An Application of ArcGIS Viewshed Analysis in Range Creek Canyon, Utah

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This paper examines the visibility of numerous remote granaries located in Range Creek Canyon of central Utah. Of the more than 400 sites recorded in the canyon, approximately twenty-five percent are storage facilities. These include granaries, (above ground storage) cists, (subterranean or semi-subterranean storage) and caches of tools or raw materials. Many of these are located in highly visible but difficult to access locations (remote granaries), while others are easily accessible but well-hidden. This pattern may represent two strategies for protecting stored resources: one in which the storage facility is plainly visible and can be easily monitored and another in which resource stores are hidden and left unattended. Using viewshed analysis, the visibility of granaries from the valley floor and from prehistoric residential sites is assessed and quantified. Recent high resolution Digital Elevation Models and georeferenced aerial photographs allow an accurate reconstruction of what is visible from each granary, i.e. archaeological sites, the valley floor and defensive vantage points. This paper will test the hypothesis that granaries are visible from the valley floor and positioned in view of residential sites. If correct, the function of this defensive positioning may be to monitor access to granaries from a distance.

Range Creek Canyon is located in the West Tavaputs Plateau of east central Utah (Figure 1). Range Creek itself is a perennial stream and a tributary to the Green River. The canyon ranges in elevation from 10,000 feet at Bruin Point to about 4,000 ft at its terminus, 30 miles to the south. It is extremely rugged and isolated, bounded by Nine Mile Canyon to the north and the Book Cliffs to the east and south. In 2002, the University of Utah became involved in archaeological research in lower Range Creek Canyon. The University of Utah and Utah Museum of Natural History have since held field schools in Range Creek Canyon each summer. Over 400 sites have been recorded including, residential locations (defined by circular surface rock alignments and charcoal stained soil), artifact scatters, rock art panels, and storage facilities.

Approximately twenty-five percent of the sites recorded in Range Creek Canyon are identified storage facilities, including granaries and cists. The construction materials, sizes, and shapes of granaries vary, but of particular interest are the locations of these features. For the purpose of this study, the granaries are grouped into two categories based on location and difficulty of access. The first includes "remote" granaries. These are located away from residential sites, on difficult-to-access cliff faces and ledges (Figure 2). They appear to be highly visible from many points on the valley floor and adjacent ridgelines. The second category includes cists and granaries located closer to the valley floor, thus more accessible from nearby residential sites, but well hidden in their natural surroundings (i.e., boulder fields, alcoves and crevices) (Figure 3). These two categories may represent two storage strategies: (1) one in which stored goods are put on display in difficult to access locations where they can be monitored to prevent theft; and (2) one in which goods are hidden in easily accessed locations close to home. These strategies are similar to examples of hoarding reported in the animal behavior literature but differ in interesting ways worthy of investigation (Vander Wall 1990).

Hoarding Theory

The practice of hoarding food has evolved independently among many animal species. Vander Wall (1990:43) explains the term "food

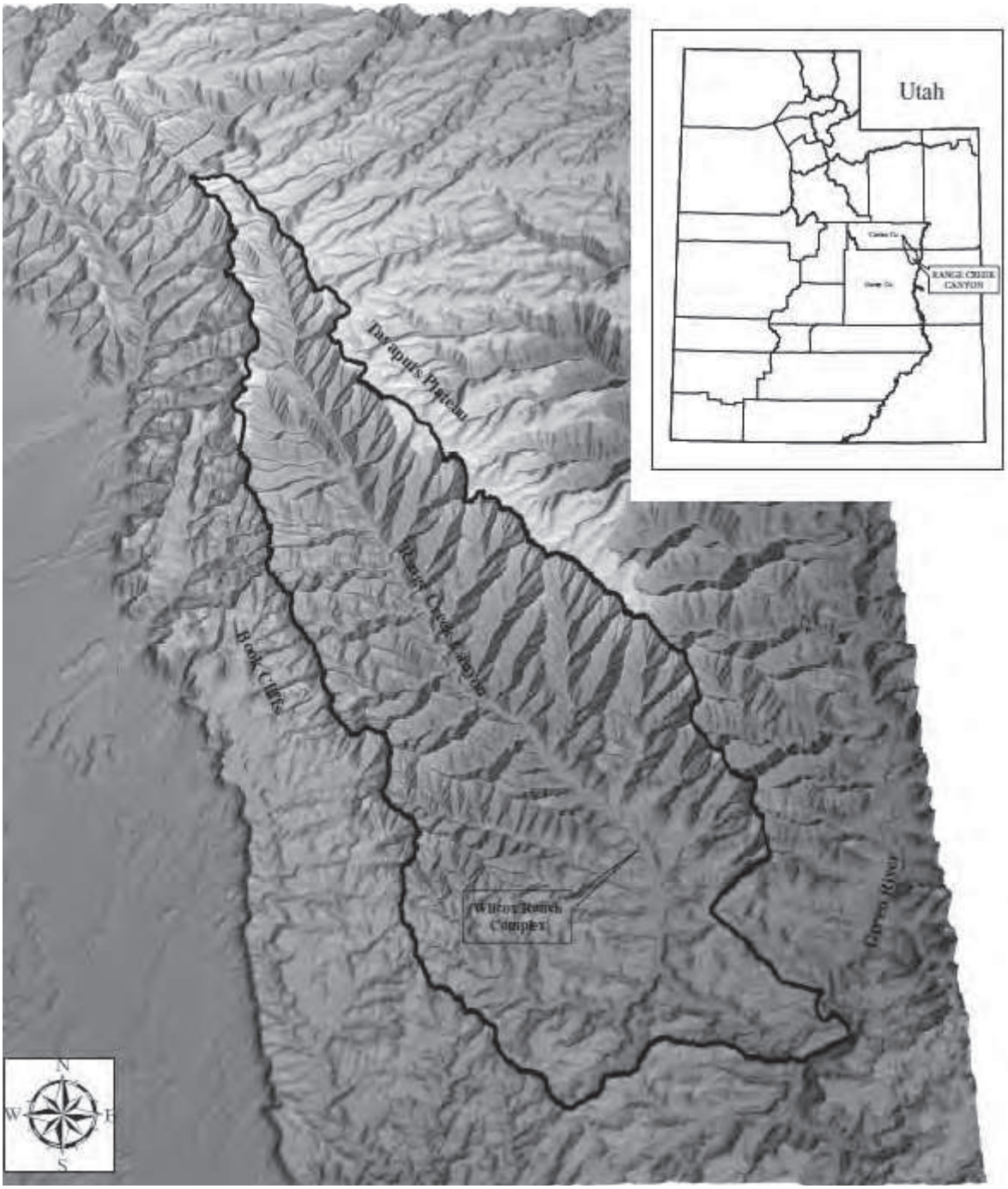

Figure 1. Relief map of Range Creek Canyon showing the surrounding land forms. Inset shows location of Range Creek Canyon in Utah. Boundary line indicates drainage limits.

hoarding" as covering "a variety of behaviors that are united by two common criteria: postponement of food consumption and food conservation through special handling." These special handling activities include hiding small amounts of food to be eaten daily and

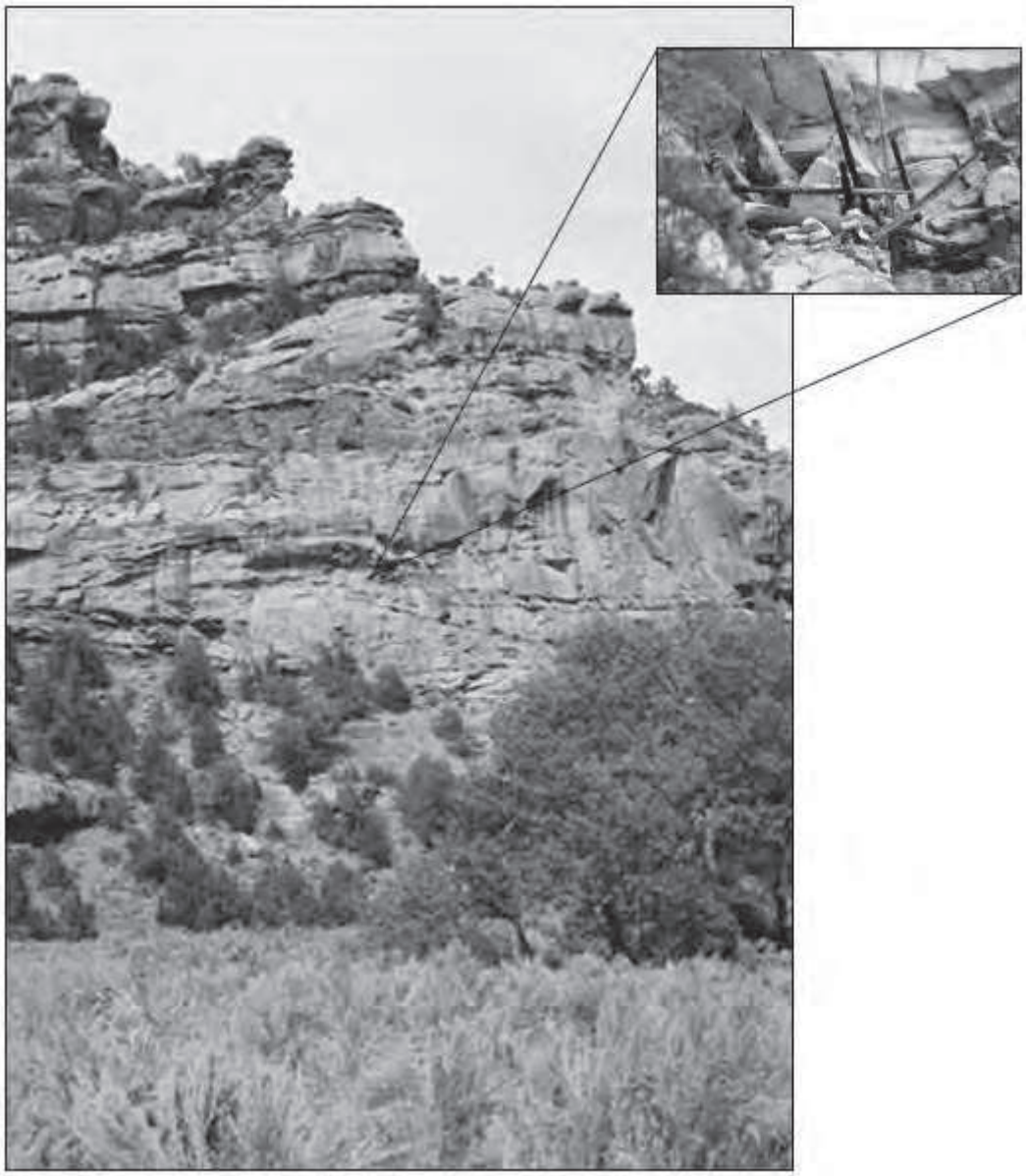

Figure 2. Photograph of remote granary. Inset shows a close up of granary built on man-made platform perched on cliff face.

sequestering larger quantities to be recovered during times of food scarcity. Methods of storage range between larder hoarding (storing a large amount of food in one location) and scatter hoarding (distributing food items at more than one location across a home range). Vander Wall's review of the diverse number of animals that store food suggests that "the environmental conditions that promote hoarding are widespread and the behavioral precursors to hoarding are not uncommon" (1990: 43).

The adaptive value of hoarding food has been expressed in a mathematical model by Andersson and Krebs (1978). The authors demonstrate that if an animal recovers a significant amount of stored food the fitness gain will exceed the costs

Figure 3. Photograph of hidden but easily accessible cist.

associated with hoarding and the behavior will be selected for and should continue in a population. If stored food is not recovered in a sufficiently high proportion, then the cost of hoarding may be too great and the practice will either fail to develop or disappear.

In Range Creek Canyon remote granaries appear to share a combination of the scatter hoarding and larder hoarding characteristics discussed by Vander Wall (1990). Three factors determine the distinction: (1) the amount of food stored at a single location; (2) the distance of the cache from the hoarder's residence; and (3) whether the cache is actively guarded. Scatter hoards are typically hidden and left unattended. They are usually numerous and contain only small amounts of a resource so that if one is pilfered, the contents rot, or the location itself is somehow forgotten, the hoarder does not lose everything (Figure 4). Animals practicing scatter hoarding behavior typically do not return to their caches until food is retrieved. Larder hoards are usually fewer in number, contain a larger amount of the resource, and are situated closer to the hoarder's residence, making them easy to access and actively defend (Vander Wall 1990).

Thus, in Range Creek Canyon, it appears that the small cists and granaries hidden in easily accessible locations (i.e., boulder fields and alcoves) are much like the scatter hoarding strategy. On the other hand, the "remote" granaries are more like larder hoards in size but they are scattered across the landscape in difficult-to-access but highly visible and easy to monitor locations. Thus, while they are not actively guarded they are protected from pilferage by their difficulty to access and high visibility. In this situation the cost of guarding is reduced. Placing a granary on public display increases the number of witnesses and spreads the cost of guarding among all participants. This

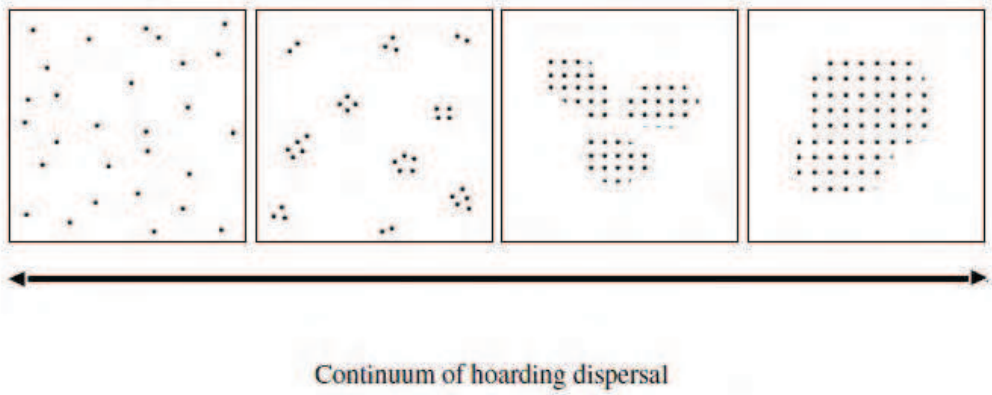

Figure 4. Scale of hoarding behavior with scatter on the left and larder on the right, modified from Vander Wall 1990.

increases the benefits of locating granaries in such seemingly costly locations.

This ability to monitor remote granaries from a distance might be the key to what is going on in the storage strategies in Range Creek Canyon. Foragers used a mixed strategy that combines characteristics of both scatter hoarding and larder hoarding. Granary location enables the forager to monitor and defend from a distance. To investigate this strategy further, it is necessary to quantify the visibility of remote granaries.

Visibility and Viewshed Analysis

This study uses viewshed analysis to quantify the visibility of the remote granaries in Range Creek Canyon. Ideas about visibility and intervisibility have always been important in archaeological research. Much of the archaeological interest in visibility studies has focused on the placement of monuments and settlements across the landscape (Wheatley 1995; Fisher et al. 1997; Woodman 2000; Llobera 2001; Jones 2006) and has applications for cultural resource management and planning (Batchelor 1999). Modern visibility analyses today calculate a line-of-sight map (or viewshed) for a location using digital models of surface topography. Viewshed calculations determine what areas can be seen from a given viewing location and determine whether a direct line-of-sight exists (intervisibility) between a set of features (Wheatley and Gillings 2002). Viewsheds calculated for each granary in this study, demonstrate whether the granary can be seen from areas along the valley floor and residential sites.

Every calculation in a viewshed analysis takes place using a continuous grid that represents the surface typology of the project area. Each cell of the grid has a built in elevation. This grid is called a Digital Elevation Model (DEM). In viewshed analysis, the visibility between each grid cell (or numerous grid cells) and each surrounding cell can be computed. Visibility is calculated by measuring the tangent from an observation point placed within a cell to each surrounding cell starting from cells closest to the observation point (in this case each granary). As long as the tangent increases in line-of-sight from the observation point, the cell is considered visible. If the tangent decreases, the cell is not considered visible. O'Sullivan and Unwin (2003) compare this function to an imaginary profile drawn from a single view point on the landscape to every other

point on the DEM (Figure 5). Successive heights along each profile are listed, where they cross a grid line, and are used to determine whether or not the point is visible (O'Sullivan and Unwin 2003: 241–242). Once a viewshed is calculated, each cell in the DEM receives a value, "one" for visible and "zero" for not visible. The final output can be displayed with only the visible areas indicated (Figure 6).

The methods used in this analysis focus on field-of-view concepts. Wheatley and Gillings (2002) define field-of-view as the total area visible from a given point on the landscape. The viewsheds calculated in this way produce a field-of-view for a point assigned to each granary site. Each granary was set as the 'observer point' and a viewshed was calculated. It is assumed that all cells falling within its field-of-view have an unobstructed view of the granary.

Granaries with a wide field-of-view should be more common in Range Creek Canyon if monitoring them from below was advantageous to the foragers. Granaries visible from a wide area are more easily defendable both when foragers are in the immediate area and able to actively watch and defend stored goods, as well as when foragers are conducting other activities within the viewshed of a granary (i.e., the larger the viewshed) the greater the number of potential witnesses. Remote granaries with the widest field-of-view will be those located well above the valley floor and perched on cliff walls with nothing blocking visibility. As well as being highly visible, the precarious positioning makes remote granaries extremely difficult to access, but only visibility will be investigated here.

Methods

To generate the viewsheds for each granary several data layers were needed as input into ArcGIS 9.2. First was the 2 m resolution DEM for Range Creek Canyon. This is a continuous grid of 2 x 2 m cells with an elevation for every cell. The second layer of input was an observer point for each granary site. These were acquired from the IMACS site forms and GPS receivers from the University of Utah's Range Creek Canyon database. A third input layer was an estimate of locations on the valley floor from which the granary could be monitored (as opposed to cliffs, ledges, ravines, etc.). This was generated by buffering 50 m on either side of a line representing the creek, thus creating a 100 m corridor that represents a conservative estimate of the valley floor (Figure 6). While this is not the most accurate measure of the entire "valley floor," it allows viewsheds generated for granaries located in narrow parts of the canyon to be compared to viewsheds generated for granaries located in wide parts of the canyon while keeping the width of the valley floor corridor constant. The final input layer was a point layer indicating the location of every prehistoric residential site from the Range Creek Canyon spatial database.

Using the 3D Analyst extension in ArcGIS 9.2, individual viewsheds were generated for seventy-two granary sites, fifty-five in the main canyon and seventeen in side drainages. Figure 6 shows one example of a viewshed output overlapping the valley floor corridor layer. The area where each viewshed overlapped the valley floor corridor was calculated for each of the fifty-five granaries located in the main canyon. The distance along the valley floor corridor (usually north to south) where the viewshed overlapped was estimated in ArcGIS using the ruler tool. In order to increase the reliability of the estimates, I took all distance measures at the same resolution and took each measurement several times then calculated the average. Figure 7 demonstrates how measurements were consistently taken along the valley floor corridor from along the center (the creek) of the area where the viewshed overlapped the corridor.

Viewsheds were also used to estimate the intervisibility between granaries and residential sites; those with surface rock alignments and charcoal staining. The residential sites were displayed and counted if they fell within the viewshed of a granary.

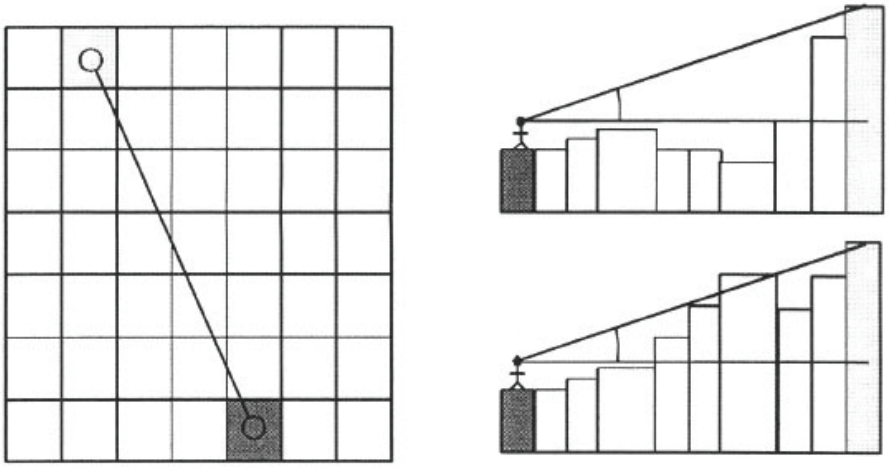

Figure 5. Illustration of how line-of-sight is calculated on a grid, modified from O'Sullivan and Unwin (2003).

The next step was to obtain direct measures of visibility. First, Larry Coats (Department of Geography, University of Utah) used technical climbing gear to access several remote granaries where he took photographs of the area of the valley floor with an unobstructed view from the granary (Figure 8). Second, ground crews with GPS receivers, documented the extent to which they could view Coats and the granary. When the human derived and ground truthed viewsheds were compared to computer generated viewsheds, the results varied. Generally, the computer generated viewsheds tend to be greater than the area actually visible by the human eye (Figure 9). This occurs because computer analysis considers only topography and visibility is equal to the line-of-sight between two grid cells. What is clearly visible to the human eye is subjective and differs from a computer simulation but the ground truthing strategy showed all of the granaries sampled to be highly visible from the valley floor corridor. As the viewer neared the furthest extent of the viewsheds on either end of the corridor, the exact location of the granary sometimes became difficult to make out but the access routes to the granary were still quite visible.

Results

All of the granaries in the main canyon had a viewshed of at least 100 m overlapping the valley floor corridor and many viewsheds covered much greater distances (Figure 10). This demonstrates that the granaries are indeed not hidden.

Of the seventy-two granaries sampled, twenty-seven had one or two residential sites within their viewsheds, whereas twenty-three had between three and eight (Figure 11). This means that people conducting daily activities could have looked up and monitored the remote granaries on the cliffs around them. A field check confirmed these findings. While standing on site 42Em3066, the locations of twenty-nine sites were clearly visible, nine were remote granaries. This area is not the norm for Range Creek Canyon because it is a particularly wide open area of the canyon with a high density of sites. Field checks from additional sites will provide a more representative sample of this phenomenon.

The accuracy of computer generated viewsheds is conditioned by the accuracy with which granaries can be located on the DEM. Locations of granaries in the Range Creek Canyon database were assigned using GPS

Figure 6. Hillshade map showing example of a computer generated viewshed output overlapping the valley floor corridor (corridor measures 50 meters on either side of Range Creek). Areas visible from the granary are shown in black.

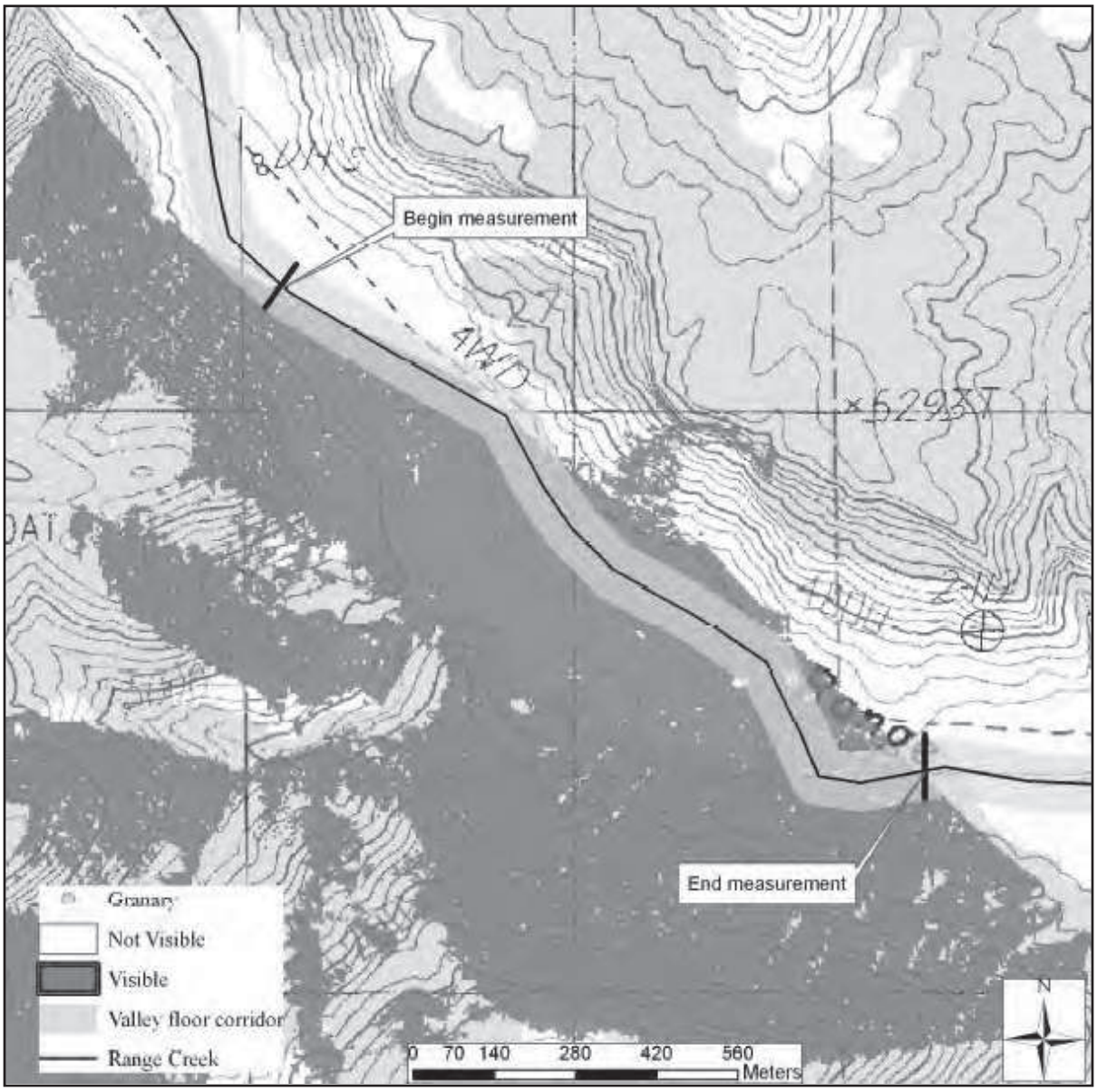

Figure 7. Topographic map showing the overlapping viewshed and valley floor corridor. The distance visible along the corridor was measured as a line down the center (Range Creek) of the overlapping area using the ArcGIS measuring tool.

derived UTMs or by crews hand plotting sites on topographic maps. Unfortunately, due to the inaccessibility of many of the remote granaries, taking a GPS recording adjacent to the granary itself is very difficult.

Many remote granary locations were recorded away from the actual granary and their true location was estimated. How, then, does the lack of accuracy in placement affect our estimates of visibility? To address this question, the locations of a sample of granary points were recalculated using a reflector-less total station. The total station was set up on the valley floor below each granary and the UTM location of the machine was recorded. The distance of the granary above the total station was recorded and added to the

Figure 8. Photograph taken by Larry Coats from a remote granary showing the visible area along the valley floor.

total station elevation to get the vertical location of the granary (Figure 12).

Viewsheds were regenerated based on the new locations of thirteen granaries. Viewsheds generated from locations recorded with GPS and topographic map estimates were compared to those refined with the total station (Figure 13). The expectation was that if the refined location was at a higher elevation then the original, viewshed would increase and the visibility would be greater along the valley floor corridor. If the refined location was lower in elevation then it would be expected that the viewshed would decrease and the visible distance along the valley floor corridor would be smaller. We were interested in whether the results changed systematically from the originally recorded location and the locations refined by the total station. We found that half of the refined viewsheds were smaller and half were larger than those previously generated (Figure 14). Increasing the accuracy of the remote granary location did not systematically change the estimates of visibility in either direction. Even with the refined locations, all of the granaries were still visible from significant distances along the valley floor corridor.

Conclusion

Despite its limitations, viewshed analysis demonstrates that remote granaries in Range Creek Canyon are visible from the valley floor. This conclusion is supported by computer generated estimates and visual assessment. Measurements reported here probably underestimate the visibility of granaries because they only examine site visibility from a conservatively defined valley floor corridor 50 m on either side of the creek. The actual valley floor is significantly wider in many areas. These estimates do not take into consideration the visibility of numerous routes by which granaries might be accessed by thieves

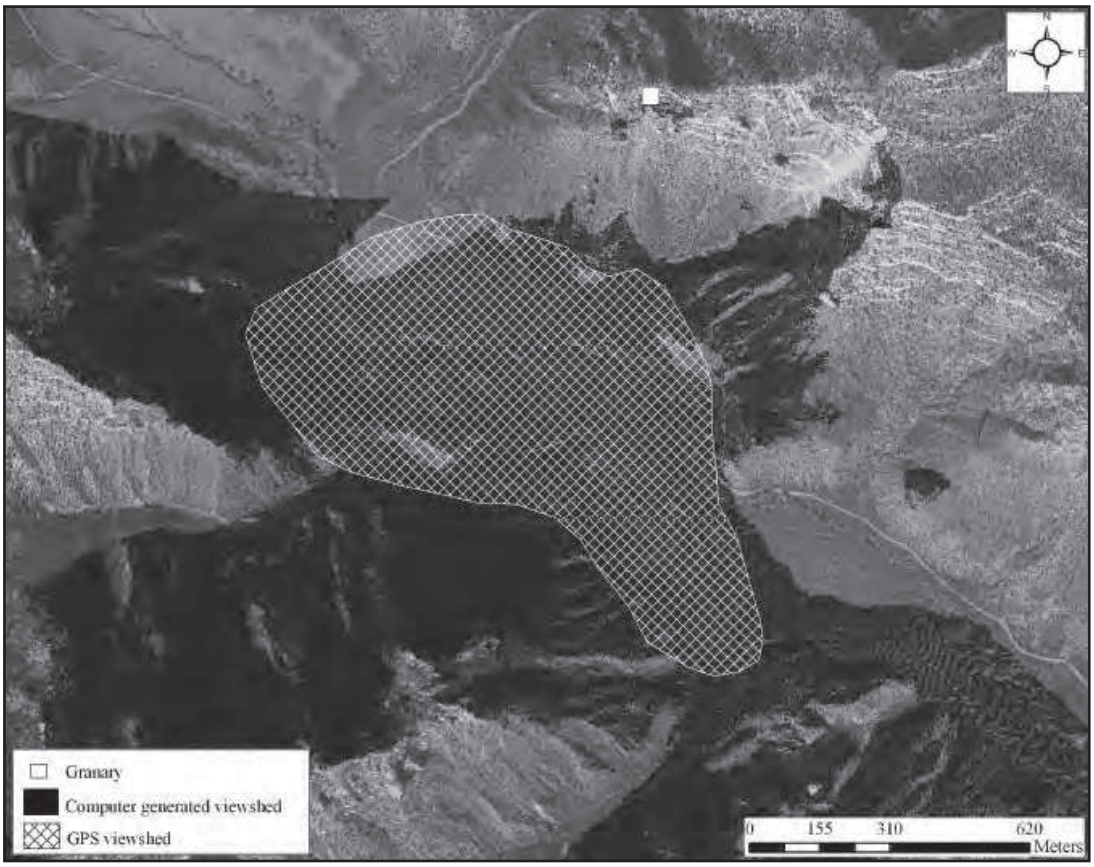

Figure 9. Aerial photograph showing the overlap of a computer generated viewshed and viewshed recorded by a GPS receiver estimating the area visible to the human eye.

as well, which may be a major consideration for a forager when choosing a granary location.

However, ArcGIS does not produce a very robust estimate of visibility. This is especially true in areas like Range Creek Canyon that have such varied topography but may be less true in areas lacking the extreme relief of this canyon allowing more precise measurements. Thus, analyzing differences between viewsheds calculated for each granary is likely to be misleading because the visible distance is only an estimate, providing more of a range of visibility rather than an exact measure. Nonetheless, the majority of granaries are visible from one or more structural sites considered residential in nature and some granaries are visible from six or more residential sites.

Nothing in this analysis contradicts the original proposition that placing granaries in visible locations is a storage strategy designed to deter theft. The odds of identifying a pilferer approaching or entering a granary is a function of how many potential witnesses are present. A larger viewshed means more potential witnesses. Given the difficulty of accessing these granaries, a pilferer would be forced to move carefully and commit to the action early on in its execution.

Having a line-of-sight view to multiple granaries from the valley floor would allow these facilities to be guarded by a relatively small number of individuals who could participate in other activities while monitoring access routes to remote granaries. This might be especially important if a significant number of Fremont

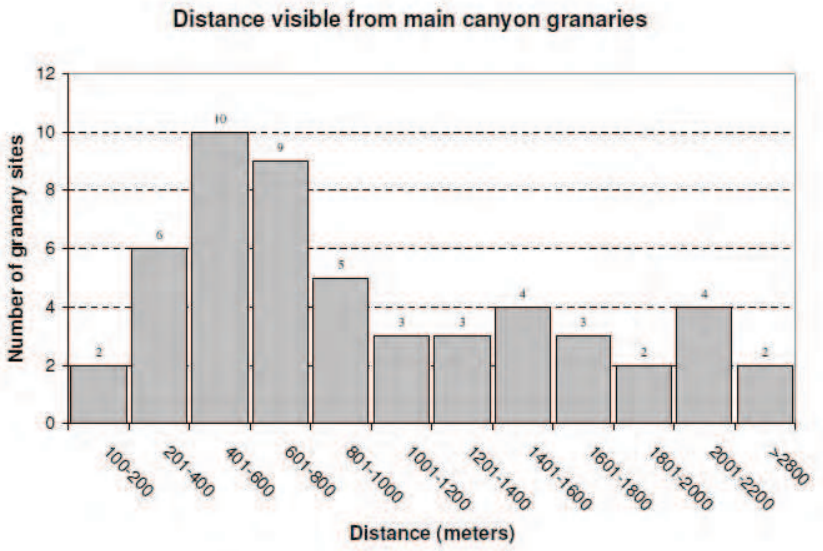

Figure 10. Histogram showing the distance visible along the valley floor corridor calculated for fifty-five granaries in the main canyon.

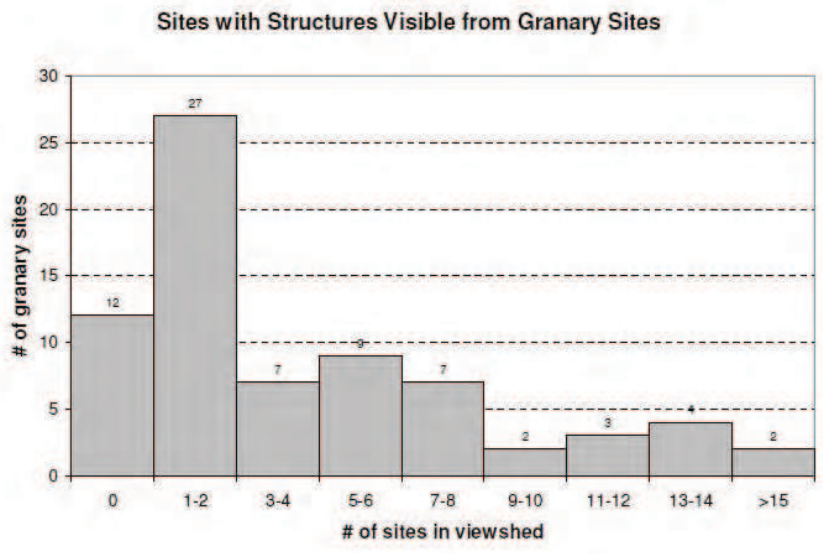

Figure 11. Histogram showing number of residential structures visible within each viewshed for seventy-two granaries in Range Creek Canyon and associated side canyons.

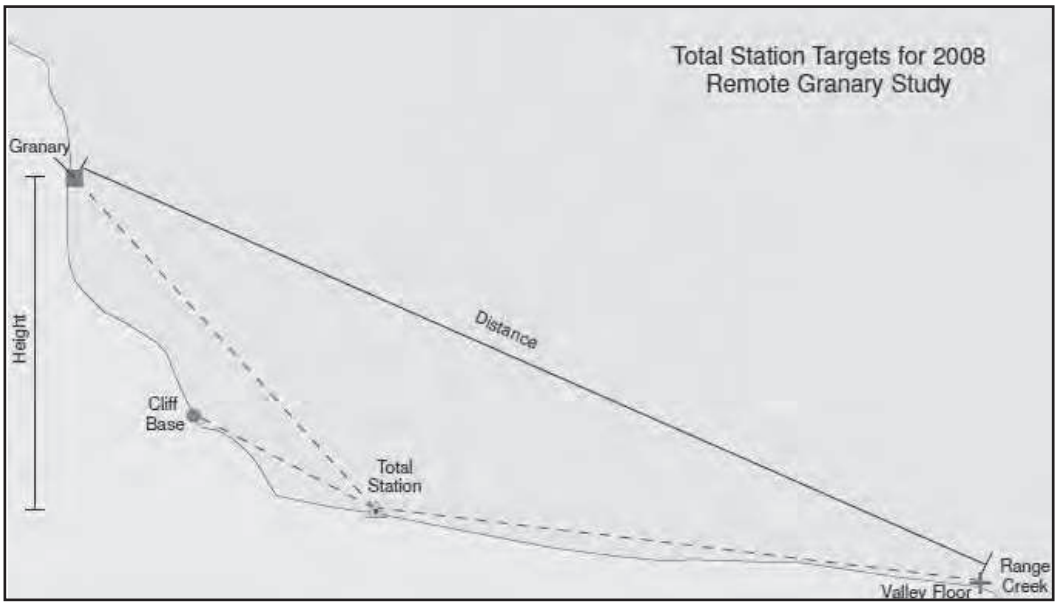

Figure 12. Schematic showing the targets for refining vertical locations of granaries using the reflector-less total station. The total station was set up below each granary and the UTM location recorded. The distance of the granary above the total station was recorded and added to the total station elevation to get the vertical location of the granary.

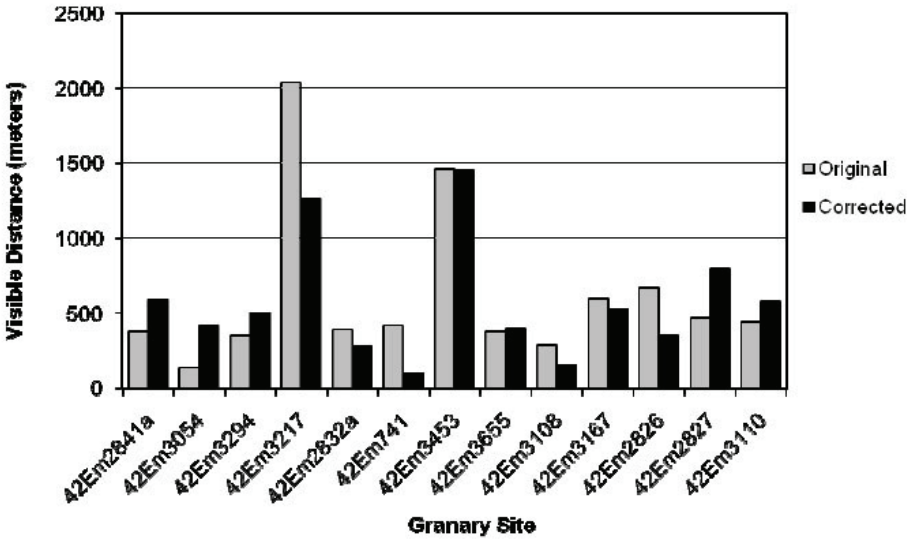

Figure 13. Histogram showing the change in visibility along the valley floor corridor for viewsheds generated from original plotted locations and locations refined by the total station for thirteen sample sites.

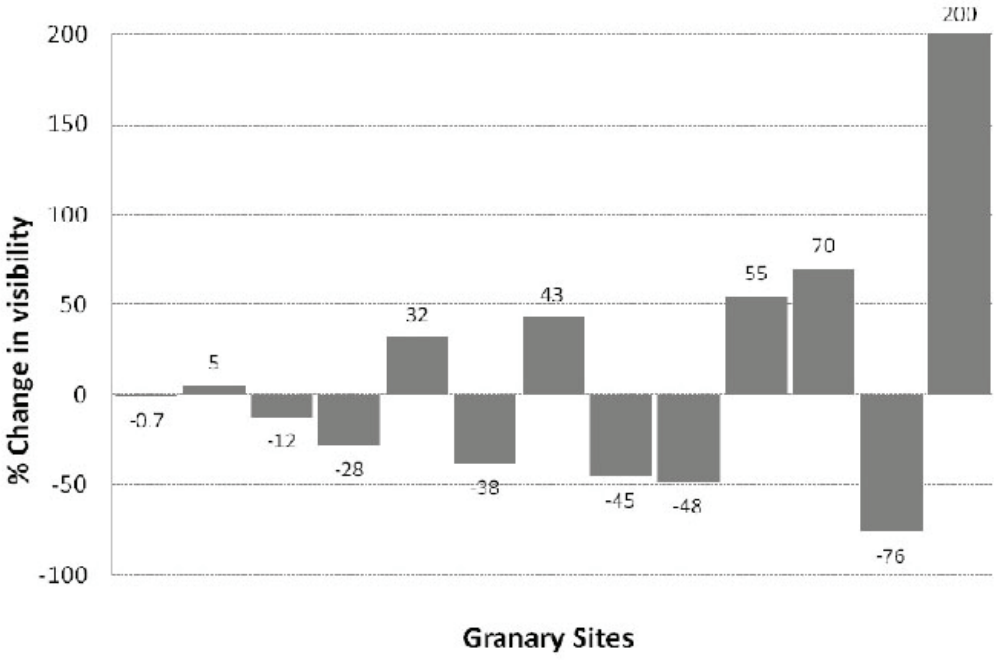

Figure 14. Histogram showing the percentage of change in visibility along the valley floor corridor, positive and negative, between viewsheds calculated from refined total station locations and earlier estimates.

foragers left the area seasonally to hunt and gather wild resources elsewhere. Fewer people would be necessary to remain in the canyon to guard stored resources. ∎

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