TECHNIQUES OF DETECTING AND DELINEATING ARCHAEOLOGICAL SITE DESTRUCTION USING HIGH RESOLUTION SATELLITE IMAGERY: AN IRAQ CASE STUDY

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ABSTRACT

Archaeological sites around the world have always been subjected to degradation and destruction as the result of looting. Nowhere is this more evident than on the Central Mesopotamian Plain of Iraq; particularly during the last decade. Because of the nature of the political and social conditions in the country, ground-based observations are extremely difficult and dangerous. For this reason researchers have had to increasingly rely on remote sensing imagery to document this damage. Until recently such studies have been challenging because of the lack of adequate area coverage and the need to depend on medium resolution sensors to detect relatively small looting pits. With the development and deployment of high resolution satellite systems the ability to identify site damage has greatly increased. This presentation will discuss the strengths and weaknesses of various techniques used to recognize and define the presence and extent of looting pits. As will be noted, such techniques rely heavily on the standard visual interpretation of shape, size, and shadow characteristics on high resolution Worldview 1 satellite imagery. In addition, it will be shown how embossing and contouring procedures can be employed for the digital enhancement of these features. Finally, the incorporation of these interpreted data into GIS databases for analysis will be discussed.

KEYWORDS: Iraq, Archaeology, Looting, Satellite Remote Sensing

INTRODUCTION

Mesopotamia, “the land between the rivers”, has been the home of numerous civilizations and empires over the last five millennia. Evidence of this settlement can be seen in the thousands of archaeological sites that dot the region; especially south of the capital of Baghdad. The settlement pattern history in Mesopotamia is one of continuous change and seemingly delicate balance (Gauche, 1998). Over the last two centuries a number of these locations have been studied and excavated by several archaeological expeditions. Some of the most extensive work was done in the central portion of the Mesopotamia Plain. One notable study was the Diyala Basin Archaeological Project in the 1950’s done by Jacobsen and Adams (Adams, 1965; Jacobsen, 1957). Adams surveyed one third of the central alluvial plain of southern Mesopotamia. His largest survey area was the central portion of the plain that he investigated from 1968 to 1975. He covered an area of hundreds of kilometers both on foot and by vehicle. In areas where ground survey was difficult or not possible, Adams supplemented his study by using aerial photographs (Adams, 1981). In addition, smaller surveys were also done to supplement the larger projects (Adams, 1972; Gibson, 1972; Wilkinson, 1990).

While such surveys shed light on thousands of years of human history, it is also true that there are forces operating to loot and destroy this history. The plundering of archaeological sites is a worldwide problem that is particularly evident in Iraq. Because of the loss of central control or authority in the rural areas following the ouster of Saddam Hussein there is little impetus to stop such destruction. In present-day Iraq there is a combination of systematic plundering and casual looting found all over the country. Evidence of this destruction was documented in an expedition organized by the National Geographic Society (NGS) in 2003 (National Geographic, 2003). Reconnaissance over flights and short-term ground visits verified the consequences of this damage. Extensive, illegal excavations were seen at such sites as Sifr and Tell Medinah (Figure 1). The methods used by the thieves are

Figure 1. The oblique photo above illustrates the raised outline and edge definition of the Sifr site as well as pitting. (Copyright of Comando Carabinieri T.P.C. Italy)

systematic and devastating. Looters will dig holes anywhere from one to five meters wide and several meters deep to uncover whatever artifacts they can find. If nothing of value is uncovered they move a few meters away and dig a new hole. This process is repeated over and over again (Figure 2).

Figure 2. The oblique photo above shows a landscape of looter pits and vehicle tracks on the Mesopotamian Plain. (Copyright of Comando Carabinieri T.P.C. Italy)

As noted in Figure 1 such excavations result in widespread overlapping pitting of a site. With such potential for irreversible destruction and loss of archaeological evidence it is vital to find out how widespread is the occurrence of this plundering. More recent evidence is needed to indicate what has been happening in the intervening years (Hamdani, 2008; Stone, 2008).

For a number of years following the fall of Hussein's government the ability to visit sites was too dangerous. While the political and military situation may be more stable today, it is still hazardous to travel to many rural areas in the country. The question then becomes how to best inventory the extent of site destruction in detail over a relatively large area. The only practical alternative would be to utilize remote sensing technology in the form of aerial photography and/or precision satellite imagery. With no civilian commercial air photo projects being flown, satellite imagery is the logical choice (Richason and Hritz, 2007). Considering the dimensions of the holes being dug, imagery with a resolution of around 1 meter would be needed. Initially Digital Globes Quickbird satellite imagery was going to be used for the research; however, in 2007 a new sensor system became available; Worldview 1. This newer satellite had better positional accuracy and resolution, approximately 50 cm, rather than the 61 cm of Quickbird (Digital Globe, 2010). Moreover, geolocational accuracy is greatly improved with Worldview 1 at 5 meters as compared with Quickbird's 23 meters.

STUDY AREA

One of the first considerations for the research project was the determination of a suitable area of study. This choice was affected by several factors, not the least of which was cost. With no high resolution satellite image coverage available for this region of the Central Mesopotamian Plain, it would have to be obtained from a commercial vendor. With this being the case the dimensions of the study area were going to be limited by the amount of funding available for the purchase of Worldview 1 imagery. Other factors influencing this decision were the density of site locations, and the author's familiarity of sites from previous research. Furthermore, the rationale for the selection was to choose some major locations to see to what extent, if any, well known sites had been damaged. The first two sites centered on specific excavations, Nippur and Abu Zibliyat, The third area chosen consisted of a single region located in an irrigation over-flow depression called Lake (Hawr) Dalmaj. The Lake Dalmaj site was chosen because previously water filled the lake basin. Today much of the lake area is dry throughout the year. Many smaller sites that were inaccessible to looters because of their isolation by water are now accessible to looters. It was thought that this area would serve as a good indicator of how widespread the problem of plundering has become. This could show that not only have major locations been attacked, but perhaps minor, undocumented ones as well (Richason, 2010). The boundaries of these three areas of investigation can be seen in Figure 3.

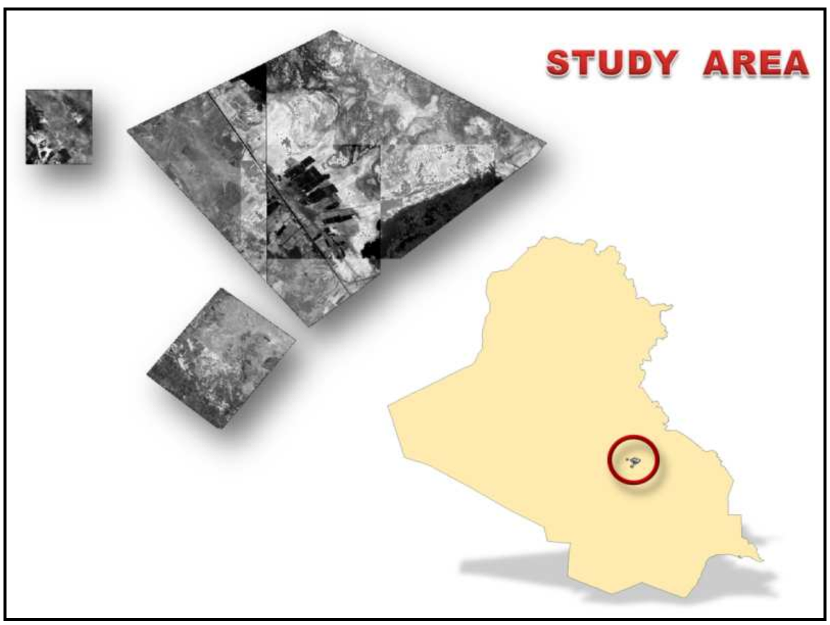

Figure 3. This figure shows the general location of the study area in Iraq, as well as a satellite mosaic of the three study area regions.

PROJECT GEODATABASE

To effectively use the satellite imagery for interpretation, it would need to be incorporated with other types of collaborative data. This was accomplished with the design of an ArcGIS geodatabase. Probably the most important of these sources would be Adams' catalog of archaeological site locations in the region. These sites would allow for a frame of reference to initially locate and delineate the extent of the sites prior to ascertaining the amount, if any, of looting damage. Prior to this research a georeferenced digital version of the catalog had already been created. When overlaid on top of the satellite imagery it was apparent that the catalog site locations and the apparent archaeological sites on the imagery were not in perfect alignment. Once again it must be remembered that the site locations gathered on the ground were the result of a wide-area ground reconnaissance survey done prior to the implementation of the Global Positioning System (GPS). The positional shifts between these two sources, while noticeable, were still within an average linear distance of about 300 meters (Richason, 2010). To compensate for these discrepancies a multiple ring buffer was performed on the catalog site points at distances of 300, 400, and 500 meters. As a result of this buffering a new feature dataset was created (Figure 4). It would be within these buffers that sites would most likely be found. With few exceptions this was the case. Once the sites were located on the imagery a polygon feature class was created to delineate the boundary extent of all sites.

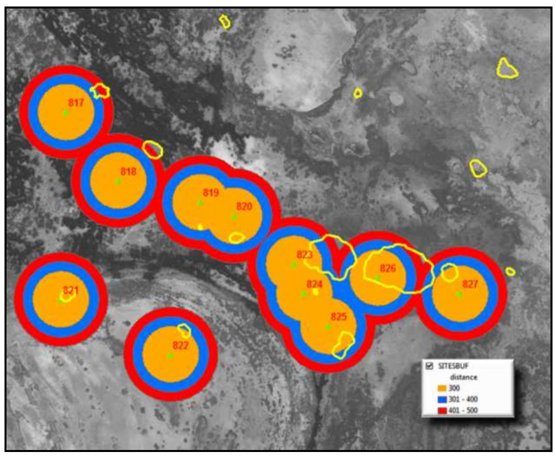

Figure 4. This is a portion of the Lake Dalmaj study area showing the labeled sites as green triangles, the boundaries of the site polygons, and the multiple ring buffers.

Additional image sets were also added to the geodatabase. These included Landsat TM, SPOT, Corona, and Radarsat imagery. While these images did not possess the needed resolution for the identification of single pits, they did provide a good backdrop for site locations and land cover/use information. Finally, to these datasets, others were created for the location of the boundaries of archeological sites, the individual looting pits, and the boundaries marking the extent of damage in each individual site.

SITE INTERPRETATION

With the mosaicking of the image segments and the creation of the geodatabase the actual interpretation could begin. For the purpose of this presentation only the area covering the northern part of Lake Dalmaj will be discussed, though the same techniques were applied to the two main sites of Nippur and Abu Zibliyat. The first task of the research was to locate the known sites recorded in the Adams' catalog. As previously noted there was not an exact agreement between these points and the apparent location of sites on the imagery. To help narrow the initial search for site locations the multiple ring buffers feature class was used as an overlay reference.

In terms of the sites, most of them stood out from the surrounding landscape reflectance. More specifically, they were differentiated by looking for areas where there was a distinct lack of vegetation. These variations in tone were easily recognized, particularly by the lack of vegetative cover on the middle of a site and a ring of vegetation around its perimeter (Figure 5). Also, the fact that these sites are mounds on level terrain meant that there was a certain amount of edge definition in the form of shadow. These were useful because wherever there is relief on the plain it is probably an ancient occupation site *(Wilford, 2003).*

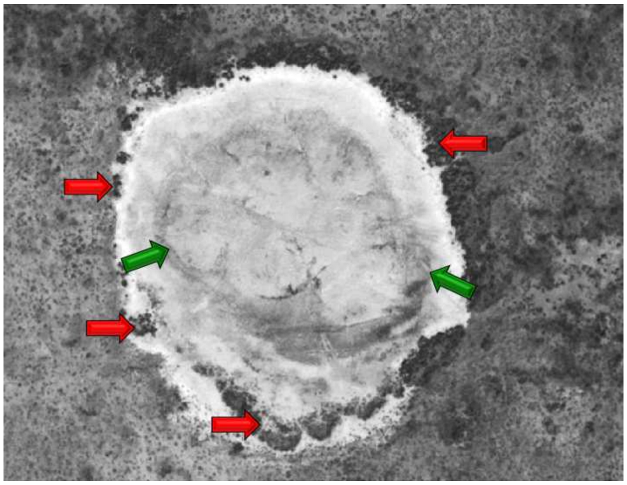

Figure 5. The image above shows an example of a representative site found on the dry lakebed of Lake Dalmaj. The red arrows show a ring of desert vegetation around the margins of the site. The green arrows indicate the effect of mound shadow providing an edge definition effect.

Aiding in the identification of these archaeological sites on the imagery were two sets of linear features; canals and vehicle tracks. Historically, settlements in this arid region have had to rely on systems of irrigation canals that were laid out over thousands of years and continue today. Early archaeological surveys in the region first noticed evidence of these canals on the ground and the Adams' survey maps indicate them as well. When studying this map there was a strong correspondence between site location and canal orientation. With careful study many of these canals were detected on the imagery and were used to correlate with site locations. For the most part, they could be identified as relatively wide, dark straight lineations (Figure 6).

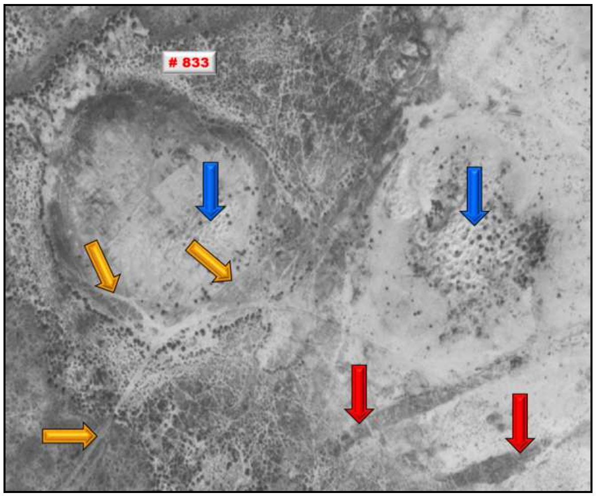

Figure 6. This is an enlargement of Site #833 on the dry lakebed of Lake Dalmaj. The red arrows are pointing at two ancient irrigation canals. The gold arrows show the positions of vehicle tracks left by looters. The blue arrows areas point to the location of looting pit concentrations.

Another important set of linear features that highlighted object associations were those between sites and vehicle tracks (Figures 1 and 6). The assumption was that these were the tracks of vehicles that the looters were using to haul their equipment to the sites and to carry their plunder away. Such tracks, usually occurring in multiple sets, were quite widespread throughout the study area. By following the paths of these tracks they usually lead to mound sites in the lakebed region (Richason 2010).

Once the general location of the archaeological sites were ascertained, specific boundaries marking their extent were delineated on the imagery. The techniques employed for this delineation were essentially basic visual interpretation. The image characteristics of size, shape, tone, and shadow were utilized not only for site demarcation, but also for pit identification. In confirming site positions and outlines, their description in the Adams Site Catalog proved quite helpful. The catalog contains descriptions of the dimensions, orientations, and distances between sites. Furthermore, some sites had multiple mounds within them that that were noted in the catalog. These notations helped to avoid confusing a group of mounds seen on the imagery as individual archaeological locations. It is also interesting to note that in some of the more remote areas of the lakebed that additional sites, not recorded in the original field surveys, were identified on the imagery and became part of the study.

After the location and extent of the sites was established, the next step of the research was to review each individual one to determine to what extent, if any, looting damage had taken place. This damage was in the form of holes or pits in the ground that looters had dug to retrieve artifacts such as clay tablets, pottery, inscribed cylinders, or anything else of value. At just about every site observed on the imagery there was evidence of illegal excavation; in most instances significant pitting was discovered. The large number of pits found at these sites was the result of the way the looting took place. Looters would start by digging exploratory holes and if nothing of interest was found they would move a short distance away and dig another. This process would be repeated again and again until a portion of a site would be turned into a honeycombed maze of depressions.

In the geodatabase a point feature class was created that would hold a pit location. Each site was then systematically studied and looting pits identified and recorded from the imagery backdrop in ArcMap. The basic image characteristics of shape, tone, and shadow were employed to make these determinations. Pit shapes tended to be either circular or rectangular, though at the scales being used most pits had a circular appearance (Figure 1). Because they were depressions the interrelationship between shadow and tone became very relevant. Regardless of their size, pits on the imagery had much in common with volcanic features or oil storage tanks. All such features have portions of dark centers as the result of shadows that are cast into depressions. Also contributing to these darker tones was the prospect of darker reflecting subsurface soil material and moisture at depth in this area of fluctuating water table levels (Stone, 2008). Around this center pit shadow was lighter reflecting material. These lighter-tones were the result of excavation debris being piled around the rim of the pit. This tended to form sort of a concentric ring "bull's-eye" effect that was unmistakable from surrounding features. Using these image characteristics individual pits were identified and digitized into the feature class.

After all possible pits were confirmed and documented another polygon feature class was generated to delineate the general form around the pit point concentration within the archaeological site (Figure 7). These two types of polygons would later be employed to calculate the density of loot damage throughout the study area. As these interpretations were being done, care had to be taken not to mistake loot pits with the forms of ancient circular mounds or building foundations; perhaps from some previous archaeological excavations.

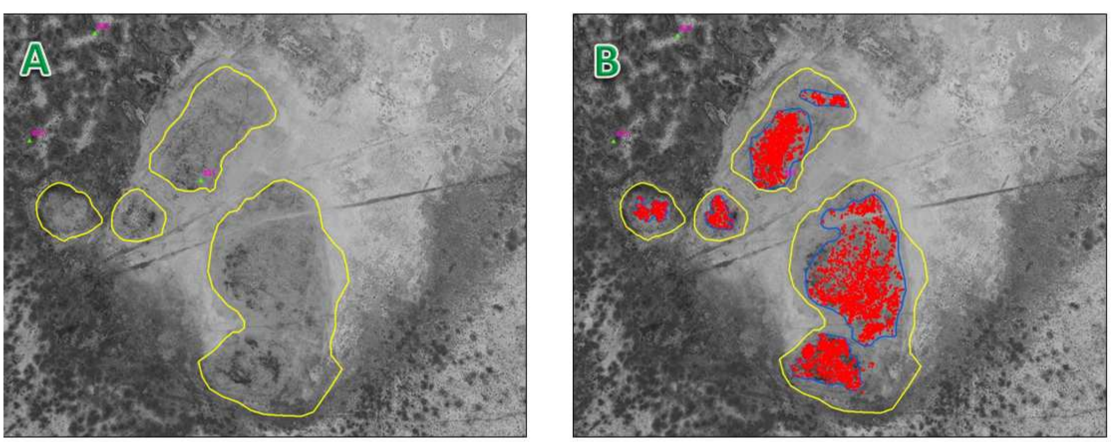

Figure 7. The two images above present the results of the initial interpretation. The image at "A" illustrates the delineation of the site in yellow. The image at "B" shows the concentration of pits represented as red dots, while the blue outlined polygons show the general areal extent of the pit damage.

Interpretation Considerations

In general, the image interpretation techniques described above were sufficient to accurately document the location and intensity of illegal excavation destruction. Still, there were instances where close attention had to be paid to correctly distinguish if an image object was really a pit or not. One of the main concerns was not to confuse clumps of vegetation, or even single plants, with dark, shadow-centered pits. Both had the appearance of small black dots on the imagery. Certain factors helped distinguish pits from surrounding plant growth. First, as previously noted, the central portions of the occupation sites tended to be devoid of vegetative cover. It was not until the edges of the site were approached that vegetation began to occur. Secondly, some of the individual shrubs tended to be larger than some of the diameters of individual pits. Furthermore, the vegetation did not have the lighter-toned ring of excavation debris around them. Related to this debris caution had to be taken so as not to misjudge looting pits with spoil debris from the excavation and maintenance of some nearby irrigation canals.

The dimensions of the loot depressions also affected interpretability as can be seen in Figure 8. There was a considerable amount of variation in the size of individual pits and therefore image resolution became an important factor the ability to detect pits with diameters smaller than 2 meters. As previously noted, the Worldview 1 satellite resolution is .5 meters (50 cm). Still, it takes a group of contiguous pixels to form an identifiable image shape. Operating at the edge of resolution (a scale of around 1:800-900) individual pit identification could be very difficult. This would become evident as a particular area of smaller pits would be enlarged; the integrity of the individual form would be lost because of pixilation. In all instances it was decided to error on the side of caution and not run the risk of over counting pit objects.

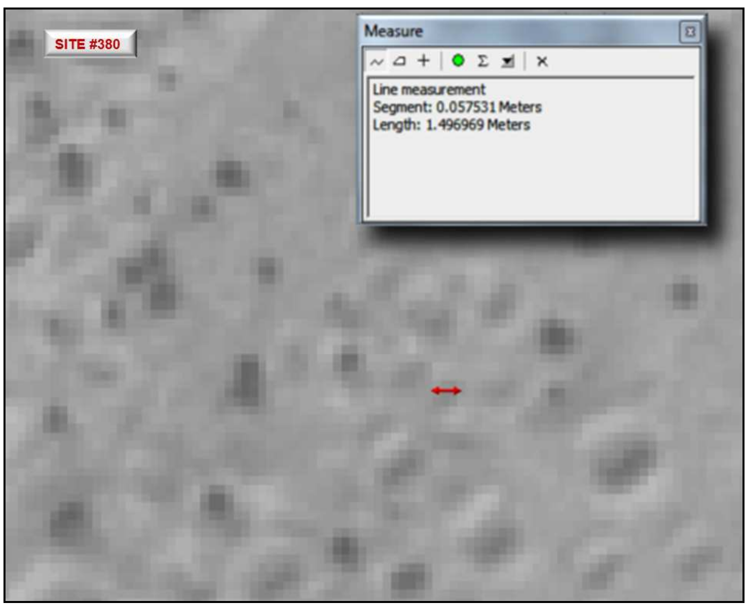

Figure 8. This is an enlargement of Site #380. The small red arrow on the image measures a pit diameter of approximately 1.5 meters.

Another serious problem that presented itself in detecting individual pits was overlapping coalescence. On some sites the number, size, and spacing of the pits was such that they appeared to blend together into one large form. This amalgamation was the result of the debris from one pit being piled onto that of its neighbor. The effect was to produce a landscape of rolling, hilly mounds of rubble making the identification of discrete pits very difficult. Further complicating pit identification was the problem of erosion and the deposition of surface material by eolian effects. During certain times of the year Iraq can be subjected to massive dust storms. For older pits that have been subjected to such conditions over the years their form and tonal reflectances will change. As they fill in with windblown material, the pit depths become shallower thus reducing the shadow effects and consequently subduing tonal reflectances. While this makes detection more difficult, it also affords the advantage of relative age differentiation (Stone, 2008).

Digital Enhancements

To support the visual interpretation process, some digital enhancement techniques were utilized. In certain areas of the image mosaic tonal variations might still be somewhat subdued. To compensate for these variations in quality digital manipulations of the imagery were applied on a site by site basis. These techniques included such manipulations as contouring and embossing which were utilized to enhance detail not readily seen on the original image. To carry out these enhancements the sites from the original image mosaic were clipped out in ArcMap and then saved as a GeoTiff file. In this format the image could be exported to a program such as Adobe Photoshop for enhancement; specifically using routines such as Contour and Emboss. In using embossing the detail of the loot pits would have a "raised" effect which offered the opportunity to better distinguish individual features (Figure 9). Another useful effect was that of contouring. This allowed for the boundary outline of individual depressions to become more evident (Figure 10). The results of both of these techniques were saved and imported back into the geodatabase where they were overlaid on the original imagery. By specifying a certain amount of transparency in the display both the imagery and the embossed enhancement could be seen together. Such composites could bring out detail, especially of smaller or degraded pits, that was not as clearly visible on the original image. Once again, care had to be taken not to confuse vegetation with pit shadows as the techniques for enhancing pits would also enhance dark vegetation in a similar manner (Richason, 2010).

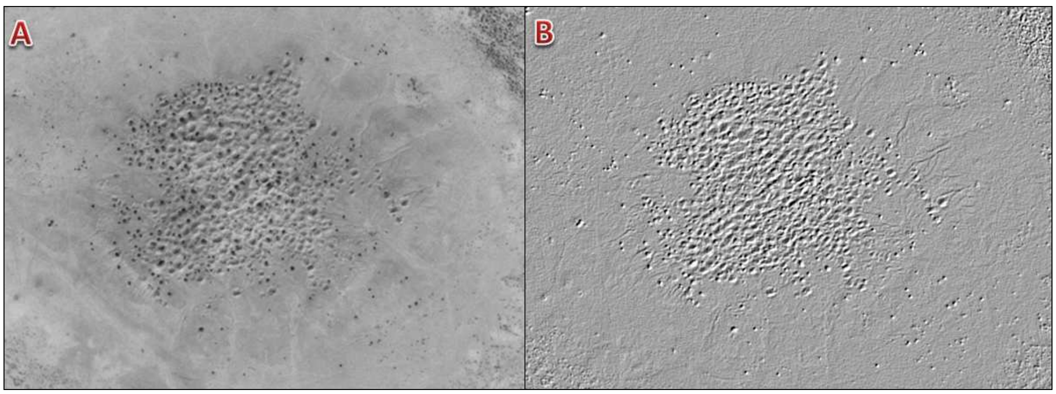

Figure 9. The image at "A" is a site in the Lake Dalmaj area which shows major loot damage. The image at "B" represents the results of embossing enhancement. Note how the pits now stand up in "relief" making them easier to detect.

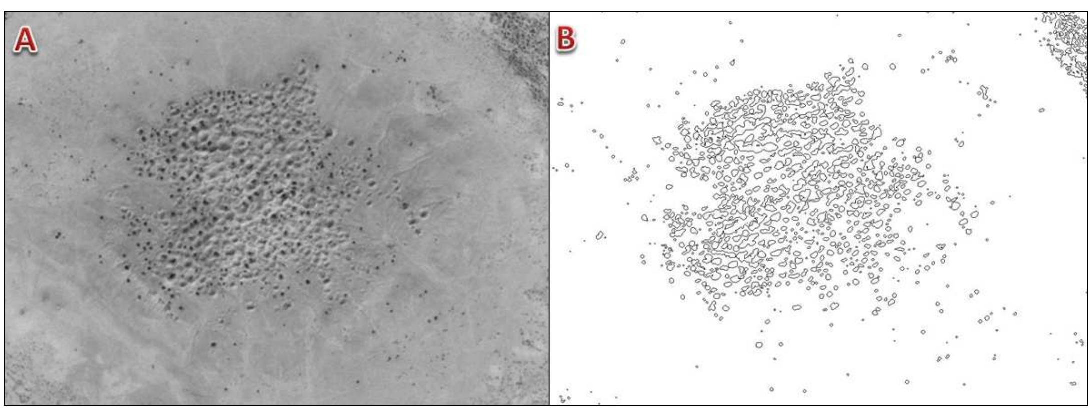

Figure 10. The image at "A" is the same as above. The image at "B" shows the results of a different type of enhancing filter, a contour trace. Here individual features are displayed as polygons shapes. Once again note how the looting pits stand out.

RESULTS AND CONCLUSIONS

With the completion of the pit count and the delineation of the enclosing areas of destruction, it was found that site destruction was significant and wide-spread throughout the study area; particularly in the Lake Dalmaj region. This can be noted in the data generated by the interpretive analysis. An initial total of 61,235 individual pits on 196 sites were found with an average of 316 pits per site. On some sites the pattern of pit damage appeared to be irregular or haphazard, while on the others portions of the site a grid-like or regular pattern could be discerned. There were also differences in the concentration of these distributions, which would vary from a site being completely covered with pit damage to others where the damage, though extensive, was concentrated in one or two parts of the site. It is interesting to note that the two larger sites of Nippur and Zibliyat have apparently not sustained the same level of destruction as the lake area. This is probably the result of these sites being better guarded and the looters perceptions that at such sites, where archaeological excavations took place for decades, most treasures of any value have already been removed.

Using the data generated from the interpretation a density map of the number pits was created to display the distribution and concentration of the destruction (Figure 11). It was then compared to the density map of the Adams site catalog (Figure 12). As might be expected areas with the greatest amount of damage are associated with the greatest degree of site concentration. This would certainly make sense in terms of looter access and activity. It should also be noted; however, that even some more remote areas in the lakebed have also sustained significant damage as well.

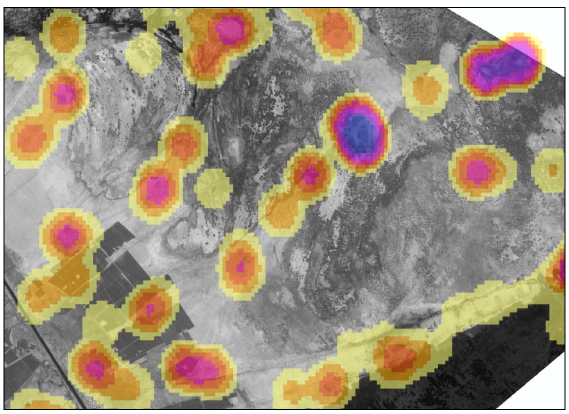

Figure 11. This image covers a portion of Lake Dalmaj. Overlaid on top of it is a raster dataset showing the density of loot pit damage relative to the area of a site. The dark blue, purple and red areas indicate the greatest concentration of damage.

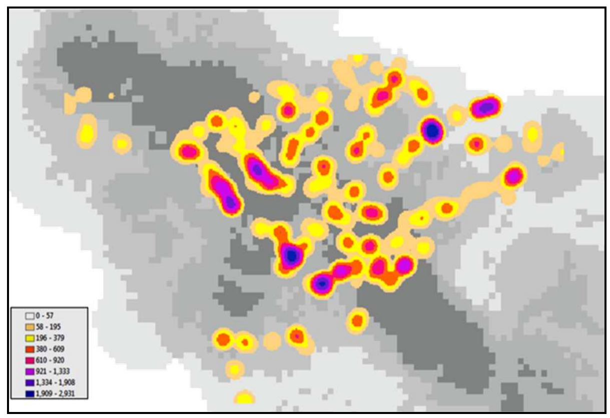

Figure 12. The map seen here is an overlay comparison of the density of site locations from the Adams, map (shown here in gray tones) and the density of site destruction for the entire area shown in color. Note the relationship between the high density areas of both.

From this research two main conclusions can be drawn. First, and foremost, the value of using high resolution satellite imagery proved to be invaluable. In an area of the world where ground investigations are not feasible and civilian aerial photograph coverage not available, the Worldview 1 satellite system provided a level of detail which made the investigation of site looting possible. While it is true that the image interpretation operated at the margins of the system's resolution capabilities, in the vast majority of cases it proved to be more than sufficient. The ability to detect and differentiate the relatively small, compact, and in some cases degraded, loot pits would have been impossible without such imagery. While other sensors are available, the accuracy and resolution for studies of this type were not available at the time of this study.

Secondly, just as important was the ability to integrate the imagery into a GIS geodatabase. Much of what was accomplished in this study would not have been possible without such a combination of data types and tools. Perhaps the most significant aspect of this investigation was the ability to incorporate the digital Adams Site Catalog of surveys as an overlay onto the imagery. It certainly sped up the search and accurate placement of archaeological locations in the search for evidence of looter impact. In addition, the creation of the pit point and destruction extent polygon feature datasets made all other maps and calculations possible. The capability to generate density displays from the digitized points provided a means of interpreting the concentrations and patterns of looter destruction in order to better comprehend the impact of the site damage.

The combination of visual site interpretation techniques and their incorporation with digital GIS tools provided the means to detect the extent of site looting destruction on the Central Mesopotamian Plain of Iraq. Unfortunately the results of the investigation clearly showed that considerable damage has occurred. While damage to the two large, prominent sites appeared to be negligible, this was not the case for smaller sites in the more remote dry lakebed of Lake Dalmaj. Every site examined showed some level of irreversible destruction. Even a small amount of such illegal excavation not can permanently degrade and compromise the integrity of a site's archaeological context.

In the final analysis this study has shown the regrettable occurrence of the destruction of archaeological sites that have existed for thousands of years. While this investigation only looked at a relatively small portion of the Mesopotamian Plain, such devastation is happening all over the country and its extent needs to be documented. Currently the only way this can be done, considering the preset political and military state of affairs, is through the use of remote sensing imagery. A more extensive spatial inventory of damaged sites is needed, as well as a temporal one. Imagery only records conditions at a specific place and time, but in the case of illegal looting not only the areal extent, but also the extent of the continuation of such looting has to be studied. Until researchers and scholars can return to the land to make onsite observations, the remote sensing perspective and GIS analysis will have to suffice.

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