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A Multi-User Mobile GIS Solution for Documenting Large Surface Scatters: An Example from the Doring River, South Africa

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This article discusses the development and implementation of a mobile GIS catch-and-release system for documenting large surface artifact scatters along the Doring River in South Africa. An integrated, cloud-based mobile GIS solution was built using a suite of ESRI ArcGIS applications with an aim to maximize the speed and breadth of techno-typological data capture, while minimizing data collection errors and post-processing requirements. The system was successfully implemented during the 2019 field season of the Doring River Archaeological Project. With the ability for project-specific customization and interchangeable hardware components, the system transcends geographic region and temporal focus. Moreover, the system accommodates connectivity limitations commonly faced by archaeologists seeking distributed database solutions. Other challenges embraced in the design include rotating personnel throughout a field season, scalability without large financial investment, and the ability to accommodate data collection needs of other components of the larger multi-disciplinary research project.

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Development and implementation of a multi-user mobile GIS solution for documenting large surface scatters: an example from the Doring River, South Africa

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Abstract

This article discusses the development and implementation of a mobile GIS solution for documenting large surface artifact scatters along the Doring River in South Africa. A mobile GIS "catch-and-release" system was developed with an aim to maximize the speed and breadth of techno-typological data capture, while minimizing data collection errors and post-processing requirements. The system is an integrated cloud-based solution built using a suite of ESRI ArcGIS applications, and was successfully implemented during the 2019 field season of the Doring River Archaeological Project. With the ability for project-specific customization and interchangeable hardware components, the system transcends geographic region and temporal focus. Moreover, the system accommodates connectivity limitations commonly faced by archaeologists seeking distributed database solutions. Other challenges embraced in the design include rotating personnel throughout a field season, scalability without large financial investment, and the ability to accommodate data collection needs of other components of the larger multi-disciplinary research project.

Keywords

Open air archaeology, GIS, GPS/GNSS, mobile computing, South Africa, stone tools, landscape archaeology

Introduction

The Western Cape of South Africa is a rich Stone Age archaeological region. Multiple excavated rock shelters indicate repeated occupation throughout the Late Pleistocene with evidence from some localities extending back into the Middle Pleistocene (Mackay, Jacobs, and Steele 2015; Jacobs et al. 2013; Mackay et al. Accepted; Marean et al. 2010; Porraz et al. 2016) (Figure 1). Changes in stone tool manufacturing across this Middle and Later Stone Age period imply recurrent technological reorganization, suggestive of broad-scale changes in resource acquisition (i.e., tool stone and subsistence products) and by extension socio-economic networks (Mackay, Stewart, and Chase 2014; Bousman and Brink 2018). Elucidating the nature of and reasons for such changes is important to understanding human behavioral evolution, particularly with respect to the origins of flexible systems of land use that have allowed our species to populate most environments on earth (Roberts and Stewart 2018).

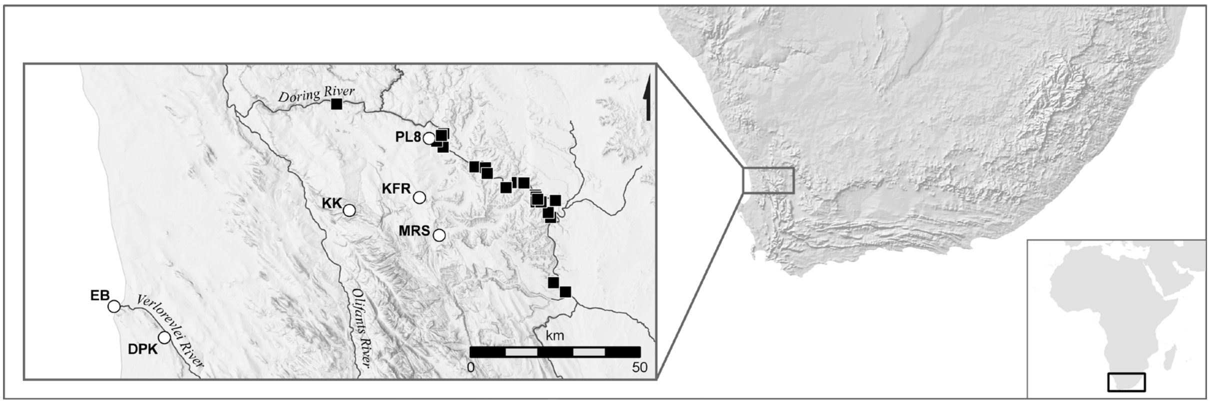


Figure 1. The Doring River Archaeological Project study area with the locations of relevant rock shelters (circles) and the 23 open-air localities (squares) identified by the DRAP thus far (EB = Elands Bay, DPK = Diepkloof, KK = Klein Kliphuis, KFR = Klipfonteinrand, MRS = Mertenhof rock shelter, PL8 = Putslaagte 8). See Figure 3 for the names of open-air localities relevant to this manuscript.

Deeply stratified rock shelter records such as those excavated in the Western Cape are exceptional archives of past human behavior, often preserving otherwise scarce organic remains (Mackay et al. Accepted; Miller, Goldberg, and Berna 2013; Porraz et al. 2013). Not surprisingly—and warranted by many measures—rock shelters draw considerable research attention in South Africa in comparison to open-air archaeological sites. Yet, open-air occupations are perhaps the most globally abundant type of archaeological sites. Focusing research efforts primarily on rock shelters may thus be biasing our reconstruction of past human land use behavior to the types of activities that took place in or around this one particular landscape context (Sharon, Zaidner, and Hovers 2014; Ames et al. 2014). Moreover, such as is documented in the Doring River watershed of the Western Cape, rock shelter and open-air localities often present non-overlapping patterns in their representation of well-defined stone artifact technocomplexes (Shaw et al. 2019). Such incongruity suggests that not only is there a potential activity bias between rock shelters and open-air sites, but that there may also be long-term changes in the use/importance of rock shelters throughout the Pleistocene, creating an additional chronological bias in our reconstructions. Understanding past lifeways and broader trends of Pleistocene human-environment dynamics therefore requires expanding the scope of investigation so that rock shelter and open-air records can be integrated, and thus regional patterns of land use evaluated.

At present, the Doring River Archaeological Project (DRAP) is focused on the analysis of a suite of open-air archaeological localities along the Doring River and evaluating them relative to the many excavated shelter sequences within the watershed (Figure 1). Dense, open-air artifact accumulations occur along the banks of the Doring River, often containing tens of thousands of artifacts, primarily stone tools, distributed across recently eroding sedimentary bodies (Low and Mackay 2016; Low, Mackay, and Phillips 2017; Lin, Douglass, and Mackay 2016; Will, Mackay, and Phillips 2015; Mackay et al. 2014). These sediment bodies typically occur as isolated stacks up to 10 meters high and covering 3000-100,000 m^2 (Shaw et al. 2019).

Preliminary evaluation of the artifacts resting on these sediment stacks suggests these open-air occupations span parts of the past 200,000 years (hereafter ka), with some localities preserving archaeological material that is likely 250 ka or older (Shaw et al. 2019). Artifacts from all major archaeological epochs are well-represented, including the Earlier Stone Age (~2000–250 ka), Middle Stone Age (~250–40 ka), Later Stone Age (~40–2 ka), and local Neolithic (<2 ka). Targeted analysis at some of these localities from 2014–2016 indicates that artifact distributions across these surfaces are at least partially clustered into time sensitive groupings or technocomplexes (Low, Mackay, and Phillips 2017; Low and Mackay 2016; Shaw et al. 2019). However, properly testing this hypothesis of chrono-spatial patterning requires systematic documentation of the provenience and characteristics of artifacts across the landforms—that is full-coverage survey at the scale of the individual artifact for the entire surfaces of the eroding sedimentary bodies.

Two further observations complicate this objective. First, total artifact numbers per locality are typically in the tens to hundreds of thousands, and 23 localities have been identified so far (Figure 1). Second, the sediment stacks are actively eroding, with data from historical structures suggesting the loss of more than 400 mm of sediment over the last two centuries. This erosion has and continues to redistribute artifacts and destroy significant quantities of archaeological information at decadal timescales (Phillips et al. 2018). Thus, in order to identify the behaviorally meaningful patterns from a rapidly diminishing resource, the DRAP required a data capture system capable of providing rapid, reliable, precise, and detailed information relating to surface artifact distributions and landscape geomorphology, which can be used to identify key areas of the localities that warrant more comprehensive follow-up analyses.

With clear questions and motivation for fine-grained analysis of the surface record in the Doring watershed, we set out to design a mobile, map-based data collection system that would facilitate relatively rapid yet thorough documentation of artifact point-provenience, as well as techno-typological and physical characteristics. In response to challenges faced during the first round of such systematic survey in 2018, which are discussed below, we sought to develop a new system for the 2019 field season. We needed a system that would be highly flexible, easily deployed across a rotating team of three to five surveyors with the possibly for additional personnel, and that would work offline—much of the Doring River region lacks cellular coverage and internet connectivity is limited and unreliable. Ideally, the system would collect reasonably high-resolution GNSS positions with associated metadata, synchronize into a central database, and integrate with the other data collection streams taking place concurrently as part of the larger project, such as geological, geomorphological, and geochronological survey and sample collection.

This paper describes the conceptualization, design, and implementation of a mobile GIS solution built within the ESRI ArcGIS environment that achieved most of these goals, as well as considering long-term equipment costs. Overall, the data collection system was designed to maximize data collection quality and efficiency, while minimizing inter-observer variation, reducing post-field season data processing, and removing the logistical and financial burden of curation and storage by not collecting the tens of thousands of items we anticipated documenting.

The Doring River Archaeological Project

Project overview

The Doring River Archaeology Project (DRAP) aims to understand the evolution of adaptive landscape use by integrating large volumes of archaeological data from both rock shelter and open-air sites within the Doring River catchment in the Western Cape of South Africa. Building on the excavated rock shelter sequences, the project is currently examining open-air localities within the watershed using a three-phase approach (see Shaw et al. 2019 for detailed explanation of the methodological approach). Phase 1 aims for rapid documentation and characterization of artifact distributions across actively eroding sediment stacks, as well as digital terrain models of each surveyed landscape using unmanned aerial vehicle (UAV) image photogrammetry and 3-d models of a sample of artifacts using structured light scanning (Figure 2). Results from Phase 1 and follow-up spatial analyses inform Phase 2 (Ames et al. Submitted), which includes more detailed analysis of specific surface clusters demonstrated to have preserved significant spatial patterning. Phase 3 draws on the combined results of Phase 1 and 2 to identify promising areas of the sedimentary stacks for sub-surface testing and systematic excavation. Despite the nested design of the phases, all three can take place concurrently at different localities throughout the region. Moreover, alongside the archaeological data collection are streams of geological, geomorphological, and geochronological data collection, which are focused on raw material sourcing, strontium isoscape development, and geomorphic landform mapping and age determination.

The foundation of the overall approach is the rapid, fine-scale documentation of each open-air surface artifact scatter, as all further decision-making is rooted in data generated from Phase 1 archaeological survey. The justification for such detailed documentation is two-fold. First, we seek to identify spatial patterning in techno-typological variation across the sedimentary stacks indicative of temporally constrained clusters. Any such clusters warrant further analysis. Second, we seek to understand the artifact distributions in relation to the surface geomorphology and landscape evolution in order to predict and select promising locations for sub-surface testing and excavation (e.g., Ames et al. Submitted). Ultimately, through a combination of full coverage survey and landscape geoarchaeology, we can integrate the surface archaeological record with the sub-surface record (from both rock shelters and buried open-air sites) to provide a comprehensive understanding of how the Doring River landscape was used throughout the Late Pleistocene and how land use practices changed over time. Here we present the development and implementation of a mobile GIS solution for conducting the rapid appraisal Phase 1 archaeological surveys—a system that emerged from challenges and lessons learned during our first implementation of Phase 1 survey in 2018.

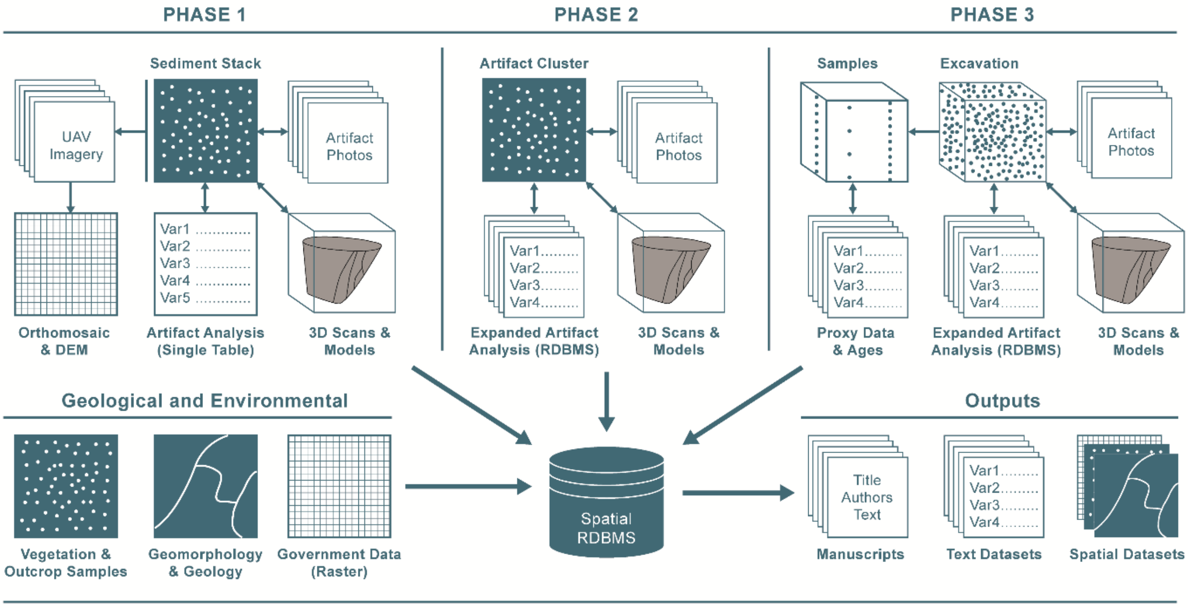


Figure 2. Schematic of the Doring River Archaeological Project data collections phases.

Phase 1 survey during the 2018 field season

In 2018, alongside a number of additional project goals, we initiated the first Phase 1 survey at the Klein Hoek 1 (KH1), Doringbos 8 (DB8) and Uitspankraal 9 (UPK9) localities (Figure 3A). The objective of Phase 1 survey was, and remains, to rapidly record the location, techno-typological attributes, and physical attributes of all cores, retouched pieces, and certain non-flaked artifacts—including ochreous rock fragments >30 mm, as well as ceramic, glass, and metal artifacts—distributed across the surface of identified sediment stacks (Shaw et al. 2019). Due to our goal of complete coverage survey for these types of artefacts, non-overlapping ~2 m wide survey transects were demarcated across an entire locality with black nylon string. Initial field testing identified 2-3 m as the maximum transect width before analysts started missing obvious artifacts within their transects—a width that generally aligns with more formal survey sweep-width experiments in arid and semi-arid environments (Banning, Hawkins, and Stewart 2011; Banning et al. 2017).

Two analysts worked concurrently during the 2018 surveys, each carrying a Trimble Juno 3B handheld device running ArcPad 10.2. Artifact locations and associated attributes were recorded into a point shapefile stored locally on each device, with a custom ArcPad data entry form. The device also auto-recorded analyst's movements at regular intervals into a second point shapefile as a track log. Analysts would start at one end of a transect and progress forward, stopping at every complete core, retouched piece, or non-flaked artifact. When such an artifact was encountered, a point was added to the map using the coordinates provided by the device's internal GNSS receiver. This automatically opened the custom data entry form, which was organized into themed tabs to aid the analyst as they progressed through the artifact analysis workflow. Analysts also carried a small point-and-shoot camera for taking photographs of each artifact and a set of digital calipers for measurements. The photo identification number and measurement data were transcribed into the appropriate variable on the Juno device. A portable digital balance was initially used to capture artifact weight during the first few days of the season, but was abandoned due to it severely limiting data capture rates.

The ArcPad form consisted predominantly of drop-down menus to reduce typographical errors. Yet, we quickly observed that errors were creeping into the system at certain points in the workflow. The most critical of these junctures was when trying to record the photo identification number or measurement data. We also found that stopping to switch devices (e.g., Juno 3B to camera) or to transcribe information across to the ArcPad form was clumsy and slow. With an estimated 5,000-7,000 artifacts to be recorded at KH1 alone, it became clear very quickly that Phase 1 survey needed to be much more efficient. For the sake of speed, we thus chose to reduce the measurement variables to only the maximum artifact dimension, substituting the rest of the measurements for a categorical shape variable (e.g., blocky, elongate, flat, flat-elongate, etc.). We also reduced the artifact types for which we would take photographs. This did allow our analysts to move more quickly across the landscape, but at the cost of not recording width, thickness, and flake scar metrics, as well as taking significantly fewer photographs.

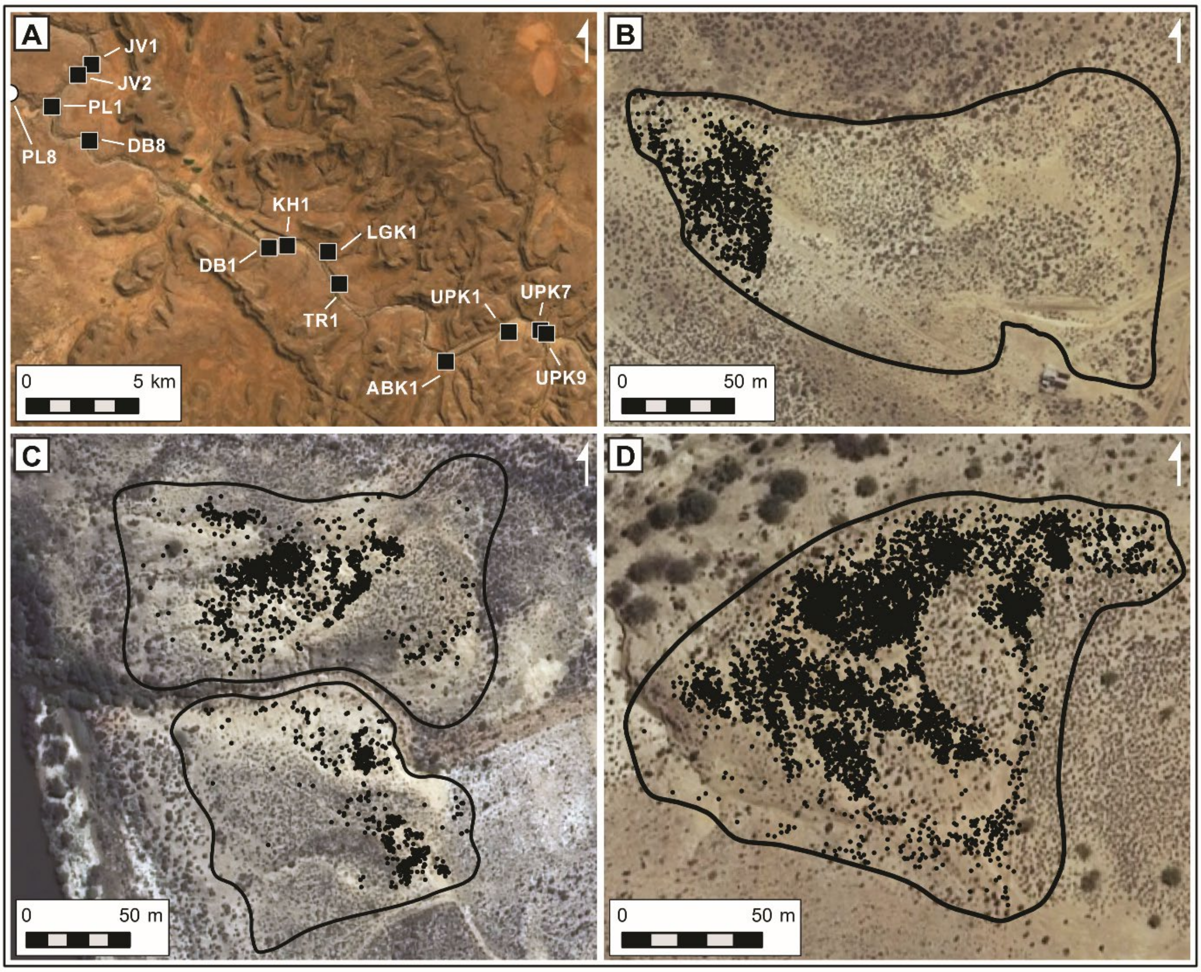


Figure 3. Results of the 2018 Phase 1 archaeological surveys: A) Locations of the localities surveyed in 2019 (PL1, DB8, KH1, UPK1, UPK7, and UPK9) with nearby identified localities that have not yet been subjected to Phase 1 survey (basemap imagery from ESRI); B) Partial artifact distribution at Uitspankraal 9 recorded in 2018; C) Artifact distribution at Doringbos 8 recorded in 2018; D) Artifact distribution at Klein Hoek 1 recorded in 2018 (basemap imagery for B–D from National Geospatial Information, South Africa).

The ArcPad-devised system was overall a success and the 2018 data of considerable value (Shaw et al. 2019; Ames et al. Submitted). Yet, the 2018 system fell short in a few key areas and if continued with these issues would likely prevent us from achieving the project goals over the remaining field seasons. The main limitation was an issue of scale. We recorded 6,747 artifacts at KH1, 1,814 artifacts at DB8, and the first 1,054 artifacts at the very large UPK9 (Figure 3B-D). Brief reconnaissance at the largest remaining known sediment stacks (UPK9, UPK7, UPK1, and Putslaagte 1 (PL1)), suggested there were between 15,000-20,000 artifacts yet to be recorded (note this does not include unmodified flakes that are not being recorded during Phase 1), let alone any additional artifacts from new localities identified during ongoing reconnaissance. We thus knew that the 2019 field season would require three to five analysts working concurrently to realistically achieve such numbers. In addition to more personnel, post-field work processing was cumbersome for the 2018 data, as external photographs from the cameras needed organizing and the separate datasets stored locally on each Juno 3B device required merging. Post-processing and data cleaning following the 2018 season took multiple weeks. We also lamented the absence of measurement data and the limited scope of photographs. Where larger crew requirements already meant purchasing additional data entry devices, we took this opportunity to completely restructure the data collection system with an aim to integrate photographs and measurements into one streamlined system, and to identify hardware options that would allow for easy scalability and flexibility if more analysts were required.

Designing the New Mobile GIS Solution

Design objectives and considerations

The needs of Phase 1 data collection are straightforward: where is the artifact located (the spatial coordinates) and what are its techno-typological and physical characteristics (associated artifact analysis)? Both types of data are easy to produce, as long as the surveyor has basic proficiency in the use of a handheld GNSS unit and the required training in artifact identification and attribute analysis. Digital data entry forms for recording survey data are not uncommon in archaeological field work, primarily used in a similar way to paper forms but reducing typographical errors, avoiding the time consuming job of transcription, and in some cases harnessing the power of networked database solutions (see papers in Averett, Gordon, and Counts 2016). The challenge for the DRAP team, however, was how to record the GNSS and attribute data in a streamlined, map-based, and integrated database workflow across a rotating team of three to five analysts, and in a setting with limited cellular connectivity and unreliable internet access.

Digitally-inclined archaeologists have been tackling many of these challenges for decades (Wallrodt 2016). Much of this work focused and continues to focus on incorporating digital form-driven database workflows into archaeological practice, either with commercial database systems like FileMaker Pro (Motz 2016; Gordon et al. 2016; Spigelman, Roberts, and Fehrenbach 2016), or by developing new non-commercial browser-based or mobile applications (Sobotkova et al. 2016; Dufton 2016; Sayre 2016; Fee 2016). Some of these solutions are designed to automatically pull coordinate data from a device's internal GNSS receiver (e.g., Cascalheira, Bicho, and Gonçalves 2017), but there are few map-based mobile GIS-oriented solutions—although some examples do exist (Tripcevich 2004; Tripcevich and Wernke 2010; Wernke, Kohut, and Traslaviña 2017; Wernke, Adams, and Hooten 2014; Wernke et al. 2016; Banning and Hitchings 2015).

One of the specific aspects of our field application that goes beyond many digital field survey mobile database solutions, however, is that we want to record the locations of individual artifacts that are relatively close together, as opposed to often only a representative central point or the boundary of a scatter. Cluster location and/or area counts and analyses are of course effective strategies in many contexts. Yet, for the Doring River sediment stacks, without point-provenience data it would be impossible to conduct the additional spatial analyses needed to identify areas and clusters for further study. Such work is possible using a combination of high resolution GNSS or surveying equipment and pairing the location with recorded artifact attributes (Holdaway and Fanning 2008), but integrating this information into one mobile GIS solution presents a set of interrelated challenges with respect to acceptable GNSS resolution, appropriate data entry devices, and the best data entry interface (Table 1). Moreover, beyond integrating the data produced by the anticipated three to five concurrent Phase 1 analysts, the system should accommodate the data collection needs of the geological, geomorphological, and geochronological project components (see Figure 2). Although the primary purpose of the new system is to streamline Phase 1 archaeological survey, we sought equipment and an interface that could support our work on geomorphic surface mapping, raw material sourcing, strontium isoscape development, and geochronology of the sediment stacks. With such a broad range of potential data collection needs, the solution we envisioned would need to handle all geometry types—points, lines, and polygons—alongside relevant attributes and photographs.

GNSS accuracy

Choosing an acceptable GNSS resolution depends on the nature of the research questions. Our goal with the Phase 1 survey is to analyze spatial patterning of cores, retouched pieces, and certain non-flaked artifacts at each locality to identify coherent surface clusters that warrant additional analyses (i.e., Phase 2), as well as promising areas for subsurface exploration (i.e., Phase 3). This goal requires reasonable GNSS accuracy. Options range from tablets and smartphones with built-in GNSS receivers that have 5-10 m accuracy through to portable Bluetooth precise point positioning (PPP) devices that require a service subscription and can provide 1-2 cm accuracy. GNSS accuracy of 1-2 cm is more than required to discern general spatial patterns during Phase 1, especially when considering the high cost of such devices and that each of the analysts would need their own receiver. Moreover, given average densities of 0.4 recorded artifacts per m^2 in our 2018 data, with rare clusters as high as 6.0 artifacts per square metre, the 5-10 m resolution of tablets and smartphones would likely compromise pattern identification, and blur the relationship between artifact clusters and sedimentary boundaries. Furthermore, many mobile phones and tablets do not often record or provide the GNSS metadata to the user, making it impossible to assess spatial accuracy.

Ultimately, we decided that a separate Bluetooth GNSS receiver provides the best long-term flexibility. A quality GNSS device may require firmware updates, but the use life will be quite long. However, devices and software interfaces tend to turnover or break much more readily. By choosing a data entry solution with separate GNSS receivers and data entry devices, we would thus be able to upgrade the data entry device in the future without the need to replace the GNSS receiver. An example of this type of technology going obsolete is the Trimble Juno 3B devices we used for our initial Phase 1 survey in 2018. The GNSS receiver functions perfectly well, but the data entry screen is very small and can be difficult to read, and the operating system is not compatible with newer applications that would help streamline data collection. As a result, the entire device would need to be replaced simply to upgrade the data entry interface. Plus, having a small Bluetooth GNSS device would allow us to place it in the location of the artifact, pick up the artifact, step away slightly, record the artifact, and then return the artifact to its original position (possibly using a golf tee or the like to keep it slightly elevated off the ground). We felt a small Bluetooth GNSS receiver best fit our research needs and was the best investment for our long-term equipment assets. Factoring in affordability and required accuracy, this limited our choice to the Garmin GLO device (100 USD per receiver) and the Bad Elf devices (200-600 USD per receiver). The ~1 m accuracy and the additional functionality of track logging and off-loading RINEX files for post-processing tipped our decision-making to the Bad Elf GNSS Surveyor (600 USD per receiver). Track logs are an important part of our data collection and the added functionality of RINEX files leaves open the potential for unforeseen future research applications.

Although base station and rover RTK GNSS systems achieve centermetre accuracy, they have traditionally cost tens of thousands of dollars and they are fairly large and cumbersome when working in remote areas (e.g., Trimble R8 system). New high accuracy systems (~2 cm accuracy) that rely on satellite-based correction services are now much more portable, but they are still rather expensive and come with ongoing subscription costs (tens of thousands of dollars for a single Trimble R10 system with CentrePoint RTX correction service). There are also new base station and rover RTK GNSS systems on the market, such as the EMLID Reach RS2 (1900 USD per receiver), which offers a much more affordable option for achieving cm-level accuracy. However, considering that each surveyor requires their own receiver, plus an extra receiver to act as a base station in areas without NTRIP correction services (such as the Doring River), the cost would quickly become prohibitive for our purposes with only a moderate crew size. A crew of five would mean spending 11,400 USD for an EMLID Reach RS2 system (five receivers as rovers and one receiver as a base station), compared to 3000 USD for five Bad Elf GNSS Surveyor receivers, or only 500 USD for a set of five Garmin GLO receivers. Considering the rapid appraisal objectives of our Phase 1 survey, the cost of cm-level accuracy could not be justified. As the hardware is interchangeable in the system we ultimately developed, other users may find that a different GNSS receiver is better suited to their project objectives.

Data entry device

The choice of data entry device is controlled by the choice of GNSS receiver. Using a higher accuracy built-in receiver would mean purchasing a device such as those offered by Trimble (i.e., the Juno, Nomad, or TDC series devices) or similar systems. Using the lower accuracy built-in receivers of current smartphones and tablets allows for the most flexibility in device selection. In this case, the decision rests more on operating system preference, device specifications (i.e., internal camera quality), or a need for devices that record and allow access to GNSS metadata. Bluetooth GNSS receivers, however, can create device limitations depending on the operating systems with which they are compatible. For example, the Bad Elf application currently only works with an Apple operating system (iOS), limiting our device options to Apple products. To keep the system portable, we chose the Apple iPad Mini 4 that has an 8MP camera, which we fitted with a rugged case. For new devices, costs per unit currently range from 400-680 USD, depending on internal storage capacity and if the device is Wi Fi only or Wi Fi plus cellular enabled. With cellular connection not an option in the Doring River, we opted for the cheaper end of that price range.

Software interface selection

Multiple data entry interfaces were considered for the envisioned system, including open-source tools such as QField (the QGIS mobile application), Open Data Kit, and Kobo Toolbox. Ultimately, the ESRI ArcGIS mobile applications allowed us to incorporate more of our required and desired characteristics in the time available for development. In particular, the ESRI applications can record GNSS metadata, interface with high-resolution RTK GNSS systems (important for Phases 2 and 3), and accommodate multiple users working offline yet still contributing data to one integrated database using ArcGIS Online (AGOL). Although many of these features are possible through the open-source options, such a system would require a heavy programming component and sustained computer science expertise during implementation, as well as for any unforeseen modifications after deployment. Although there is some scripting involved using the ESRI applications, this is within the realm of an intermediate to advanced GIS user. Although potentially appropriate to our needs, other commercial applications, such as Wildnote, or open-source options that would likely to incur additional costs, such as FAIMS (Sobotkova et al. 2016), were not considered, as the School of Earth, Atmospheric and Life Sciences at the University of Wollongong has an institutional license for ArcGIS products.

The conceptual design

The data collection system was designed within the ESRI ArcGIS environment using four applications: ArcGIS Pro, AGOL, Collector for ArcGIS (Collector), and Survey123 for ArcGIS (Survey123). Fundamentally, the system uses an offline-enabled web map interface (Collector) to record location and satellite metadata of artifacts via a separate Bluetooth GNSS receiver (Bad Elf GNSS Surveyor), along with the basic artifact category and associated photographs. We then modified the map to provide a link to a custom-designed XLSForm (Survey123) that incrementally progresses through techno-typological and physical attributes of the artifact using question skip-logic and defined data entry parameters that promote consistency across users. The entire suite of tools was implemented on handheld tablets (iPad Minis), which—when internet connectivity was available—could be synced into a single cloud-based data repository (AGOL). After the field season, the data can be exported for post-processing and analyses (Figure 4).

Artifact clusters, geomorphic areas, and sample locations only require recording a few associated attributes (Online Resource 1), which are easily entered in the Collector interface. However, the artifact attributes to be recorded vary according to the artifact class—that is whether the artifact is a core, retouched piece, or a non-flaked artifact. Moreover, certain values for some artifact attributes require follow up information, and, in other cases, possible valid responses for an attribute are contingent on responses to previous ones. In this sense, there is a hierarchy inherent in the artifact analysis attributes as well as contingency across the hierarchy. A standard attribute list interface as provided by Collector is ineffective in this situation. The current version of Collector (version 20.1.0 at the time of writing) does allow for customisation of the attribute list order, display labels, default values, and required entries, as well as a few other features. However, a "smart" data entry form is preferred that allows for question omission/addition using conditional statements, as well as the ability to filter drop down menus based on previously entered data. An example of the former would be only to display the core type variable when an artifact is identified as a core. An example of the latter would be to filter the technocomplex (i.e., Acheulean, Still Bay, Howiesons Poort, Robberg) drop down menu only to those options relevant to a selected archaeological epoch (i.e., ESA, MSA, and LSA). We integrated this type of functionality for the Phase 1 survey using an XLSForm deployed in Survey123.

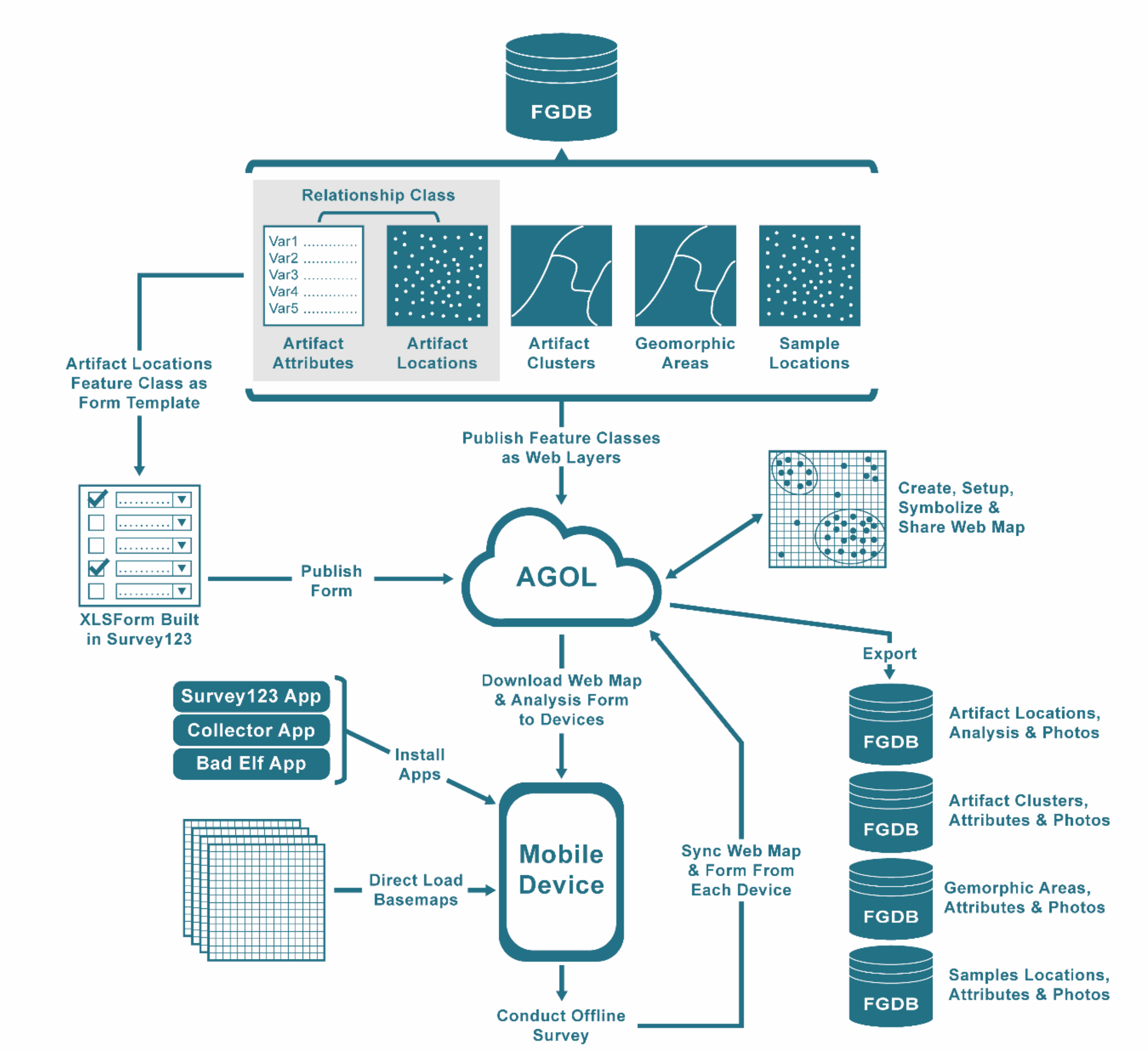


Figure 4. Schematic of the new mobile GIS solution for Phase 1 archaeological survey (FGDB = file geodatabase; RDBMS = relational database management system).

Constructing the mobile GIS system

In order to operationalize this system, we first established what spatial data we would record and the associated attributes for each item (Online Resource 1). With this information in hand, the first step was to create a file geodatabase in ArcGIS Pro with the five essential elements: point feature classes for artifact and sample locations, polygon feature classes for artifact clusters and geomorphic areas, and a standalone table for the artifact analysis attributes (Figure 4). All necessary fields were added to the relevant attribute tables, and then domains (i.e., possible attribute values) were established within the geodatabase and associated with relevant attributes. Lastly, a relationship class was defined between the artifact locations and the artifact analysis table. All of these elements include Global ID fields that help manage distributed databases with offline data creation and have editor tracking enabled—the latter will automatically record the username and the date at time of feature creation, as well as the username and date of the most recent edit. Of particular note here is that in addition to Global ID and tracking edits, the artifact locations point feature class only contains attributes for the artifact class and GNSS receiver information, the latter automatically added using the Add GPS Metadata Fields geoprocessing script provided by ESRI. The related artifact analysis table contains all techno-typological and physical attributes along with a duplication of lithic class and the GNSS coordinates, the purpose of which will be explained below. Once prepared, each of the four spatial feature classes were published to AGOL. Note that geodatabase properties are honored when publishing to AGOL, so the relevant domains and the relationship class are published automatically. As such, the table does not need to be published separately.

Next, the artifact locations feature class was used as a template for an XLSForm using the Survey123 Connect for ArcGIS desktop application. By using the existing feature class as a template, the fields from the related table are automatically included in the XLSForm schema and the geodatabase domains are used to generate choice lists for each attribute. However, the form still requires customization to ensure it only populates the artifact analysis related table, as well as to structure user interaction with the form (i.e., question hierarchy and contingency). Critical to this step is deleting variables related to the artifact locations feature class from the schema so only those variables from the related table remain, as well as ensuring the submission URL points to the correct location in AGOL. Question types were implemented as appropriate to each attribute (i.e., select one, binary, etc.), using question grouping and conditional statements in the "required" and "relevant" columns of the XLSForm schema to control question hierarchy and contingency (Online Resource 2). XLSForm syntax allows for highly varied form design but these details are not discussed here, as explanations and support are widely available online. Once complete and functioning as desired, which can be tested within Survey123, the form was published to AGOL.

Once all needed elements were published, a web map was created in AGOL with all feature layers and the settings adjusted to allow photograph attachments and offline data creation, as well as setting sharing privileges with all anticipated analysts—all analysts need their own AGOL account to login. One important aspect here is that a basemap is required in the web map. However, if the study area is large, this background imagery can consume valuable storage space on the mobile device or be cumbersome to download. To avoid this issue, a blank polygon feature that covered the entire study area was created and converted to a tile package, which was then published to AGOL and used as the basemap for our data collection web map. It is also possible to use the built-in ESRI basemaps for offline use, with offline areas being predefined within the Manage Areas settings of the webmap in AGOL.

After preparing the web map, the mobile devices were provisioned with the necessary applications: Collector, Survey123, and the Bad Elf GNSS application. Additional relevant basemaps—aerial imagery, geological maps, topographic maps—were prepared as tile packages in ArcGIS Pro and directly loaded onto the devices as well. To allow Collector and Survey123 to work together, the feature pop-up window for the web map was customized to display a hyperlink that when selected opens a new artifact analysis form in Survey123 and auto-populates the lithic class, GNSS coordinate data, and the Global ID. The lithic class establishes which variables are relevant, the Global ID is the link between the point locations and the artifact analysis table, and the GNSS coordinates were included as a redundancy that ultimately proved highly valuable (see below). Analysts then signed into the Collector and Survey123 applications and downloaded both the web map and the data entry form, respectively. From here, data collection could occur and when an internet connection was re-established the device could then be synced back to AGOL. At the end of the field season, the data components were able to be exported as individual geodatabases containing the point/polygon features and their associated attributes, as well as any related tables and/or photographs (Figure 4). Refer to Online Resource 3 for a detailed guide to constructing the mobile GIS system outline here.

Implementation: the Doring River Archaeological Project 2019 Field Season

The Doring River Archaeological Project team conducted fieldwork between mid-February and mid-May of 2019 using the mobile GIS system outlined above. There was a rotating crew of three to five analysts, each one working with a Phase 1 data collection kit consisting of an iPad Mini, a Bad Elf

GNSS Surveyor, a set of Bluetooth digital calipers, and photo scale (Figure 5). Here we discuss the particulars of the mobile GIS system workflow.

In-field workflow

As in 2018, each locality was divided into ~2 m transects using black nylon string. Upon arrival at the site each day, the Bad Elf devices are switched on and track logging activated. Bluetooth devices – the Bad Elf and digital calipers – are paired with the respective iPads in their kits. Analysts then begin walking along their assigned transect stopping at all cores, retouched pieces, and certain non-flaked artifacts. When encountered, the Bad Elf GNSS is placed in the location of the artifact and the artifact is then picked up for preliminary analysis while stepping away from the GNSS receiver. Once the GNSS is registering an acceptable accuracy (<3 m), a point is added to the web map in Collector**.** An attribute list is presented to the analyst for data entry (Figure 6A). For the Phase 1 artifact locations, the only attribute is the lithic class—either core, retouched piece, or non-flaked. This is also the stage where photographs can be taken using the internal iPad camera. Minimal cores and unworked ochreous rock fragments were generally not photographed. Once satisfied, the analyst submits the entry, which stores the data locally and produces a customized pop-up window showing the lithic class and GNSS data for the entered point, as well as an 'Artefact Analysis' link (Figure 6B).

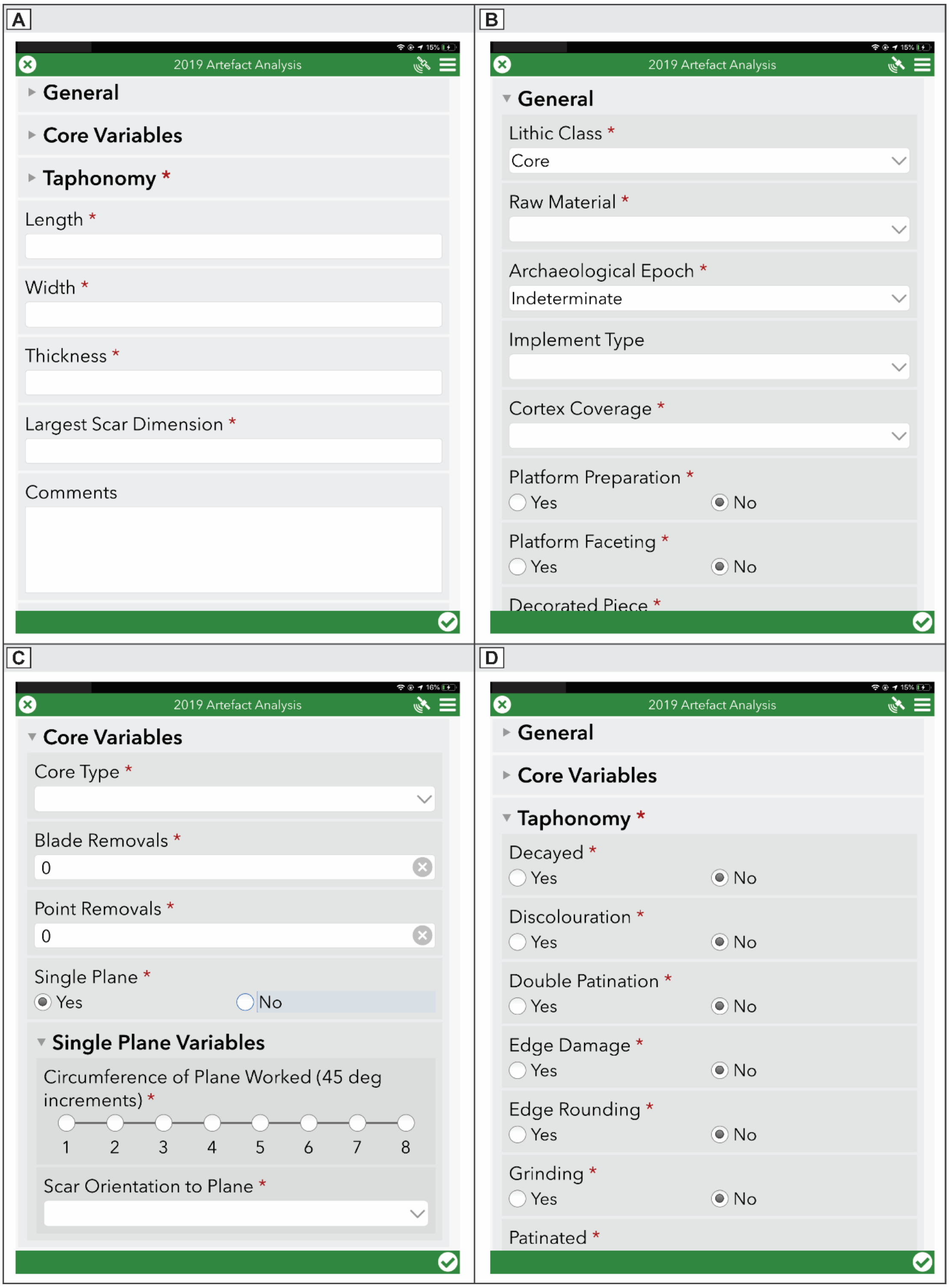
Figure 5. Phase 1 archaeological survey kit: A) iPad Mini 4 in rugged case; B) Bad Elf GNSS Surveyor, C) Photo scale; D) Bluetooth digital calipers.

Displaying the lithic class and the GNSS data allows the analyst to verify that the point was recorded properly. If not, the point can be deleted, or there is also the option to edit the information. Selecting the "Artefact Analysis" link opens a new data entry form in Survey123, and automatically populates the form with the lithic class, GNSS coordinates, and Global ID of the associated point in Collector. From here, the analyst progresses through the data entry form, which includes three sets of variables relevant to all artifacts, and a fourth set of attributes specific to only cores.

All artifacts require responses for the general group of attributes, the taphonomic variables, and the measurements (Figure 7A). General information includes variables such as raw material, archaeological epoch and industry, as well as cortex coverage and type (Figure 7B; Online Resource 1). Included in this general group is the binary variable to indicate if a 3D scan is required for a particular artifact. The default for this variable is set to "no." When "yes" is selected, the form provides a unique identification number that is calculated based on a concatenation of the username of the analyst (established at sign-in) and the time of form creation (month-day-hour-minute-second)(Online Resource 2). This unique identifier is transcribed/inscribed onto a metal foil tag, which is then nailed into the ground at the source location for that artifact. The artifact is placed in a zip seal bag with a matching paper tag. At the end of each day, all flagged artifacts are transported to the field house for 3D scanning and high-resolution photography. Once completed, these artifacts are returned to the location of their matching tag.

Located by : cames.uow
GNSS Receiver : Bad Elf, LLC #004825
Fix Type : GPS
Latitude : -32.03851467
Longitude : 19.40823450
Altitude : 243.20
Number of Satellites : 7
Fix Date & Time : 03/21/2019 07:44 PM
Global ID : {190FBBF3-9FF7-4C88-A844-8F9442F617B2}

Figure 6. Screenshots of the Collector for ArcGIS interface: A) Adding a new Phase 1 artifact point location; B) Customized pop-up window after submitting a new point displaying the GNSS metadata and “Artefact Analysis Form” custom URL scheme link; C) The “Layers” menu where other features can be toggled on and off for display or editing purposes; D) The option to add a new artifact location, archaeological cluster, geomorphic area, or sample location when all layers are active.



A

▸ General
▸ Core Variables
▸ Taphonomy *
Length *
Width *
Thickness *
Largest Scar Dimension *
Comments

B

▾ General
Lithic Class *
Core
Raw Material *
Archaeological Epoch *
Indeterminate
Implement Type
Cortex Coverage *
Platform Preparation *
○ Yes ● No
Platform Faceting *
○ Yes ● No
Decorated Piece *

C

▾ Core Variables
Core Type *
Blade Removals *
0
Point Removals *
0
Single Plane *
● Yes ○ No
▾ Single Plane Variables
Circumference of Plane Worked (45 deg increments) *
○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8
Scar Orientation to Plane *

D

▸ General
▸ Core Variables
▾ Taphonomy *
Decayed *
○ Yes ● No
Discolouration *
○ Yes ● No
Double Patination *
○ Yes ● No
Edge Damage *
○ Yes ● No
Edge Rounding *
○ Yes ● No
Grinding *
○ Yes ● No
Patinated *

Figure 7. Screenshots of the custom-designed XLSForm data entry system in Survey123 for ArcGIS: A) The main variable groups, measurements fields, and comments box; B) A subset of the general group variables; C) A subset of the core group variables; D) A subset of the taphonomy group variables.

All artifacts also require values for a series of 11 binary variables that record the presence or absence of different taphonomic conditions, such as edge damage, potlid scars, or double patination (Figure 7D; Online Resource 1). The default for all values is set to "no," thus only requiring the analyst to quickly change the relevant variable to "yes." The last variables applicable to all artifacts are measurements (Figure 7A). These are not set apart in a group and occur at the bottom of the form along with a text box for comments. Fields for length, width, and thickness are visible for all artifact classes, and a fourth measurement for largest flake scar dimensions becomes available if the artifact class is set to core or the implement type is core-on-flake. Measurements are taken and entered using the Bluetooth digital calipers, making for rapid data entry and avoiding transcription errors. Lastly, the comments box provides the analyst with an opportunity to add additional information in a free-form narrative format. This is the only variable that requires typing, as the rest are drop down menus or button selections.

If the lithic class is a core, a core variables group will also be visible between the general and taphonomy variable groups (Figure 7C). There are at minimum four questions in the core variables group, but there could be as many as 16 depending on the nature of the core being analysed (Online Resource 1 & 2). The core variables group is also visible when the implement type for a retouched piece is recorded as core-on-flake.

Once the form is complete, the analyst clicks submit (the check mark in the bottom right corner) and the form will be validated. If any required variables are missing, an error message is displayed, which is established in the XLSForm schema. If validation is successful, the completed form is stored locally within Survey123. That completes the process for recording an artifact during Phase 1 survey. The analyst can now return to Collector and the process repeated as additional artifacts are encountered along their transect.

If an analyst wants to record an archaeological cluster (e.g., a high-density area of similar raw material or flakes), or if a device is going to be used for documenting geomorphic areas or collecting samples, the process is similar. First, the required data entry layer is switched on in the "Layers" menu (Figure 6C). If multiple layers are active when a feature is added to the map, an intermediary menu will be presented asking which layer you are attempting to edit (Figure 6D). If the selected layer is "Sample

Locations," the point data collection process is the same as described for artifacts, except there is no associated "smart" form entry through Survey123. Rather the few attributes needed are recorded directly to the attribute list within the Collector application, with some minor customization to the order and display of the attribute list by configuring the editable layer pop-ups in the AGOL webmap. However, if a polygon data type is selected, there is an option to create the polygon in continuous mode or by placing individual vertices—our team uses the continuous recording method. Once activated, the analyst simply walks the perimeter of the observed cluster or geomorphic area, stopping the process once returning to the original starting position. After defining the polygon feature, an attribute list is presented for feature characterization. There is also the option to take accompanying photographs (Online Resource 1). Editing capabilities exist for polygons as well, including deleting or modifying individual vertices.

Syncing locally stored data

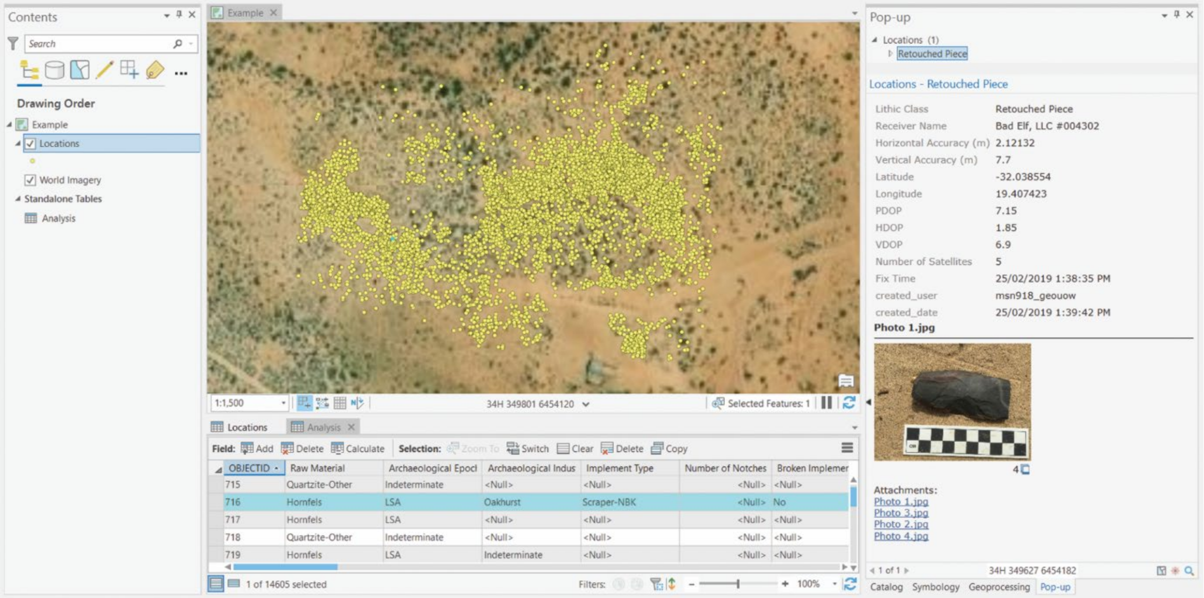
Whenever an internet connection was available, the devices would be connected and the data synchronized to AGOL. We were able to conduct this sync almost daily, although there were periods when the internet was unavailable or the internet speed or bandwidth available was too slow/limited to complete the overnight sync. The longest period without a successful sync during the 2019 field season was three weeks. In such circumstances, the data, which is stored locally on each device within a folder specific to the user signed in at the time of data collection, can be backed up to a computer or external hard drive. As the procedures for this process vary according to device and operating system, we direct the reader to the appropriate online support documentation for their situation.

The sync procedure is a two-step process. As the Survey123 form populates a table related to the artifact locations web layer, it is impossible to have a table entry without a corresponding point in the web layer. As such, it is imperative to synchronize the data from the Collector app first. As this is the longest process due to associated photograph, this process was started immediately upon return to the field house and left to run overnight. There were on average two photos per artifact, with an average photograph data size of 511 kilobytes—the photograph resolution and hence data size can be adjusted within the Collector app. First thing the next morning, the Survey123 data would be synchronized, completing the process. This second step is fast, taking less than one minute in most cases. The sync will also download any new point features and images in the web layer to the device. However, in our situation of limited internet speed with regular internet disruptions and frequent power outages, this sync setting was changed so photos were uploaded to AGOL but not downloaded to each of the devices. Even though individual photos were relatively small, synchronizing hundreds to thousands per day was already stretching the capabilities of our internet connection and unnecessary to be on all devices for our workflow.

Post-field season data processing

At the end of the field season, each of the four elements were downloaded from AGOL for post-processing and data analysis. Where all four elements were collected with photograph attachments, they were downloaded as file geodatabases. This format incorporates all photographs and their relationship with the associated spatial feature. The export functionality is built into AGOL and it worked seamlessly for the archaeological clusters, geomorphic areas, and sample locations. The latter of the three was over 5 GB due to the associated photographs. However, our artifact locations and analysis data is nearly 15 GB and although it could be viewed and analyzed within AGOL, it would not download properly. It could only be downloaded in two components through ArcGIS Pro: the point features as a file geodatabase with associated photographs and the artifact analysis table. As such, the relationship between the point features and analysis table was broken. Yet, because the GNSS coordinates were pulled across into the artifact analysis table during field collection, re-establishing this relationship was relatively straightforward.

Post-processing the data to re-establish this link as well as checking for data entry errors and merging with the 2018 data took only a day and a half of work following the field season. Data summaries and spatial analyses were able to begin immediately (Shaw et al. 2019; Ames et al. Submitted), and coherent databases were available to be browsed within ArcGIS Pro, including associated photographs (Figure 8). Although 15 GB is a large FGDB, the default size for datasets in FGDBs is 1TB and can extend up to 256TB if necessary. Where our cleaned, master FGDB is stored locally on a laboratory computer, we are not currently concerned with the large file size created by storing the photos within the FGDB. If this is of concern for others data management protocols, alternative linked database solutions for the photographs will need to be explored.



OBJECTID	Raw Material	Archaeological Epocl	Archaeological Indus	Implement Type	Number of Notches	Broken Implemer
715	Quartzite-Other	Indeterminate	<Null>	<Null>	<Null>	<Null>
716	Hornfels	LSA	Oakhurst	Scraper-NBK	<Null>	No
717	Hornfels	LSA	<Null>	<Null>	<Null>	<Null>
718	Quartzite-Other	Indeterminate	<Null>	<Null>	<Null>	<Null>
719	Hornfels	LSA	Indeterminate	<Null>	<Null>	<Null>

Locations - Retouched Piece

Lithic Class	Retouched Piece
Receiver Name	Bad Elf, LLC #004302
Horizontal Accuracy (m)	2.12132
Vertical Accuracy (m)	7.7
Latitude	-32.038554
Longitude	19.407423
PDOP	7.15
HDOP	1.85
VDOP	6.9
Number of Satellites	5
Fix Time	25/02/2019 1:38:35 PM
created_user	msn918_geouow
created_date	25/02/2019 1:39:42 PM

Attachments:
Photo 1.jpg
Photo 3.jpg
Photo 2.jpg
Photo 4.jpg

Figure 8. Screenshot of the ArcGIS Pro interface for exploring the Phase 1 survey master database, with related photographs and artifact analysis data.

Phase 1 Survey Results

Survey results are only briefly presented here with a focus on comparing the data collection efficiency across the 2018 and 2019 field seasons. Detailed artifact results and analyses are presented elsewhere (Shaw et al. 2019; Ames et al. Submitted).

Comparing the 2018 and 2019 data collection results

In 2019, the DRAP team recorded 14,605 artifacts with 29,414 associated photographs across four sediment stacks (Figure 9)—nearly 75% more artifacts than during the 2018 season in eight fewer data collection days (Table 2). As expected, having more analysts working concurrently resulted in considerably more artifacts recorded per day. Moreover, the streamlined data entry workflow allowed us to record all desired attributes in our rapid appraisal survey and take considerably greater numbers of photographs without sacrificing the rate of data collection. The overall average number of artifacts recorded per device each day was actually 9.2% higher in 2018 (82.2 compared to 73.0). However, in 2019, the larger crew included a range of experience levels with the daily average number of points recorded per device/analyst ranging from 49.7–109.3, with the more experienced analysts producing daily averages of 77.3–109.3 artifacts per day. In 2018, the rotating two-person survey crew consisted almost exclusively of more experienced analysts with averages of 77.1–97.5 artifacts recorded per day. This data is for only the three most common analysts in 2018 and excludes the first 8 days of 2018 when the details of the system were being finalized. These three analysts also participated in the 2019 field season, suggesting that the average per person daily totals were in fact comparable across the two seasons, with slightly higher upper limits in 2019 even with the additional variables added to the workflow. The daily pace of the junior analysts is thus reducing slightly the 2019 daily averages, while at the same time—and more importantly—critically increasing the crew-wide daily average by 73.5% from 150.3 in 2018 to 260.8 in 2019. Moreover, the 2019 average rate per analyst is reduced slightly because one analyst would frequently work a half day of Phase 1 survey and then spend the remainder of the day working on other components of the larger project, such as mapping geomorphic areas—a luxury afforded because of the larger crew size and the flexibility of the new equipment. Particularly telling is that by the end of the 2019 field season when the new mobile GIS system became well established, the daily totals began to outpace any achieved in 2018. The highest daily crew-wide total in 2019 was nearly double that from 2018 (636 compared to 330), and the highest single analyst daily total was 42.8% greater in 2019 to that from 2018 (257 compared to 180 and by the same analyst in both years).

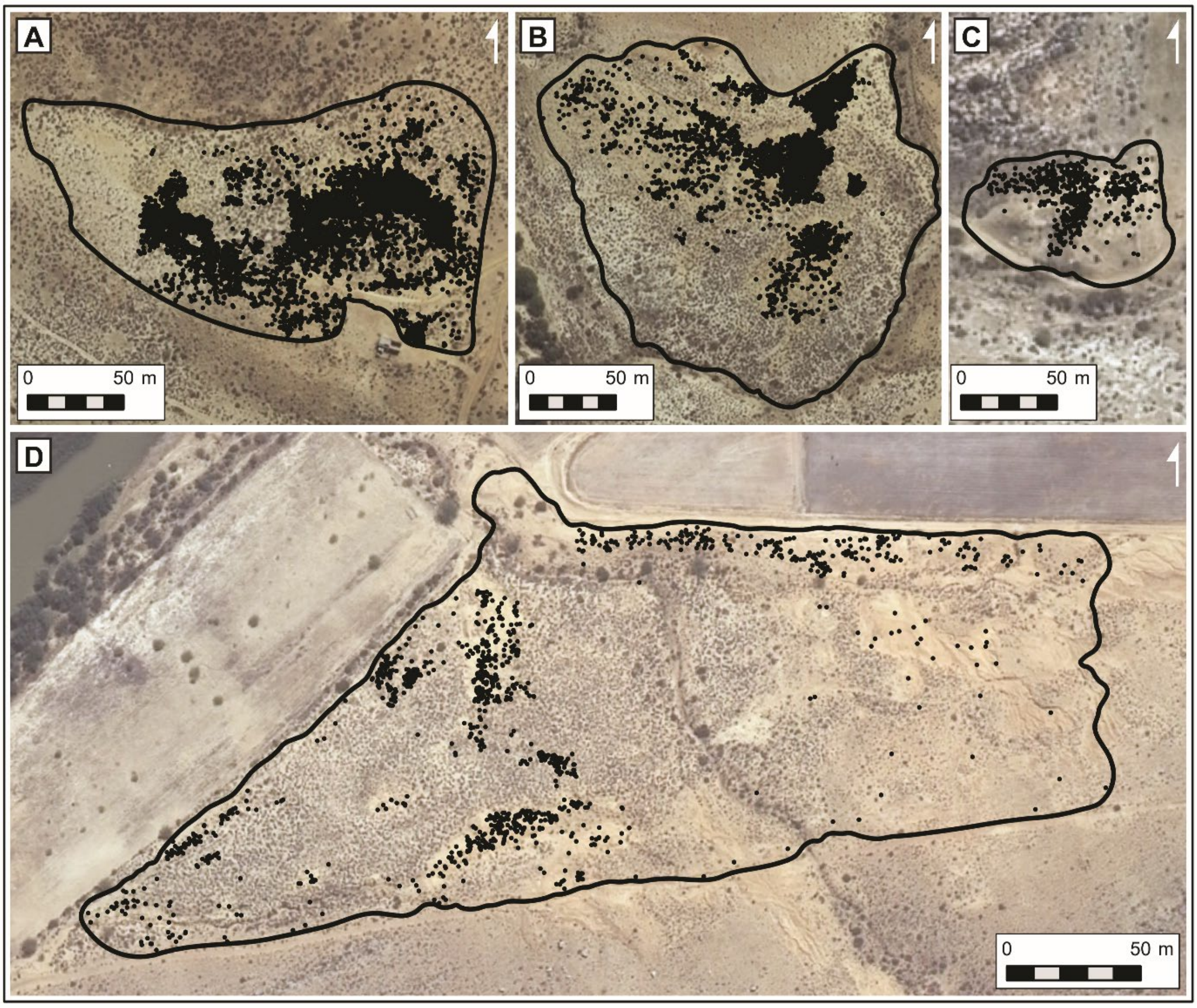


Figure 9. Results of the 2019 Phase 1 survey: A) Partial artifact distribution at Uitspankraal 9 recorded in 2019; B) Artifact distribution at Uitspankraal 7 recorded in 2019; C) Artifact distribution at Putslaagte 1 recorded in 2019; D) Artifact distribution at Uitspankraal 1 recorded in 2019.

Overview of the archaeological survey data

Combined with the 2018 data, the Phase 1 survey has thus far documented 24,220 artifacts across six localities (Figure 10 and 11). Approximately a third of these (30.8%) are attributed to a particular archaeological epoch, and 7.2% to a particular technocomplex (Table 4). Artifact distributions are inhomogeneous across the sedimentary bodies and preliminary analysis indicates the distributions are correlated with terrain properties (e.g., elevation and slope) and surface geomorphology, particularly areas of past and active erosion, yet also cluster in ways that are indicative of behavioral aggregates (Shaw et al. 2019). For example, detailed analysis of the Phase 1 data from KH1 identified a cluster of Still Bay artifacts concentrated in an erosional embayment—Phase 2 analysis of this material is ongoing

(Figure 11). Moreover, it is highly likely that the deposits flanking the Still Bay cluster preserve related buried remains with the potential for excavation and age determination (i.e., Phase 3). However, erosional sensitivity modelling indicates this area of the locality is under imminent threat of continued erosion and potential loss of stratigraphic context and behaviorally significant patterning (Ames et al. Submitted). As a result, Phase 3 analysis of these deposits at KH1 is a priority for the upcoming field season. Similar and additional analyses of the Phase 1 survey data are in progress for the other surveyed localities.

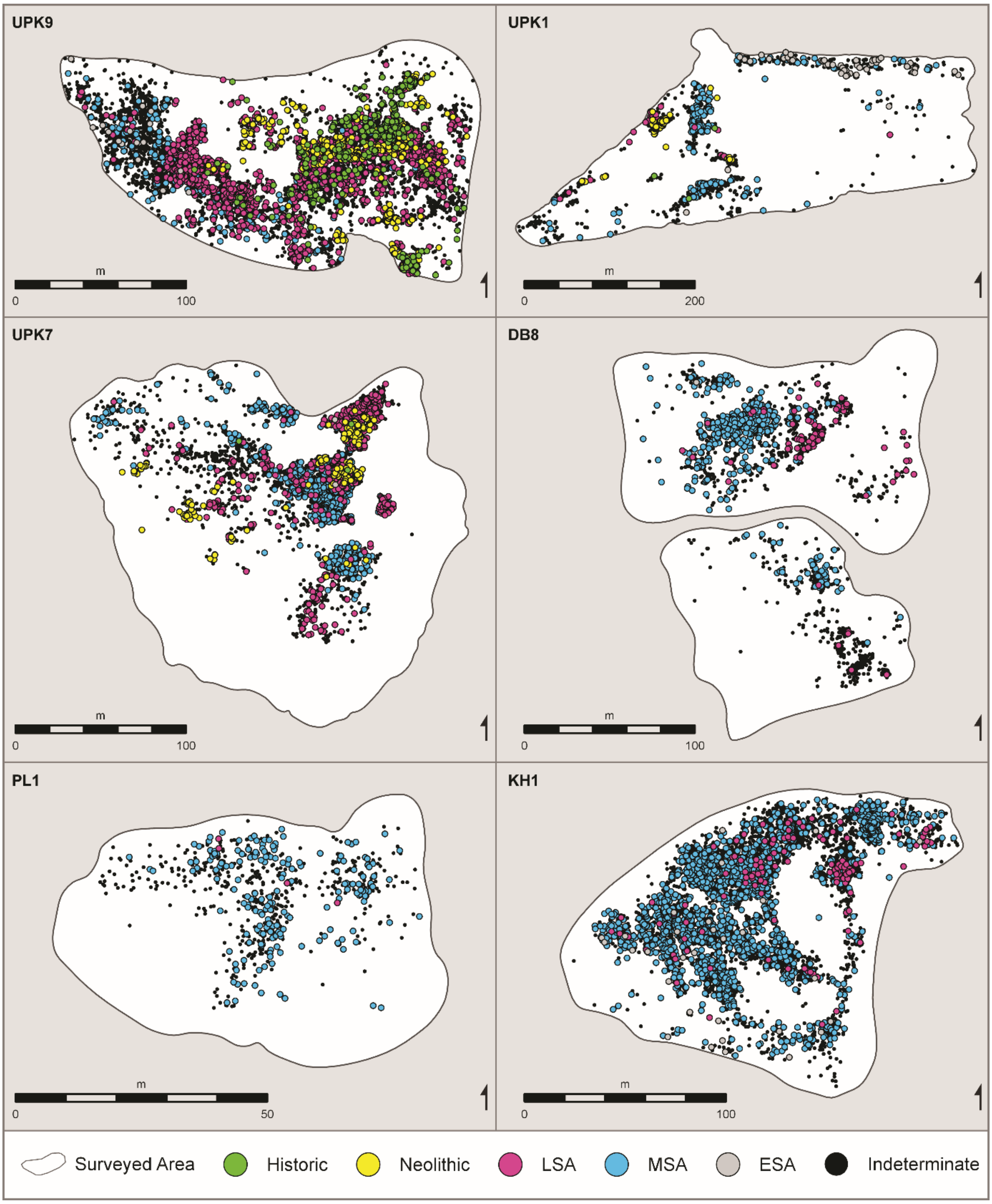


Figure 10. Artifact distributions of the combined 2018-2019 Phase 1 survey data symbolized by archaeological epoch.

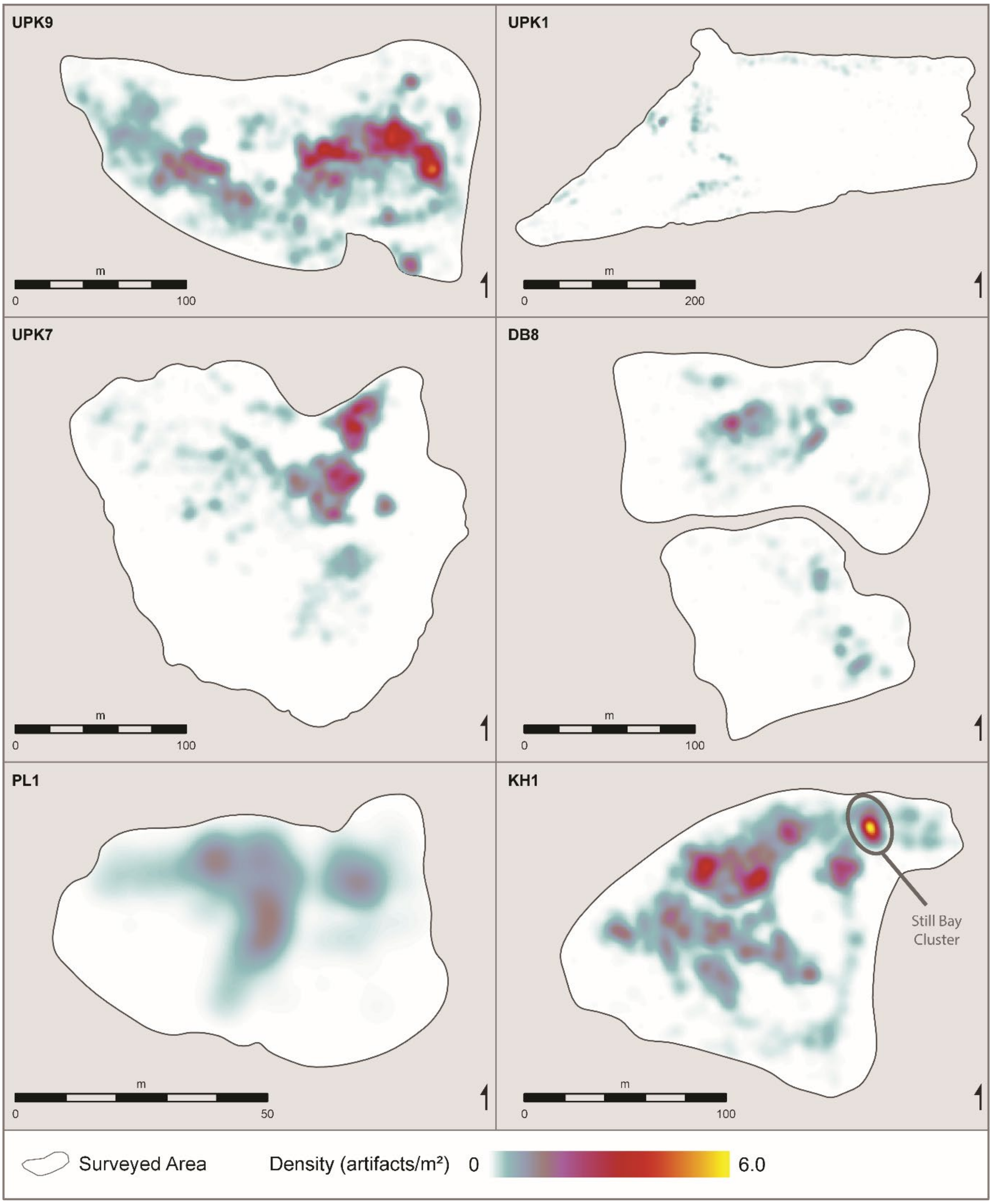


Figure 11. Kernel density using a 6 m search radius of the combined 2018-2019 Phase 1 survey data for each locality.

Discussion

One of the key advantages of the new system is its flexibility. Additional data layers can be added as needed, and a variety of data collection web maps can be prepared for different data collection teams or tasks. Although in 2019, the DRAP only took photographs, audio and video attachments are also possible, including the use of QR codes for associating sample tags with their related spatial data entry. As such, the overall conceptual design of the mobile GIS solution transcends geographic region or temporal focus, and could readily be applied to a wide variety of archaeological survey (and possibly excavation), whether point, polygon, or line driven in their approach. This flexibility was experimented with throughout the 2019 season by successfully designing and deploying a data collection web map specific to the geologically-focused data collection team (see below). The ability to connect with higher resolution GNSS equipment, such as Real-Time Kinematic (RTK) systems, opens up even further data collection possibilities—something we intend to explore during Phases 2 and 3 of the DRAP.

Minor edits were also made to the XLSForm early in the field season. In particular, we found that multiple analysts were frequently finding ‘thumbnail’ scrapers, yet this artifact type was not included in our initial implement type list. Analysts were noting these types in the comments box instead. The XLSForm schema was edited offline in the Survey123 Connect desktop application to include this implement type and re-published. Simply refreshing the form on each device, something that takes a few seconds, distributed the new form to all analysts. This does require an internet connection, however, which proved challenging during the 2019 season. On one occasion, for example, it was necessary to drive 20 km to the nearest hilltop with cellular reception and hotspot a mobile phone while sitting inside the vehicle in order to send modifications to AGOL and then download them to the necessary devices. Such workaround solutions may not be available to more remote projects, however.

As the hardware components of the system are interchangeable, the flexibility of the system extends to the devices that can be used, allowing them to be tailored to project objectives and budget. Each of our Phase 1 survey kits (iPad Mini 4, rugged case, Bad Elf GNSS Surveyor, and Sylvac Bluetooth digital calipers) cost approximately 1550 USD to assemble, but this cost could increase or decrease depending on the choice of GNSS receiver and data entry device. For example, the design and testing phases for this workflow were conducted entirely on an after-market iPhone SE (150 USD) before switching to the new iPad Minis. Moreover, the geologically-focused data collection team operated the same data collection system on a Samsung Galaxy Tab A (SM-T380) device running Android 7.1.1 paired with a Garmin GLO Bluetooth GNSS receiver. As the geological team’s data entry does not require calipers, the entire data collection kit cost was 250 USD (150 USD for the tablet and 100 USD for the GNSS receiver). This flexibility in device choice provides an opportunity for cost savings, as older tablet and smartphone models and second-hand devices can be used without sacrificing GNSS resolution. Moreover, it provides a potential format for distributed data collection during field methods courses by allowing students to use their own mobile devices where possible. The reverse is true as well, in that the small, handheld GNSS receivers can be swapped for high accuracy RTK or satellite-based correction service GNSS systems. Devices can also be upgraded for options with larger screens, more internal storage, and cellular connectivity where necessary.

The major limitation is that the system is built within a commercial software application. For researchers and instructors affiliated with universities that have an institutional license this is less of an issue. Yet, for those who are not, the ESRI suite of applications can be cost prohibitive. Fortunately, there are open source options that provide some of the same functionality, including archaeologically-specific options (Sobotkova et al. 2016; Fee 2016; Cascalheira, Bicho, and Gonçalves 2017), although in many cases these will likely require more involved coding and scripting to setup and manage, or hiring specialized personnel or services to arrange the setup of the system. Efforts in this direction of creating open-source solutions should continue to be a priority, however. Other minor limitations we experienced include devices overheating and occasionally batteries dying before the end of the workday. Devices (and operators) sometimes overheated when midday temperatures approached or exceeded 40°C, requiring cooling intervals of 15-30 minutes. Battery life issues were solved by bringing three multi-device portable charging units to the field each day and topping up batteries as needed during water and lunch breaks.

Conclusion

In response to challenges and limitations of the initial 2018 Phase 1 survey, the DRAP set out to design a new multi-user mobile GIS data collection system to accommodate a rotating crew of three to five personnel, and one that could maximize data collection quality and efficiency and reduce post-field data processing. After careful consideration, an offline-capable, cloud-based mobile GIS system was created using a suite of ESRI ArcGIS applications. The solution satisfied all of our requirements and nearly all of our preferred characteristics. Additional desired variables were able to be recorded within one system, including measurements and photographs, and, despite this increase in information, the per analyst daily rate of data collection was the consistent with that from 2018. Yet, because a larger crew was now possible, the overall quantity of data collection was nearly 75% greater in 2019 over eight fewer field days. Moreover, as an integrated database solution, the new system preserved all relationships between artifacts and photographs, and dramatically reduced post-processing time. Perhaps the most promising aspect of this system is its scalability and flexibility. The low error rate, easy data integration, small post-processing and data cleaning requirements, and the relatively low equipment cost for additional data collection kits means this system could be implemented for very large field teams, or the components adapted to meet different project data accuracy requirements.

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Disclosure Statement

The authors report no potential conflict.

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Tables

Table 1 Objectives and considerations for the new mobile GIS data collection system

Objectives	Requirements	Preferences
• Record artifact location and attributes efficiently	• Work offline without cellular signal or reliable internet	• Record GNSS metadata (e.g., horizontal accuracy)
• Balance analysis detail with speed of data entry	• Handle rotating personnel over a long field season	• Interface useful for other data streams
• Reduce errors (auto-entry, menus, question skipping)	• Achieve reasonable GNSS resolution (~1 m)	• Equipment beneficial for teaching and learning
• Ease of use with minimal training requirements	• Minimum one full day of battery life	• Minimal equipment upkeep and maintenance
• Scalable system if additional personnel required	• Relatively low-cost equipment with reasonable life spans	• Integrate with high accuracy GNSS equipment
• Reduce post-processing requirements with an integrated database solution	• Manage relationships between artefacts, attributes, photographs, and scans	• Limited programming or scripting to allow for non-expert modification

Table 2 Summary and comparison of 2018 and 2019 Phase 1 data collection results

		Crew-wide summary			Summary by analysts			
Year	# Points	# of days	Avg. points/day	Highest daily max.	# analyst days	Avg. points/day	Range of avg. points/day	Highest daily max.
2018	9616	63	150.3	330*	117	82.2	45.8–92.4	180*
2019	14605	56	260.8	636	200	73.0	49.7–109.3	257

*Excludes first eight days of 2018 as they include inflated totals due to changes in the data entry procedure after this time.

Table 3 Summary of combined 2018-2019 Phase 1 survey results by locality and archaeological epoch and industry

	Surveyed locality							
Epoch & technocomplex	**UPK 9**	**UPK 7**	**UPK 1**	**KH 1**	**DB8**	**PL 1**	**Technocomplex total**	**Epoch total**
ESA	**16**	**2**	**51**	**30**	**1**			**100**
Acheulean	*1*		*18*				*19*	
Fauresmith			*1*	*3*			*4*	
MSA	**242**	**783**	**166**	**1929**	**434**	**193**		**3747**
Early MSA	*1*	*1*		*2*	*5*		*9*	
Still Bay	*1*	*9*	*9*	*183*	*6*		*218*	
Howiesons Poort	*5*	*11*	*5*	*10*	*6*		*37*	
Post Howiesons Poort	*2*	*51*	*2*	*32*	*10*	*2*	*99*	
Late MSA	*12*	*95*	*28*	*230*	*28*	*81*	*474*	
LSA	**1687**	**542**	**34**	**129**	**76**	**4**		**2472**
Early LSA	*1*	*55*	*1*	*10*	*21*	*4*	*72*	
Robberg	*267*	*36*		*28*	*20*		*351*	
Oakhurst	*238*	*59*		*4*	*6*		*307*	
Wilton	*83*	*49*	*4*	*10*	*9*		*155*	
Local Neolithic	**491**	**178**	**102**					**771**
Historic	**374**	**3**	**4**					**381**
Technocomplex Sub-total	*611*	*376*	*68*	*512*	*91*	*87*	*1745*	
Epoch Sub-total	2810	1508	357	2088	511	197		7471
Indeterminate Epoch	6676	2777	895	4659	1303	439		16749
Total Artefacts	**9482**	**4285**	**1252**	**6747**	**1814**	**636**		**24220**

Supplementary Online Material

Online Resource 1 Detail of the attributes associated with Phase 1 artifact locations, archaeological clusters, geomorphic areas, and the artefact analysis table, as well as the domains used to create drop down menus and selection lists.

Online Resource 2 XLSForm schema deployed in Survey123 for ArcGIS.

Online Resource 3 Procedure for Constructing the Phase 1 Mobile GIS Survey System used by the DRAP during the 2019 Field Season.