid passage (or chest height for high-ceiling passage), and relative humidity is measured at mid passage (or chest height). The location of measurements is marked on a 1:240, paper copy of the plan map of the cave. Typically the measurements are made at 50 foot intervals throughout the cave. The club has also used dataloggers to record temperature fluctuations within caves, but because fluctuations in most caves are minimal, we feel the measurements taken with the Extech are more than adequate to detect climatic or human caused changes to temperature and humidity within most caves.

Photo Monitoring

Photo monitoring is established using a handheld, digital camera with greater than 10 mega pixels and camera-mounted flash. The point from which the photo is taken is marked on a 1:240, paper copy of the cave map, and a brief description of the feature and the magnetic azimuth of the photo view is recorded while in the cave. Magnetic azimuths are taken with a Suunto KB-20 360R compass.

Club members have repeated photos taken by previous club members from earlier years and also repeated archived, historic photos taken from as long ago as 1912. Before in-cave work, club members digitally label cave name and photo number on each photo to be repeated. This facilitates managing the photos if they are dropped or shuffled in the cave. Each photo is then printed (usually in black and white) on 8.5 by 11" paper and laminated. The 8.5 by 11" format makes the prints easy to view in the cave and the lamination protects the prints from the cave environment and rough handling. Club members relocate photo points within the cave, view directions using map points and recorded azimuths, and mimic framing by holding the laminated prints beside the camera and until the views are similar.

Although better quality photos could be taken with a higher quality camera, and more precise framing of views could be achieved using a tripod set to a measured height above a point marked in the cave, the beauty of the cave club's method is it is quick and relatively easy to establish and repeat. This allows club members to establish many more photo points than they would if they needed to set up a tripod, measure camera heights, and manage a more expensive camera and an off-camera flash. It also makes it easy to add additional points during repeat monitoring trips. The club's results using this "quick and inexpensive" method are impressive. The method requires careful study of repeat and original photos to detect changes in views that are "slightly off", but sitting in front of a computer comparing cave photos is less challenging than hauling extra gear and fine tuning view directions while in a cave. An example of a repeated and an original photo with slightly off views is presented in Figure 1.

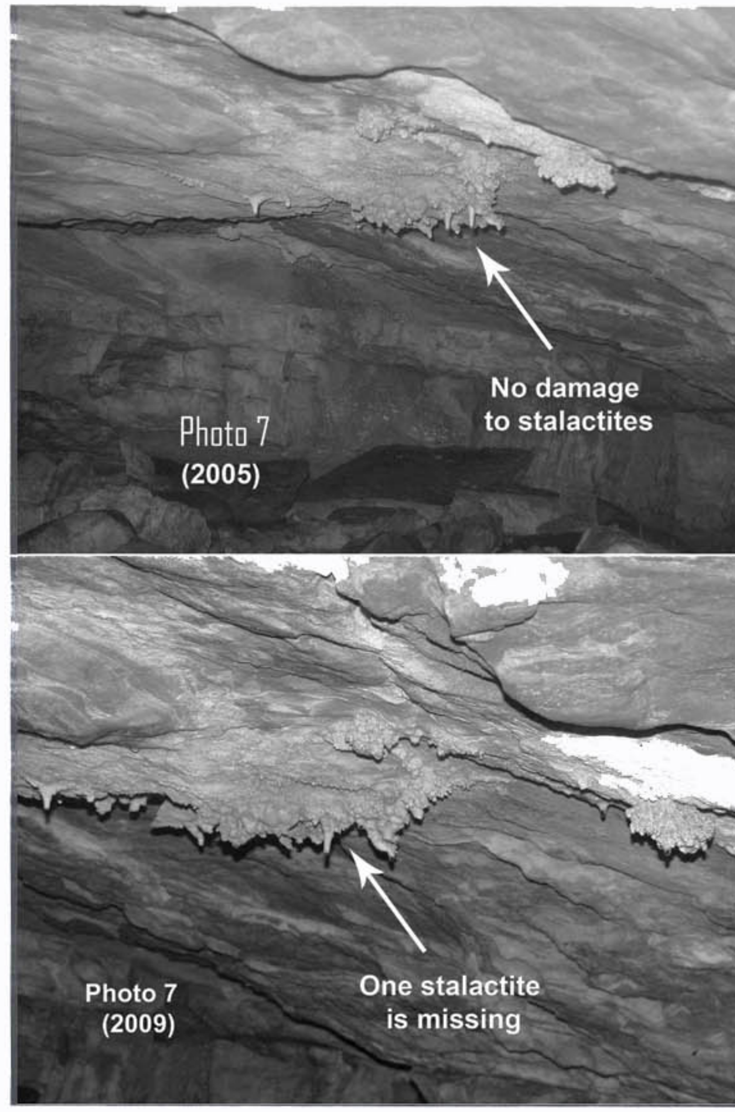


Figure 1. An Example of a slightly off photo view used by the club to detect changes to mineral features

Visitor Impact Point and Visitor Impact Area Monitoring

Visitor Impact Point (VIP) and Visitor Impact Area (VIA) monitoring are established using simple procedures described in the 2006 edition of Cave Conservation and Restoration (Bodenhamer, 2006). In overview, these procedures involve locating, describing, and classifying human-caused changes to cave features by marking points (VIP) or drawing areas (VIA) on a detailed map of the cave. The club classifies impacts to cave features using the scheme described in Cave Conservation and Restoration, but has added classification schemes for the fragility, significance, and management of cave features. Classification schemes are described later in this article.

The club has experimented with using ArcPad on handheld Trimble Junos for in-cave collection of visitor impact and other types of monitoring data. We have loaded cave maps and drop-down menus into the Junos. This allows us to digitally draw points, polygons, and transcribe descriptions while in

Figure 2. Cave club members using a Juno

the cave that can be directly uploaded into GIS following the monitoring trip. This greatly reduces the amount of time it takes to enter data into GIS. However, the Junos with ArcPad are expensive, about $900, which makes them challenging to acquire and worrisome to transport and use in a wet, rugged cave environment. Furthermore, the Junos seem to work well for collection of point data, but because the small screen it is difficult to draw polygons. A photo of club members recording monitoring data with a Juno is presented in Figure 2.

Representing Data in GIS Layers

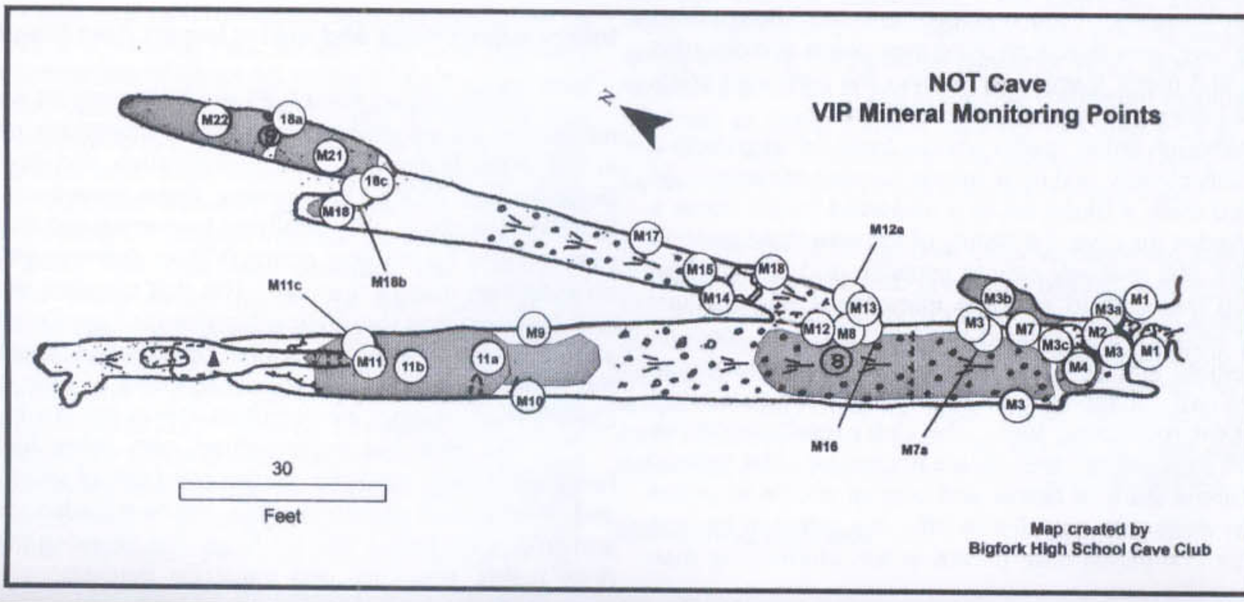
Detailed cave maps are essential to establishing in-cave monitoring using methods practiced by the Bigfork High School Cave Club. Preferably, maps are at a scale of 1:240 with most features larger than 2 feet in diameter locatable on the map. As a prelude to monitoring, club members have mapped a few caves, remapped a few others, and improved the details on quite a few more,

Once a detailed map of the cave is obtained it is digitally scanned, and all information on the map, except for the plan, is removed using Photoshop. Next the cave plan is rotated so that north is oriented up the page. The oriented view is then added as a layer in ArcMap and classified so that map lines show black and background is transparent. Lastly, the cave plan is placed in the correct location on a topographic map, imagery, or other base layer, using georeferencing and measuring tools. If the survey data is available this is also used to georeference the map. Often times cave survey data is not available. We feel that the survey data is not essential to establish or repeat monitoring, and if the sketch of an existing map is of high quality, establishing monitoring should take precedent over remapping the cave. In most cases, monitoring will more directly influence management than resurveying a cave that already has a useable cave map.

The georeferenced cave plan is a raster image and will lose quality the farther it is zoomed out. Also, because its background is transparent, it is difficult to see against the base layer. To remedy these problems, a polygon outlining the raster cave map and omitting internal detail is added as another layer. This second layer is a vector image that can be made visible at all scales and also colored to provide an appropriate background for the raster-image cave plan. The vector image, as with all subsequent layers, can be added as a feature class or shape file. However, adding layers as feature classes makes them more versatile and if all layers, including the cave plan, are in the same projection, the whole project can be downloaded onto a mobile device, such as a Juno.

After raster and vector image of the cave plan are created, separate layers are created for each type of monitoring. Temperature and humidity measurements, photo monitoring, and VIP monitoring, are all input into GIS by marking the location of each recorded measurement, photo point, or feature, at the appropriate location on the raster cave plan by

Figure 3. Example of VIP Mineral Monitoring



using the pencil tool in editor. VIA monitoring is input in the same way, except a polygon layer is used instead of a point layer. As points (or polygons) are drawn, the description of the feature represented at the point (or polygon) is added to the layer's attribute table along with other information that was collected in the cave. Separate VIP and VIA layers are created as needed for different types of resources such as mineral features, biological features, paleontological features, cultural resources, and so on. Also, hyperlinks for photos are established as photo points are drawn. An example of a map showing VIP Point data is presented in Figure 3 and part of the attribute table for these points is presented in Table 1.

Classification of Feature Type, Significance, Fragility, and Condition

The Cave Club classifies monitored cave features for: (1) type, (2) significance, (3) fragility, and (4) condition. The classification is intended to be used as a guide for planning and assessment of management activities. The classification takes on slightly different meaning depending on whether the features are mineral, biological, cultural, or so on. For brevity, we focus on explaining the classification of mineral features herein.

Type

A one- to four-word description of the type of feature is included in a separate column in the attribute table. These are standardized for a project (or within an area) so that the types can be queried and represented graphically. Examples of feature types for biology include bat urine stain, wood rat midden, bone, insect exoskeleton, and so on. Examples of feature types for mineralogy include calcite drip and seep deposits, gypsum deposits, calcite subaqueous deposits, and so on. Feature type classification can be used to determine the abundance and distribution of features within a cave. It also can be used to compare and establish relationships between different types of features.

Significance

Features are classified based on their local and regional abundance. Significance can be used to prioritize management to help protect rare and unusual features.

1. Common - Feature is present and abundant in almost all caves in the local or management area.

2. Uncommon - Feature can be observed in about one-third of caves in the local or management area.

3. Locally Significant - Feature can only be observed in one to three caves in the local or management area.

4. Regionally Significant - Feature can only be observed in a few caves in the state or region.

Fragility

Mineral features are classified in general terms for fragility. This classification is based on the impression of club members as to how likely the feature is to be damaged by humans. Fragility classification can be used to develop travel routes through caves. Also, relating feature damage to feature fragility will indicate how careful visitors are being.

1. Resistant - Feature seems unlikely to be accidentally damaged by human visitors at the current rate of visitation. Disturbance would involve an intentional act of vandalism.

2. Fragile - Feature may be inadvertently damaged by careless visitors who are unaware of the features

Table 1. Attribute Table for Map in Figure 3

Pt#	Description	Significance	Fragility	Condition 2011	LAC
M1	Popcorn on most of wall (polyline)	Common	resistant	No observable impact	indicator
M1	Popcorn on most of wall (polyline)	Common	resistant	No observable impact	indicator
M2	2 – 2.5 x ½ x 3 in draperies about 1 ft broken	Common	resistant	Severe 2	indicator
M3	Flowstone on wall (polyline)	Common	resistant	No observable impact	indicator
M3	Flowstone on wall (polyline)	Common	resistant	No observable impact	indicator
M3a	Flowstone at climb-down traffic wear (polyline)	Common	resistant	Light	indicator
M3a	Flowstone at climb-down traffic wear (polyline)	Common	resistant	Light	indicator
M3b	Flowstone at climb-down across from climb-down (poly)	Common	resistant	No observable impact	indicator
M3	Flowstone on wall (polyline)	Common	resistant	No observable impact	indicator
M3c	Stalactites and sodastraws along ceiling drop, Less than 25% broken (polyline)	Common	resistant	No observable impact	indicator
M4	Soda straws from 1 to 2 in about 20 in area about 25% are broken (poly)	Common	Fragile	Heavy	indicator
M5	Stalactites, snowballs on ceiling cover about 20% of surface. Stalactites from 1in to 3 feet long. Less than 25% broken.(poly)	Common	resistant	Heavy	indicator
M6	Column 3 in dia X 1 ft long	Common	resistant	No observable impact	indicator
M7	3 – 6 in diameter base stalactites all broken	Common	Fragile	Severe 3	indicator
M12	Stalactites at ceiling drop most are broken (polyline)	Common	Very fragile	Severe 3	indicator
M7a	2 – 2 in dia stalactites both broken	Common	Fragile	Severe 3	indicator
M8	Draperies Most have tips broken	Uncommon	resistant	Severe 1	indicator
M9	Flowstone covers most of wall	Common	resistant	No observable impact	indicator
M10	Flowstone and draperies on wall Flowstone is n top ¼ of wall, Draperies go down 3 /4 of way from top. Draperies are up to 1 foot wide. Tip of one is broken (poly)	Uncommon	resistant	Heavy	indicator

sensitivity. However, conscientious visitors are able to minimize disturbance.

3. Very Fragile - Feature is likely to be damaged by even the most careful visitors.

Note: The above fragility classes are used with the same explanation for paleontology and cultural resources, but for biology the verb "disturbed" is substituted for "damaged" and the class "fragile" becomes "susceptible to disturbance" and "very fragile" becomes "very susceptible to disturbance".

Condition

Features are also classified based upon the amount and severity of human-caused damage or impact. Condition classification is completed each time monitoring is completed so changes can be assessed to evaluate the effectiveness of management at limiting visitor impacts. The condition class for resources that extend over an expansive area is averaged over that area. This can lead to some variance in precise interpretation. We have been experimenting with methods such as laser projection of standardized grids and photo correlation, but even without these improvements condition classification can provide managers with valuable information. In general, all types of resources are assigned condition classes. These are: no observable impacts, light impacts, heavy impacts, or severe impacts. Explanations of classification for most mineral features are explained below:

1. Impacts to silt, mud, or sand floor surfaces

A. No Observable Impact - The feature could have been altered by human activities, but no impacts can be observed.

B. Light Impacts - Light brushing of surface covering less than 25% of surface area OR faint depressions covering less than 25% of surface area.

C. Heavy Impacts - Trenching is less than 1/4" deep OR brushing of more than 25% of surface area OR noticeable depressions covering 25 to 75% of surface area.

D. Severe 1 Impacts - Trenching greater than 1/2" deep OR depressions 1/2" deep or greater OR depressions cover 50 to 75% of the surface area.

E. Severe 2 Impacts - 75 to 100% of surface is completely altered by 1/2" or greater depressions.

F. Severe 3 Impacts - Pits and fill caused by human digging activities half altered natural surfaces OR human activities have altered natural water flow and flooding patterns resulting in redepositon of deposits.

2. Impacts to floor surfaces covered by cobbles or angular rocks.

A. Light Impacts- Mud smears, boot marks, or other traffic wear cover less than 50% of the tops of the cobbles or rocks.

B. Heavy Impacts - Mud smears, boot marks, or other traffic cover 50 to 100% of the tops of the cobbles or rocks.

C. Severe 1 Impacts - Mud or other traffic-caused debris is deposited in thick layers 1/4" or greater OR cobbles

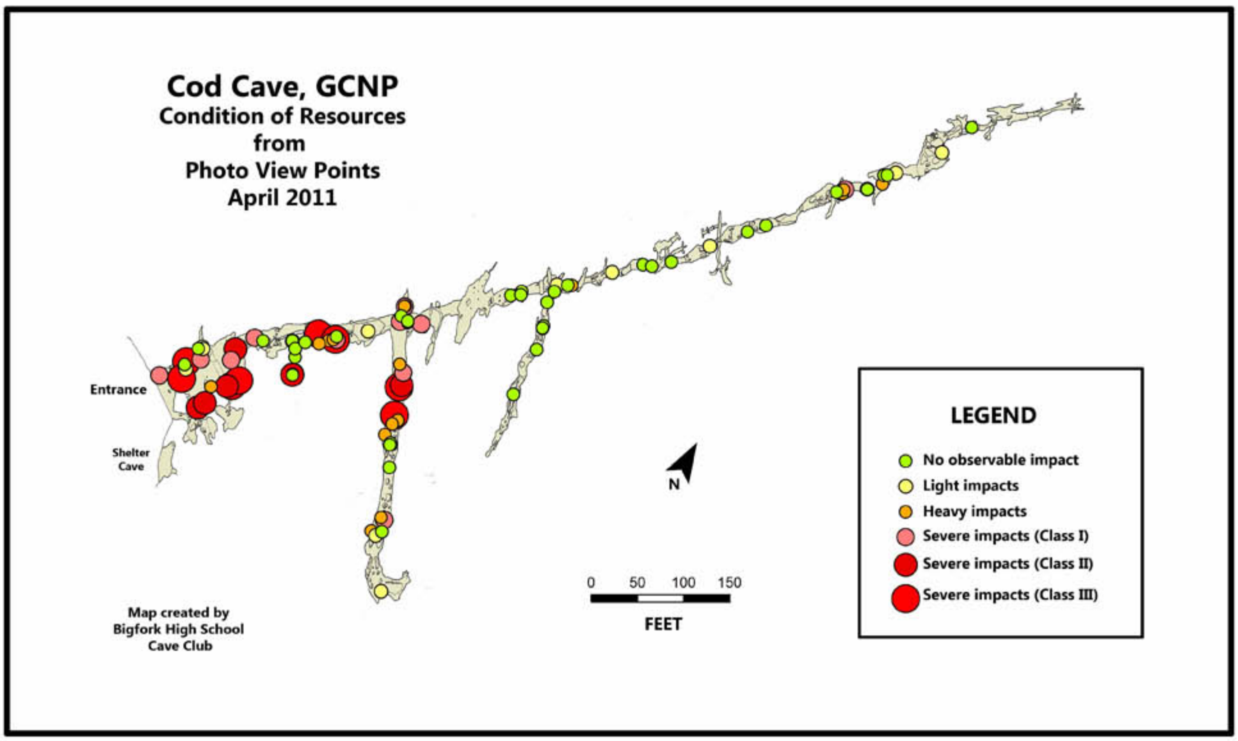


Figure 4. Example of Feature Conditions

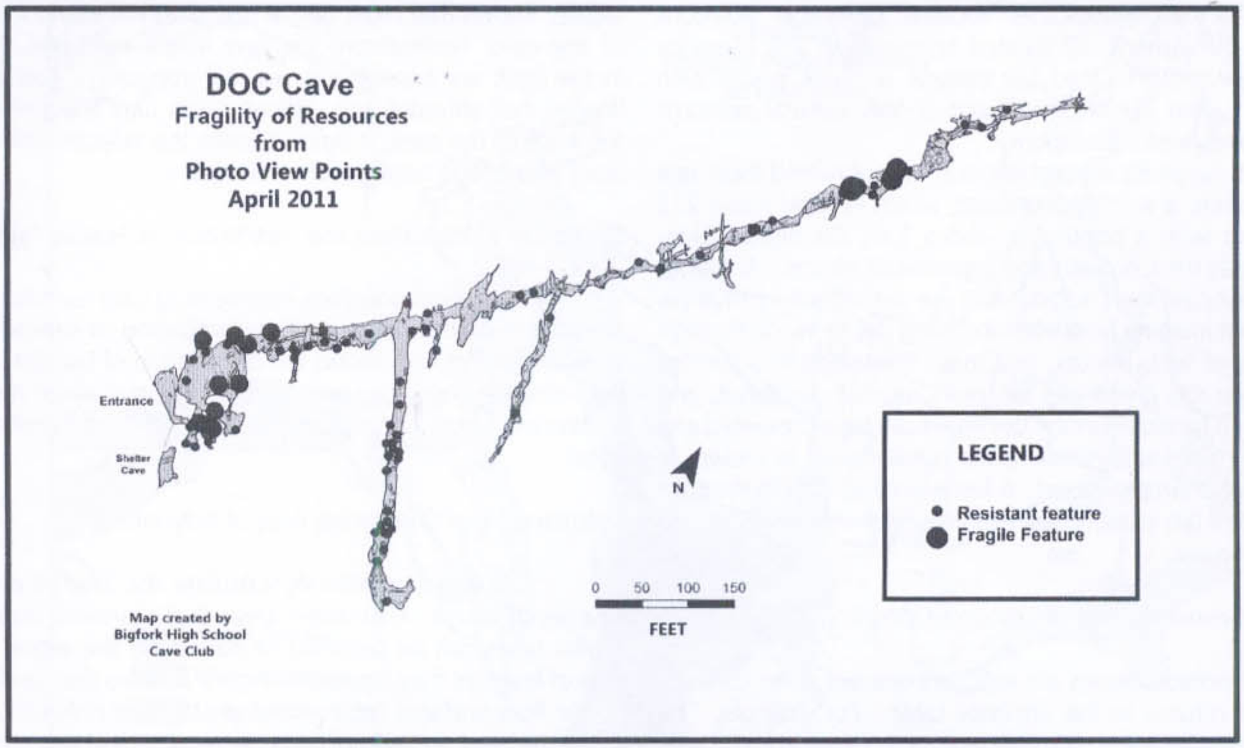


Figure5. Example of Feature Fragility Represented Graphically.

or rocks are rolled to side of a pathway to form a trench that is about half as deep as the diameter of the larger cobbles or rocks.

D. Severe 2 Impacts - Mud or other traffic caused debris has mostly covered cobbles or rocks, but they are recognizable as cobbles or rocks OR a trenching is greater than the diameter of the larger cobbles or rocks.

E. Severe 3 Impacts - Pits and fill caused by human digging activities have altered natural surfaces OR human activities have altered natural water flow and flooding patterns resulting in redepositon of deposits.

3. Impacts to bedrock or flowstone floor surfaces.

A. Light Impacts - Mud smears, boot marks or other traffic wear cover less than 25% of surface area.

B. Heavy Impacts - Mud smears, boot smears, or other traffic wear cover 25 to 50% of surface area.

C. Severe 1 Impacts - Mud smears, boot marks, or other traffic wear cover 50 to 75% of surface area OR mud or other human transported debris is deposited in thick layers up to 1/4" OR up to 10 % of surface is chipped or broken from traffic wear.

D. Severe 2 Impacts - Mud smears, boot marks, or other traffic wear cover 75 to 100% of surface area OR mud or other human-transported debris is deposited in thick layers over 1/4" thick OR over 10 % of surface is chipped or broken from traffic wear.

Severe 3 Impacts - Surface has been intentionally altered by "mining" or vandalism or other activities involving intentional breakage of the surface.

4. Impacts to Speleothems

A. Light Impacts - Speleothem(s) lightly stained with mud smears, skin oils, or other deposits left by human traffic.

B. Heavy Impacts - Surface of the speleothem(s) altered by humans touching the surface OR a layer of mud or other human-transported debris up to 1/16" has been deposited on the surface.

C. Severe 1 Impacts - Up to 25% of speleothem(s) broken.

D. Severe 2 Impacts - 25 up to 50% of speleothem(s) broken.

E. Severe 3 Impacts - Over 50% of speleothem(s) broken.

Analysis of Cave Resources using GIS

GIS is a wonderful tool to organize and analyze cave monitoring information. As an example of the program's capabilities, consider the amount of raw data collected by the cave club when they established monitoring for 11 caves in Grand Canyon National Park. Their data includes 474 located photo points with photos, descriptions, azimuth, and classification of views; 329 located mineral VIP points with descriptions and classifications; 153 located VIA mineral feature polygons with area calculations; 251 located VIP biological points with descriptions; 99 located biological polygons with area calculations; 57 located temperature and humidity measurements; 26 located VIP cultural resource points with descriptions and classification; and 5 VIA cultural resource polygons with area calculations.

At the park's request the club has submitted their data in two formats: a written document, which evolved into a 233 page report with a photo CD, and a 5.66 GB digital folder containing all the GIS layers and hyperlinked photos. Arguably, it is probably prudent for data to be submitted in multiple formats, but imagine how overwhelming it is to wade through 233 pages of text, photos, and maps contained in a written report when GIS layers can be easily queried, analyzed, and displayed. In fact, data in the GIS layers can be represented and analyzed in many ways that are too cumbersome to present in a conventional written report. A few examples of how the cave club has used GIS to represent and analyze monitoring data are explained below.

Graphical Representation of Resource Conditions

Condition classes are assigned number value codes in a separate column in the attribute table. For example, "no observable impacts = 0, light impacts, = 1, heavy impacts = 2, and so on. These are then symbolized in the properties menu and represented as graduated symbols of different colors. An example of a map exported out of GIS, which shows conditions of cave features as viewed from photo view points is presented in Figure 4. The map shows a concentration of severe impacts near the front of the cave. The impacts drop off at a difficult climb, which probably selects visitors to the back of the cave. However, examination of resource fragility (see Figure 5), which were symbolized in a similar fashion as were condition classes, shows that most fragile resources are in the front part of the cave. Furthermore the few fragile resources that are in the back are heavily and severely impacted. This analysis implies that although the difficult climb may select visitors to the back of the cave, it doesn't make the selected visitors less likely to damage fragile cave resources.

Evaluation of the Extent and Distribution of Feature Types

Points and polygons representing cave features can be coded and used to illustrate the distribution of selected types of features. Figure 6 shows the distribution of bat sign near in the entrance area of a cave. This information could be useful in directed future bat research or in design and installation of gates.

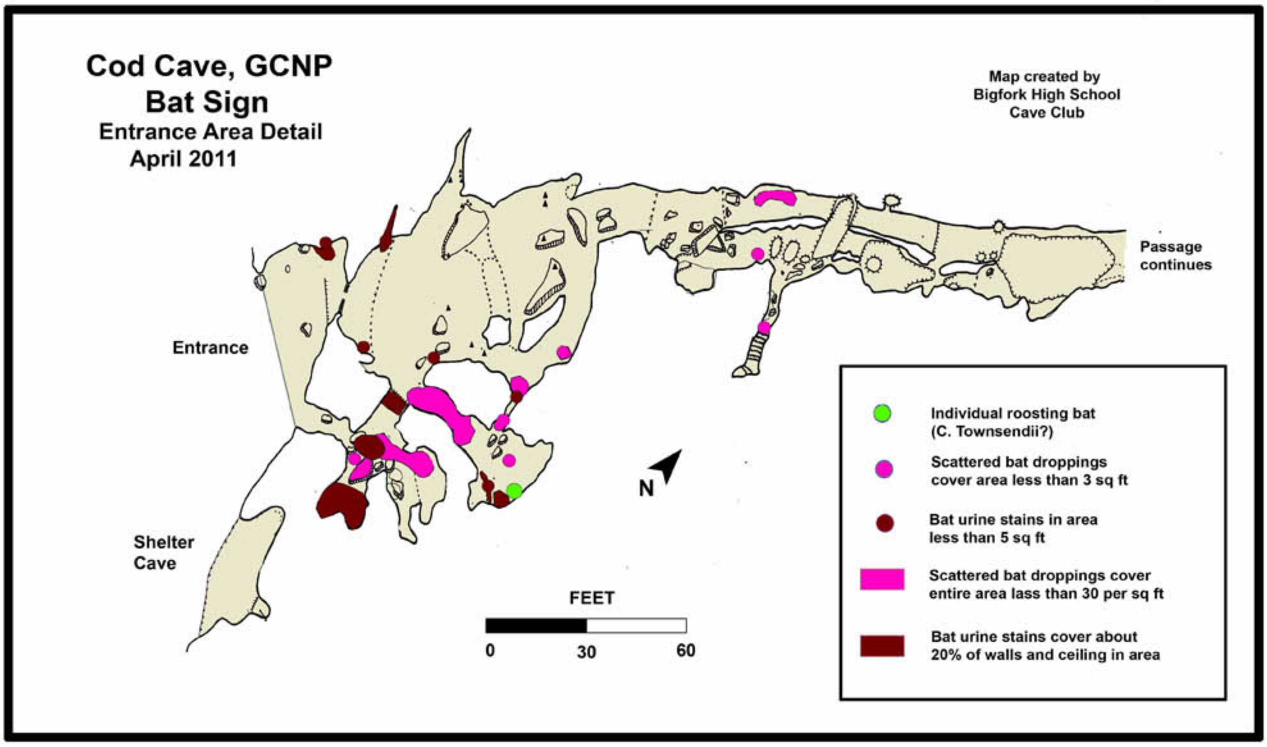
Calculating and Comparing Area of Polygons

GIS will automatically calculate the area of polygons in a geodatabase. Calculated areas that represent features of similar types can be summed to determine the extent of the type of features they represent. Figure 7 shows the condition of fragile floor surfaces represented as classified polygons. Table 2 lists the total area of each condition class and percentage of the total area of fragile floor surfaces. This information can be used to assess current conditions and quantify future changes.

Calculating Statistics and Averages for Classified Features

GIS can calculate averages and other statistical properties for feature classes that have been assigned number values. Table 3 presents the average condition of features as viewed from photo points for nine caves in Grand Canyon National Park. As in the first example, condition classes are assigned a number value code: "no observable impacts = 0, light impacts, = 1,

Figure5. Example of Feature Type Distribution



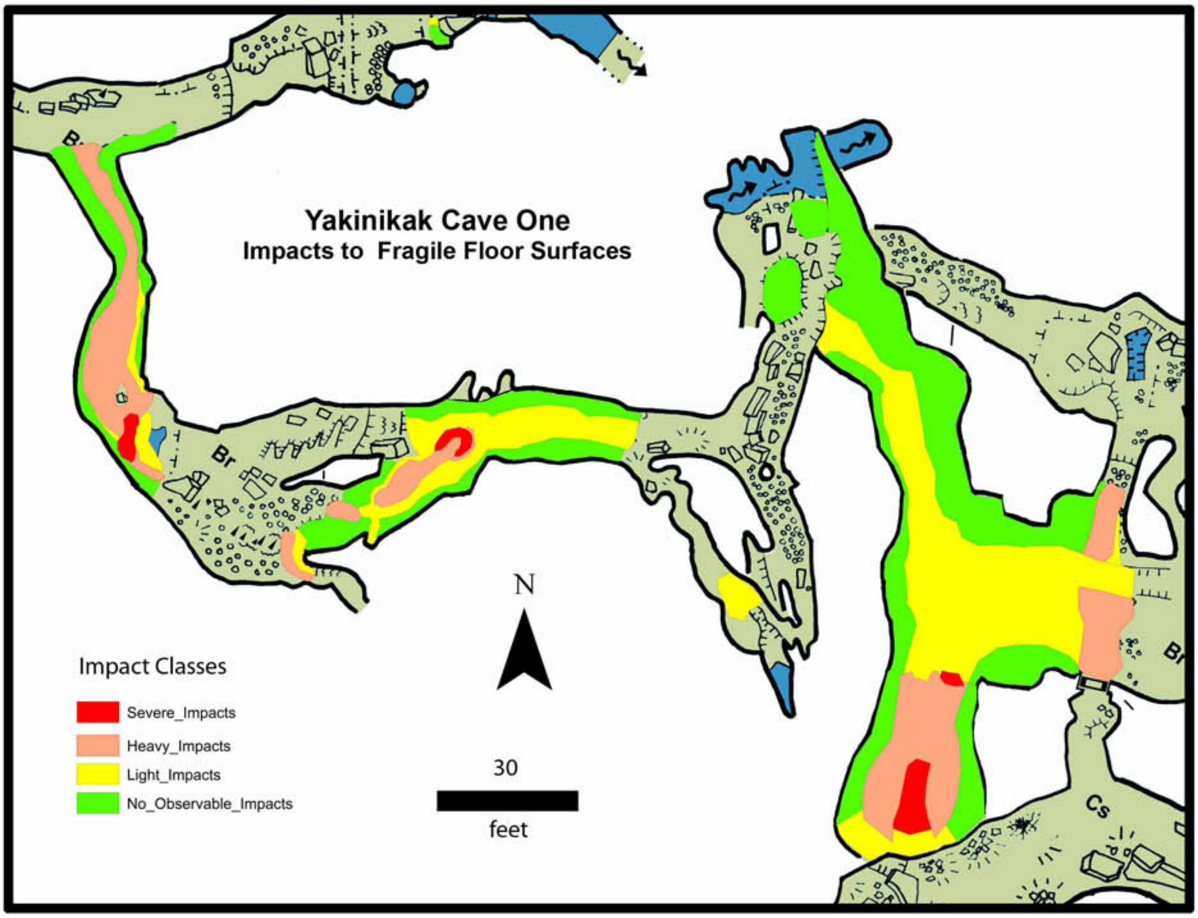


Figure 7. Fragile Floor Surfaces Represented as Classified Polygons

heavy impacts = 2, and so on. Condition class averages can be used to evaluate the overall condition of features in each cave. In this example, caves with condition averages greater than 1.2 are in poor overall condition, and those with averages less than 1 are in good overall condition. Table 3 also gives the standard deviation of each condition average. These can be used to get an impression of how concentrated impacts are within a cave. In general, a lower standard deviation indicates the condition of features is more similar and visitor impacts are spread out more uniformly through the cave. Whereas, a higher standard deviation indicates the condition of features is more variable and impacts are probably concentrated at a few locations.

Directly Linking Monitoring and GIS to Management

Most of the time monitoring only indirectly influences cave management. In a common scenario managers are compelled to take action after reading reports and viewing presentations in which monitoring has shown dramatic changes to cave resources. Unfortunately, this almost always happens after much resource damage has occurred. Furthermore, it is more common that monitoring is not at all connected to management and management decisions are made based on incidental observations or impressions.

The Bigfork High School Cave Club has developed a simple procedure to directly link monitoring to management using GIS and a Limits of Acceptable Change (LAC) model. LAC was developed in the 1980's by the US Forest Service for planning and management of wilderness (McCool and Cole, 1997). In theory, the procedure developed by the cave club can be designed to detect small changes before significant or large numbers of resources become severely damaged using GIS to facilitate analysis of changes. Once monitoring and GIS indicate damages have reached a threshold of change (or LAC), managers are prompted to initiate predetermined management actions. Using Poia Lake Cave in Glacier National Park as an example, the procedure is further explained below.

Poia Lake Cave is slightly over a mile long with an annual visitation of about 150 people. The cave contains some calcite and moonmilk flowstone and a few stalactites. It also contains thick deposits of wood rat middens and provides habitat for a small number of individually roosting bats and cave adapted microinvertebrates. Monitoring for features is linked to management in a multi-step process.

First, features are assigned a LAC management class based upon significance, aesthetics, and social input.

Impact Class	Area of floor in class (meters)	Percent of total fragile floor
No Observable Impacts	409.15	49.7
Light Impacts	234.38	28.5
Heavy Impacts	157.05	19.1
Severe Impacts	21.83	2.7

Total of fragile floor = 822.41

Table 2. An Example of Area Calculations for Expansive Feature Classes

Management classes are explained below:

1. Indicator – It is recommended the feature be managed as an indicator of human-caused changes that could eventually lead to damage of other more valuable resources.

2. Conserve – Feature is of high scientific and aesthetic value, but is relatively common or resistant to human disturbance. It is recommended the feature be managed so that visitors can experience and enjoy the feature in near pristine conditions.

3. Preserve – Feature is of very high scientific and aesthetic value, is relatively rare, and could be easily damaged by human visitors. It is recommended the feature be managed so that it will be maintained in near pristine conditions, even if this requires limiting visitor access.

For Poia Lake Cave, all features were assigned to the indicator class.

The second step in the process involves setting an LAC threshold for each management class and committing managers to a predetermined management action should the threshold be exceeded. For Poia Lake Cave it was decided that if monitoring detected any changes to conserve or preserve features, or change was detected at 5% or more of the indicator features, managers would meet to develop a more restrictive management.

The third step involves implementing predetermined management based on monitoring findings. Monitoring for Poia Lake Cave was established in 2005 and repeated in 2009. Monitoring showed no change to conserve or preserve features, but changes to 9% of the indicator resources. Most changes were minor, but to prevent more serious damage managers met and decided to place a sign in the entrance of the cave, increase patrols, and repeat monitoring in two years to see if even more restrictive management is warranted.

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Cave	# Photo Points	Condition Average for Photo Points	Standard Deviation for Averages
ART	46	0.439	0.607
DOC	103	1.553	1.60
DOC (before climb)	70	2.014	0.85
DIM	8	1.5	1.322
FIN	32	0.406	0.744
GAR	17	0.764	0.730
HOP	43	0.046	0.301
NOT	47	1.085	1.426
ROS	17	1.705	1.225
TRE	43	0.883	1.165
WOW	57	0.561	0.710

Table 3. Average Condition Values for 9 Caves in Grand Canyon National Park

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