Maximizing E-Data Collection

A Novel Approach for Data Collection and Transmission Using Tablet Technology

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New technologies with archaeological potential are introduced seemingly on a daily basis, and tablet technologies, in particular, are taking the archaeological world by storm. Archaeologists all over the world are exploring ways to apply these new tools to projects and use them in various applications in their own work. But does this technology really represent an improvement over the pen-and-paper standard, or are these tools just shiny new toys for archaeologists to play with? This question has emerged in relation to the rapidly expanding use of iPads and similar devices in archaeological fieldwork. This article introduces a novel approach for using tablet technology for data collection in the laboratory setting and for integrating the data for analysis within a geographic information system (GIS). During a recent laboratory session, we developed a protocol that uses tablets to facilitate collection and transmission of data in a manner that

ABSTRACT

While tablet devices are becoming commonplace in archaeological research, the transfer of data for analysis is a matter of critical concern. As geographic information systems (GIS) are increasingly incorporated into our archaeological research, there is a need not only to streamline data acquisition, but also to collect data that can be used in conjunction with high-level spatial analytical tools, such as those available in ESRI's ArcGIS. During a short lab season, various methods of paper-free data collection and cross-platform transfer using these user-friendly devices were tested. It was found that both iPad and Android-based systems present great advantages in terms of portability and electronic data acquisition. However, file compatibility and transfer of data across multiple platforms present a number of important drawbacks. The present case study focuses on the development of a data collection protocol implemented by the Proyecto de Investigación Arqueológica Zaña Valley (PIAZ), Peru, that moves beyond these limitations. The ultimate incorporation of data collected using tablet devices demonstrates the potential for this tool in archaeological research, along with the pitfalls for projects that rely heavily on GIS. Significant findings regarding the advantages, as well as the limitations, of e-data collection, transfer, and storage are discussed.

Aunque las tabletas digitales se están volviendo más comunes en la investigación arqueológica, la transferencia de datos para su análisis es un asunto crítico. Mientras que la incorporación de los sistemas de información geográfica (SIG) a la investigación arqueológica ha ido en aumento, no sólo existe la necesidad de simplificar la adquisición de los datos, sino también de recopilar datos que puedan utilizarse junto con herramientas analíticas espaciales de alto nivel, como lo son aquellas disponibles en ESRI o ArcGIS. Durante una corta temporada de laboratorio, se pusieron a prueba distintos métodos libres de uso de papel para la recolección de datos y para su transferencia a través de distintas plataformas utilizando estos dispositivos fácilmente de usarse. Con base en esto, se encontró que los sistemas para iPad y Android presentan grandes ventajas en términos de portabilidad y de la adquisición de datos electrónicos. Sin embargo, la compatibilidad de archivos y de la transferencia de datos a través de plataformas múltiples presenta un número considerable de inconvenientes. El siguiente estudio de caso se enfoca en el desarrollo de un protocolo para la recoloección de datos, implementado por el Proyecto de Investigación Arqueológica Valle de Zaña, Perú (PIAZ), que trasciende estas limitaciones. La más reciente incorporación de datos recopilados, utilizando tabletas, demuestra el potencial de esta herramienta a la investigación arqueológica y las dificultadas a las que se enfrentan los proyectos que dependen fuertemente de SIG. Los hallazgos significativos, en relación a las ventajas, así como a las limitaciones de la recolección, transferencia y almacenamiento de datos electrónicos (e-datos) son analizados aquí.

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easily integrates tablet technology with digital photographs and a spatial database and that permits immediate visual access to artifacts of interest. Although far from resolving critical technological issues, such as seamless data transfer across multiple platforms, this article contributes to the timely discussion of the use of tablets for data collection, particularly their use in the laboratory.

We address problems commonly encountered by archaeologists working outside their home regions and countries, namely issues of distance from and limited contact with artifact collections. Combined with the reality of small budgets and short field and laboratory seasons, the inability of archaeologists to export artifacts from remote locations to home institutions for analysis presents many challenges. This is particularly true for projects, such as the Proyecto de Investigación Arqueológica Zaña Valley (PIAZ) in Peru, which began as a pilot study in 2010.

During the 2013 lab session, our goals were to conduct preliminary diagnostic evaluation of surface-collected ceramics and establish data collection protocols for future research. The lab session spanned two weeks and took place in the laboratory at the Museo Naciónal Sicán, Ferreñafe, Peru. Within this constrained period, our challenge was to collect mappable data on ceramic artifacts, while documenting the variety of forms and styles across the site. To this end, three digital technologies—tablet computers, a digital camera, and a laptop computer—were used. Even though a number of other projects have successfully used iPads and other tablet devices in archaeological field research, we remained skeptical of this method as applied to specific laboratory needs. We were primarily concerned with the ability to continue analysis beyond the lab session and the transfer of data into our existing spatial database structure. We found that cross-platform data transfer had a major effect on lab work and on the way we collected data.

TABLETS, CROSS-PLATFORM DATA TRANSFER, AND DIGITAL SOLUTIONS

There are many advantages to using tablets in the field: Their portable design, combined with long battery life, Internet connectivity (e.g., WiFi and cellular), integrated global positioning system (GPS), and touch-screen technology, makes them indispensable tools for archaeological research. By moving to digital data collection, researchers worldwide have increased the efficiency and accuracy of in-field data collection and greatly simplified data management and curation procedures (e.g., Austin 2014a; Betts 2012a; Bria 2013; Ellis and Wallrodt 2011; Fee et al. 2013; Vincent et al. 2013). Off-the-shelf and custom applications (hereafter apps), which are usually single function programs, are used to collect a considerable variety of textual and tabular data, record GPS coordinates and locational data, create vector plan maps of excavation units, and capture imagery. However, all of these apps share a key limitation: none is a stand-alone solution for archaeological data collection.

Often, as in the PIAZ case study, transporting artifacts internationally is not only legally restricted, but also time and cost prohibitive and, thus, opportunities to work with collections are limited. Digital technologies clearly have the potential to resolve many issues that arise. While laptop and desktop computers remain the discipline's standards, critical features of tablets, such as touch-screen technology for recording hand-written notes, internal cameras for capturing images, integrated WiFi and cellular connectivity for sharing information, and storage capacity sufficient to store all information on a single unit (see also Dubas et al. 2012), make them an excellent solution. Despite the obvious advantages of using tablet devices, the inability to transfer data seamlessly across different computer platforms remains a constant constraint.

Although iPads and other mobile devices have been successfully used in archaeological field research, the collection, management, and transfer of archaeological data are complicated tasks that require the use of multiple apps and programs. These issues are an artifact of mobile operating systems (OS)[1] in general and the types of data their associated apps can collect and transfer in particular (see Al-Rayes 2012; Griffey 2012). Most tablet operating systems use apps to carry out specific computing tasks while hiding information about file structures from users (Olsen and Malizia 2012), whereas personal computers traditionally store and manage files that are accessible on their more robust operating systems (World Almanac Education Group, Inc. 2009). Though tablets were not originally meant to function as primary computers, their use and technological capabilities are quickly changing (e.g., Broida 2014; Weber and Horn 2012).

In archaeological applications, tablets have produced excellent results as paper-free data collection and image cataloging devices in both the field and the lab. Off-the-shelf and customized mobile apps (see Table 1) have dramatically transformed our ability to collect data during archaeological fieldwork. Ellis and Wallrodt's (2011) pioneering study in Pompeii combined (1) data collection with iPads using FMTouch; (2) the Pages app for note taking; (3) OmniGraffle (Omni Group 2014) to manage excavation matrix data; (4) iDraw (Indeeo, Inc. 2014) for generating Portable Document Format (PDF) maps of units and features; (5) a photo app for storage and management of daily excavation photos; and (6) a total station to efficiently and accurately record complex archaeological data and quickly produce comprehensive site plans. Proyecto de Investigación Arqueológico Regional Ancash (PIARA) followed the Pompeii model (Bria 2013). Using iPads and a similar range of apps in conjunction with a Filemaker database, PIARA effectively streamlined data collection and produced standardized, accessible data for long-term investigation. The E'se'get Archaeology Project (Betts 2012a) has moved beyond the traditional scope of archaeological data collection by applying virtual reality technology to generate 3D models of excavation units from digital photographs (Hrynick 2012) and by using iDraw to generate vector maps of units, features, and profiles, which are then exported to AutoCAD (Betts 2012b). Betts and colleagues have resolved their digital data storage and management issues by using iPads in conjunction with PDF Expert to create fillable forms and export files to special crew member folders in Dropbox[2] (Betts 2012c).

Other projects have developed custom apps to carry out specific tasks and meet particular needs, using both iOS- and

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TABLE 1. Useful Applications (Apps) for Archaeological Data Collection

Application (App)	Data Output Type	Projects
Archaeology Sample Collector (Android OS): Record geographical coordinates, tabular data, and notes, and attach image and media files.	Text files (.txt)	n/a
Collector for ArcGIS (Agnostic): Record geographical data and update pre-existing base maps.	ESRI shape files	n/a
Filemaker Go (iOS): Design fillable forms with text and images; fully compatible with FilemakerPro[a] (replaces FM Touch).	Filemaker pro (.fmp), CSV, PDF	Bria 2012
iDraw (iOS): Render scaled digital maps export them to AutoCAD or Adobe Illustrator.[b]	Editable vector layers to Photoshop PSD[c]	Betts 2012b; Bria 2012; Ellis and Wallrodt 2011
Offline Topo Maps (iOS): Store a library of topographical maps and mark points of interest.[d]	n/a	n/a
OmniGraffle (iOS): Generate excavation matrices; compatible with OmniPresence[e]	Various image files	Bria 2012; Ellis and Wallrodt 2011
OsteoSurvey (Android OS): Collect form-based osteological data	CSV	Austin 2014a, 2014b
PDF Expert 5 (iOS): Design fillable PDF forms for multiple OS. Managed in Adobe Acrobat.	PDF and text support	Betts 2012c, 2012d
PKapp (Agnostic): Create fillable forms using HTML5.	CSV	Fee 2012; Fee et al. 2013; Pettigrew 2012
Theodolite (iOS): Capture and geotag photos (and video) and record points using integrated compass, inclinometer, and range finder).	Email, text, and KML files	n/a
123D Catch (iOS): Create 3D images from photographs. Works with AutoCAD software and images can be 3D printed.[f]	AutoCAD (.dwf and .3ds)	Betts 2012a; Hyrnick 2012

[a]Filemaker Support: www.filemaker.com/support

[b]iDraw for iPad: http://www.indeeo.com/idraw/ipad.html

[c]Photoshop PSD files: http://www.adobe.com/devnet-apps/photoshop/fileformatashtml/#50577409_72092

[d]Offline Topo Maps https://itunes.apple.com/us/app/offline-topo-maps/id376535806?mt=8

[e]OmniGraffle http://www.omnigroup.com/omnigraffle

[f]AutoDesk 123D http://www.123dapp.com/catch

Android-based tablet devices. PKapp for iPad, designed by Dr. Sam Fee, was used for data collection in the Pyla-Koutsopetria Archaeological Project (Pettegrew 2012). The app uses fillable forms to record excavation data (e.g., units, elevations, Harris matrices, and soil descriptions), and then exports the data in comma-separated value (CSV) file format via email.[3] Using PKapp and other apps, project members documented archaeological fieldwork and produced excellent records of excavation units without losing data (Fee et al. 2013). The OsteoSurvey app (Austin 2014b) is an open-source series of eXtensible Markup Language (XML) files for bioarchaeological data collection designed using Open Data Kit (ODK) and exports data in CSV format. OsteoSurvey limits the amount of data entered by using skip logic to assist the user to fill out osteological data forms, thus significantly reducing recording time and errors commonly encountered in the field and in the lab (Austin 2014a). The OpenDig (iOS) platform consists of three applications working together to facilitate comprehensive archaeological data collection, storage, and transfer on both mobile (tablet) and stationary (laptop) devices (Vincent et al. 2013). The Tall al-'Umayri project used the OpenDig platform to meet the challenges of integrating data from multiple sources by uploading the primary database online (http://umayri.opendig.org/).

With the ability to record, store, and retreive data recorded with tablet devices, it would seem that problems of transferring data have been resolved. At present, however, data transfer from tablet devices is often limited to the exportation of CSV or tabular data files, which are limited in the type of data they support (i.e., numeric and text). GPS coordinates easily captured and emailed with apps such as Theodolite (Hunter Research and Technology, LLC. 2013) are transmitted as tab-delimited text files, which must undergo a significant amout of processing before use. Although PDF Expert records live data in fillable forms, each form must be saved as an individual file (i.e., it is not possible to add pages to fillable forms), requiring later assembly and processing. Furthermore, as GIS-based investigations become common, the linking of geospatial data and the need to create more "geographically aware databases" (Vincent et al. 2013:542) have become critical concerns. While Keyhole Markup Language (KML) files effectively bring together different kinds of data from various sources (Google 2013), KML was designed to transport representations of geographical data into geobrowsers such as Google Earth (Open Geospatial Consortium 2014) and not for the recording of data attributes. A critical challenge that remains for tablet users in the lab is the development of an efficient way to collect rich data that is not only standardized across multiple platforms and

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devices, but is also geographically aware and compatible with data recorded in the field.

E-DATA COLLECTION AND TRANSFER PROTOCOLS IN A LABORATORY SETTING

Moving beyond the popularity of tablets for cataloging and archiving, many researchers are beginning to adopt them for flexible, paper-free, standardized data collection in the field. This has raised a number of questions about the most appropriate methods for tablet use in the laboratory, including questions about how tablets can be used to: (1) eliminate the time-consuming tasks of recording data on individual forms; (2) reduce errors when transferring data to laptops or personal computers (PCs) from iPads and Android tablets, while maintaining provenience and data integrity of collected samples; (3) generate high-quality data for manipulation and analysis outside the lab; and (4) generate live data and seamlessly export it to, rather than from, spatial databases.

Below we present the specifics of our approach and introduce techniques we developed for cross-platform data storage and GIS manipulation using tablet devices in the lab. We hope to stimulate a dialogue concerning the analytical boundaries of tablets and the possible solutions to widespread problems of integrating laboratory data with data obtained in the field. We offer a critical assessment of tablet devices, the data collection and recording capacities of which were tested against a digital camera and laptop computer. We hope that our experience will help spur the development of methods best suited to archaeological research in the laboratory as well as in the field.

OVERVIEW OF PREVIOUS WORK

We provide a brief overview of our earlier work that stimulated the development of the novel approach advocated here. During fieldwork carried out in the middle Zaña River valley, department of Lambayeque, Peru, in June-July 2010, the project's geodatabase was developed. Members of the PIAZ project carried out surveys in the Zaña Valley, focusing on the Songoy-Cojal site complex situated on the north bank of the Zaña River. Prospection activities concentrated on mapping residential architecture and collecting diagnostic materials from the modern-day surface. Here, as in other remote areas, high-quality remote-sensing data, such as LiDAR and Landsat, are either not available or not accessible, and many researchers must generate high-quality spatial data using analog maps or from scratch. For this reason, the original map layers were built from GPS[4] data recorded during the pilot study (Guzmán and Sharp 2010; Sharp 2010). The PIAZ crew verified the spatial integrity of the GPS data using Peruvian national maps[5] and Google Earth satellite images of the region. Today, this process can be streamlined using an iPad and Theodolite app to record data in the field and transfer it to Google Earth, although mapping using a precision GPS unit is the preferred alternative.

In addition to GPS data, surficial artifacts were collected during the survey. Ceramic artifacts are abundant on the surface throughout the site, while other materials such as bone, shell, and metal occur less frequently. As a result, two purposive area collection strategies were implemented: (1) the collection of diagnostic artifacts from within architectural boundaries and (2) the collection of diagnostic artifacts from looted areas without standing architecture (i.e., systematic sampling of alternating 10-m units). Site photos were incorporated into the project database along with their associated geographical data (see Figure 1). Materials were inventoried, boxed, and stored in the Museo Naciónal Sicán, and the tasks of cataloging and diagnostic analysis were reserved for a later date.

Among the key contributions of the pilot study was the creation of the flexible PIAZCat geodatabase, which was designed to grow as technology transforms. A geodatabase is a "container" that holds data sets and associated spatial geometries (e.g., points, lines, and polygons), which can be visualized as GIS map layers (or feature classes). As a number of scholars aptly recognize (among them Arroyo 2009; Brouwer Burg 2013; González-Tennant 2009; Tennant 2007), the advantages of structuring archaeological data in a geodatabase are immense. When using ArcGIS, there are three types of geodatabase options: the file geodatabase, which holds various types of GIS data sets independently in a file system folder; the personal geodatabase, which stores and manages data files within the Microsoft Access program (.mdb); and the ArcSDE geodatabase (or multiuser geodatabase), which is a collection of GIS data sets held in a relational database-management system (RDBMS).

The PIAZCat is a personal geodatabase consisting of five layers (see Figure 2): (1) walls and terraces (lines); (2) monumental architecture and *huacas*[6] (polygons); (3) master inventory (points); (4) site sectors (polygons); and (5) damage zones (polygons). Although not recommended for large data sets, creating a personal geodatabase allows researchers to make user-friendly forms for data entry, to manage attributes, to perform table operations and complex queries using structured query language (SQL), to incorporate JPEG images using OLE (Object Linking and Embedding), to export data in a variety of formats (e.g., Excel spreadsheets, PDF, text files, or generic database files), and to handle text when working with attribute values. The critical limitations of the personal geodatabase format are its size restrictions (2 GB) and ties to the Microsoft OS platform (see also ESRI 2014). As a fully functional application designed for Windows OS, the Microsoft Access database is incompatible with iOS and Android mobile operating systems, a critical limitation revealed during the 2013 lab session.

DATA COLLECTION WITH TABLETS AND GEODATABASE EXPANSION 2013

In July 2013, lab work to document artifacts collected during the 2010 season presented an ideal opportunity to use tablet devices to expand the variety of information contained in the geodatabase (Figure 3) and to develop a data collection protocol that could be implemented during upcoming fieldwork. We explored a number of alternatives and consequently developed a novel method for data collection, storage, and management

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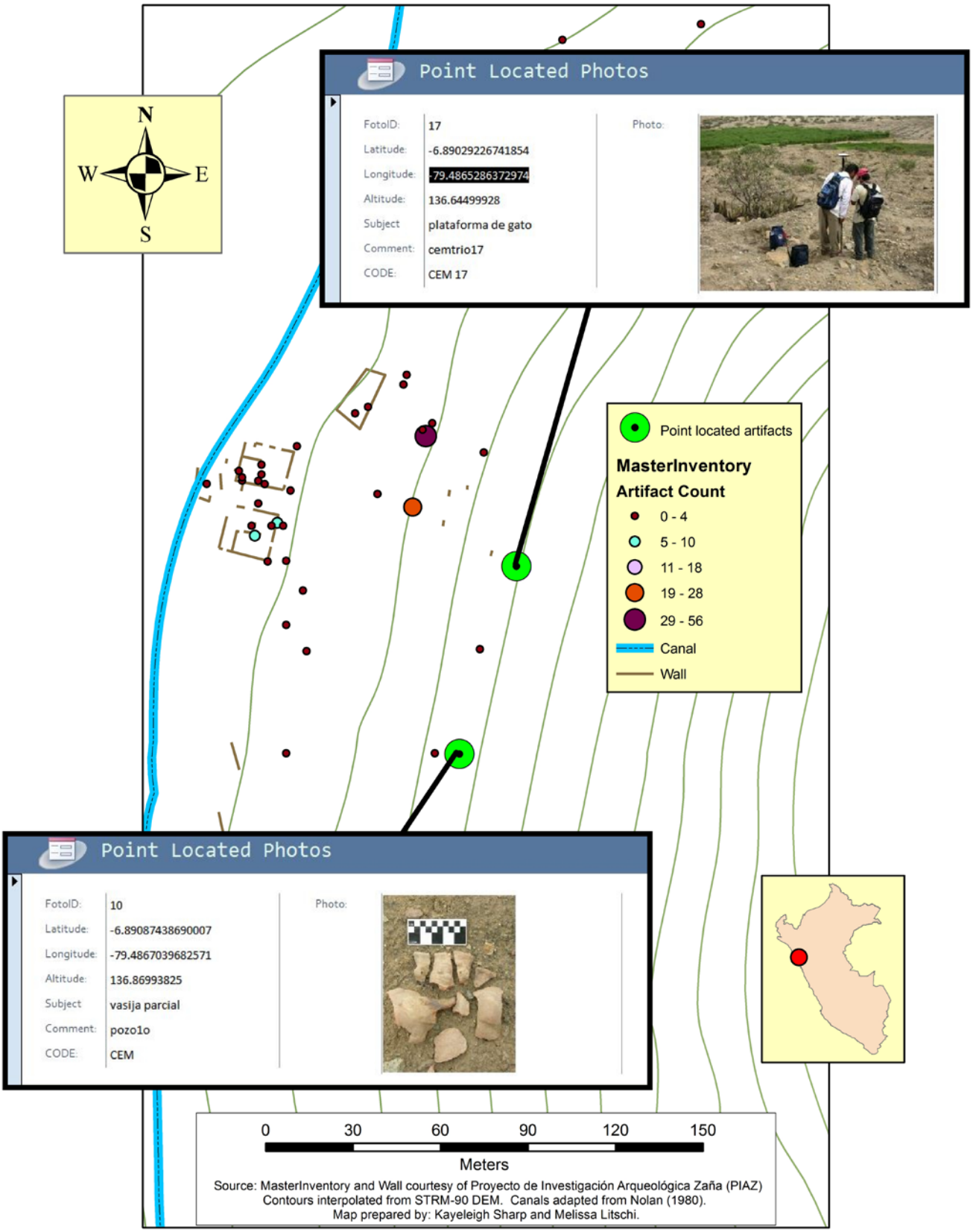


FIGURE 1. Map showing two examples of artifacts and photos located by geographical coordinates on the Songoy-Cojal site basemap. Five-meter contours are based on STRM 90 m DEM and canal systems were adapted from Nolan (1980).

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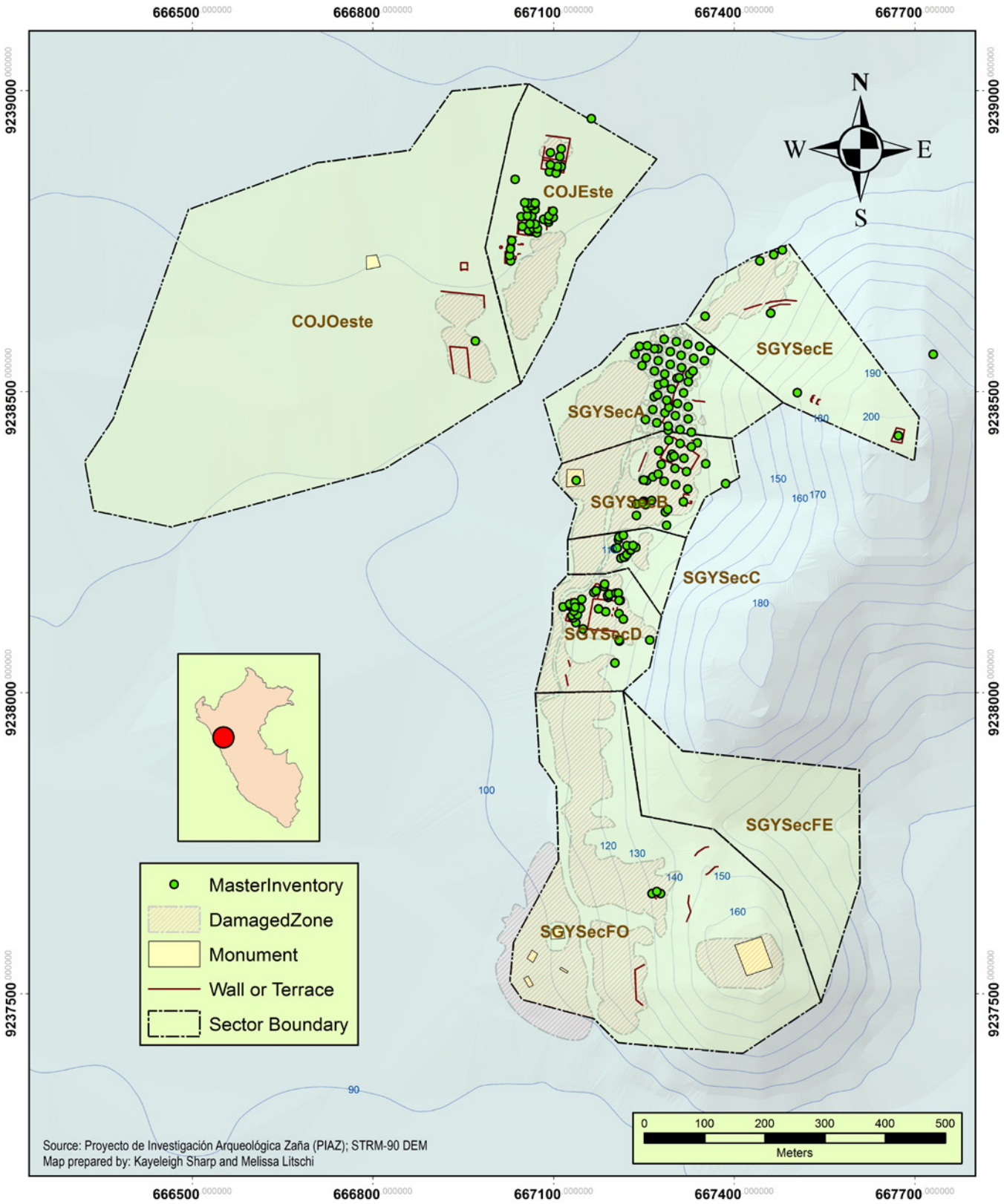


FIGURE 2. Map of Songoy-Cojal site complex, showing the original five map layers generated in 2010. Background TIN and contours are based on interpolation of STRM 90 m DEM.

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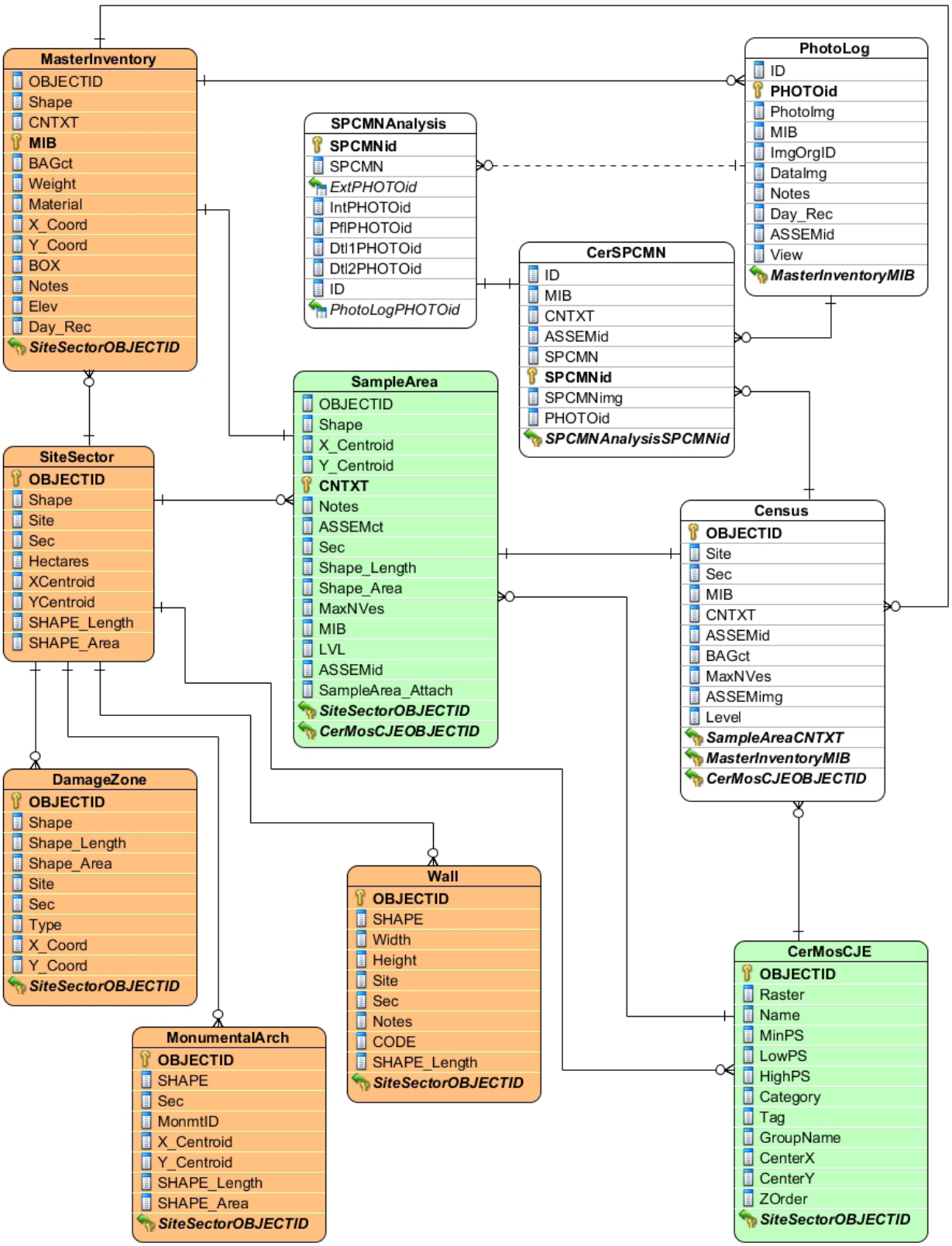


FIGURE 3. Database schema showing relationships among spatial feature classes and non-spatial data tables in the geodatabase. Spatial feature classes include the five original map layers (shown in orange) and two new layers added in 2013 (shown in green). The non-spatial data tables (shown in white) were generated in 2013 using data collected on the tablets.

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that can be used across multiple devices and that permits instant spatial contextualization of newly acquired artifact data.

PIAZCat Geodatabase Expansion

In order to avoid many of the cumbersome data-transfer steps mentioned earlier, we first chose to eliminate use of the tablet during data collection, entering data directly into the geodatabase using a laptop. Data entry on the laptop was not the ideal solution for our data collection needs. The goals of the 2013 lab session were (1) to integrate data on surficial ceramics collected during the pilot study into our geodatabase; (2) to identify criteria useful for exploring technological variation in ceramics at the site; and (3) to determine future excavation loci. The need to identify and add attribute categories (i.e., categories related to artifact production rather than style) during data collection made form-based data on the laptop collection bulky and inconvenient. By capturing images and recording data using the tablets, we would gain the flexibility to identify and expand attribute categories in the geodatabase tables while working outside it. This strategy would also allow us to work with the collection after the conclusion of the laboratory session by maintaining access to visual records of the artifacts of interest.

The time that would have been spent recording data on fillable forms and compiling them at a later date (see Betts 2012c) or labeling artifacts for reference and entering data directly into the database was reallocated to collecting information. After experimenting with data entry using spreadsheets, we quickly discovered that by implementing a simple low-tech graphical work-around (importing images into S-Note or Notability, taking notes, and exporting these as PDFs) many issues were resolved. Our initial procedure, thus, included three basic steps: (1) photographing artifact assemblages (all diagnostic artifacts collected from a specific surface context) and detail images of selected specimens; (2) creating PDFs and collecting data on top of artifact images; and (3) visualizing data for spatial analysis using ESRI's ArcGIS.

Step 1: Digital Artifact Assemblage Photographs and Non-tablet Data Collection

The context-based assemblage constitutes the foundational component of our spatial analysis, which seeks to answer questions concerning the nature of, and relationship among, activities carried out in specific loci at the archaeological site. In the laboratory, photographs of assemblages taken with the default cameras installed in the iPad or the Android tablets produced substandard results for a primary archival image catalog. This necessitated one additional step: we began photographing artifact assemblages using our Nikon Coolpix L810 point-and-shoot digital camera. We selected this camera because of its high macro imaging capability to capture excellent detail, a feature lacking in the integrated tablet cameras but essential to future in-depth analysis of the photos. The Nikon imagery was of sufficiently high quality to meet our visual objectives to identify vessel part, surface quality (e.g., clouding, sooting, or encrustation), and the actual and relative size of fragments in a given context (Figure 4). In some cases, the ability to see shape and sphericity of large-sized temper inclusions and surface texture (e.g., wiping or burnishing) exceeded expectations. With this adjustment, assemblages were photographed during the morning hours (ideal lighting conditions for capturing more accurate color representation and detail), downloaded to the project laptop and added to the database at midday, and transferred to the tablets for later data recording (cf. Betts 2012c).

Artifact assemblages were recorded in exterior, interior, and profile views (see Figure 5). Fragments were systematically photographed side by side to establish a general conceptualization of the ceramic group recovered from each collection area. Experiments revealed that the easiest way to capture provenience data was to photograph tags, listing information recorded at the time of recovery, in each of the three views. In addition, metric graph paper backgrounds were used so that approximate dimensions could be reconstructed from the photos. The assemblage strategy was useful for immediate visualization and identification of the qualitative characteristics, such as relative size of specimen and condition of fragments, as they occur in a single defined collection area, and for understanding how ceramics of different types presented in a particular context.

While the quality of the artifact assemblage photos was more than adequate for basic ceramic characterization, it was not possible to distinguish finer details such as temper size or surface quality (e.g., presence of striations due to wiping or finger-dragging). Detail views of selected ceramic fragments were recorded individually, using the digital camera's macro function (Figure 6). For the surficial samples, we were concerned with the ability to make relative color assessments (e.g., burnt, sooted, or unevenly-fired ceramics) on artifacts contained in the context-based assemblages. Precise color readings on selected specimens were recorded using a Munsell chart, rather than reconstructed from digital images.[7] An important point to consider is that, even with high-quality photographs, a color standard such as an IFRAO scale or a professional Kodak color standard should be photographed along with artifacts in order to make accurate color assessments from photographs (see Kodak 2014), particularly those captured in the field.

Step 2: Data Collection with Tablets

Step 2 involved assembling and transferring images taken with the digital camera to tablet devices and using the images as a PDF form for collecting select metric and color data (Figure 7). The touch-screen functionality of tablets provides a unique advantage over paper or laptop data recording. Using off-the-shelf Notability (iOS) and S-Note (Android) apps, data was recorded directly on or beside images in the PDF report. While this meant sacrificing the ability to query and sort information immediately, which is a key advantage of form-based data entry on tablets and other devices, the ability to take notes and maintain these original records while working with a single image file was a major advantage of this technique.

After creating an image catalog from the digital photographs, images and their associated MasterInventory Bag ID (MIB) were queried to generate reports in the Access database. As size limitations are a primary concern with the personal database structure, Picasa photo manager was used to batch edit original photographs and to generate HTML pages consisting of reduced JPEG images (1024 pixels for assemblages and 320 pixels for the general catalog), which were then pasted into MS Access tables

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FIGURE 4. Assemblage photo (exterior view), showing relative size of ceramics fragments, surface quality, temper, and slip.

for future analysis. The generated reports consist of assemblage photos, MasterInventory BAG ID (MIB), and photo ID (ID) for reference and sorting. PDF reports for each user were uploaded with user IDs (e.g., AssemReport_initials) and synced across multiple devices using the project Dropbox folder. The PDF technique preserved visual integrity and provenience information for each assemblage without taking up excessive space in the personal geodatabase. It also provided centralized access to all visual, qualitative, and metric data (i.e., data were stored in a single PDF created for each user). Once the digital archive was created, data collection focused on specific attributes that could not be reliably reconstructed from the images (i.e., color, rim and neck-height measurements, and percent of vessel present) on relevant specimens.[8] The key advantages of using the PDF forms in conjunction with cloud storage and tablet devices were that our original records remained accessible and that we could terminate the short lab session with confidence, knowing that data on other attributes of interest (e.g., relative size and condition of the ceramic artifacts) could be collected later.

Advantages of the PDF/Tablet Approach in the Lab. One of the many advantages of our MS Access PDF reports is that they function as persistent backdrops for collecting and storing original data in a single file that can be accessed across multiple platforms by multiple users. A similar strategy implemented by the E'se'get Archaeology Project (Betts 2012a) used the PDF Expert app to create fillable forms for data recording, image cataloging, and note taking in the field. Like the PDF drawings

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exported from iDraw by the Pompeii Archaeological Research Project members (Ellis and Wallrodt 2011), the PIAZ reports hold static information. In each case, PDF files can be distributed quickly, but data must be transferred into a database management system later, either by combining individual PDFs and then exporting them or by entering the data manually. We find that a benefit of using the note-taker apps (i.e., S-Note and Notability) to record notes on imported PDF files is the ability to add pages and capture new images within pre-existing files, an option not available when using fillable forms. While both fillable and static PDF techniques produce excellent results when used in conjunction with tablets, there are key differences in data entry and in the number of files created. While the PIAZ reports can be uploaded to Dropbox as a single file, which streamlines workflow and significantly improves file management, fillable forms offer the advantage of standardized information output. The weight of these trade-offs is contingent upon the questions being asked of our data (see also Austin 2014a).

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FIGURE 5. Assemblage photos showing the three views. Exterior and interior views were shot with tags and on grid paper to maintain provenience and allow for approximate size estimates: (opposite page, upper) exterior view; (opposite page, lower) interior view; (above) enhanced profile view of fragments photographed in a sandbox; profiles are highlighted in blue.

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FIGURE 6. Detail images of ceramic fragments: (upper) fragment with unidentified encrustation; (lower left) fragment with fingermarks and striations from wiping; (lower right) fragment with hand modeling, applique, and evidence that the surface was worked when wet.

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FIGURE 7. Sample page from the exported PDF showing original data recorded with ceramic images in background.

After experimenting with direct data recording using the project laptop, it was determined that, although desirable, immediate entry into the database was not necessary in the lab. While many projects, including our own, have adopted tablet technology to improve efficiency and accuracy in the field (or lab) data collection process, researchers run the risk of re-creating traditional unit and feature forms or handwritten notes, without exploring alternatives that might be better suited to their research objectives. While the design of a customized app that would perform all tasks is an intriguing possibility, we were able to enter data directly into the project geodatabase and produce comprehensive reports at the end of each day, which streamlined workflow and data management.

In the PIAZ case, PDFs were preferable to datasheet recording because they contain detailed images of the ceramic artifacts, which reduces the bias and ambiguity that can arise from metric data presented in isolation (see also Austin 2014a; Betts 2012d). The PDF strategy also makes possible the identification of the precise location where samples and measurements are taken. In the laboratory, the ability to pinpoint precise locations where color, metric, or even semi-quantitative readings are obtained is a major asset. When preparing samples for qualitative or semi-quantitative analysis (e.g., when employing devices such as portable X-ray fluorescence or pXRF analyzers), it is advantageous to track readings and to be able to identify the precise location from which readings were taken.

In sum, the decision to adopt the seemingly low-tech PDF solution for data recording presented a number of unexpected advantages. PDFs were an easy way to generate a persistent record of data collection "events" as they happened each day in the laboratory. We found the reduction of paper storage, improved file management, and instant backup to be among the critical advantages of entering data on PDFs using tablet devices in the lab. Data entry, while old-fashioned, was expedient after data was recorded in PDFs. For those who are comfortable recording hand-drawn sketches and handwritten notes, the PDF serves as a powerful interface between traditional analog techniques and spreadsheet-style, form-based data collection.

Step 3: Integration of Tablet Data Collection Protocol with Geodatabase Application

Data collection using tablet devices will move into the field in the upcoming season. As intrasite spatial variation of ceramic artifact styles and production methods are of central concern to our broader research, we opted to explore how best to visualize the spatial distribution of both the surficial ceramics and the

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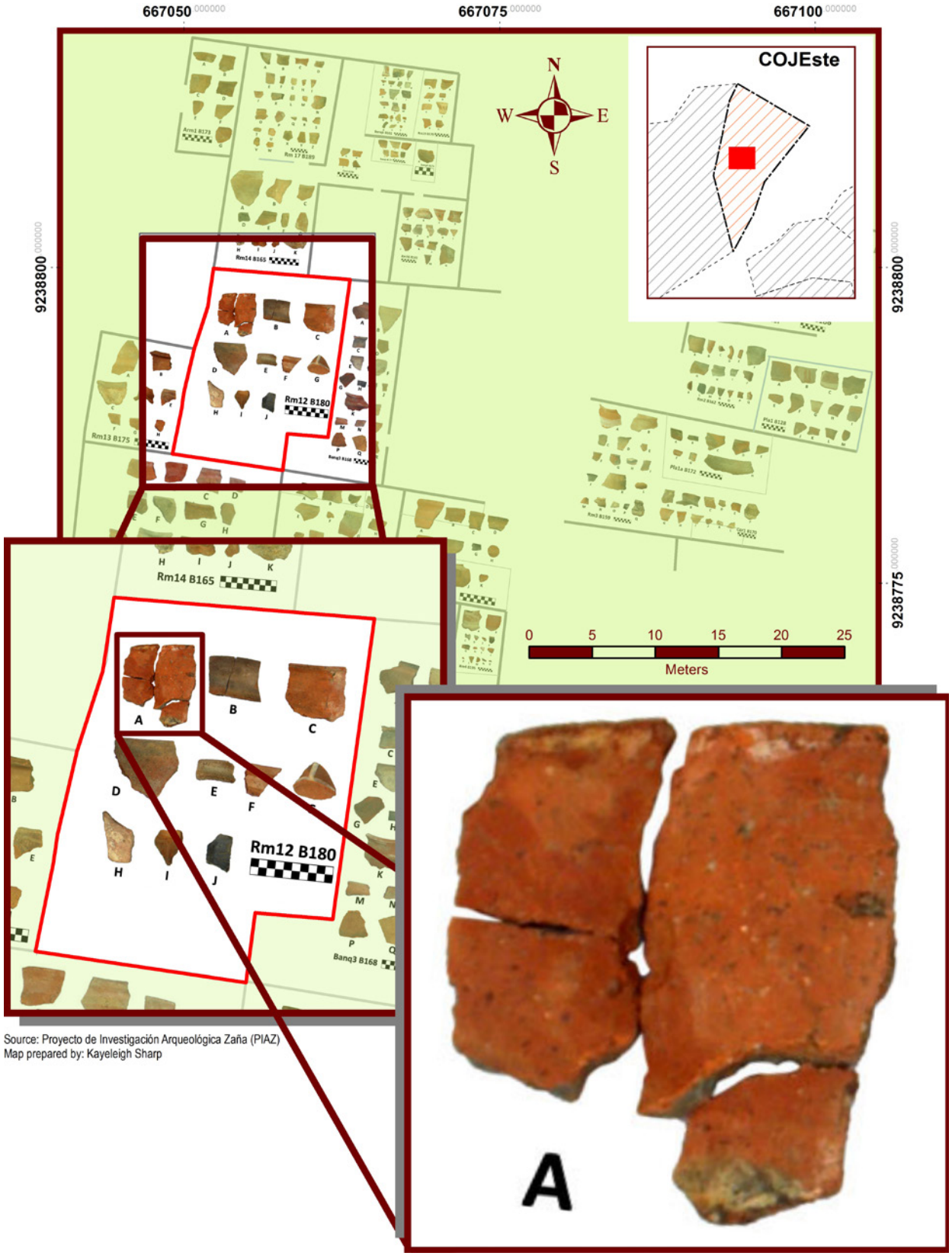


FIGURE 8. Map of artifact mosaic in ArcMap 10.2.1 with successive zoom to structure and artifact level.

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characteristic combinations that were emerging in this simplified version of reality. To achieve this, we developed an artifact census and a ceramic artifact mosaic, both of which were stored in the personal geodatabase structure. The mosaic facilitated immediate visualization of all collected ceramics within their associated contexts, favoring distributions of artifact assemblages rather than distributions of individual artifacts represented by graduated symbols or dot distributions. The census provided the quantifiable data with which higher-level spatial statistical analysis will be carried out via SQL queries and ArcGIS. These queries and tools will help us to explore and visualize meaningful relationships between artifacts and collection areas to determine future excavation loci.

The Artifact Mosaic. We took an inventive approach to the mosaicking technique typically reserved for the analysis of regional data. The traditional method utilizes subsurface magnetic or ground-penetrating radar (GPR) data, as well as aerial photographs, LandSat, or LiDAR images, to produce composite pictures of large regions that can then be visualized at a glance (e.g., Craig 2012; Goodman and Piro 2013; Johnson et al. 2006; Wernke 2012). Our approach focused on generating a mosaic that emphasized detail within architectural units. Each area-based assemblage photo was georeferenced within its associated collection area, which created the mosaic layer in the geodatabase (Figure 8). Because the geodatabase's base layers were already in place, it was easy to associate artifact assemblages with their geographical points of origin. Our novel approach for generating artifact mosaics from ground-level data makes visualization an immediate possibility.

Constructing a Statistically Analyzable Artifact Census. By implementing the PDF approach using tablet devices, we had a flexible data management system for individual artifacts, as well as for those grouped by spatial context. Traditional data tables store information summarized in attribute fields in one line of data. Our research design prioritizes artifact assemblages (in this case, ceramics) over individual artifacts in order to gain a more holistic view of activities carried out in a specific context. The artifact census is organized much like a population census, wherein sample areas are the focal points of investigation and data on individuals is incorporated and preserved within each spatially delimited sample area. The artifact census allows us to query and isolate meaningful combinations of attributes for mapping.

By creating the mosaic layer used in conjunction with the census, we were able to reconstruct the distribution of area-collected artifacts to gain instantaneous visual access to assemblages and their spatial relationships (Figure 9). Because the mosaic is a layer in the geodatabase, it functions as an active, rather than static, visualization alongside empirical data and can be analyzed spatially and statistically. Operating with the underlying assumption that surficial remains are in some way indicative of subsurface content, we used the mosaic, in combination with other map layers, as a tool for data mining and representation. When used in combination with tablet devices, the artifact mosaic visualization and artifact census are valuable field resources, functioning as top-layer references by which informed comparisons between loci can be made as excavation proceeds.

Practical Laboratory and Field Considerations and Recommendations

In addition to the technical and data transfer considerations mentioned above, there are a number of practical issues to consider when using tablets in the lab. We tested the capacity of both Android- and Apple-based systems as data collecting tools, evaluating their user-friendliness and testing their applicability for meeting the needs and demands of our archaeological research. We found that the Apple-based system was not as user-friendly for taking handwritten notes. The Android system, like Windows-based systems, uses a precision stylus and has superior text-recognition capabilities. Importantly, neither system used in 2013 lab work interfaced directly with spatial databases or with the Microsoft Access program. In this regard, and for applications incorporating GIS, we recommend using a tablet or hybrid with the Windows OS, which is more powerful and can be used directly with Windows-based programs, such as ArcGIS.

Using tablet devices was extremely convenient: one team member recorded measurements and their location in a PDF, while another collected measurements from actual specimens. This strategy also helped keep the tablets clean—a concern in both field and laboratory settings—because the team member working with artifacts did not subject the units to ever-present dust particles, which tend to filter into highly sensitive components despite the use of protective cases.

Another concern when using portable tablet devices in conjunction with cloud storage is Internet connectivity. While we were able to use the museum's wireless network to transfer data between the tablets and the project's laptop, other solutions are necessary when Internet resources are not available (e.g., the PIAZ field site). Data can be loaded off-line onto both the Apple and the Android tablets through the USB charging cable, provided that the appropriate data management software is installed on the laptop. The Android tablet offers the additional option of using an SD card, while new Windows-based tablets include a USB port. These options allow expedient data transfer between digital devices, but are not as convenient as online solutions, which are ideally suited to tablet devices.

DISCUSSION AND CONCLUSION

To return to the question posed at the beginning of our paper, does tablet technology really represent an improvement over the pen-and-paper standard, or is it just a shiny new toy? While digital technologies have the potential to offer solutions to a wide range of problems in archaeology, we were skeptical of the utility of tablet-based solutions. In addition to the limitations of cross-platform data transfer, there is at present a need to develop a full-service app that meets the empirical needs of researchers while making use of existing advantageous features. The tablet's ability to capture images (or to import them from files) and the ability of users to zoom in on particular aspects of interest while taking notes are perhaps the most remarkable improvements over the pen-and-paper standard. The inability to transfer live data directly into data tables associated with the PIAZCat geodatabase proved to be its greatest deficit. Although we set out to record ceramic artifacts, carry out preliminary anal-

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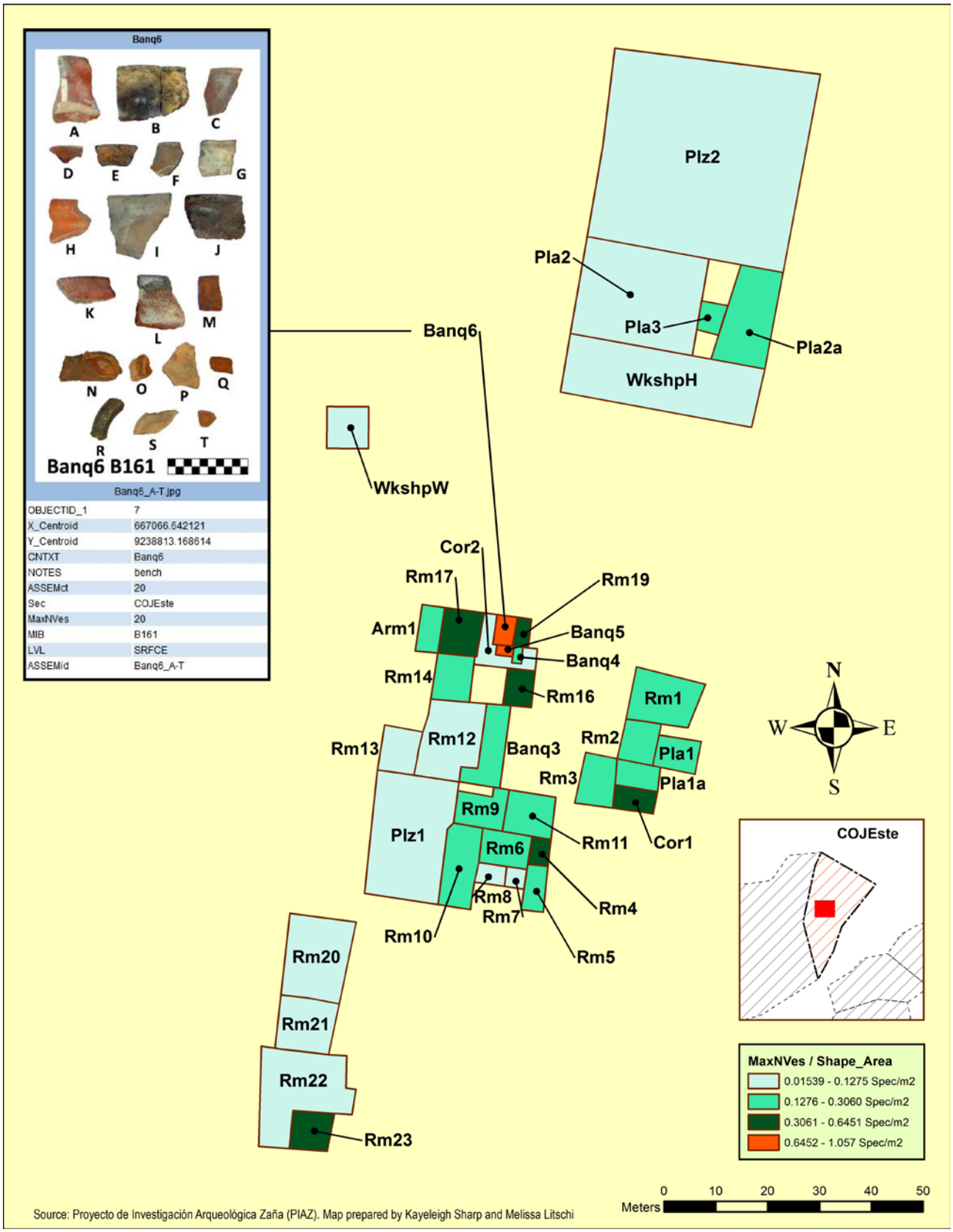


FIGURE 9. Graphical representation of the artifact census as it is mapped. Census data is displayed in pop-up windows linked to each sample area.

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ysis, and establish data collection protocols for future field and laboratory seasons, using tablet devices to accomplish these goals was not the one-stop solution we had hoped it would be. While we were successful in some areas, we discovered that there is room for major improvement in others.

Important archaeological projects have successfully used both iPads and Android-based tablets in the field. We tested the functionality of both types of data collection devices in the lab and found, not surprisingly, that not all tablets are created equal. One of the greatest advantages of Apple tablets is app availability; many of the apps designed for and tested by archaeological projects are iOS-based apps with no comparable Android counterpart. However, despite many assumptions of Apple convenience, the Android tablet generally outperformed the iPad in terms of user-friendliness and ease with which data was recorded—important points to consider before fieldwork is conducted. For both systems, there are various apps that offer textbox and handwriting-to-text features to ensure that handwriting legibility does not become an issue. In these cases, it is essential to double-check that the app correctly records numeric data, and, in this regard, the Android's performance was superior.

Both Apple and Android tablets had battery lives that sustained full days of image viewing and note taking, which is an important advantage in the field and in the lab. While we agree that tablets are remarkably successful as paper-free data collection and cataloging devices, there remains a significant need to explore and refine customized programming alternatives; the developers of OsteoSurvey, OpenDig, and PKapp are leading the way. We must also push the boundaries of these extremely portable devices while making use of their built-in assets.

In circumstances such as ours, under which artifacts must remain in the laboratory and in the host country, the tablet and the PDFs were indispensable tools for precision data recording and long-distance transport. While the PDF method departs from popular form-based applications, when used in conjunction with other specialized apps, it is a relatively direct solution to a complex problem. It is insufficient to simply collect data in more efficient ways, particularly when faced with the challenge of visualizing and analyzing it long after the artifacts have been returned to storage. By replacing traditional spreadsheet-style recording forms with digital images of artifacts, a technique that has been occasionally implemented in other field-related contexts (see Betts 2012a; Bria 2013), we resolved issues of time-consuming data recording on multiple forms (or in multiple apps) and of transferring it intact for later elaboration.

Of course, the strategy outlined herein is not without some critical limitations. The PDF method alone is not conducive to live data entry in standardized fields for use in higher-level analytical programs. The utility lies in the ability of PDFs to store records persistently in their original form. Unfortunately, the translation of data from a tablet to an external database (or a spatial database) remains a multistage process. An immediate solution would be the use of a Windows-based tablet to collect data using a standard suite of software, including higher-level analytical programs such as ArcGIS. An ideal long-term solution to data collection needs in the lab would be the development of a platform-agnostic app that incorporates form-field data collection with the ability to capture photos, annotate them, and transfer all data simultaneously.

While we await such a solution, it is imperative to consider how data will be utilized so that appropriate app and data transfer selections can be made before embarking on field or lab research. The method outlined above proved a useful solution to the complex problem of incorporating data from the lab. As the PIAZ project proceeds and technologies continue to transform our archaeological research, we will undoubtedly face new challenges and the need to adapt to them and refine our methodologies. Meanwhile, tablet technologies appear to present the best option for paper-free data collection both in the field and in the lab.

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Data Availability Statement

The ceramic fragments from the Proyecto de Investigación Arqueológica Zaña Valley are curated at the Museo Naciónal Sicán, Ferreñafe, Peru (phone: +51 74 286469; email: museosican@hotmail.com / museosican@speedy.com.pe; website: http://sican.perucultural.org.pe). Requests for access should be addressed to the museum director and sent via email. Artifacts are stored in boxes with corresponding bag numbers (1–223). PIAZ map layers are available online at: http://geocommons.com/users/PIAZ/overlays.

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Notes

1. Apple iOS is the lightweight operating system designed for Apple mobile technologies such as iPads and iPhones. Android and Windows mobile operating systems work with Windows OS (TechTarget 2014).
2. Dropbox is an online file hosting service that offers cloud storage and file synchronization capabilities.
3. In version 2.0, PKapp will include photo capture so images can be attached to forms and a dictation recording feature, which will reduce data-entry recording time in the field.
4. Thales ProMark3 handheld GPS (see Magellan 2005) loaned to us by the Department of Geography and Environmental Sciences, Southern Illinois University, Carbondale.
5. IGN (2010)
6. *Huacas* is a Quechua term referring to a sacred location, commonly used to refer to major artificial mounds at archaeological sites.
7. All photo manipulation was done in Photoshop CS4 and Picasa.
8. Relevant specimens include n = 139 specimens with rims and n = 85 specimens with intact rims. Color was recorded for n = 103 selected specimens.

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