INTEGRATING GIS AND PHOTOGRAMMETRIC RECORDING FOR EXTENDED SEABED ARCHAEOLOGICAL RESEARCH, MARSA BAGOUSH, EGYPT

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ABSTRACT:

Photogrammetry and GIS technologies are developing rapidly and becoming more affordable. They have also emerged as significant archaeological tools as a result of an increasing level of automated workflow in data acquisition and processing. Moreover, these techniques offer considerable reduction in the cost of underwater archaeological research. That is in addition to significant enhancement in research plans, management, and results, especially in extended seabed archaeological projects. Therefore, these technologies are utilized as essential aspects of the underwater archaeological research project in the site of Marsa Bagoush, Egypt. The site is located 250km west of Alexandria, and it takes the form of a bay, almost 650,000 m^2. Marsa Bagoush (ancient *Zygris*) was mentioned by *Claudius Ptolemaeus* in the 2^{nd} century AD as one of the main anchorages along the northwest coast of Egypt between Alexandria and Marsa Matrouh (ancient *Paraetonium*).
This paper presents the results of the on-going digital documentation of the site which is a major part of an underwater archaeological investigation project. The paper will discuss the promising application of photogrammetry in underwater archaeology. It will also look at the integration of GIS Database techniques, which represent accurate methods of documenting topographical and archaeological elements and obtaining three-dimensional digital models of the site and its contents.

1. INTRODUCTION

An underwater archaeological survey for the site of Marsa Bagoush started in 2015. So far, it is the only underwater archaeological project, along the Egyptian Mediterranean coastline, which takes outside Alexandria. The site of Marsa Bagoush is located 250km west of Alexandria. It was known in antiquity as (*Zygris*). In the 2^{nd} century AD, it was mentioned by *Claudius Ptolemaeus* as one of the main anchorage sites between Alexandria and Marsa Matrouh (ancient *Paraetonium*). In 1861, as part of a coastal survey of North Africa, the British Royal Navy surveyed the site of Marsa Bagoush and published the first map of the site; the map showed a series of rocks that bordered the bay from the north and east (Fig.2). The first mention of archaeological remains at the site of Marsa Bagoush was in a note published in the International Journal of Nautical Archaeology in 1996 (Abdel Aleem, 1996). The late Egyptian Oceanographer Anwar Abdel Aleem wrote about a discovery that he accidently made in 1968 in the bay of Bagoush, which he believed to be the remains of an ancient shipwreck. In 1996 the Institute of Nautical Archaeology (INA) conducted a limited survey of the site where few intact early Roman amphorae were located. However, no further exploration of the site was made, until the rediscovery of the site in 2010. Nonetheless, actual investigation of the site did not start until 2015 when systematic survey of the site began by a team from Alexandria University (Khalil, 2017). In 2018 the survey extended westwards where another natural anchorage existed c.2.5km to the west of Zygris. The anchorage of (*Ladamantia*) was mentioned in the ancient Roman guidebook, *Stadiasmus Maris Magni* of the 3^{rd} century AD. It was described as having a rather large island and a harbour accessible with any wind. The survey also revealed that ancient *Zygris/Ladamantia* were among the largest and most active ancient anchorages along the northern coast of Egypt, they have been in use by ships and seafarers from as early as the 3^{rd} century BC to the early 20^{th} century. (Khalil, 2017).

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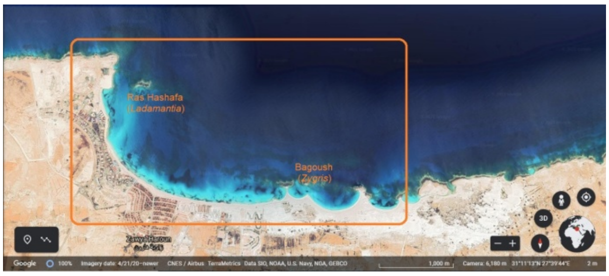

Figure 1. The site of Marsa Bagoush/,Ras Hashafa (Google Earth : directed link below in references)

2. RESEARCH AND SURVEY CONTEXT

.In 2010, the site of Marsa Bagoush was rediscovered by some students from Alexandria University. However, the comprehensive study of the site, by a team from the Alexandria University Centre for Maritime Archaeology & Underwater Cultural Heritage (CMAUCH) started in 2015, with support of the UK-based Honor Frost Foundation. The ongoing Marsa Bagoush Research Project (MBRP) aims to conduct a systematic underwater survey of the site which includes locating, recording and dating the submerged archaeological remains, as well as investigating the site's formation and

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development processes, with the aim of developing a management strategy for the site that includes utilizing it for education and training purposes. In doing so, the MBRP utilized photogrammetry techniques, for documenting several areas on the site.

The first part of the site that was surveyed was ancient (*Zygris*), which takes the form of a bay about 900m EW x 300m NS, with a maximum depth of 10m (Fig.1). The bay is well protected by a headland that projects from its eastern end and by a series of submerged reefs that reduces wave action inside the bay.

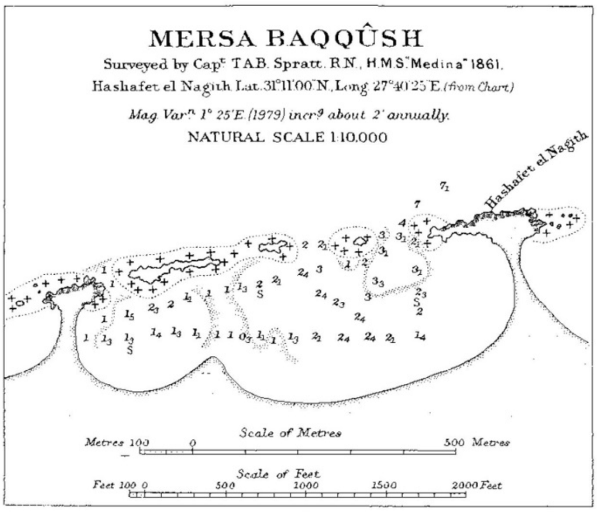

Figure 2. A map of Marsa Bagoush produced by the British Navy in 1861 (Donald White and Arthur P. White)

The existence of submerged reefs at the entrance of the bay close to the water surface represents a hazard for ships entering the bay during rough seas (Khalil, 2019). From 2015 to 2018 *Zygris* (c.340, 000 m^2), was visually surveyed by diving teams, and then GPS reading were taken as general reference points. During the survey, evidence for at least three shipwrecks was identified. The wrecks date back to the Hellenistic, Roman, and Islamic periods. Then in 2018 another part of the site was discovered, which was ancient *Ladamantia*. It is a large bay to the west of Zygris, which was found to contain extensive evidence for maritime activities including different types of amphorae and the largest collection of ancient anchors found in Egypt outside Alexandria. Accordingly, about c. 480,000 m^2 was surveyed and the underwater archaeological material was documented (Khalil, 2019).

Since the outset of the project, and taking into account the budget limitation, the application of photometric techniques was chosen as the main documentation technique. Indeed, this low-cost and user-friendly method for acquiring high-resolution datasets, is well-suited for such research with financial and logistical limitations (Semaan and Salama, 2019). On the other hand, the size of the site, the large amount of archaeological material discovered, and its wide chronological range, which extends over two millennia; all indicated the need for a GIS database system. The GIS system was used to record the location of the archaeological objects and their distribution on the site, and to help with the analytical study of the discovered archaeological material. However, the use of such methods and techniques was very much influenced by the nature and characteristics of the Marsa Bagoush site.

3. DATA ACQUISITION OF PHOTOGRAMMETRIC RECORDING

Documentation of archaeological sites is a key element of any archaeological field project. For underwater archaeological sites, documentation takes even a further dimension due to the unique nature of such sites, It is evident that the underwater environment contributes effectively to the preservation of material culture, which makes underwater archaeological sites an invaluable source of information on different aspects of ancient societies. On the other hand, for documenting underwater archaeological sites, various techniques and approaches are being utilized. Visual documentation of archaeological sites through drawings, sketches, high-quality images, maps, and Photogrammetry has been carried out for decades (Drap, 2012: Chiabrando et al., 2011). However, recently, using photogrammetry techniques to record cultural heritage has developed into a standard documentation tool (Repola, et al., 2018). Photogrammetry enables archaeologists to record information in great details, also helps the non-diving researchers to experience some underwater archaeological investigation without needing to physically visit the site (Wright,. et al., 2020; Van Damme, 2015). Computer-vision photogrammetry, which uses images to create measurable three-dimensional geometric models of the archaeological materials through the use of compute capabilities and Programmes apply certain algorithms to perform this task. This technology has been developed only during the last decade, and various Programmes, whether paid or open source, are able to perform this function.

3.1 Underwater Photogrammetry

3.1.1 Data acquisition, equipment, and materials: The underwater environment imposes limitations on photogrammetric photo shooting (Skarlatos, et al., 2012). The primary step in making precise tridimensional models from Computer Vision Photogrammetry is to capture photographs in a good quality. Choosing the correct camera and accessories is fundamental to guarantee that clear and appropriately colored photographs are captured (Yamafune, 2016). There are many factors that should be considered to achieve that goal, some of them related for the nature of each underwater site and its characteristics, and some others are related to the photographer. With regards to the site in question, the ancient anchorage of Marsa Bagoush is affected by the prevailing N-NW wind. Archaeological material is located at depths ranging from 2m to 25m. Both rocky and sandy seabed extend across the site. The site also features clear water which offers a good visibility mostly exceeding 15m. However, occasionally water current result in stirring sand and seaweeds particles which adversely affect visibility. Accordingly, photo shooting condition varied considerably throughout the surveying process due to the variation in lighting conditions which were affected by the depth, nature of seabed, and water clarity.

Since 2015, the main camera that has been used during the underwater survey is a DSLR camera (Nikon D800, equipped with 12-24mm wide lens, and ikelite underwater TTL housing). Moreover, lately, we started using a full frame mirrorless camera (Sony a7r II, equipped with 16-35 wide lens, and Nauticam underwater housing). When shooting with any equipment, the focal length was kept always above f/ 7.6 to avoid blurry images, while the shutter speed was adjusted according to the visibility and the lighting conditions, as well as ISO setting. Using wide angle lens on a professional camera with full-frame sensor, offers very high quality, sharp images, with the ability to cover wider range of space while, at the same time, allow getting closer to the object, to avoid potential optical noise, This is an important factor in capturing crisp images for successful underwater photogrammetry (Yamafune, 2016). On the other hand, both underwater housings used are equipped with a compatible dome which takes a hemispherical shape to allow light to enter the lens thought the underwater housing perpendicularly; therefore, it can minimize the refraction caused by the different densities of the water and air (Zhukovsky, Kuznetsov, & Olkhovsky, 2013). Furthermore, using an adequate light strobe is essential to solve two main problems in this particular site; firstly, lower lighting condition in some deeper spots, and secondly the effect of the light-column problem caused by shadows projected from the water surface in shallow depth. Moreover, when employing manual photography methods, the diver's underwater orientation, hence the ability to maintain the level of the flight plan, are the most significant factors in the precision and accuracy of data acquisition. (Abdelaziz, and Elsayed, 2019). Thus, the flight plan developed by K. Yamafune was utilized in Marsa Bagoush project to achieve best practice for this step of work (Yamafune, 2016)

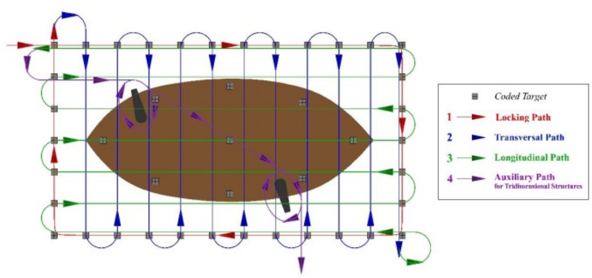

Figure3. Recommended flight path for photogrammetric recording (Yamafune).

Moreover, manual setup of grid was applied using measuring tapes, scale bars, and leveling tools to prepare each site for photography. During photogrammetric recoding 80% of overlapping and 60% of side-lapping were respected, which is highly recommended by most experts in that field and also processing software developers, to achieve the desired results in aligning images. Transversal and longitudinal paths had been captured vertically to cover each visible part, then the auxiliary path better to be captured in 45 degrees that is to cover any tridimensional features around the site.

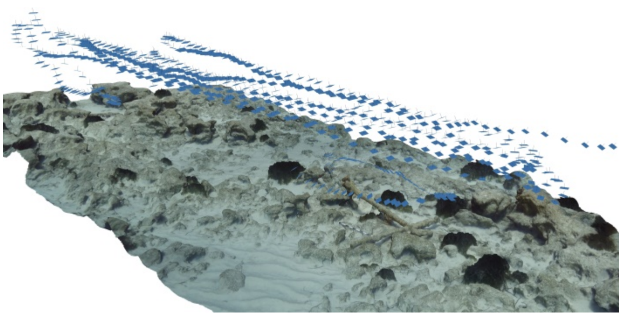

Figure 4. Capturing Path of 3D model of a Roman anchor (M. Salama)

3.2 Photogrammetric data processing

As previously stated, the site of Marsa Bagoush is an ancient anchorage, which has been used for over two thousand years. Therefore, many archaeological remains from different periods were scattered throughout the site. As a result, each spot was recorded separately, with its contents and surroundings, resulting in numerous sets of images varying in color and lighting balance according to the conditions of each spot. This required managing image collections as well and adjusting colors and lighting using photo-editing packages. To perform this task, the team used Adobe Lightroom and Photoshop for editing images in such an environment. Since the beginning of the project, a relatively high-end portable workstation was acquired. It is equipped with an Intel Core i7- 6700K (4GHz) processor, dual NVIDIA GeForce GTX 980M video card and 46GB RAM. The availability of such capabilities had a significant impact on managing and processing data directly on site. It was possible to process up to 2000 images in one chunk, which enabled checking the quality and consistency of the images, as well as whether they needed to be recaptured. This, in fact, represents a critical element due to limited time and, budget available for fieldwork.

Over the past decade, a number of software packages using Computer Vision Photogrammetry (also known as multi-image photogrammetry, or close-range photogrammetry) became available to archaeologists (Skarlatos and Rova, 2010; Doneus et al., 2011; Drap, 2012; Henderson, Pizarro, Johnson-Roberson, & Mahon, 2013; Zhukvsky, Kuznetsov, & Olkhovsky, 2013; McCarthy and Benjamin, 2014). The one under commercial title AGISoft metashape, has been utilized for this task, is described as “a stand-alone software product that performs photogrammetric processing of digital images, in addition to the camera auto-calibration function, which was utilized during the whole campaign, then generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales”(Agisoft LLC, 2021). This software is recommended by many experts, due to simplicity, more reliability, more over all workflow, from camera calibration to textured mesh production, are neatly combined in a single software package (Van Damme, 2015). Moreover, the software sets forth a full control over each processing step that means producing 3D models can be adapted to optimal quality, and resolution to be archived for digital documentation processes, which meets the project’s objectives.

3.3 Geo-referencing

Tying 3D models created for each site with a local coordinate system requires having correct scaling, positioning, orientation, and inclination, in accordance to the real site plan. This was done by using pre-set frame of two 1mx1m metal scale bars placed perpendicular to each other using a metal base to install the scale bars perfectly on it, positioned at the edges of the site. The edges of the 2 fixed scale bars represent 3 control points with X, Y, and Z axis. They were held down to the seabed using lead weights, supported by a spirit level to adjust the inclination. Moreover, depths were recorded by diving computer for each corner representing the Z axis, and by a compass to set directions. Moreover, when capturing photos, that setup was recorded as a visible feature to appear as a genuine part in the final 3D model of each recorded area. Accordingly, for the purpose of geo-referencing, a number of three markers were created to act as local control points (CPs) that placed over each corner of the scale bars edges. Afterwards, the fixed distances added orderly for two points to represent the X for one, and the Y for another, while the two values were kept at 0 and 0 for the third point. Then, the depth records were added to Z axes in the photogrammetric model. Finally, the software recalculated correct distortion and updated the whole model to be located and georeferenced to these control points. Accordingly, any distance or points over the geometrical shape of the model could be easily measured and located (fig.5). The rationale behind this method is that it gives a simple and straightforward procedure that does not necessitate a lot of prior knowledge or special skills in applying mathematics or making measurements underwater. Furthermore, this setup is simple to source and prepare. In addition to the low cost, it resulted in a small error margin not exceeding 0.20 cm, which is acceptable in many cases when compared to the same results obtained using other methods, particularly in the case of the relatively difficult application underwater. In case that it was necessary to export and display globally georeferenced orthophotos or Digital Elevation Model (DEM) of some specific areas to GIS Database or other mapping software, a number of at least three or four iron rods were fixed onto the seabed, distributed across site, then the global coordinates of each point were separately reordered. After processing this information, georeferenced images were ready for export, and DEM, when opened in any mapping platform, they appear in the right place and at the appropriate real scale (fig.6).

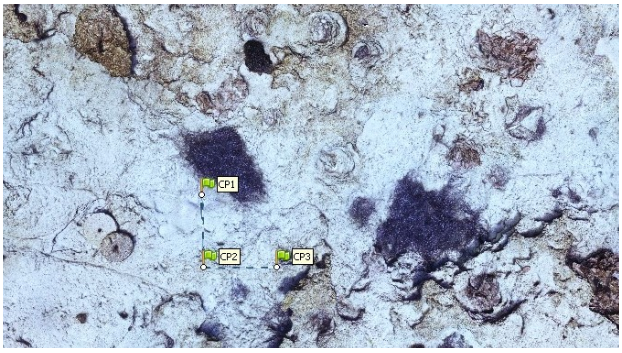

Figure 5. Local Coordinates Points of 3D model (M. Salama)

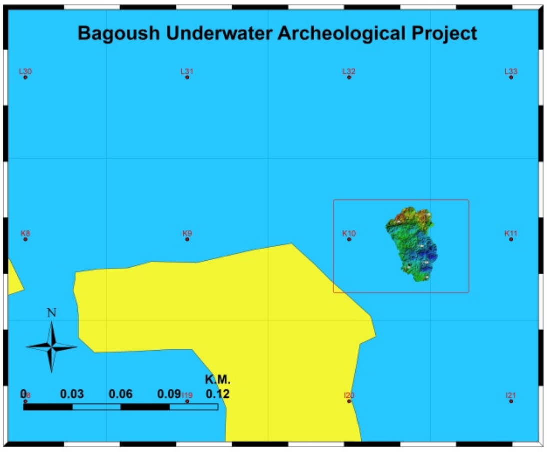

Figure 6. DEM is displayed on the base map (M. Salama)

3.4 Results of Photogrammetric Recording

During six seasons of fieldwork extending for almost ten weeks, about 20000 images were captured, to generate 3D models for seven areas containing archaeological materials with average dimensions 15mx10m each. 7 individual batches measuring more than 1,500 m^2. More than fifty 3D models of ancient anchors or amphorae were developed (fig.7). That required converting images into textured 3D models in four steps of processing 1) Align photos, 2) Build dense cloud, 3) Build mesh, 4) Build texture. The software allows generating geo-referenced ortho-images, DEM. Moreover, it provides 2D sketching and drawing tools for section and plans extraction, generating basic animation. In addition of its ability to generate PDF file of decimated 3D models which facilitate data sharing and extracting measurements and dimensions. Thus, all maps and materials that are produced allow further archaeological research to be carried out following fieldwork. This particularly useful due to limited official permissions for field seasons (Henderson, et al., 2013).

Figure 7. 3D models of ancient anchors (M. Salama)

4. DATA ACQUISITION OF GIS RECORDINGS

Following several discussions on available and suitable techniques that can be utilized to build a GIS for the site, the team decided to utilized the ArcGIS program produced by ESRI. The first step was to obtain high resolution satellite imagery of the target area, to be able to define the features and characteristics of the site at the present time. The georeferenced images were added into ArcGIS and used to create a basic map for the site. A virtual gird of 100mx100m squares was created to cover the entire site that will be surveyed. The grid is the reference based on which all future work will be conducted (fig.8). Consequently, the work plan included having diving teams visually survey each square underwater after determining its location and limits through a GPS device. The survey was conducted using a 50m rope baseline survey which was held by 4 – 5 divers with overlapping visibility, to make sure that each square was covered thoroughly. Each team was equipped with DSLR camera, measuring tapes, tags, scale bars, SMBs, in addition to a GPS device attached to a buoy floating on surface, and attached to rope held by one of the divers. At the beginning of each dive live tracking function was activated with an interval log every 30 seconds throughout the dive: hence the GPS records the track of the dive. When, archaeological material was located, the team stops the survey, and move towards the object to start tagging, measuring, and photographing it. This process takes at least 3-5 minutes, during which GPS device takes several records for the same point. Once this is done, the survey is resumed again. Utilizing such method in surveying and recording archaeological materials proved to be the most effective in that case. The method mentioned needs no personnel or vessels on the surface to assist in surveying and recording the underwater site. It is worth mentioning, however, that the GPS device used is the Garmin Marine handheld unit, inReach edition SE+, which has an error margin of approximately 1m. This is a relatively acceptable accuracy level for determining the locations of archaeological material, in light of the unavailability of more advanced GPS measuring devices, for both economic and administrative reasons.

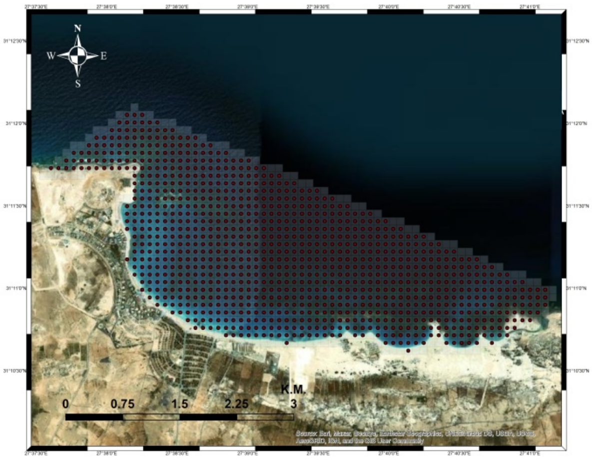

Figure 8. A gird of 100mx100m squares, ArcGIS (M. Salama)

When photogrammetry was required for a specific area, to be used for exporting DEM and georeferenced orthoimages, in this case, while preparing the area for photo shooting, at least 3 datum points of iron rods were fixed into the seabed, to tie the model to the global coordinate system. After the 3D model was created, the control points were identified on it and their global coordinates were entered. Then the DEM and orthoimages were created. These orthoimages are ready to be exported to ArcGIS mapping and spatial analysis software. Once there, the orthoimages are displayed automatically in the correct positions and with the correct scale. The purpose of this procedure is to indicate the position of those areas and their distribution on the base map, to help understanding the archaeological context of the site (fig.6).

4.1 GIS data processing

After the completion of the data acquisition process, data is directly archived and categorized before the data entry in the GIS database. For example, the GPS live tracking data had to be transferred directly after each dive to another software, where the path is converted, to a set of coordinate points that take the same pattern as the dive. Hence, it could be seen that a certain number of GPS records were concentrated in certain points, which are locations of the artifacts that were recorded. The same process was repeated until all coordinate points for each artifact were identified, then renamed and converted to be displayed on the base map typically in accordance to the global coordinate system (WGS84). Afterwards, different layers were crated for different types of artifacts, i.e. amphorae, lead-stock anchors, iron anchors, etc. (fig.9). Moreover, an attribute table was generated for each layer to record the acquired information about each point. That included dimensions, date, type, material, depth and date of discovery, in addition to linking the points to the object's photos. This would facilitate the process of searching, analyzing, comparing and extracting conclusions from the database as part of the scientific research of the site.

5. DISCUSSION AND FUTURE WORK

The methodology described here includes the use of modern technological tools, which became available and quite common to adopt in different fields.

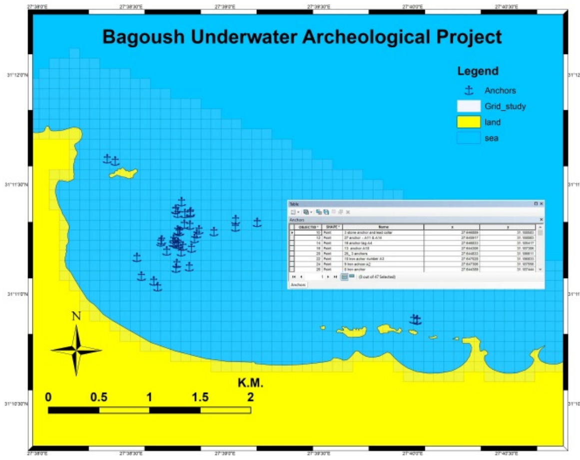

Figure 9. A Layer of Anchors with an attribute table (M. Salama)

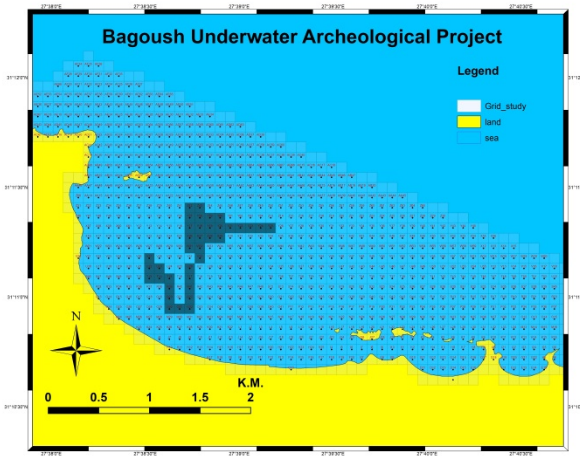

Figure 10. Surveyed Squares covering 3,600 m^2 (M. Salama)

For example, photogrammetry, which has developed significantly during the past decade, is no longer used exclusively by engineers and geometers. Currently, this technology contributes effectively, and became essential, to the field of digital documentation of cultural heritage and archaeology. It considerably saves time and effort during fieldwork due to its various forms of data analysis and presentation of 3D models, sketching, and information extract, for the purpose of archaeological documentation, especially for underwater sites. Moreover, education, research, as well as presentation to the public, in different ways to increase awareness of the value and significance of underwater cultural heritage and archaeological sites.

On the other hand, GIS databases greatly help in organizing and linking information, presenting it in distinctive ways, and developing an informed interpretation of the topographic and archaeological characteristics of sites. It also contributes to effective organization and management of survey and excavation date, and to help determine the potential areas for surveying according to the available information. As mentioned previously, after applying the virtual grid, the surveying team of ten divers was able to cover more than 3,600 m^2 in ten days (fig.10). In the following field season, the team hopes to obtain underwater geophysical surveying equipment to produce comprehensive topographical maps of the entire site. It will also help in obtaining more accurate locations for the archaeological material and providing a better interpretation for the site formation process over time.

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