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SPECIAL ISSUE

Drones in Archaeology

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On the cover: Quadcopter DJI-Phantom 2 Vision, equipped with a built-in camera and second GoPro camera, mapping at Cantona, Puebla, Mexico (Photo by Gerardo Gutiérrez).

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EDITOR'S CORNER

Anna Marie Prentiss

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The word "drones" conjures up a mixed bag of imagery spanning military actions to corporate operations. But drones, more formally identified as Unmanned Aerial Vehicles, or UAVs, can also be very useful tools for archaeological research. Our discipline seeks data on scales ranging from the highly minute of individual objects to distributions of cultural materials across entire landscapes. Data collection on the landscape scale is time consuming and expensive. Consequently it is to our great benefit to develop and use new tools such as UAVs to more effectively accomplish this work.

Guest editors Gerardo Gutiérrez and Michael Searcy provide a fascinating collection of articles for this special issue of the *SAA Archaeological Record* titled "Drones in Archaeology." In their introduction they develop the concept of UAVs from historical and mechanical standpoints before discussing the utility of these devices for collecting archaeological data via remote sensing. Gutiérrez and colleagues review the basics of measuring variability in topography using UAVs. Mark and Billo demonstrate the use of low altitude UAVs in photographing rock art in the American Southwest. Parcero-Oubiña and colleagues provide a low-cost UAV approach to mapping large prehispanic settlements in the Atacama area of northern Chile. Meyer and colleagues consider the use of UAVs for cost-effective mapping of the Mayan port site of Conil. They subsequently discuss the pros and cons of UAV technology compared to traditional total station mapping. Baliño illustrates the use of UAVs to build digital terrain models using photogrammetry at the site, Cerro de la Máscara, in Sinaloa, Mexico. Harrison-Buck and colleagues introduce the use of UAVs in situations of rapid data collection on threatened sites, in this case, the Mayan site, Saturday Creek, Belize. Wechsler and colleagues consider the utility of commercial UAV technology in archaeological applications, for example, on the island of Rapa Nui, Chile. To close out the set, Michael Searcy discusses the regulatory framework within the United States for use of UAVs.

In other content, we receive an important update from SAA President Diane Gifford-Gonzalez. We are also fortunate to have a Volunteer Profile column from former SAA President Jeff Altschul. His reflections on his recent presidency and some of the major regulatory and funding challenges we face today are worth a close read. Finally, Sean Nāleimaile provides the latest installment of our Native American Scholarships Committee column series.

INTRODUCTION TO THE UAV SPECIAL EDITION

Gerardo Gutiérrez and Michael T. Searcy

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The past several years have seen a marked increase in the use of Unmanned Aerial Vehicles (UAVs; aka drones). UAVs are small, portable, and more affordable than ever. They currently are being used in agriculture, film, search and rescue, energy, real estate, and public safety, among other industries. Globally, the UAV market generates approximately $8 billion a year and is projected to have a compound annual growth rate of 19 percent over the next five years (Business Insider 2015).

Archaeologists have already begun to use UAVs in several ways. These include reconnaissance, aerial photography, site documentation, mapping, and photogrammetry. There is big potential for other applications like site preservation, monitoring, and aerial remote sensing. Smaller cameras and sensors that can be mounted to several different types of UAV formats are being produced, creating the potential to hoist many different tools into the air. Comparable to the introduction of GIS and GPS technology into the field of archaeology, UAVs have the potential to change the game for archaeological research as creative minds work to develop new methods and equipment that streamline data collection in the field.

The contributions for this special issue began as a symposium at the 2015 Society for American Archaeology's 80th Annual Meeting in San Francisco entitled, "Archaeological Applications of Unmanned Aerial Systems (Drones)." The primary purpose was to showcase some of the many uses of UAVs in archaeological research projects being carried out all over the world. The session was exciting, and the papers highlighted how this technology has the potential to change how we carry out certain aspects of archaeological research in the future. At the same time, it helped everyone involved realize that there is room for improvement in regards to standardizing methods and establishing best practices, especially concerning safety.

One of the issues UAV operators face in the United States is the Federal Aviation Administration (FAA) regulation of U.S. airspace. Currently, the FAA is drafting laws that will regulate the use of UAVs. While there are some policies in place, the new regulations, set to be passed sometime in 2016 or 2017, will "limit flights to daylight and visual-line-of-sight operations. It also addresses height restrictions, operator certification, optional use of a visual observer, aircraft registration and marking, and operational limits" (FAA 2015). These changes in legislation won't necessarily limit the use of UAVs in archaeological research, but there will be a series of regulatory steps that any operator will have to take to fly commercially or for academic research. Much like the procedures necessary for archaeological permitting for research or contracts on public lands or for federal projects, archaeologists will also be required to be certified to fly UAVs on any projects slated for UAV use.

Another problem confronting UAV operators is negative publicity. The handful of incidences where UAV operators have carelessly flown or crashed their drones seem to be the ones that get highlighted in the media. The use of drones in military operations overseas has also created a cantankerous atmosphere and false ideas that their use for commercial or academic purposes will lead to shady practices, like aerial surveillance in U.S. airspace. The Aerospace Industries Association (2015a, 2015b) and other organizations are working to dispel myths about UAVs with promotional materials and by focusing on their successful use in many different industries. Archaeologists should also work to improve the reputation of UAVs as they report their findings in academic outlets as well as in the popular press. We should emphasize the methods we use to maintain safety standards and follow regulations.

It is inevitable that archaeologists will continue to incorporate UAVs into their routine archaeological research programs, and the research in this issue provides just a few examples of how UAVs are used today. Because the commercial UAV industry is emerging and new technologies are being incorporated into UAVs every day, it is likely that many of the formats and systems used in these projects will be outdated by the time this issue is published. Regardless, it will hopefully start a long tradition of archaeological research that incorporates UAV technology in a way that will make for better research outcomes and a streamlined workflow.

Getting to Know the UAV Platform

The UAV platform has its origins in the 1930s pastime of radio-controlled model aircraft. The idea behind this craft was to build a realistic miniaturized model of an airplane, have it fly, and control it remotely through radio frequencies. The U.S. Air Force began experimenting with UAVs for reconnaissance missions in 1962, after the Soviet Union shot down a U-2 spy airplane and captured its pilot (Jones 1997:2). During the Vietnam War, the Strategic Air Command employed the AQM-34 Lightning Bug, a UAV the size of a small plane propelled with retro-rockets and capable of recording real-time video, photography, and electronic intelligence. This equipment was considered one of the most successful military UAVs of the Cold War. With the emergence of spy satellite programs in the 1970s (CORONA, ARGOS, LANYARD) (Parcak 2009:53), the Air Force UAV program was terminated (Jones 1997:4). The U.S. Navy re-introduced the use of reconnaissance UAVs in 1985, when it purchased a dozen Pioneer Tactical UAVs from Israel. The success of this platform in the first Gulf War and the Yugoslavian conflict of the 1990s promoted major investment in the technology. High Altitude Endurance Unmanned Aerial Vehicle (HAE UAV), like the Global Hawk and the DarkStar, represented the most advanced defense UAV of the last decade.

As has happened before, once military technological developments are declassified, they usually find wide adaptation to civilian purposes. Early adopters of UAVs in archaeology used powerful gasoline fixed-wing model aircrafts and helicopters to take low altitude imagery before 2004 (Eisenbeiss 2009; Przybilla and Wester-Ebbinghaus 1979; Quilter and Anderson 2000), but these prototypes were limited by simple navigation equipment, extreme vibration from the fuselage, and the requirements for maintaining a delicate combustion engine in difficult environments like mountainous regions and tropical rainforests (Eisenbeiss et al. 2005). Successful multi-rotor micro-UAVs hit the commercial market in 2008 (e.g., Draganfly, Microkopter), but with prices ranging from $10,000 to $40,000, many research disciplines could not afford them. Unsurprisingly, the radio-control hobbyists caught up immediately using kits with motherboards, GPS, multi-rotors, autopilot systems, electronic compasses, gyroscopes, and first person view radio-control (FPV R/C). Do-It-Yourself (DIY) UAVs with cutting edge technology can now be put together in a garage for $1,000, assuming scholars can spend valuable time on this task.

Table 1. UAV Classification (after Bendea et al. 2007).

UAV Category	Range (km)	Climb Rate (m)	Mass (kg)
Micro	1	250	<5
Mini	<10	150–300	150
Close Range	10–30	3000	150
Short Range	30–70	3000	200
Medium Range	70–200	5000	1250
Medium Range Endurance	>500	8000	1250
Low Altitude Deep Penetration	>250	50–9000	350
Low Altitude Long Endurance	>500	3000	<30
Medium Altitude Long Endurance	>500	14000	1500
High Altitude Long Endurance	>1000	20000	<1500

There are two types of UAV platforms: (1) rotary wing with horizontal primary rotors, like helicopters, quadcopters, hexacopters, octocopters, etc., depending on whether they are equipped with one, four, six, or eight engines; and (2) fixed-wing UAVs, with diverse configurations ranging from hang gliders to elliptical wings. Depending on their horizontal range and maximum altitude, they are classified from micro-UAVs to High Altitude Long Endurance (Table 1). Multicopter drones are ideal for situations that demand continual recording of data from a fixed point or the capture of data at very low elevations and slow speed. These drones are manageable due to an integrated GPS that controls its position in real time and a digital compass that allows them to hover over a fixed point and rotate on its own axis. Micro-UAVs multicopters move at speeds of up to 15 m/sec (54 km/hr). Fixed-wing drones can have cruising speeds of 80 km/hr, with ranges of 50 km, and maximum ceilings of 5000 m. In the U.S., however, the legal ceiling altitude for UAVs is only 120 m. Fixed-wing drones can remain longer in the air (40-50 minutes) and cover a larger surface area in flight. The UAV platforms can fly manually or in autopilot using waypoints and are programmed to return to the same spot from where they took off, if they lose their signal with the base station. For navigation, the off-the-shelf UAVs rely on ground flight control applications that need to be run from tablet microcomputers and cell phones. Basic flight control is provided via Wi-Fi signal. The micro-UAV platform is also very portable; many weigh between 1-3 kg and fit easily in travel bags (Figures 1 and 2). UAVs are relatively resilient and allow dozens of flights without major maintenance. Crashes do occur and propellers and rotors can break easily, but the light weight of the micro-UAVs and their polymer, EPO foam, or carbon fiber bodies prevent major damage, especially if they fall on vegetation. These qualities make UAVs formidable instruments, filling a gap unoccupied by any other platform and providing easy deployment and maneuverability compared to balloons, kites, and gliders.

Figure 1. Quadcopter DJI-Phantom 2 Vision, equipped with a built-in camera and second GoPro camera, mapping at Cantona, Puebla, Mexico (Photo by Gerardo Gutiérrez).

Figure 2. Fixed-wing photogrammetric drone, carrying a 24 megapixel Sony Alfa 6000 camera. Prototype built by students of the Department of Anthropology and RECUV, University of Colorado-Boulder (Photo by Gerardo Gutiérrez).

Photogrammetric Equipment

The drone is only an aerial platform and data acquisition needs to be performed by remote sensors, in this case by digital photographic cameras. Unless the UAV is powerful and allows heavy payloads, the weight of the camera will constrain what can be done and the quality of the topographic modeling. The ideal camera for an off-the-shelf UAV needs to be small, light, have a large capacity solid-state memory, long-lasting lithium batteries, but most importantly, a large camera sensor. Octocopters can carry 35 mm full frame Digital Single Lens Reflex (DSLR) cameras (e.g., Canon 5D and 20D with 28 mm lens) that provide detailed and high-quality images. Entry level micro-UAVs have less payload capacity, and researchers have been experimenting with a variety of compact cameras with smaller sensors (e.g., Ricoh GR with 28 mm lens; Olympus PEN E-2 with 17 mm lens; Leica M8 with 21 mm lens). These cameras capture crisp, high resolution imagery, but they can be as expensive as full size DSLR cameras, and some require an external intervalometer or electronic modifications to operate remotely. With a payload of circa 220 g, micro-UAVs could not lift a full frame DSLR camera. GoPro Hero cameras are an affordable alternative with a built-in intervalometer that can be programmed for timed shots in a wide range of time lapses and a polymer case that protects against hard crashes. We have seen drones receive significant damage after accidental crashes, while the attached GoPro camera was unharmed. The GoPro cameras have a Complementary Metal-Oxide Semiconductor (CMOS) sensor size of 1/2.3 inches that can capture an image of 12 megapixels (4000 x 3000 pixels), with a focal length of 2.9 mm.

Photogrammetric processing with UAV imagery has been simplified by the availability of commercial software (e.g., Agisoft PhotoScan, Autodesk 123D Catch, ARC 3D, Leica Photogrammetry Suite, Photo Modeler Scanner, and Recap Photo). Agisoft PhotoScan has become the standard photogrammetric program and has rendered excellent results in archaeological contexts (De Reu et al. 2013; Doneus et al. 2011; Lo Brutto 2012). PhotoScan runs powerful "Structure from Motion" (SFM) algorithms to align digital photography, which allows the generation of point clouds and polygonal meshes through multi-view stereo-matching algorithms (Verhoeven 2011). Polygonal meshes are needed to generate Digital Surface Models that vividly capture entire landscapes and their associated topography, vegetation, geomorphology, and anthropogenic elements, as well as for Digital Elevation Models.

Photogrammetry using micro-UAVs provides an alternative to topographic mapping with total stations and Real Time Kinematic Global Navigation Satellite System (GNSS) by reducing considerably both fieldwork costs and time. A modern UAV can be flown by just one person as pilot and spotter to keep track of the drone's position. Using an entry level off-the-shelf quadcopter without modifications has the potential to capture data for some 25 ha per flight (500 m x 500 m). Thus, one can prepare ground control points the first day, fly the UAV the second day, and have preliminary results at the end of the third day. The UAV platform offers archaeologists the opportunity to participate more directly in the capture and processing of raw data than they usually have with satellite or airborne LiDAR. Depending on the quality of the cameras used and the elevation of the UAV, photogrammetry provides imagery of small areas with resolutions of .5 to 7 cm (Oczipka et al. 2009); this is a pixel size that commercial satellites cannot yet provide. In just one year, from spring of 2014 to the summer of 2015, we have seen an explosion of multicopter UAV models, software, and applications that facilitate archaeological mapping, which will likely continue. Designers of fixed-wing UAVs (airplanes and wings) are also working on resolving the problems of take-off and landing using the automatic pilot in a reduced space. Fixed-wing UAVs can easily map 1 km^2 per flight with high resolution cameras and as well as a LiDAR sensor like the very expensive RIEGL VUX-1UAV or the much cheaper Velodyne models. Undoubtedly, the future looks bright for topographic archaeology.

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ARCHAEOLOGICAL TOPOGRAPHY WITH SMALL UNMANNED AERIAL VEHICLES

Gerardo Gutiérrez, Grace Erny, Alyssa Friedman, Melanie Godsey, and Machal Gradoz

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There is an emerging technology that is rapidly modifying archaeological practice: the use of an unmanned aerial vehicle (UAV) or an unmanned aircraft system (UAS), popularly known as a "drone." This technology provides a mobile and affordable aerial platform capable of carrying active and passive sensors, and it is now in use in archaeological research everywhere. Given the dramatic drop in prices for off-the-shelf UAVs, many archaeologists are beginning to use them in the field with mixed results and non-standardized approaches. This article addresses the process of learning to use an entry level UAV and its applicability to mapping areas of a couple acres to several square miles. We share here our experiences in mapping with UAVs and offer a practical workflow to obtain different photogrammetric products, especially Digital Surface Models (DSMs), geo-referenced orthophotos, Digital Elevation Models (DEMs), and pseudo-3D models for topographic mapping. The processes presented comply with the following requirements:

(1) Use only standard mapping equipment already in the toolbox of any archaeological project;

(2) Use only an entry level off-the-shelf UAV and cameras acquired with a budget in the range of $1,000, accessible to any graduate student or small project;

(3) Use systems with a smooth learning curve so that anybody could operate and deploy them safely; and

(4) Streamline a step-by-step methodology to process the data by someone with basic knowledge of cartography, topography, and GIS.

Topographic Mapping with Total Stations versus Photogrammetry with UAVs

Initial mapping experiences with photogrammetry from UAVs have presented quantitative and qualitative advantages in mapping when compared with more standard methods (Barazzetti et al. 2010; Bendea et al. 2007; Eisenbeiss et al. 2005; Karel et al. 2014; Lo Brutto et al. 2012; Oczipka et al. 2009); however, to date, no study has assessed the results of mapping the same feature with both the UAV platform and total station to establish equivalent parameters of cost, benefit, and accuracy. It is difficult to compare different mapping methods while in the field, given uncontrollable logistical variables and the high costs of performing experiments in real-time situations. A solution for this problem is to map the same feature in a controlled situation and measure the time it takes to do it with both mapping methodologies. We conducted several experiments by mapping an artificial, flattened mound of 3 ha in extent, a height of 5 m, and a volume of 70,000 m^3, located on the East Campus of the University of Colorado-Boulder, until we corrected a methodology to achieve an accuracy in the range of ± 3 cm. For this exercise, we used a reflectorless total station CST/Berger 56-CST305R with a 5-second accuracy. The UAV platform used was a quadcopter DJI-Phantom 2 Vision, modified with a 12 megapixel GoPro Hero 3+ Black Edition. The academic version of Agisoft PhotoScan Professional 1.1.6.2038 was used to process the aerial images, while the program Surfer 12 was used to generate topographic maps from both the DEM produced by PhotoScan and the XYZ data obtained with the total station.

Methodology

It took a total of 11 hours to map the artificial mound with 2,388 points using the total station. The instrument was aligned to the north of the UTM grid, WGS 84, Zone 13N, and the coordinates of the first station were obtained with a Trimble Geo 5 Series GPS. For the survey we used a mixed grid/judgmental strategy, with a 5 x 5 m grid and captured an average density of 3 points along break lines and 1.5 points on flat areas per each reticule of 25 m^2.

For UAV mapping, the first step was to establish ground control points in the field and measure their XYZ coordinates

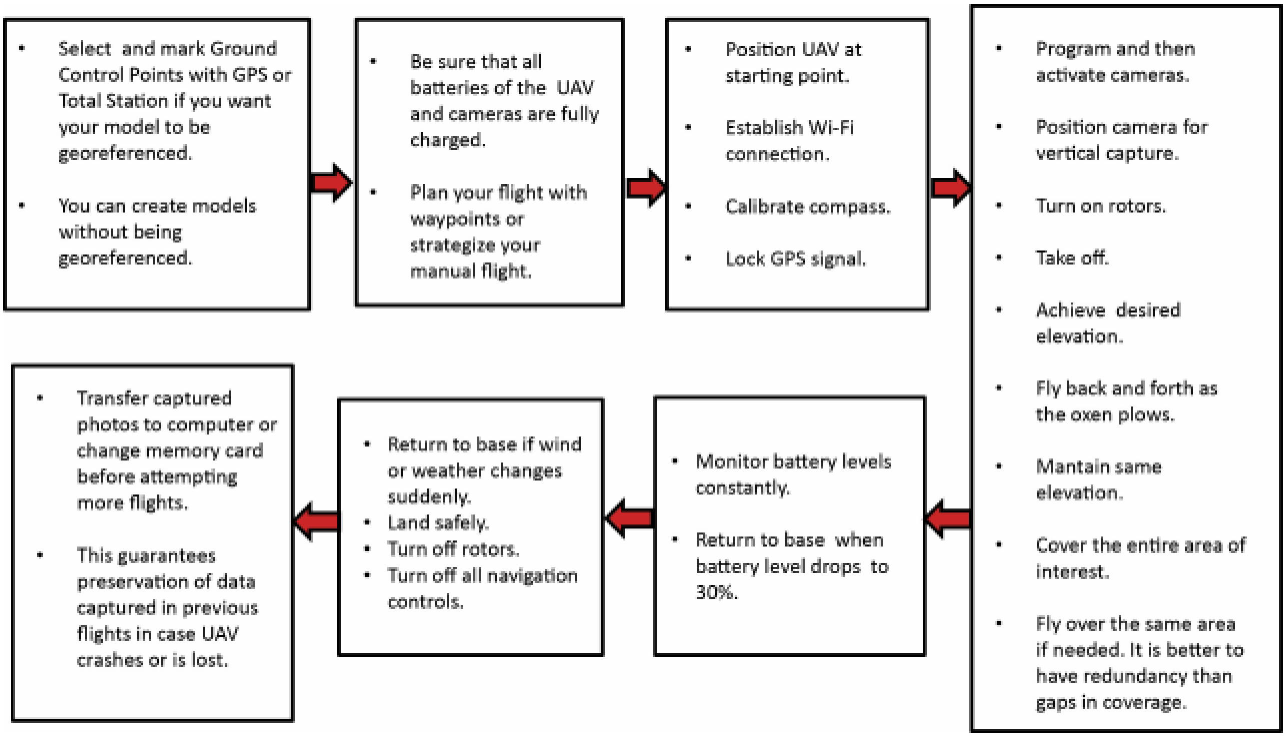

Figure 1. Steps to capture field data with UAV.

with the total station (Figure 1). Then the UAV was prepared to map the 3 ha mound and its surroundings (12 ha); one person acted as pilot, one person monitored the application, battery level, and telemetry, and one was designated as spotter to keep a constant line of sight with the drone during flight. The drone was piloted manually at 80 m from ground level at a speed of 3.3 m/s, during 8 minutes, resulting in a pixel size of 4.62 cm. The GoPro Hero 3+ Black Edition camera was programmed to take 1 photograph every 5 seconds to produce a high density of images with more than 80 percent forward overlap and side lap, guaranteeing redundancy in coverage.

Processing Data

Perhaps the best aspect of using a total station is that once the survey is finished, all the topographic data was already formatted in XYZ coordinates of UTM WGS 84 grid, Zone 13N; thus, no trigonometric processing was needed. We used Surfer 12 to run a *kriging* interpolation algorithm. In less than a half hour, we were producing contour maps and 3D models (Figure 2).

Processing data from the UAV required more steps and time. We used Agisoft PhotoScan to process 26 images taken with the GoPro camera. We used a laptop Dell M6800 with a 64-bit operating system and a processor Intel(R) Core(TM) at 2.60 GHz with 16 GB of RAM memory. We followed the workflow of PhotoScan. First, ground control coordinates were identified on the corresponding photograph. Masks were placed to eliminate areas that we did not want to include in the model. We ran an alignment, built a high-quality dense cloud and mesh, and then obtained texture. It took an hour of computer time to produce a DSM, but one must be prepared to spend sessions of four to five hours to correct errors of interpolation during the building of the dense cloud, mesh, and texture, because errors do occur. Nonetheless, the quality of the DSMs produced by PhotoScan is breathtaking and certainly worth the time invested in processing the models (Figure 3). The DSMs vividly captured precise details of the mound and the entire landscape surrounding it. The orthophoto created by PhotoScan was of excellent quality and was easily exported to Google Earth and ArcGIS, Surfer, and other mapping software. We used the data cloud of the DSM to produce a digital terrain model. For this, we exported a DEM, with one XYZ point per meter,

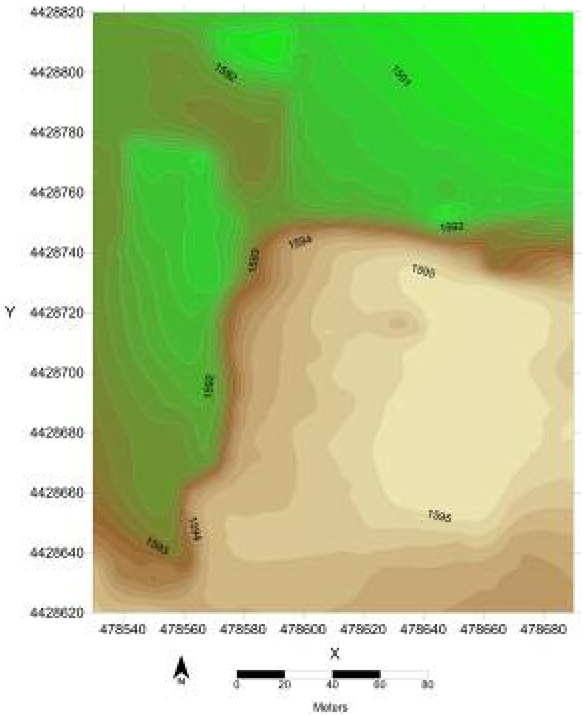

Figure 2. Contour map of the mound created from data taken by Erny, Friedman, Godsey, Gradoz, and corrected by Gutiérrez with the total station. Coordinates in UTM WGS 84, 13N; elevation in meters.

Figure 3. Digital Surface Model (DSM) in PhotoScan of the Jennie Smoly Caruthers Biotechnology Building on the East Campus of the University of Colorado-Boulder (photogrammetric data captured by Gerardo Gutiérrez).

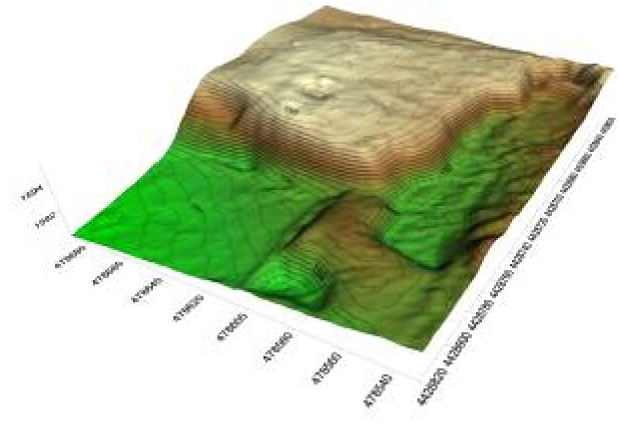

Figure 4. Pseudo-3D modeling of the artificial mound created by photogrammetry using the UAV platform. Coordinates in UTM WGS 84, 13N, elevation in meters (photogrammetric data captured by Gerardo Gutiérrez).

from Agisoft PhotoScan to Surfer 12, and we obtained a contour map showing the topography and the shape of bushes, lampposts, and cars. We returned to the mesh in PhotoScan and manually eliminated these elements, including shadows. We ran another mesh and exported a second DEM to Surfer 12. This time we produced a contour map that captures more details than that created with the total station (Figure 4). There are many factors affecting the accuracy of the model, especially photogrammetric distortion caused by vegetation and shadows and the quality of the camera lenses. The position of some images can also create high and low objects or "artifacts" that do not exist in reality and produce false XYZ values when exported to other programs. Regardless of this possible error, the results are still impressive. The critical issue here is to be aware that these types of errors may be present and may require attention during the modeling process to eliminate unwanted "artifacts" that can create high points in the topography. In total, the products obtained using photogrammetry and the UAV were: (1) a set of high-quality aerial georeferenced photographs of the area to be used in ArcGIS; (2) aerial video of the landscape; (3) an exportable mesh for post-processing in other 3D professional software; (4) a Digital Surface Model for landscape analysis; (5) a general projected orthophoto; (6) a DEM to be used in ArcGIS or CAD software, as well as in Surfer.

We have shown here how it is possible to map with an inexpensive off-the-shelf UAV and cameras; however, as with all equipment, the use of UAVs has pros and cons (Table 1). A major issue for photogrammetric mapping with UAVs is

Table 1. Pros and Cons of Total Station and Photogrammetry with UAVs.

Total Station PROs	Photogrammetry with UAV PROs
Tested	Inexpensive for entry models
Accurate	Flexible
Reliable	Smooth learning curve
Durable	Easy to operate
Easy data processing	Quick to obtain data in the field
Maps everywhere.	Many products
Total Station CONs	**Photogrammetry with UAV CONs**
	Poor mapping in dense vegetation
Expensive	Complex system prone to have failures
Steep learning curve	Accuracy depends on GCP
Difficult to operate	Processing data is time-consuming
Time consuming in the field	High risk of crash or get lost during flight
Few products	Repairs costly for electronic components
	Expensive to update to advanced models
	It will eventually crash

dense vegetation canopy, since bushes and trees will be represented as topographic elements. Shadows are problematic; thus, one should fly at times when sunlight will cast minimal shadows. Snow accumulation can also create false topographic forms. All these factors affect the accuracy of photogrammetry, especially the elevation values. Currently, the technology dramatically reduces the time needed to capture data in the field, which is significant given the costs associated with archaeological fieldwork. Still, there is a significant increase in computing time in the laboratory. To obtain a high-quality DSM, be prepared to spend many hours in front of a computer.

Overall, UAVs provide a versatile alternative mapping tool to traditional total station topographic mapping. Nevertheless, we are not saying that UAVs will completely replace standard equipment or that we can simply learn to fly UAVs and forget about formal cartographic and topographic training. Although GPS telemetry can be stored in the metadata of aerial photographs, the best modeling results depend on having an accurate armature of ground control points (GCP), and the field instruments that can provide such accuracy are the total station and the RTK GPS. Otherwise, a DSM without georeferencing is just a beautiful illustration, not a scientific tool for archaeological recording.

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LOW ALTITUDE UNMANNED AERIAL PHOTOGRAPHY TO ASSIST IN ROCK ART STUDIES

Robert Mark and Evelyn Billo

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Examples of low altitude unmanned aerial photography of rock alignments, geoglyphs, and petroglyphs illustrate advantages to researchers who require a plan view to accurately map sites that are accessible via drone flights. Land managers who need surveys or periodic documentation of sites that may be threatened by natural or human disturbance also benefit from this relatively low cost supplement to traditional forms of documentation. The use of Unmanned Aerial Systems (UAS; aka, drones) for archaeological applications is growing throughout the world. But in the United States, their commercial use has been delayed. The Federal Aviation Administration (FAA) has taken the position that a UAS can only be used for recreation until regulations are promulgated.

We first became interested in UAS technology after completing our three-year project that documented the rock art of Sears Point, Arizona. The study area included seven geoglyphs, defined as large earth figures with either geometric or representational designs, and large numbers of rock alignments, rock rings, and rock piles. During the study, a hot-air balloon traverse, a light aircraft, and even a helium-filled balloon were used to photograph some of these features (Weaver et al. 2012:35–38). None of these techniques were fully satisfactory, although all gave limited results, and the altitude at which the Cessna aircraft flew was particularly good for large overviews of the 3 km^2 study area. After the completion of the project, the DJI Phantom quadcopter became available at a relatively low price. Although it could not be used for our contract work due to the FAA interpretation of their regulations, we purchased the original Phantom, a GoPro camera, and began a new hobby. Since 2013, we have used the Phantom and the Phantom 2 Vision+ to photograph rock art panels, geoglyphs/intaglios, and rock alignments. These photographs assist in seeing associated features, such as rock piles, trails, and disturbed areas. Our first recreational activity was to photograph a very complex rock alignment near the Sears Point study area. Created from hundreds of relatively small stones that could be easily disturbed and presented an enigmatic pattern from ground level, the entire alignment would be difficult to map accurately without the aerial view (Figure 1). We are unaware of any publications that mention or discuss the origin, meaning, or use of this rock alignment. This successful flight was followed by a return to the Sears Point area to photograph some of the archaeological features best seen from the air, including the mesa top with the Agua Caliente racetrack (Johnson 1983:79). At other locations we were able to see rock alignments in the UAS photographs that we had not documented during the ground survey. The use of UAS in archaeological survey and mapping projects could substantially improve site documentation.

There are probably several hundred intaglios in the southern Arizona and California deserts, most along the lower Colorado River corridor (Ezzo and Altschul 1993:5; von Werlhof 1987:1) and generally associated with the Colorado River tribes. Many intaglios are poorly documented, and are being degraded by natural weathering processes and by human impacts including off-highway vehicle use. Wilshire et al. (2008:295), and Kockelman (1983:422–23) mention a growing concern with ORV damage to intaglios and other desert archaeological sites. Several sites have been fenced, but not always before damage occurred. Early pre-damage aerial photographs of some of the better-known intaglios exist, but they are rare. A more complete photographic record of these fragile desert features is needed. Figure 2 shows a comparison of photographs of the Parker Rattlesnake taken from an airplane in 1983 (Bridges 1986:66) and 22 years later by the quadcopter camera. Degradation in the head, tail, and body outline is obvious. In addition to weathering, visitors appear to have removed the rocks that formed the rattles. We have continued with our activities by locating and photographing 13 intaglios with the quadcopter over the last two years (http://www.rupestrian.com/intaglios.html). Figure 3 provides an example of one of the more complex designs asso-

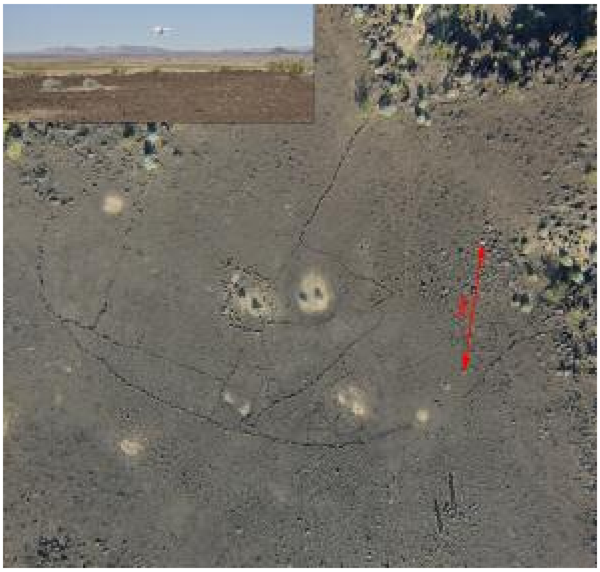

Figure 1. Complex, fragile rock alignment near Sears Point, Arizona, seen from above, and from the ground in the inset. UAS is a practical, noninvasive method to accurately document this feature.

Figure 3. One of the clusters of geoglyphs within the Ripley Intaglio complex, near the lower Colorado River, south of Blyth, California, but on the Arizona side of the river. See more examples at http://www.rupestrian.com/intaglios.html

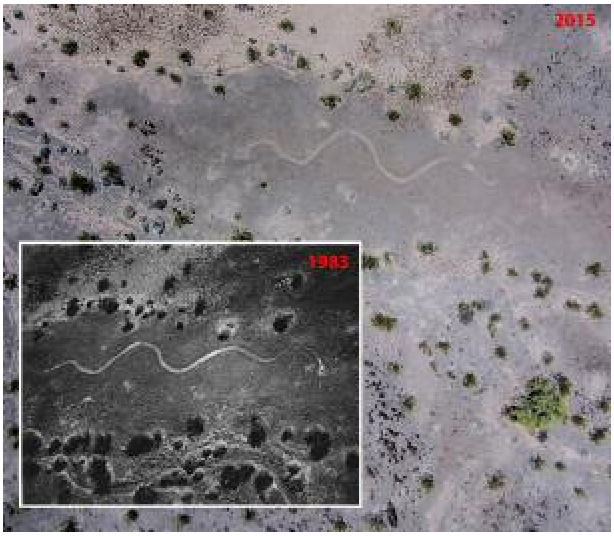

Figure 2. Parker Rattlesnake Geoglyph photographs taken 22 years apart show the effects of time. Inset, with permission, © Marilyn Bridges 1983 http://marilynbridges.com/pages/portfolio_ancient/native_america_ParkerRattlesnake_Parker_Arizona_information.html. Quadcopter image taken by Evelyn Billo using DJI Vision on the iPad to communicate with the camera on a Phantom 2 Vision+.

Figure 4. Photograph of Sky Rock, a large horizontal petroglyph panel near Bishop, California; note 20 cm scale in upper right.

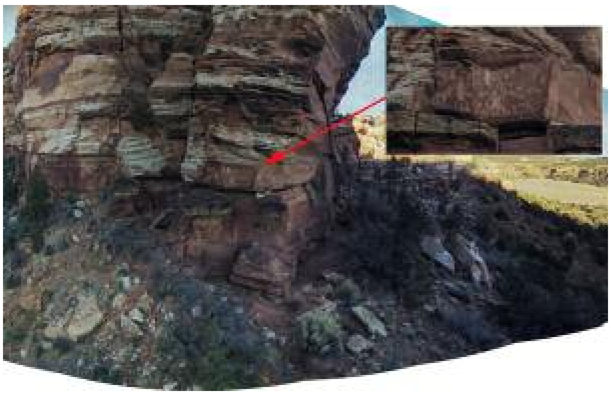

Figure 5. An inaccessible northern Arizona cliff-side petroglyph panel. Location panorama is stitched from several images taken with a GoPro camera mounted on a Phantom quadcopter.

ciated with the Yuman Creation story. This imagery from above allows updates to previously published drawings and photographs, such as the Ripley Geoglyph Complex Feature B in Johnson (2006:56), the plan view of geoglyph group 2 in Holmlund (1993:33–34), and the annotated aerial photograph in von Werlhof (2004:11). We note that each of these examples vary in detail. All photographs show the enclosed cross pattern clearly without the double lines shown by Johnson in his drawings, but confirm some other trails he shows that are not on other renditions.

Our low-altitude unmanned aerial photography system has also been useful in photographing horizontal rock art panels that cover the tops of very large boulders. Documenting panels like this with traditional methods would have required walking on the actual petroglyphs to photograph very oblique portions to stitch together. Not only could this damage the resource, it does not give the accurate perspective one gets from directly above that is shown in Figure 4. This system provides another advantage when photographing rock art that is on high cliff panels that are not otherwise accessible (Figure 5). The quadcopter camera captures the entire panel whereas images shot from ground level cannot document the lower glyphs as they are blocked from view. In addition to overhead photographs, we have used the quadcopter to take overlapping images of an outcrop on top of one of the Sears Point mesas that has petroglyphs and cupules. Photos were assembled with PhotoScan software into a 3D model. Free iOS software, Pix4D Capture, automates a flight path for photogrammetry photography. To take full advantage of these images in order to create digital elevation models or orthophotos requires the purchase (or renting) of expensive photogrammetry software, such as PhotoScan Pro or Pix4Dmapper.

Our use of inexpensive drones has demonstrated its great potential for rock art documentation; however, we are still waiting for FAA rules that permit uses beyond recreation. These regulations are in review, but the final adoption date is unknown and unpredictable. In the interim, we have applied for a Section 333 Exemption, which would allow us to start offering this technology to government agencies and other land managers who have a need to document archaeological sites from the air.

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MAPPING ON A BUDGET

A LOW-COST UAV APPROACH FOR THE DOCUMENTATION OF PREHISPANIC FIELDS IN ATACAMA (N. CHILE)

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Drones are quickly becoming common tools for archaeological fieldwork. Although hi-tech drones are still expensive and require some specialized skills, a number of low cost and ready to fly Unmanned Aerial Vehicles (UAVs) are easily obtainable and do not require a significant investment or a steep learning curve. Here, we present a landscape-oriented case study in which drones were used to complement and improve the process of data recording and documentation in the field. We focus on methodological design, results, and an assessment of costs and benefits.

Our project analyzes prehispanic agrarian landscapes in the Atacama Desert of northern Chile (Figure 1). This area is considered the driest place on earth, with an arid landscape of sandy dunes. During the Late Intermediate and Late Horizon or Inka periods, the population living in the Atacama Desert increased its dependency on large-scale agriculture, and water became an even more critical resource than at any time before. Our study assesses the built agrarian landscapes of three sites: Topaín, Turi, and Paniri (see Parcero-Oubiña et al. 2012, 2013, 2014). Our main interest is to understand the Late Intermediate and Inka agricultural systems in terms of scale, technology, and changes over time. How much terrain was cultivated? How was water managed? How was production organized? What technological changes can be observed before and after the Inkas appeared?

We first focused on building a comprehensive record, documenting the evidence available. A few important issues influenced our methodology: (1) we were limited to short field seasons (2 to 3 weeks); (2) we had only a small team (4 to 8 people) for mapping and surveying; and (3) we had excellent visibility of the archaeological features (Figure 1). The last point means that we had more visible archaeological features than in any temperate or tropical regions, but this also demanded more detailed mapping.

Given these conditions, we designed a "seeing from above" approach, which relied on extensive use of satellite imagery to assist and guide the process of field survey. We acquired three overlapping GeoEye 1 images with a spatial resolution of 50 cm in the panchromatic band, which covered an area that included the three sites under analysis. The visibility of archaeological features in the satellite images is remarkable, and it allowed us to produce a complete GIS-based spatial database in just a few field seasons. Nonetheless, we felt that these images did not provide sufficient detail in some areas to produce maps that were highly accurate. This was especially noticeable in settlements with a high density of architectural remains. For these features, we decided to rely on the UAV platform in combination with photogrammetry.

We used a DJI Phantom 1, a compact digital camera, and the Agisoft Photoscan software. The DJI Phantom is one of the most widely used entry level quadcopters because it is small, affordable, and easy to use. Still, the model that we used had a couple of drawbacks: (1) it could only be operated in manual mode; (2) battery life was 5-8 minutes with a loaded camera; and (3) it was designed specifically to work with the GoPro camera with wide-angle lens. To address these disadvantages, we brought 10 extra batteries to the field, so that we

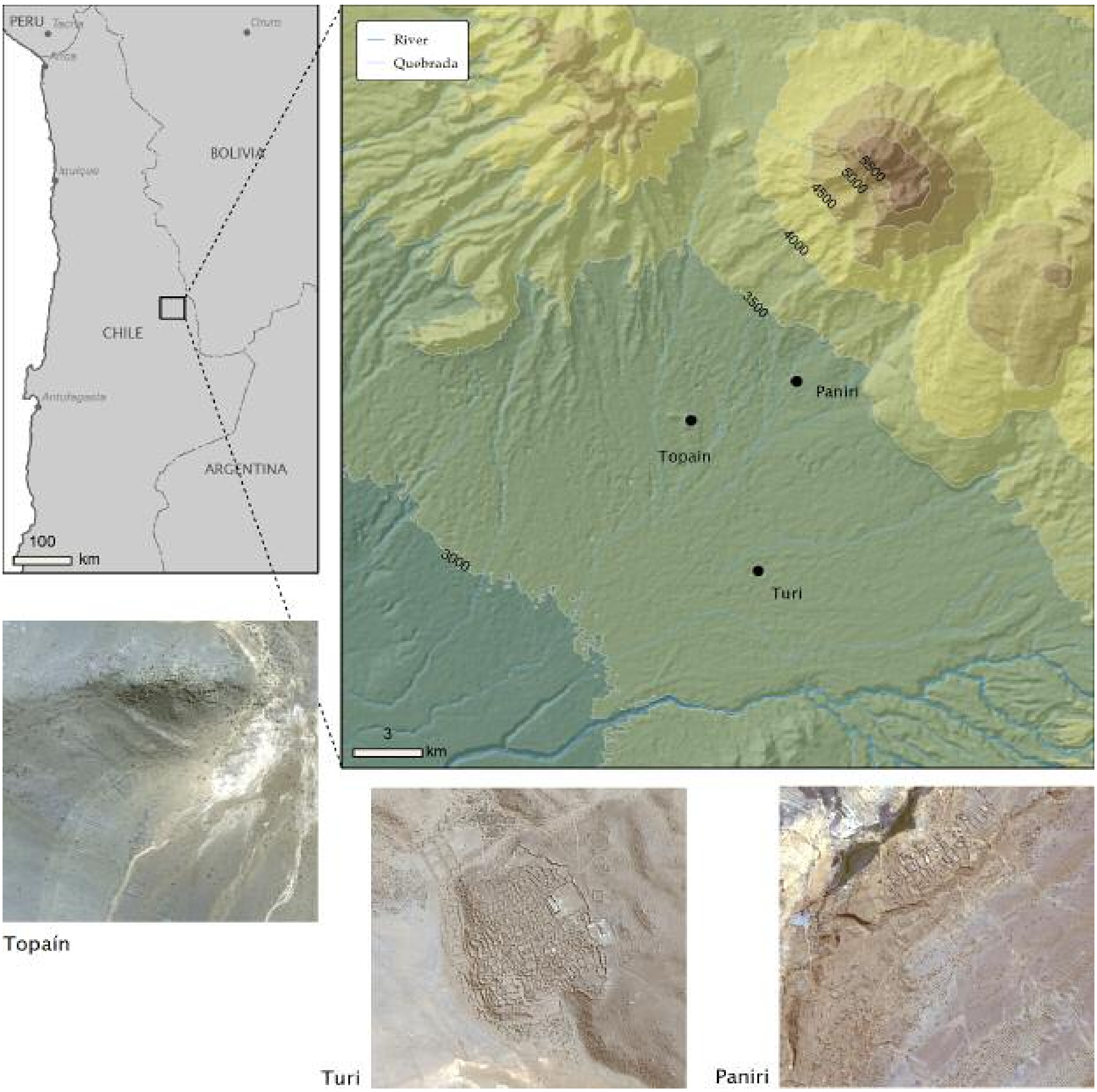

Figure 1. Location of the study area, the three sites under analysis, and aerial (satellite) view of the main settlement areas and their immediate surroundings. This image provides a good impression of how visible the archaeological features are in the field.

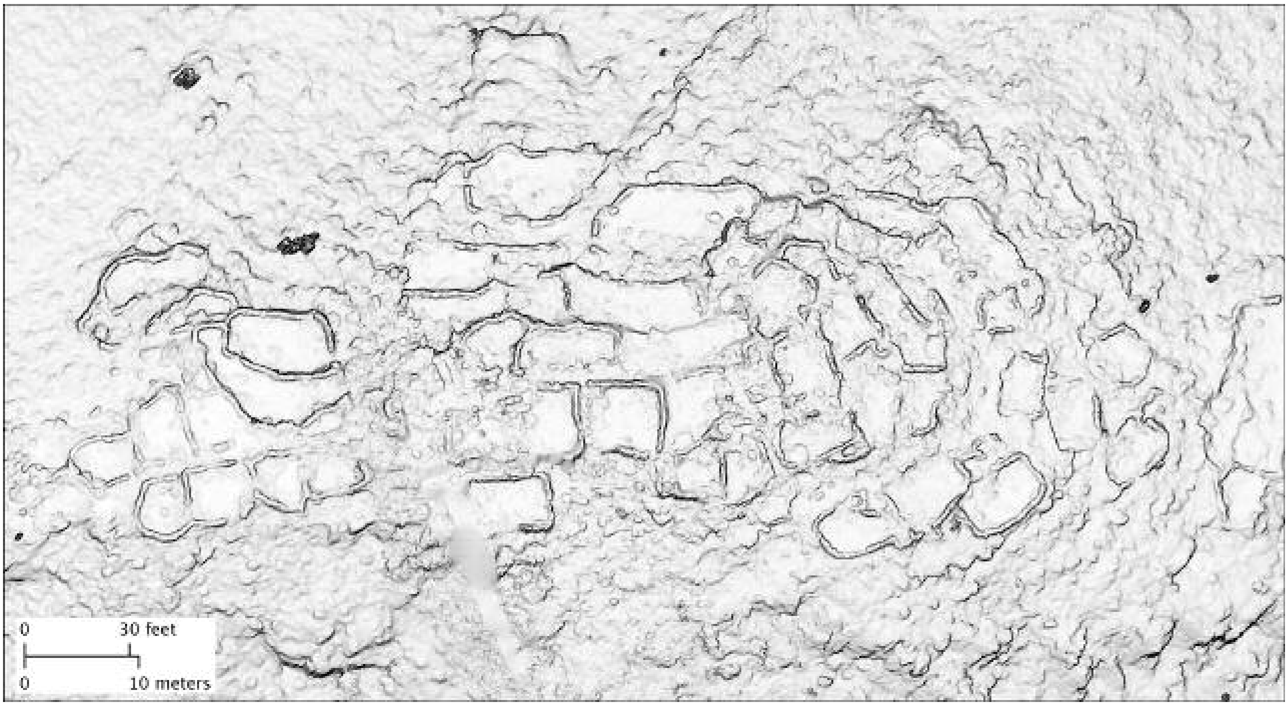

Figure 2. Sky View Factor visualization of the DSM of the central sector of Topaín. This visualization enhances the contrast between the walls and the interior of the constructions, and between them and the rocky surface of the hill. The DSM has a resolution of 1 cm.

could fly about 2.5 hours per day (including the time required to change out batteries); we also replaced the GoPro camera with a Ricoh GR-2, which was then replaced by a Canon Ixus 140 after a crash. To use the Canon camera, we installed the firmware Canon Hack Development Kit (CHDK). We programmed these cameras to work at intervals of 3 to 5 seconds, depending on wind conditions.

The lack of flight planning capabilities for the Phantom 1 was the most challenging drawback, since it is difficult to know the precise position of the drone in mid-air. We developed a field procedure to guarantee that we were taking pictures over our areas of interest by dividing these areas into quadrants and positioning the operator and two assistants on three of the quadrant's corners. The quadrant was covered by zig-zag movements, whose limits were marked by the assistants raising their arms. Considering the short battery life, the area to be covered could not be very large, so there was typically a direct line of sight between the operator and the two assistants.

In terms of results, three primary products were obtained: high resolution orthoimages (between .5 and 2 cm); detailed plans of the architecture of settlements based on the orthoimages; and high-resolution DEMs. All were produced by processing the photos in Agisoft Photoscan, a Structure from Motion software extensively used in archaeology (e.g., Verhoeven 2011; De Reu et al. 2012).

We covered the settlement areas of both Topaín and Turi, and five sections of cultivated fields in Paniri (a total area of circa 25 ha). The areas vary in size, which, combined with the slightly different resolutions of the final images, meant that different numbers of photos were needed in each case. On average, approximately 100 photos per ha produced models with 1 cm of resolution, while 300 photos per ha were needed for results with .5 cm of resolution. Figure 2 presents a visualization of the Digital Surface Model (DSM) representing the central part of the settlement of Topaín. The DSM has a spatial resolution of 1 cm. It is visualized here with the Sky View Factor technique (Zakšek et al. 2011), which highlights the flattened surfaces inside the constructions and the variability of the preserved heights of the walls delimiting them.

A good way to evaluate the usefulness of these outcomes is to compare them with what existed before. Figure 3 illus-

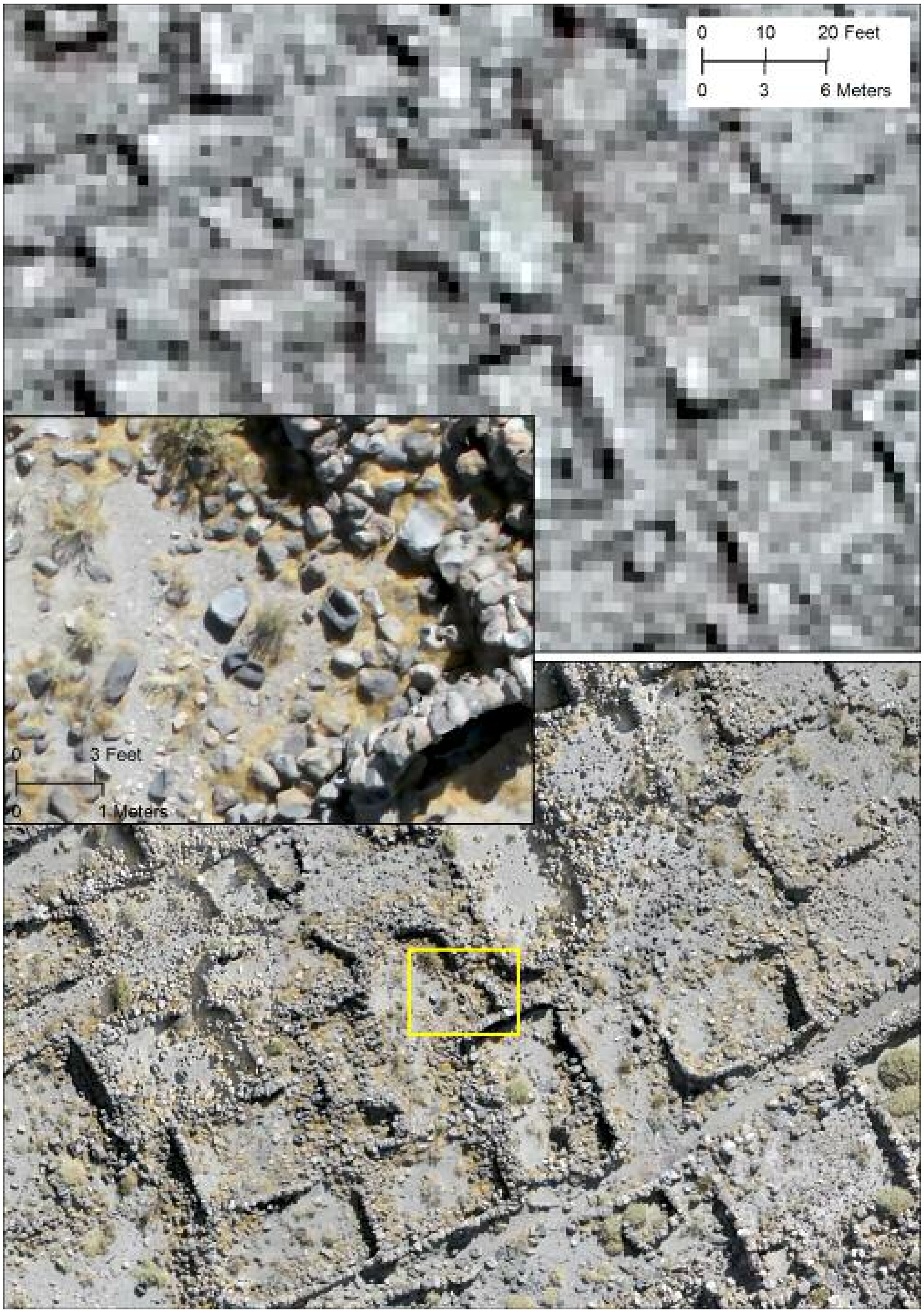

Figure 3. Comparison of a sector of the Turi settlement site as seen in the GeoEye 1 image (top) and the orthoimage we produced (bottom). In the inset, a detail from orthoimage highlights clearly distinguishable grinding stones.

trates how the settlement area of Turi appears in the GeoEye image compared to the orthoimage we produced. The improvement is obvious, especially if we assess the details: in the new orthoimage every individual stone stands out, allowing the identification of specific grinding stones located on the site surface. These images allowed us to produce detailed construction plans equivalent to drawings at a scale of 1:20.

In terms of cost-benefit, after discarding the non-usable photos (out of focus, shots taken during take-off and landing, etc., about 20 percent of the total), we ended up with almost 4,700 photos for the abovementioned 25 ha of fields and settlement sites. The working time was less than 15 hours in the field, with a four person team. The total equipment cost was around $1,500 (euros, in our case; this may vary depending on the country). Compared to the cost of equivalent work with traditional field methods (line drawings done in the field at a 1:20 scale), costs are remarkably low.

This approach was possible thanks to the conditions of the area: the excellent surface visibility of archaeological features and the very sparse vegetation, which makes a DSM almost equivalent to a Digital Elevation Model (DEM). UAV results are, in this case, part of the broader approach; by themselves, they would only provide a restricted view of the landscape. UAV use makes sense as part of a wider methodological design and as a tool to tackle specific problems (e.g., detailed recording of certain elements). In practical terms, time investment needs to include consideration of significant computer processing time, which will depend on the final products that need to be obtained.

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UTILITY OF LOW-COST DRONES TO GENERATE 3D MODELS OF ARCHAEOLOGICAL SITES FROM MULTISENSOR DATA

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With the emergence of low-cost multicopters on the market, archaeologists have rapidly integrated aerial imaging and photogrammetry with more traditional methods of site documentation. Unmanned Aerial Vehicles (UAVs) serve as simple yet transformative tools that can rapidly map archaeological sites.

The ancient Maya port site of Conil is located along the Laguna Holbox of northern Quintana Roo, Mexico. Established as early as 200 B.C., Conil supported a sizable population well into the Colonial period (Andrews 2002). Initial excavations were conducted by William T. Sanders (1955, 1960). Conil appears to have played a significant role in facilitating coastal trade along the northern coast of the Yucatan Peninsula. The aim of the aerial surveying was to obtain an accurate Digital Elevation Model (DEM) of the site that could be compared to a model that was created using a ground total station (Glover 2006).

Methodology

This investigation focused on the ability to use Structure From Motion software (SFM) for identifying Maya settlement structures. Our objective was to carry a high resolution visible light camera optimal for SFM over a large area: 2 x 2 km. The Sony QX1 offers a very high resolution sensor with 20.1 MP and an ideal form factor. We used a 20 mm fixed prime lens for optimal focal length and size. We wanted to optimize weight for a certain image quality and found the QX1 to be the best choice. Further surveying was conducted with a modified Canon S100 for Near Infra Red (NIR) imaging. NIR imaging highlights contrasts in plant colors and can commonly represent settlement features.

A 3DRobotics Aero-plane (Figure 1a) was used as well as the Volantex Ranger to carry the camera. These fixed wing platforms offered a flight range of approximately 50 km including a safety margin for landing and wind variations. The QX1 was rigidly mounted in the airframe pointing downwards to capture the data from a bird's eye view, and the shutter was triggered every second from the flight controller. The fixed wing flies at a survey speed of 17 m/s and was flown at altitudes of 100, 200, and 400 m; ground resolution at those altitudes are 1, 2, and 4 cm/pixel, respectively. SFM requires images perpendicular to all faces to optimize geometric accuracy, therefore a quadcopter was used to obtain the imagery from the sides of the elevated mounds. A custom designed and manufactured quadcopter (Figure 1b) was built for long endurance high-resolution imaging. This aircraft also carried a QX1, however, it was held in place with a brushless gimbal to maintain orientation and stability.

An open source software called Mission Planner was used to plan the waypoints of the aircrafts in autonomous flight. The pilot was required to do manual take-offs and landings due to obstacles on the field from where the platforms were launched. For the fixed wing, the software automatically generated the flightpath given the camera, altitude, and area variables. An overlap of 70 percent and sidelap of 65 percent was used to ensure that enough features were visible in multiple images, so that an accurate point cloud could be created. It is also important to have sufficient overlap in case one image is unusable due to bad focusing or exposure. For the multirotor aircraft, a point of interest was set on the center of the mounds, and the aircraft circled that point while always pointing the camera at the mound.

Figure 1. Volantex Ranger fixed-wing platform (left) and a custom designed and manufactured quadcopter (right).

Data Processing

We use Agisoft Photoscan Professional to create SFM reconstructions from our aerial imagery. Photoscan processing has multiple stages: sparse point cloud generation, dense point cloud reconstruction, meshing, and texturing. For geometrically accurate visualization, we use the dense point cloud, visualized with a custom point cloud renderer (El-Hakim et al. 2004). We mesh the point cloud, enabling the generation of a digital elevation model (DEM) and a textured photorealistic orthophoto (Figure 2).

A large amount of memory is required to process large datasets (128GB or 256GB of RAM) to meet these needs. To prepare imagery of a large area for processing, it must first be divided into individual batches which can be run efficiently (Crandall et al. 2013). Each chunk should include all the images of one region, but also have images that overlap with neighboring regions, to ensure that chunks can align well. Having geotagged images of a survey area can help in determining how to chunk the image set.

Results and Evaluation

A total of 8,000 images were collected with both the fixed wings and the quadcopter of the Conil site. They were processed in one week on a multiple computing platform to form a dense point cloud of the site. The model was composed of over 100 million points. Warping can be found when there is a lack of coverage, which is often visible at the edges of the model. To minimize any inaccuracies, only the core of the site was selected, and all edges were eliminated. Multirotor images were found to add minimal value to the geometry of the mounds; however, they were effective in adding textured detail. The ground resolution achieved was 1 cm/pixel. A DEM was derived from a mesh and the height is indicated using a color scale. It was found that there is a displacement in the model of less than 1 m over 1 km.

The dataset was cropped to highlight the features around the main mound of Conil (Figure 3). Structures 1 and 2 are both visible on the SFM dataset as they are both over 10 m tall. The trapezoidal geometry can be seen for Structure 1 on both models; however, this visualization of the DEM limits the resolution of smaller features that include elevated platforms on top of Structure 1. Smaller features, which are less than half a meter in depth, such as the *sacbe* and the structures to the South-West of Structure 1, are clearly visible on the SFM. It is to be noted that the usefulness of SFM is limited in areas with high and thick tree coverage, as there is no easily identifiable change in altitude. This can be seen in the upper right corner of Figure 3.

Conclusion

Drones provide complementary data with higher resolution and better depth models than satellite imagery. They provide a scalable solution to environments where access and surveying is difficult. It is important to keep in mind that this methodology does require skilled piloting and mission control expertise. The site of Conil was documented with the total station over a period of two weeks, while the aerial imaging for the SFM data was done in under a day, highlighting the usefulness of large scale mapping in a short time period with SFM.

Limitations of this study are due to the reduced effectiveness of using UAVs to generate SFM models in areas with tall trees, as well as high grass to see small features.

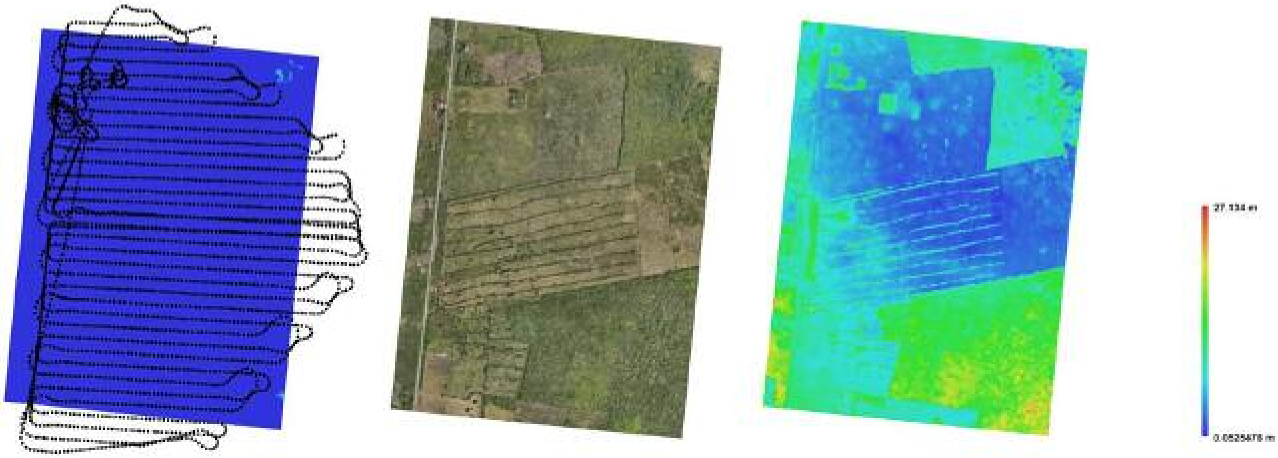

Figure 2. Point cloud and mesh used to generate a Digital Elevation Model (DEM) and an orthophoto.

The UAV platform is susceptible to environmental conditions, especially high wind speeds, which require careful planning of operations. The fine elevation variations which were picked up with the SFM show how powerful SFM is when using efficient image data and good processing. The sensitivity of the depth accuracy is on the order of a few centimeters. The DEM of the SFM data shows that all structures that were initially documented with a total station were also highly visible in the DEM of the aerial dataset, in addition to new ones not previously documented. The use of total stations will remain critical to accurately obtain points in the field from which the DEM can be georeferenced.

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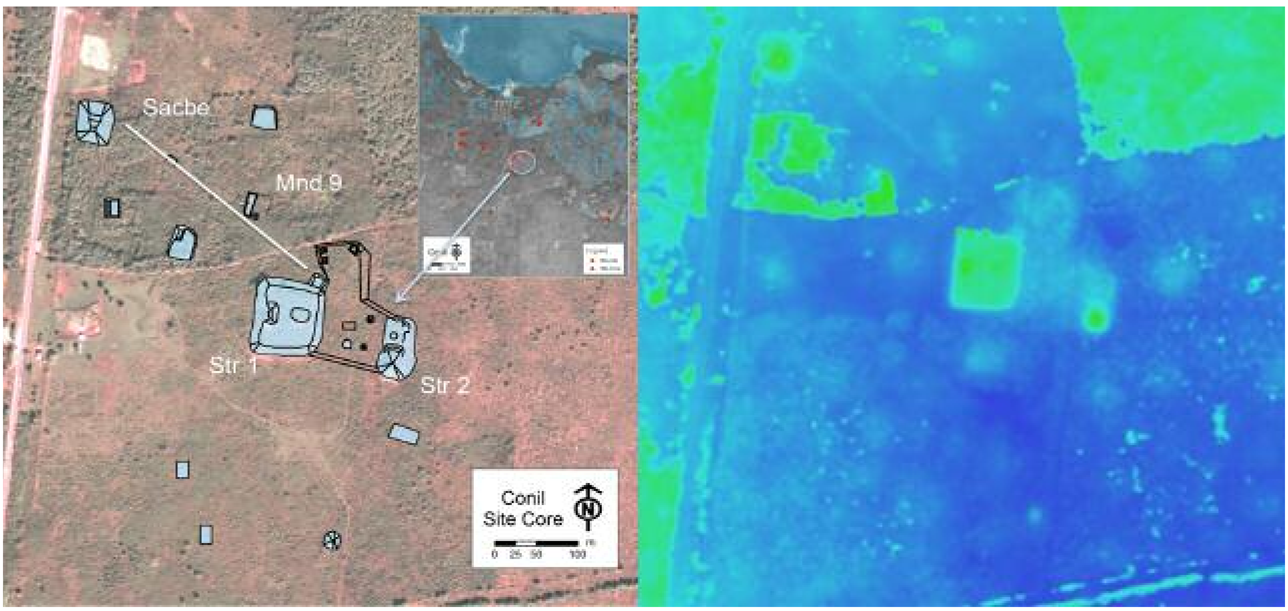

Figure 3. Structures 1 and 2 of Conil. Note that the usefulness of SFM photogrammetry is limited in areas with high and thick tree coverage.

PROCESSING A DETAILED DIGITAL TERRAIN MODEL USING PHOTOGRAMMETRY AND UAVS AT CERRO DE LA MÁSCARA, SINALOA, MEXICO

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Unmanned Aerial Vehicles (UAVs)—better known as drones—are becoming the must-have tool in archaeological survey (Lasaponara and Masini 2011). Here, I present the case study of Cerro de la Máscara to test the combined potential of the UAV platform, Structure from Motion photogrammetry, and GIS post-processing.

Cerro de la Máscara, Sinaloa, Mexico

Cerro de la Máscara (Hill of the Mask) is an archaeological site where more than 300 petroglyphs have been reported. It is situated 200 km north of Culiacan, in the state of Sinaloa, Mexico, along the northwest margin of the Fuerte River.

In 2014, we surveyed Cerro de la Máscara to clarify its legal boundaries and to create a topographic map of the terrain. Given that the rugged terrain and thorny vegetation of Cerro de la Máscara would have made it difficult and dangerous to map with a total station, we decided to survey it using photogrammetry with images captured from a UAV platform.

We used a DJI Phantom Vision 2+, a total station and a GPS unit, and the software Pix4D Mapper (Capture), AgiSoft Photoscan Pro, LASTools, EXIF Tool, and ArcGIS 10.1 with the Geostatistical Analyst extension. We first placed ground-control points with the Total Station around the area to be mapped with the drone (Figure 1). We then placed pink 30-cm-diameter markers large and contrasting enough to be visible from the air. Since the camera included with the DJI Phantom Vision 2+ has a fish-eye lens, it required locating the points within the middle of the flight path to avoid distorted photos, which result from images taken on the margins of the lens. The newest versions of Agisoft Photoscan are expected to correct some of this lens distortion, but, in the process, the photographs will be cropped at the edges.

Using the free application Pix4Mapper Capture (Beta), which is a ground station designed exclusively for a DJI Phantom Vision 2+ with no need of a NAZA mode controller, a total of 63 photographs separated by 10 m each were taken atop Cerro de la Máscara (Figure 2). Pix4Mapper can control the flight automatically from take-off to landing, take all the photos, and simultaneously rectify the GPS EXIF data while downloading the photos into an electronic device, such as a smartphone or a tablet. The problem with Pix4Mapper is that it records the flight elevation with reference to the departing point (e.g., 50 m) and not the actual elevation above sea level. To create a georeferenced image, one needs to delete the altitude information from the GPS EXIF data using the Exif Tool: (for Windows use [—-Delete altitude tag (e.g.): exiftool -a -gpsaltitude= *.jpg"]; for Linux: [./exiftool -a -gpsaltitude= /home/DIRECTORY/]).

The images of Cerro de la Máscara were processed with Agisoft Photoscan in a PC Intel Core 7, with 8GB RAM using GPU processing (8 cores). In less than one hour, the photos were processed, with optimized coordinates for the camera positions. In less than three hours, the Digital Surface Model of Cerro de la Máscara was finished. The orthophoto was exported along with the point cloud as a LAS file (1,588,085 points), which is a public file format to store LiDAR 3D point cloud data. The point cloud was processed in ArcGIS using LAStools, a free, open-source set of multi-platform tools to process point cloud data. First, the module *lasground* was used to extract bare-earth points from the entire point cloud. It classified the point cloud generated on Photoscan into ground points (class = 2) and non-ground points (class = 1). Since Cerro de la Máscara is a rocky, steep hill, the options "wilderness" and "ultrafine" were selected to process this dataset, investing more computational time in finding the initial ground estimate and taking into account

Figure 1. Some of the ground control points. Here, the image has already been cropped.

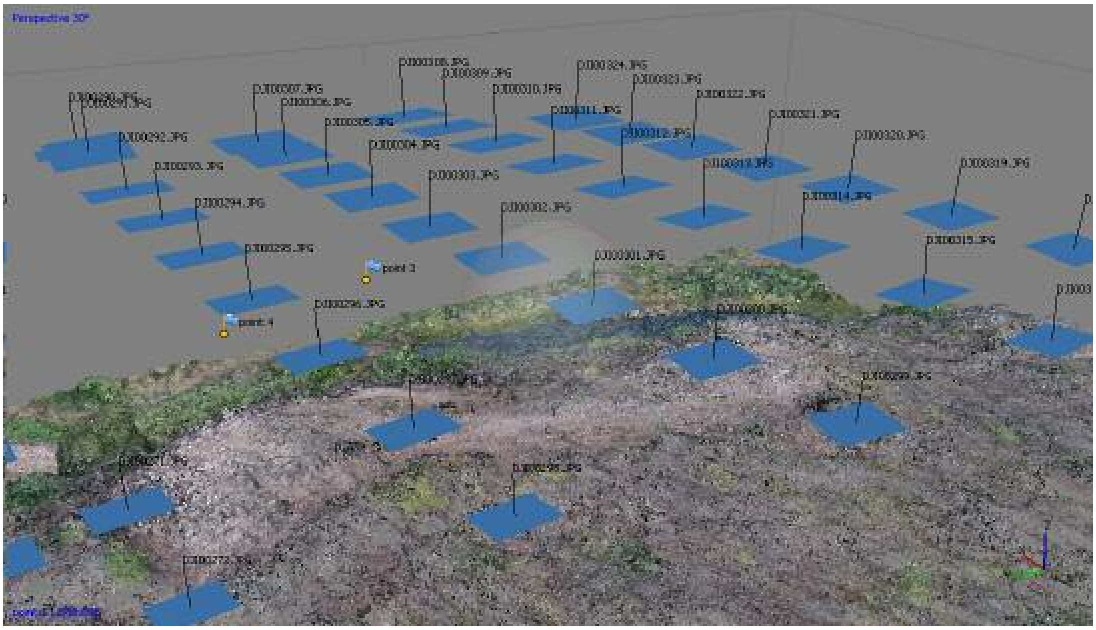

Figure 2. Photo grid on Cerro de la Máscara.

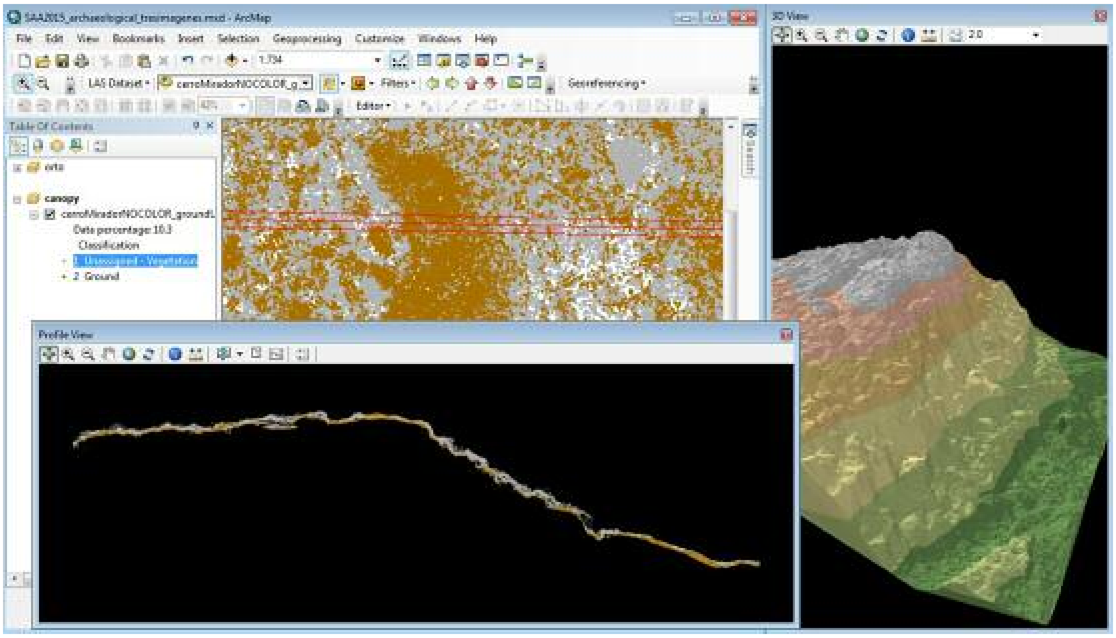

Figure 3. LAS dataset toolbar and some features to explore with the point cloud.

the vast amount of vegetation cover on the hillslopes. Afterwards, *las2las* was used with the option "keep_class 2" to extract only the ground points.

The resulting point cloud can be used as is directly in ArcGIS. The LAS Dataset toolbar allows the immediate conversion of the point cloud into a contour map, an elevation map, or even a slope or aspect map using a triangulated irregular network (TIN). Also, a 3D model and a profile of the point cloud can be displayed (see Figure 3). Nonetheless, in order to obtain a smoother surface, a different method from TIN was used. The point cloud was interpolated with a geostatistical method called ordinary kriging, using the Geostatistical Analyst extension in ArcGIS. Kriging has been tested many times in order to measure its reliability as a predictor of unknown values. Particularly when the samples are randomly distributed (e.g., elevation values), kriging can accurately predict unknown values of a finite sample when contrasted to a set of known values (e.g., bare-earth points) (see Li and Heap 2014; Oliver and Webster 2014).

In less than 24 hours, a Digital Terrain Model (DTM) from Cerro de la Máscara was completed, along with an orthophoto and a Digital Surface Model (DSM). Most of the canopy had been removed and kriging helped us to fill in the gaps among the observed points. In Figures 4 and 5, it is possible to see the differences between the DSM and DTM in the slope and hillshade maps. In the DTM, the slopes of the hills are preserved, but those "slopes" related to vegetation are removed. It must be noted that the quality of the model and its accuracy are related to the quality of the photos and how they were taken (resolution, lens deformation, altitude, and quantity). Since the pixel resolution and information gathered to generate this surface were taken 50 m above the ground, some rocks are not depicted properly in the DTM, even though they are part of the ground surface; nor are they processed as part of the vegetation due to the algorithm used by LAStools. Here, I would highlight that if we increase the quality and resolution of the photos and the overlapped areas, we also increase the accuracy of the model; therefore, LAStools will create a better bare-earth point cloud (Class 2) but at the cost of increasing the computing time and hardware resources.

This method clearly complements and enhances traditional topography with a total station and LIDAR. With the addition of the UAV platform, archaeologists can take advantage of the full potential of aerial imagery by controlling when, how, and where to take a picture at a very low cost. With some initiative and not much money, one can create a sophisticated mapping system equipped with high-resolution multispectral photogrammetry and, in the near future, even LiDAR sensors. Drones will save time in the field and change the way we do archaeological mapping.

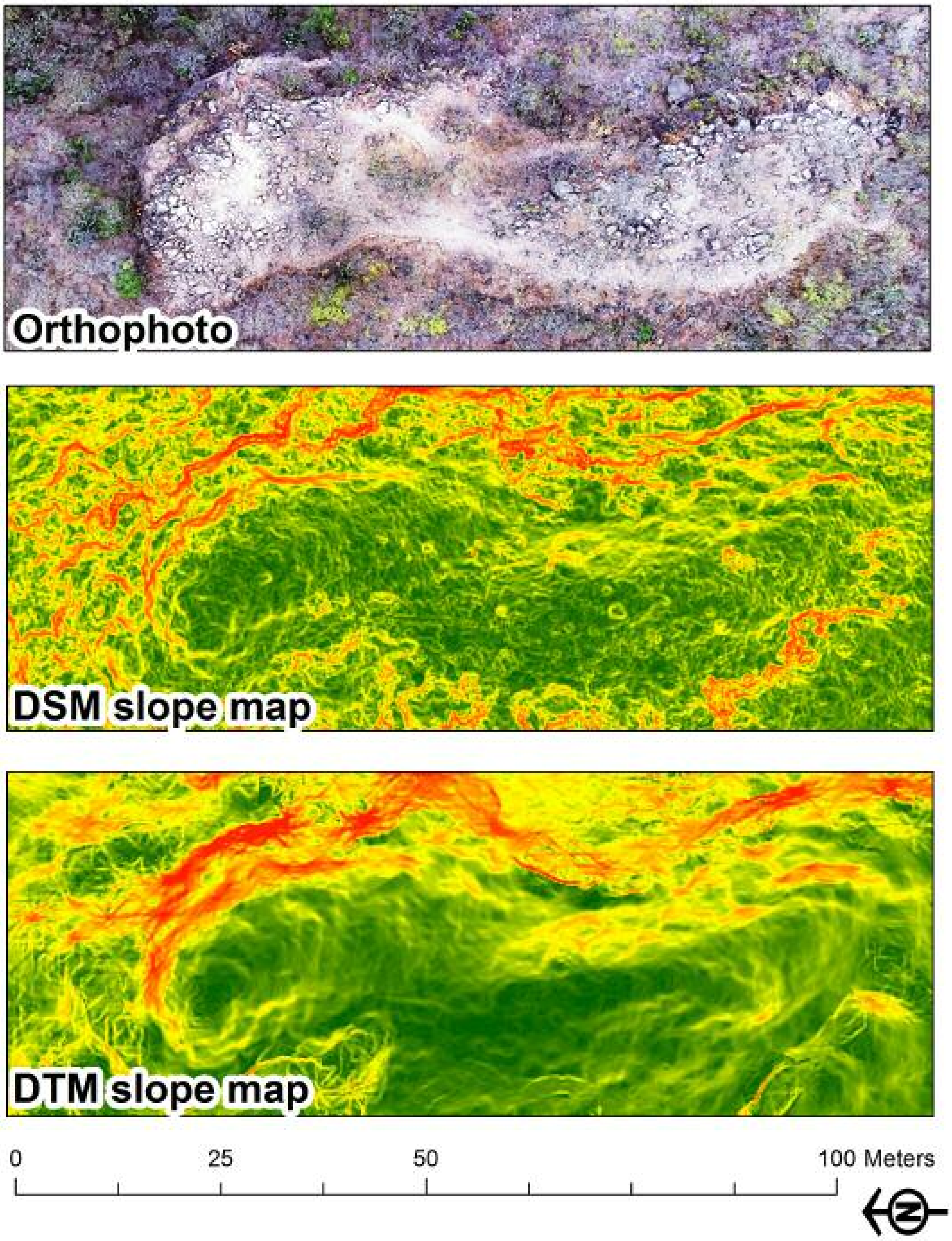

Figure 4. Comparison of slope maps.

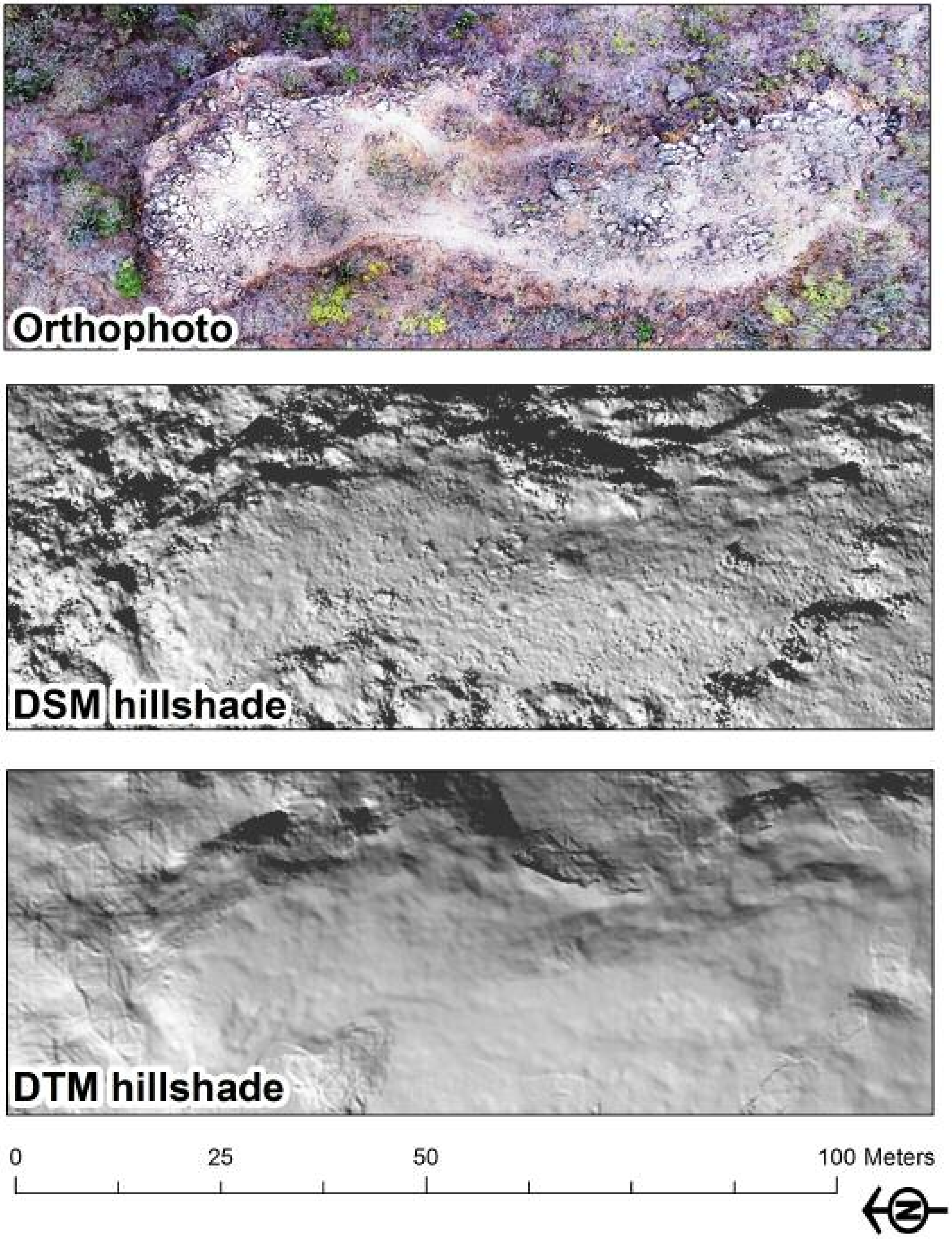

Figure 5. Comparison of hillshade maps.

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USING DRONES IN A THREATENED ARCHAEOLOGICAL LANDSCAPE

RAPID SURVEY, SALVAGE, AND MAPPING OF THE MAYA SITE OF SATURDAY CREEK, BELIZE

Eleanor Harrison-Buck, Mark Willis, and Chester Walker

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Unmanned Aerial Vehicles (UAVs), otherwise known as drones, offer a relatively inexpensive method for rapidly surveying and mapping archaeological sites in open areas with minimal vegetation and are particularly useful for salvage situations where sites are under threat of destruction. Drones are becoming increasingly common in archaeology because they offer a powerful and effective method for revealing surface and subsurface features of archaeological sites (e.g., Casana et al. 2014; Smith et al. 2014; Wernke et al. 2014). UAVs offer an efficient means of collecting extremely high-resolution imagery in open areas with broad aerial coverage, such as cleared pasture and agricultural fields. In optimal conditions, drones can produce aerial mapping and 3D landscape modeling with centimeter accuracy. In the case of Saturday Creek, an ancient Maya site in Belize (Central America), photogrammetry with UAVs offered an optimal aerial technique for mapping large portions of the site (Figure 1). While the site core is located in bush, the majority of the Saturday Creek hinterland settlement is located in open fields that were mechanically cleared of jungle vegetation between 10 and 25 years ago. Over the years, most of the stone—the remnants of once intact ancient Maya architecture—have been systematically removed by Mennonite farmers to avoid damage to their plows. The repeated plowing and removal of stone has shaved off more and more of the mounds each year, making it difficult to discern them on the ground, especially in the case of the smaller mounds (Lucero et al. 2004). Salvaging what we can of Saturday Creek before further destruction occurs is a primary goal of the Belize River East Archaeology (BREA) Project and was one of the reasons for using UAVs to photogrammetrically map the settlement in the open agricultural fields.

Mapping the Site of Saturday Creek with Drones

The drone mapping at Saturday Creek was aimed at documenting the hinterland settlement before further damage to the mounds occurs. When Willis and Walker arrived at Saturday Creek in January 2014, the hinterland settlement had just been plowed, but not yet planted, creating optimal visibility. The fresh plowing churned up artifacts, and numerous scatters of material culture were readily visible on the surface. Because there was little to no vegetation cover, even the lowest mounds were visible and subtle archaeological features were detectable with photogrammetric survey. In less than two days, Willis and Walker flew four drones across an area of Saturday Creek measuring roughly 7 km^2. They used two different kinds of drones, a multi-rotor UAV called a MikroKopter Hexakopter and an ardupilot fixed-wing drone called a Swinglet CAM. These ready-to-deploy, lightweight UAVs have onboard systems that include a digital camera, a GPS, and a radio receiver, which is controlled by a ground-based computer via a 2.4GHz radio modem for data transfer. A total of 14 missions were flown with the Swinglet CAMs and another eight flights were flown with the multi-rotor UAVs. A total area of approximately 620 ha (1,530 acres) was mapped in approximately eight hours of fieldwork and yielded about 2,500 high-resolution photographic images.

For high-resolution mapping, the goal is to generate a very dense Digital Terrain Model (DTM), which produces an aerial photo-mosaic and recreates the topography of the region. This is accomplished through a digital process called photogrammetry that extracts 3D data from a series of overlapping images using commercial photo-merging software. To link the series of aerial images of Saturday Creek, a series of Ground Control Points (GCPs) were placed on the ground at

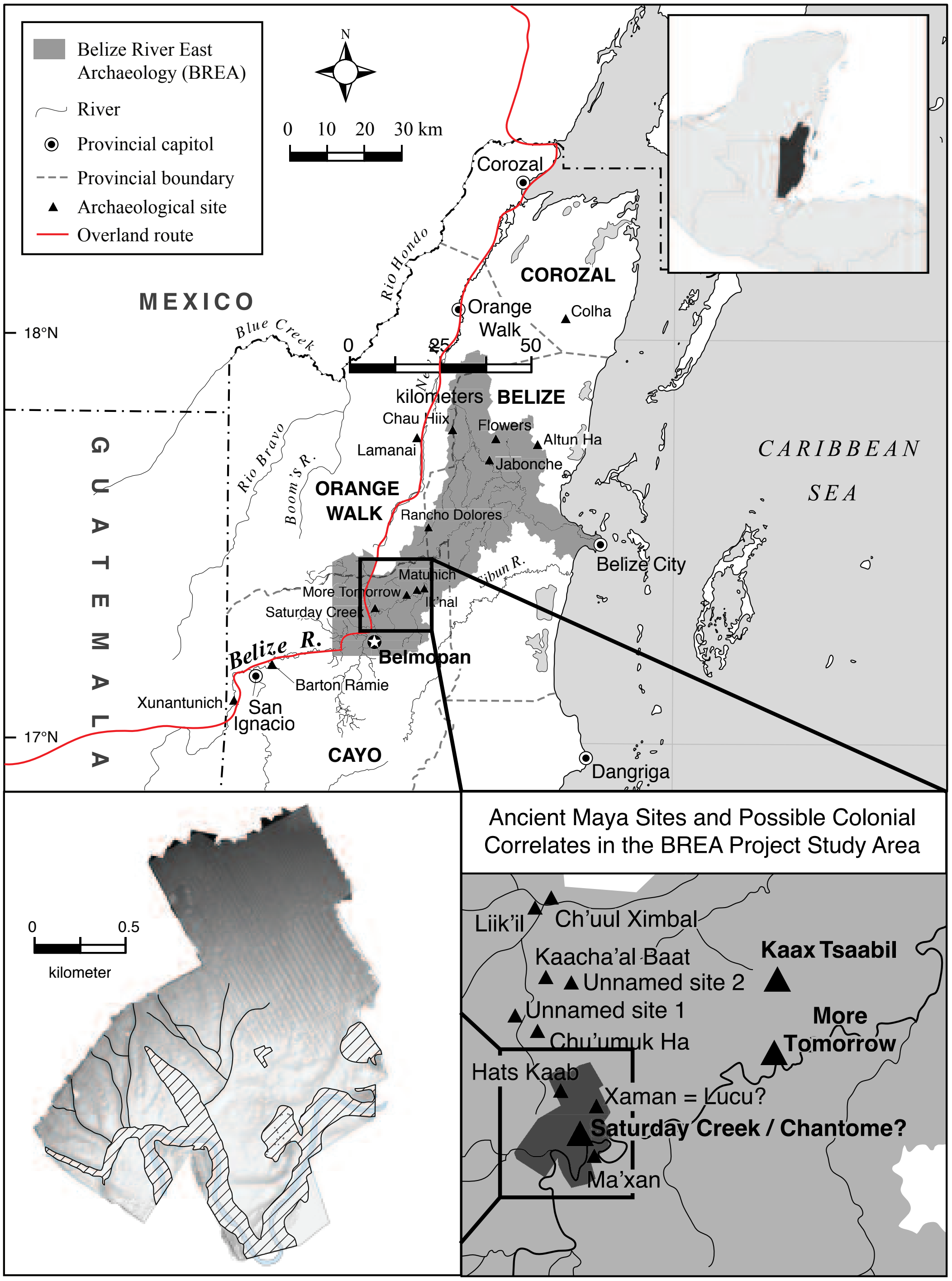

Figure 1. The BREA Project study area, shown in gray (above) with two inset maps (below) demarcating the drone survey area (map prepared by M. Brouwer Burg).

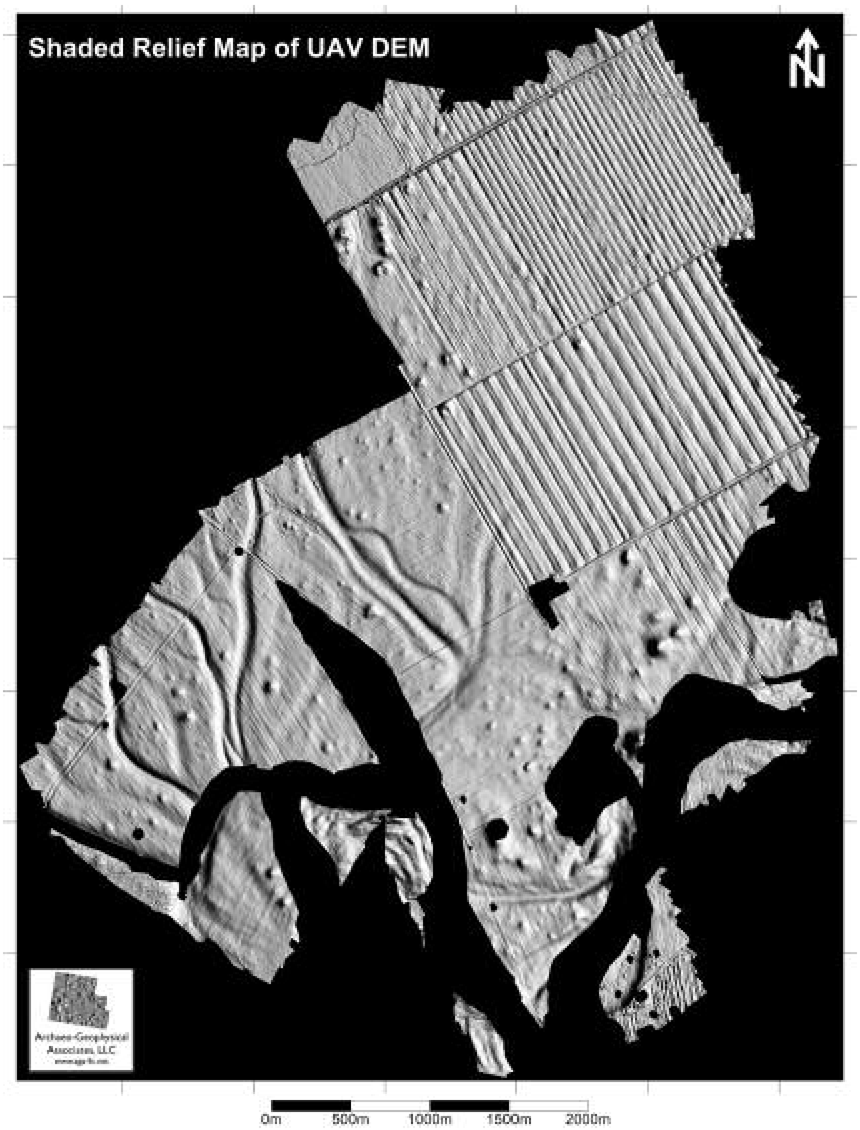

Figure 2. DEM with virtual illumination highlighting mound presences (created by M. Willis).

several geo-referenced locations in the open fields prior to the UAV flights. Under optimal conditions, the precise location of the imagery can be established to within ± 10 cm. The software uses the estimated camera positions of all the tiled images to derive a 3D polygonal mesh of the ground surface, producing a digital elevation model (or DEM). Using Global Information Systems (GIS) software, a hypsographic map was created with 5-cm contours as well as a slope model.

Results

At Saturday Creek, the low house mounds in the hinterlands are difficult to discern on the ground due to repeated plowing over the years and removal of stone from the mounds. After analyzing the 3D data, an unprecedented number of archaeological features were identified in the open fields. Most of these appear to be small earthen mounds that are low to the ground, which we interpret as the remains of

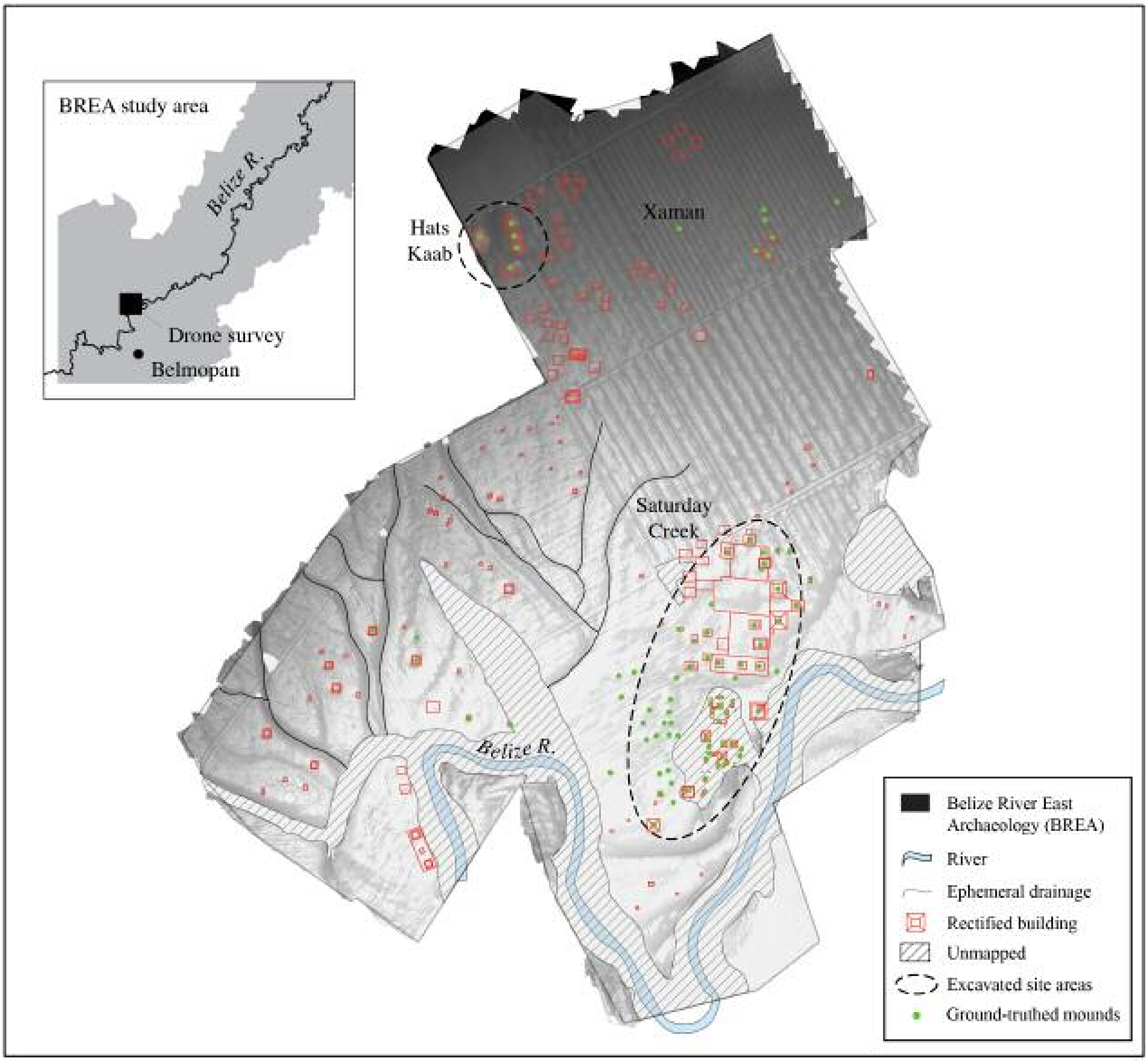

Figure 3. Rectified map of Saturday Creek site core and hinterland settlement (created by M. Brouwer Burg).

ancient Maya platform structures. These mound features become more obvious in the GIS when a virtual light source is used to illuminate the model from highly oblique angles (Figure 2).

The densest settlement appears to be to the north of the site core in the vicinity of Hats Kaab. This large complex resembles an ancient Maya E-Group architectural configuration. It contains a triangular arrangement of structures that may have served to commemorate astronomical events, among other functions (Brouwer Burg et al. 2015; Runggaldier et al. 2013). Although most of the hinterland settlement consists of small to medium sized mounds, the Hats Kaab complex represents one of the more substantial plaza groups in the hinterland area, located about a kilometer to the north of the Saturday Creek site core. The Hats Kaab group was cleared of forest about 10 years ago and, according to locals, the mounds were bulldozed substantially. During the summer of 2011, the Hats Kaab complex that covers an area roughly 380 m x 350 m was mapped with a Nikon TDS by the BREA survey team (see contributions in Harrison-Buck 2011). This involved the collection of around 1,000 data points with the Total Station, which took about two days (roughly 14 hours) to map. In January 2014, Walker and Willis were able to map this same area in about three minutes using drones. Both produced comparable contour maps of the mounds. The map created with the TDS has the advantage of the archaeologist's trained "eye," catching precisely what is there and in some cases recording small details that are not picked up in the photogrammetric map. The map produced by the TDS is also "cleaner" than the photogrammetric image, omitting certain things, like plow marks, that the unmanned drones do not filter out. However, the expedience of the UAVs is unparalleled. In less than two days (the total time it took to map Hats Kaab with the Total Station), Willis and Walker were able to cover an area over 50 times the size of Hats Kaab and expediently map an archaeological landscape that consists of a dense and expansive regional settlement. The results of this study leave little doubt that in high-risk situations, such as Saturday Creek, where destruction of the archaeology is occurring at a rapid pace and time is of the essence, drones offer a fast and effective solution, providing detailed maps of a site in a fraction of the time it takes to map with a Total Station. We produced a preliminary rectified map of the drone survey based on a combination of the aerial imagery, elevation data from the DEM, and groundtruthing (Figure 3). The green dots on the map show the mounds that have been verified to be archaeological in nature via pedestrian survey. These locations contained evidence of mounded architecture, and surface inspection also revealed associated artifact and/or daub scatters on nearly every mound feature. A cursory inspection of the diagnostic ceramic material found on the surface indicates that many of these structures were continuously occupied from Preclassic to Postclassic times (ca. 500 B.C.–A.D. 1200).

Discussion

The results of the photogrammetric mapping with UAVs reveal startling new data on the settlement density around Saturday Creek. We can now say that Saturday Creek was a large city center with a densely settled supporting population. We believe it served as a central node on the landscape and continued to be densely populated through time because of its location at an important crossroads. The Spanish accounts suggest that the overland route extended south from the Chetumal Bay in Mexico to the head waters of the New River in Belize, known as Ram Goat Creek, and then continued overland through swamp and pine savannah until it reached a partially submerged "natural bridge" of stone that the Spanish used to cross Labouring Creek (Jones 1989:138, 312, [n.35]; see also Scholes and Thompson 1977:45). From there, the route was said to head south overland to an arrival point on the Belize River named "literally, 'the hamlet where Chantome had been'" (Jones 1989:287–288), suggesting that this site was no longer occupied when the Spanish arrived. We believe that Chantome is the ancient name for the Saturday Creek site (see contributions in Harrison-Buck 2011, 2013, 2015).

Over the past several BREA field seasons, we have attempted to further define the location of the north-south overland route and the associated Contact-period settlement. We conducted a least-cost path analysis in GIS, isolating the most efficient route for movement across the landscape (Brouwer-Burg et al. 2014). We carried out a series of pedestrian survey transects and identified a string of Maya settlement that runs roughly north-south in a linear path between Labouring Creek and the Saturday Creek site (Harrison-Buck 2015). In addition, we carried out a series of test excavations in the Saturday Creek site core and have found evidence of Spanish artifacts in the context of Maya ritual cache deposits, lending support to the identification of this site as Chantome (Harrison-Buck 2015). Finally, although further testing is needed, the results of the drone survey present evidence of particularly dense settlement to the north of the Saturday Creek site core in an area we refer to as Xaman, which we believe may represent the town of Lucu.

Concluding Thoughts

In the tropics, archaeological sites like Saturday Creek that have been subject to modern farming practices for years are thought to have little to no archaeological value because of the highly destructive nature of the bulldozing and repeated plowing. In the Maya Lowlands, these sites are often ignored by archaeologists in favor of sites covered in forest. Yet, despite the impacts of industrialized agriculture at Saturday Creek, surface collection and excavation of the E-Group has demonstrated that a large amount of archaeological data still exists even in the midst of this highly effaced earthen architecture (Brouwer Burg et al. 2015; Runggaldier et al. 2013). Moreover, the UAV aerial imagery shows the existence of numerous preserved earthen mounds that, in many cases, are almost imperceptible when standing on the ground. The drone results from Saturday Creek—a site that has endured repeated plowing for as many as 25 years—demonstrates that these damaged archaeological landscapes are worth salvaging and can yield valuable data.

As a mapping tool in archaeology, drones are more commonly used in naturally open areas with exposed ground, such as barren deserts or xeric shrublands (Casana et al. 2014; Smith et al. 2014). Although few have considered using drone technology for mapping in the tropics, numerous archaeological sites are bulldozed and cleared of bush every year as a result of industrialized agriculture. Our study of Saturday Creek attests that UAV technology is particularly useful for providing detailed 3D maps of dispersed settlements across large expanses of open fields, which would be time-consuming and arduous to map with a TDS. Moreover, the Saturday Creek drone data produced a Digital Terrain Model (DTM) that contained over 100 million individual elevation points, which is comparable to the resolution collected by LiDAR systems, but took a fraction of the cost and time. Photogrammetric mapping with UAVs offers an inexpensive and expedient method for salvaging important site information before it is further damaged or erased all together.

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TECHNOLOGY IN THE SKIES

BENEFITS OF COMMERCIAL UAS FOR ARCHAEOLOGICAL APPLICATIONS

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With the ability to generate on-demand, high-resolution imagery across landscapes, unmanned aircraft systems (UAS) are increasingly becoming the tools of choice for geospatial researchers. Low-elevation aerial platforms are uniquely suited to disciplines that require data that can be rapidly generated over large spatial areas at relatively low cost, yielding outputs with high spectral, spatial, and temporal resolutions.

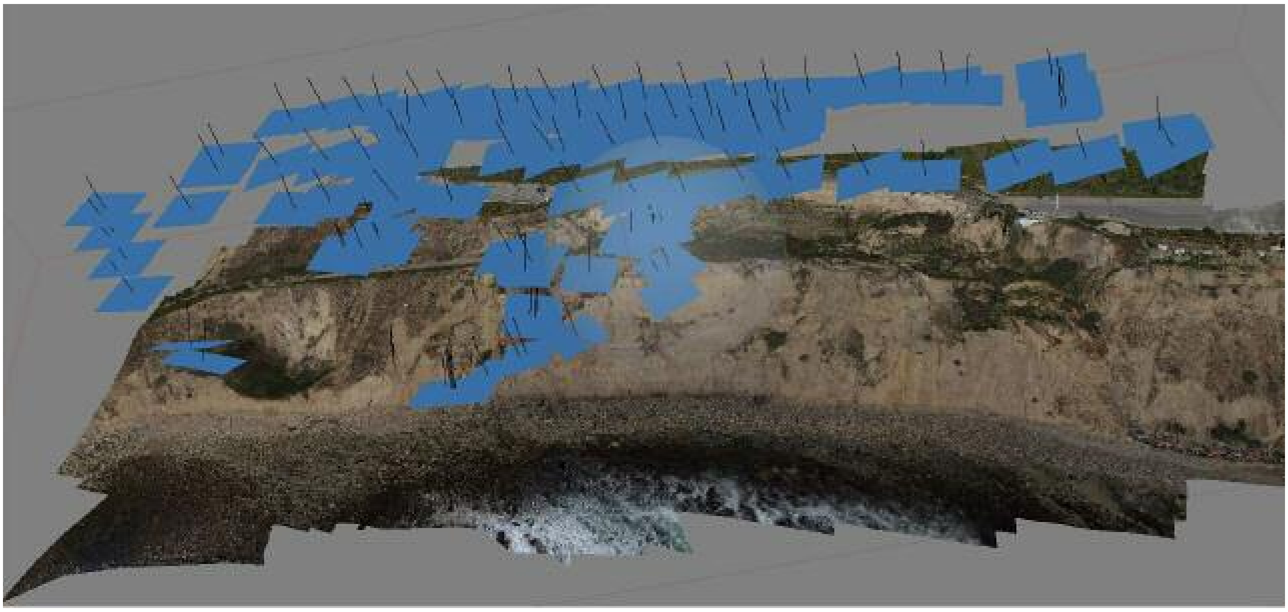
At California State University-Long Beach (CSULB), we have initiated a program to deploy and evaluate a number of UAS designed to conduct archaeological, land cover, and terrain analyses. We have collected aerial imagery using kites, blimps, fixed wing hobby aircraft, and quadcopters and have obtained varied results. Our findings indicate that if the goal of an acquisition is to generate a mosaicked image for visual reference, then lower-cost platforms such as kites, blimps, and quadcopters are likely to be sufficient. If, however, the goal of an aerial acquisition is to generate remotely sensed imagery that can be used for accurate and precise assessment of locations on the ground, imagery should be systematically generated to permit temporal analyses and longitudinal studies. Although the upfront costs are higher, we have found that the use of a high-end commercial UAS solution provides the most reliable results and that the products warrant the greater initial investment. Here, we describe our experiences using a commercial UAS solution—the first generation Trimble X100 and second generation UX5.

UAS

The ability to generate accurate data from the results of an aerial acquisition depends on: (a) image quality, (b) image overlap and consistent flight height, (c) properly spaced and accurately recorded ground control points for georeferencing, and (d) effective and consistent procedures for post-processing data (Trimble 2013). The Trimble UAS accommodates each of these factors.

Maintaining consistent flight height and overlap using kite and blimp photography is not feasible. Images taken from these platforms have irregular and insufficient overlap to generate orthophotos that can be effectively georeferenced. While the capability for systematic mission planning is becoming available in lower-priced systems such as the DJI Phantom 3 or the 3DRobotics Iris/Solo, the functionality provided by the integrated commercial system, in our experience, is presently unsurpassed. Figure 1 depicts the dramatic differences in camera positions (using Agisoft Photoscan Pro) for missions flown using a kite, as compared to the X100.

The Trimble (previously Gatewing) X100 and its successor the Trimble UX5 UASs are differentiated from low-cost unmanned aerial vehicles (UAVs) in a number of ways. Procedures for generating flight plans, operating the system while in flight, flight pre- and post-checklists, and post-processing of data are provided and integrated. Flight plans are initiated on a Trimble Yuma rugged PC tablet, which also serves as the interface while the unit is in flight. The heart of the Trimble system is its "ebox" which is nested in, and protected by, an impact-resistant foam body that is strengthened with a carbon-fiber frame. Pitch, roll, and yaw are detected via onboard sensors and recorded for each photo so that corrections can be applied during post-processing. The system is launched from a catapult that controls takeoff angle and elevation (Trimble 2015), and the flight is automatically piloted via the onboard computer. Automated flight plan generation for areas of interest, combined with dynamic compensation for flight conditions, ensures systematic parallel flight lines and yields consistent overlapping photos and a reliable ground sample distance. As a consequence of these factors, precise measurements of objects on the ground can be made from derived orthophotos.



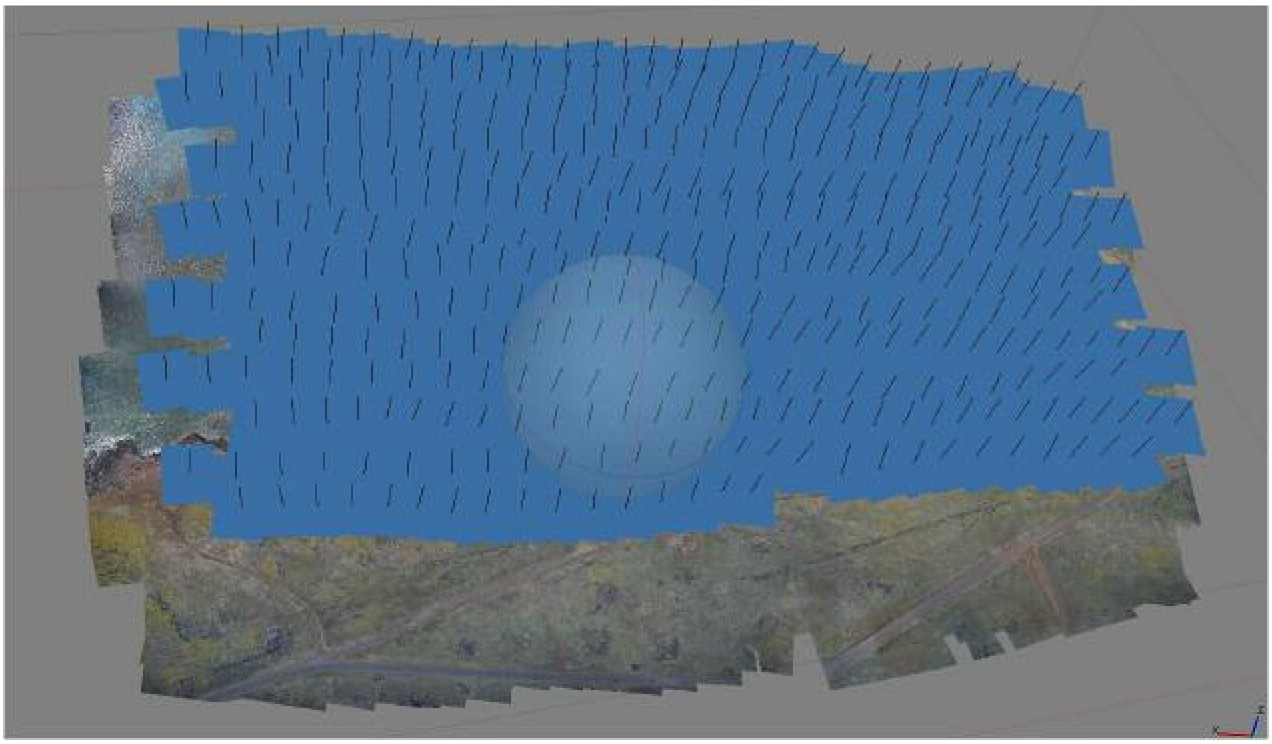


Figure 1. Comparison of Camera Positions from (1a) DGI Phantom and (1b) UX5. Camera placements are shown as Blue Rectangles.

The UX5 is designed to accommodate a Sony 5100 24MP camera using a fixed-focus, high-quality Voigtländer lens. Trimble offers both conventional and near infrared (NIR) versions as system options. We utilize both models in our research: conventional color for DEM and photogrammetric applications and NIR for feature extraction and land-cover mapping. The relatively large detector array of the cameras enables coverage of more area on the ground per photo, and this type of camera can generate results with up to 2-cm ground sample distance (GSD). A flight height of 125 m covering a 1-km^2 study area with an 80-percent overlap would require 26 flight lines, take approximately 36 minutes, and produce approximately 1,014 images with 4 cm GSD.

Study Area

Systematic coverage is required for producing reliable and repeatable results. The ability to produce systematic coverage is invaluable for data collection in areas that are difficult to access. Rapa Nui, Chile, also known as Easter Island, is one of those areas. Rapa Nui is a small (150 km^2) island located in the eastern Pacific, about 3,500 km from the mainland of Chile and 2,550 km from Pitcairn, the closest island.

The entire island can be conceived of as an archaeological resource. Beginning with the arrival of humans in the thirteenth century A.D., prehistoric populations built *moai*—the iconic stone statues for which the island is known and *pukao*—the large red-scoria hats associated with the *moai*. They also built *ahu* (rectangular stone platforms), along with a variety of house features, ovens, and gardens known as *manavai*, circular stone wall gardens used to cultivate crops such as taro and banana (Bradford 2009; Bradford et al. 2015). Much of the island's surface is dominated by cultivation features, known as lithic mulch gardens, in which small pieces of bedrock were used to enrich the nutrient poor soil (Hunt and Lipo 2011). For analytic and measurement purposes, the structure and spatial distribution of these domestic and cultivation features requires mapping using a systematic approach to imagery collection. Understanding the spatial distribution of these features within the landscape requires such systematic landscape scale surveys.

In cooperation with the Chilean Consejo de Monumentos, Chilean National Forest Corporation (CONAF), the Direccion General de Aeronautical Civil (DGAC), and the Easter Island Development Commission (CODEIPA), we flew the Trimble UX5 along the South Coast of Rapa Nui between January 9 and 17, 2015. Our efforts consisted of over 26 missions covering an area of approximately 18.5 km^2, flown at an elevation of approximately 100 m. Twenty-six orthophotos (some overlapping) were generated from over 20,000 photos (Figure 2). In some cases, the same study area was flown using a true color camera as well as a NIR camera.

Feature Evaluation

The key to making sense of orthoimagery is its effective integration with existing datasets. In 2013, we developed a comprehensive database that combined the work of Shepardson (2006) with surveys conducted by Carl Lipo and Terry Hunt (Lipo et al. 2013). This database contains the location of 962 separate *moai* features with over 130 fields of qualitative and quantitative attribute information for each feature. It also contains locations of other features, such as *pukao*, *moai* roads, and *manavai* (Schumacher 2013).

The orthophoto from the January 13, 2015 flight, covering an area of the island known as Vaihu, demonstrates the utility of just one of the UX5-derived orthophotos for feature recognition and evaluation. This flight covers .58 km^2 with a spatial resolution of 4 cm.

The area of Vaihu has one *ahu*, eight *moai*, and three *pukao* (Figure 3). While the GPS positions from the *moai* database do not fall directly on the *moai* in the orthophoto, they are within 2 m of the intended *moai*; this is a distance well within the stated 2- to 5-m accuracy specifications of the GPS equipment used to locate them (Figure 3b). The georeferenced *moai* from the orthophotos are even more precisely located than the GPS positions and can be used to refine their locations. A sample of (N = 30) measurements made from the image accurately reproduced the on-ground measurement recorded for one *moai* within one standard deviation. The point clouds derived from the imagery offer the opportunity to further measure the *moai* from a ground-perspective rather than the nadir view offered by most aerial imagery. We have also experimented with using a near infrared (NIR) camera to record data from wavelengths outside of the visible spectrum. These wavelengths are beneficial for mapping vegetation patterns such as those associated with *manavai* and lithic mulching. The systematic flight plans and consistency in derived products enable overlay and integration with multiple images taken at different days, with varying sensors and using alternative datasets (e.g., multispectral satellite imagery).

Data Integration—Information vs. Knowledge

We argue that systematic surveys provide a reproducible and accurate approach to landscape-level archaeological surveys. With up to 2-cm resolution, these fully georeferenced and

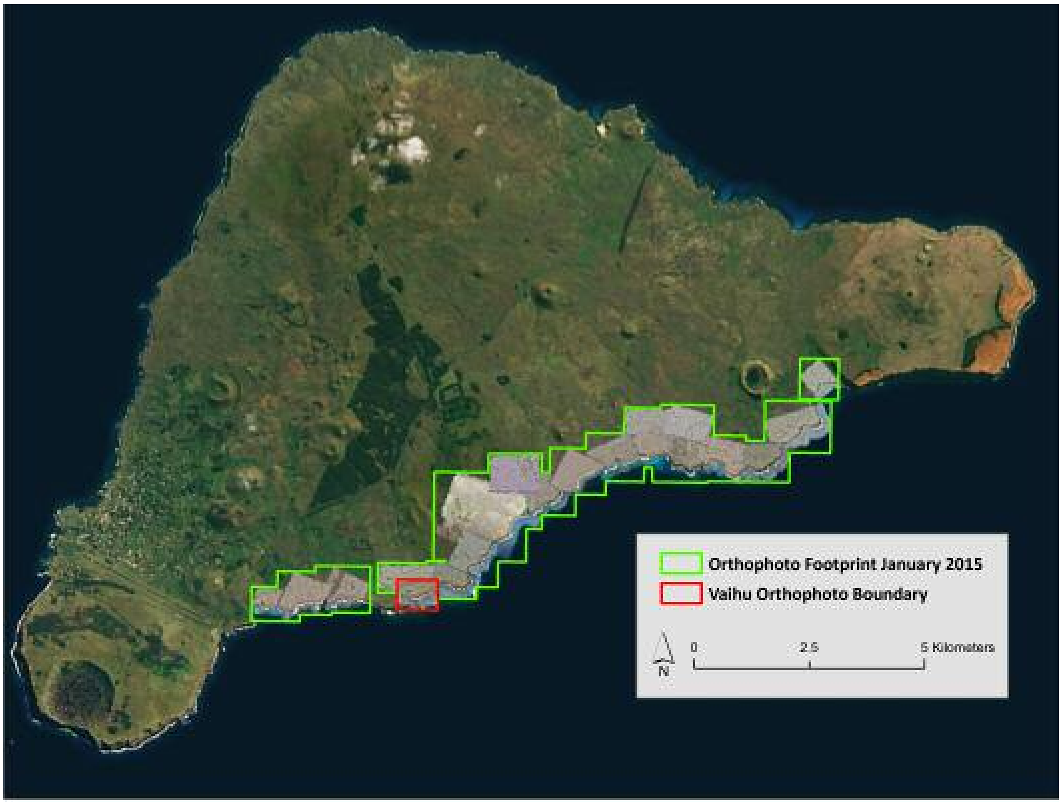


Figure 2. Study area.

rectified images can be used to map the location of many classes of artifacts at scales that are routine in archaeological analyses. The imagery produced with these UASs can serve as baseline datasets for longitudinal studies and change detection. For example, repeated systematic documentation of landscapes might prove useful for tracking changes that occur as a consequence of tourism, development, or changes in moisture and vegetation.

With the growing interest in the field of unmanned aerial systems, new design techniques, innovations in payloads, such as thermal cameras, hyperspectral sensors, and LiDAR collection, and continued advances in digital cameras are under continual development. The future of documenting and maintaining the archaeological record lies in the establishment and integration of geospatial databases.

These capabilities, however, come at a price not only in terms of the technology but also in terms of the time and energy required to "make sense" of the information. UAS and UAV technologies generate an abundance of data. Thousands of photographs are generated and integrated into orthophotos. To ensure repeatability of results, these must be cataloged and numbered systematically. Protocols for metadata must be developed and applied across study areas to ensure repeatable and consistent workflows and to develop protocols for file naming and file structure management. Once achieved, these data can be integrated with other comparable datasets, including LiDAR, multispectral satellite imagery, and ground-based geophysical studies, at an accuracy that is reliable and useful for spatial analyses.

Transforming information into knowledge is a challenge of the big-data era (Wurman 2015) and is exemplified in the process of UAV-based data collection efforts. Remotely sensed imagery generated from UASs constitutes another example of "big data," with attendant processing and data management issues. Researchers must become aware that the benefits of such datasets to the collection, documentation, management, and preservation of the archaeological record can be realized only with the aid of effective technologies and data management protocols.

a

b

Figure 3. Images produced in the Vaihu area of the south coast of Rapa Nui, Chile; (a) UX5 orthophoto at 1:2000; (b) moai and pukao with locations from the database at a scale of 1:125; (c) hill shade of the DEM generated from orthophotos at 1:125; (d) slope generated from the DEM.

c

d

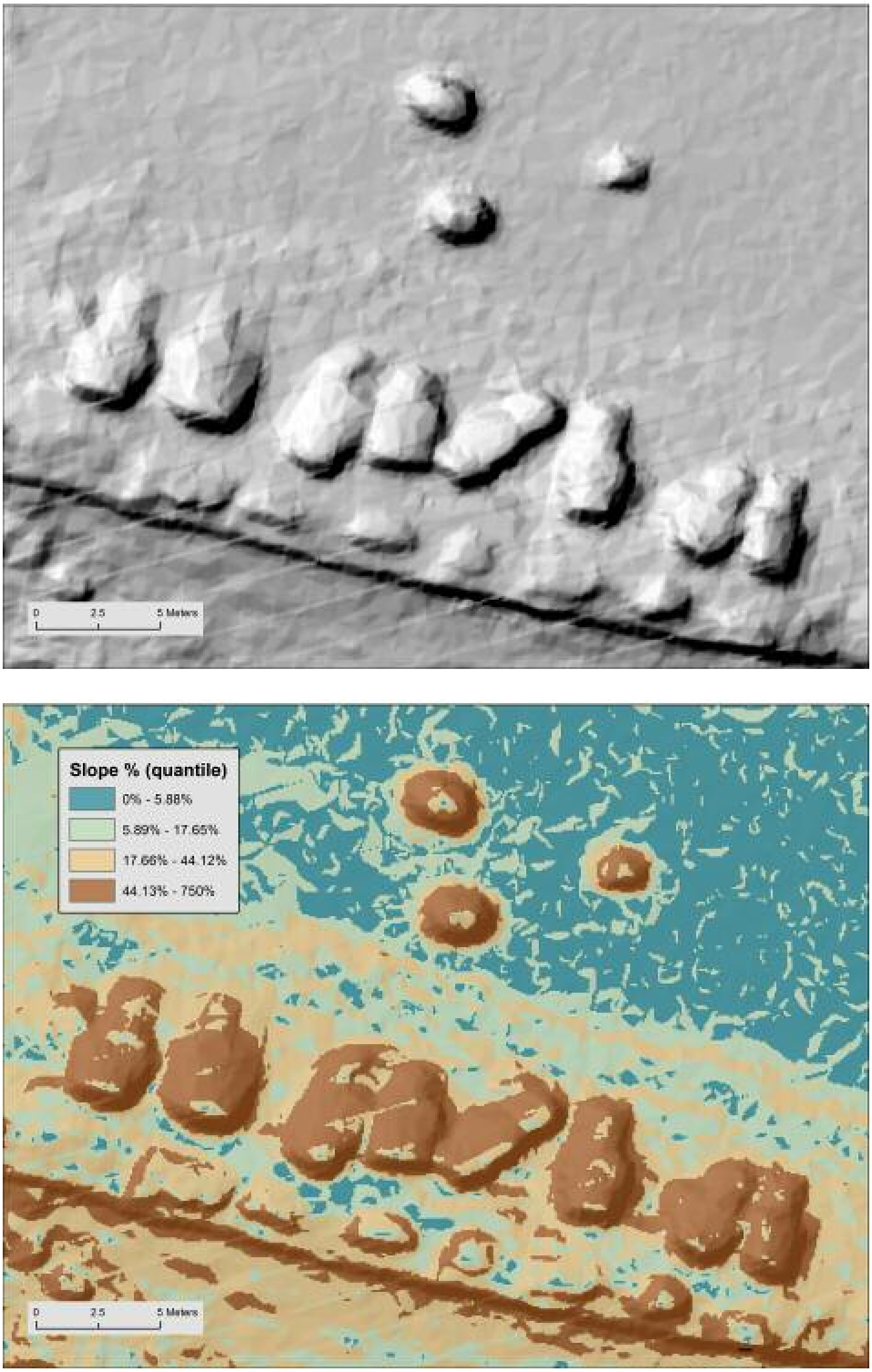


Figure 3. Continued.

Conclusion

Remote-sensing techniques are essential for meeting the demands of the "conservation ethic," whereby damage to the archaeological record is minimized (Hunt and Lipo 2008). Remotely sensed imagery, if collected and catalogued effectively and efficiently, can serve as an invaluable resource for documentation and preservation of the archaeological record. Understanding the archaeological record on an island such as Rapa Nui, where the entire island is a potential study site, is well suited to a top-down data generation research design provided through remotely sensed imagery. This approach is essential for baseline mapping of archaeological resources and monitoring and mapping the impact of tourism on these archaeological treasures. Systematic aerial surveys also enable measuring and recording characteristics of features that are inaccessible due to physical and political constraints.

The technological landscape of aerial platforms is rapidly changing and diversifying, providing users with a wide range of options. While the X100 and UX5 are among the more costly options of the solutions we have deployed, users who rely on the creation of high-quality, consistent, rapid, and repeatable imagery will find the simplicity of integrated technology essential. The X100 and UX5 can fly in the greatest range of weather conditions of all of the platforms and produce the best set of images covering the largest area with the greatest precision. Other solutions can approximate the output of these systems, but the potential for failure is higher due to idiosyncratic hardware, component failure, and weather constraints.

In our experience over the past six years using aerial remote-sensing technology, the higher end commercial alternative has provided output that yields accurate and repeatable surveys. This consistency enables the type of reference baseline that is essential for longitudinal studies documenting the archaeological record and assisting land managers in protecting resources. We have also found that the amount of data generated in such studies requires the development of methods and procedures for documenting, processing, and disseminating these large datasets. A multidisciplinary approach to the use of geospatial technologies will result in derived data that are consistent, comparable, and can be added to and shared across study areas. Standardized data management and processing procedures have yet to be developed and agreed upon across disciplines. However, these are essential for enhanced understanding of the archaeological record and scientifically based knowledge building. The UAS data collection platform is undoubtedly the next generation in field method development for archaeological applications. The key to success in terms of positive impact to the discipline will be made in the development of procedures, tools, and data stores that will offer a means of making sense of all of these new classes of Big Data.

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DEALING WITH LEGAL UNCERTAINTY IN THE USE OF UAVS IN THE UNITED STATES

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The integration of Unmanned Aerial Vehicles (UAVs/drones) is well underway in archaeological investigations. They have proven to be cost-effective, expedient, and accurate instruments in photographing, imaging, and monitoring archaeological sites throughout the world. But unfortunately the Federal Aviation Administration (FAA) of the United States has lagged in establishing regulations for the operation of drones in American airspace. Current policies restrict their use for most commercial purposes, and this has prevented pilots of UAVs in the U.S. and scholars from developing new methods and tools associated with drones. This paper outlines the progress made thus far by the FAA in developing regulations for the operation of UAVs in the U.S. I begin with a brief explanation of current regulations, planned revisions for the long-term, and loopholes under which some UAV operators are flying.

Current Regulations

Currently, small UAVs can be operated in one of two situations: (1) if they are flown as a hobby or recreational/model aircraft or (2) if any entity or pilot is given a Certificate of Authorization (COA) or exemption under Section 333 of the FAA Modernization and Reform Act of 2012. Rules that are associated with the former include the following (FAA 2015a):

- You cannot fly for profit, but can for enjoyment or "personal interest."
- You must fly below 400 feet (122 m).
- When flying within five miles of an airport, you must notify the airport of the flight.
- You should keep your UAV within eyesight.
- You cannot fly above "sensitive infrastructure or property (power stations, water treatment facilities, correctional facilities, heavily traveled roadways, government facilities, etc.)."

These are just a few of the rules for those flying non-commercially and for fun, but those operators who would like to fly for profit or are considered "public entities" (government agencies, public colleges/universities, law enforcement), are required to obtain a Certificate of Operation or a Section 333 exemption. Existing FAA regulations require that "any aircraft operation in the national airspace requires a certifi[ed] and registered aircraft, a licensed pilot, and operational approval." Section 333 of the FAA Modernization and Reform Act of 2012 (FMRA 2012, Conference Report accompanying H.R. 658 of the 112 U.S. Congress, Report 112-381, February 1, 2012) allows the Secretary of Transportation to authorize UAV operators to fly in national airspace. By applying through the FAA, permitted operators may fly in designated areas and for their permitted purposes only. Public entities are required to use the UAVs only for "governmental functions," and permits are issued usually for only two years. It has been reported that many commercial entities are being issued COAs and exemptions only if they have a licensed pilot to operate the aircraft. In addition, these authorizations are given on a case-by-case basis and, at the beginning of 2015, only 159 petitions had been granted, while another 150 requests were still pending. Unfortunately, the application process can take up to 60 days. Many have taken longer; one I examined took about 130 days from the date it was requested. This backlog of applications is only likely to grow, as will the time it takes for them to be processed.

The FMRA of 2012 also required that the "operational and certification requirements" should be developed no later than December 31, 2015. But in a meeting of the House Committee on Transportation and Infrastructure on Wednesday, December 21, 2014, the committee pressured the FAA on the likely completion date of the regulations. Gerald L. Dillingham (GAO 2014) testified that they would not likely be ready until late 2016 or early 2017. This is not only unfortunate, but unacceptable.

So what happens to entities (commercial or otherwise) who have been identified by the FAA to be using drones against their published policies? Many have been sent cease and desist letters, indicating that further operation of their UAVs without permission could result in prosecution. But many believe that the FAA's power to prosecute is tentative at best. This is due to the fact that the FAA has failed to successfully prosecute any UAV operators under their current "policies."

In the *Huerta v. Pirker* case, the defendant, Raphael Pirker, was hired to fly a UAV over the University of Virginia campus in 2011 to collect aerial imagery. The FAA claimed he was reckless in the operation of his UAV and operated the vehicle without a permit, but in March of 2014, an administrative law judge at the National Transportation and Safety Board agreed with Pirker that the policies set by the FAA were not regulatory in that no rules or regulations regarding UAVs had yet been established. The FAA appealed, but in January 2015 a settlement of $1,100 (as opposed to a potential $10,000 penalty) was reached. While Pirker was fined for the reckless operation of his UAV, he was not penalized for operating the aircraft without a proper permit; nor did he admit to flying against any policies set by the FAA (Pirker 2015). The results of this case suggest that the FAA would want to expedite the completion of their regulations so as to be able to control airspace being used by UAV operators. The results also suggest, however, that UAV pilots in the US may be able to fly without serious repercussions until official regulations are completed, unless they do so recklessly.

FAA 2015 Framework of Regulations

The FAA has made some progress. On February 15, 2015, they proposed a framework of regulations for small UAVs (under 55 pounds). The purpose of outlining these guidelines was to allow the public to comment on them; the comment forum was open for 60 days. It is important to note that these are only proposed regulations. Some of these rules include the following (FAA 2015b):

- You must be at least 17 years old to operate a small UAV.
- You must have visual line-of-site during operation.
- You cannot fly more than 500 feet (152 m) above ground level.
- You may fly only in daylight hours.
- Pilots would be required to pass an "aeronautical knowledge test at an FAA-approved knowledge testing center" every 24 months.
- The operator may have to be vetted by the Transportation Security Administration.
- You would have to obtain an "unmanned aircraft operator certificate."
- Aircraft could be inspected at any time by FAA personnel.
- Aircraft would have to be marked like larger aircraft.

Many of these proposed rules include costs to UAV pilots, some of which are one-time payments, others of which are recurrent annual fees. Several of these are considered compliance costs and include fees for knowledge testing, small umanned aerial systems (UAS) registration (in effect for hobby or recreation operators of small UAVs as of December 21, 2015), and TSA security vetting. The FAA estimates that startup costs for a small UAS operator/owner would be around $214 and $164 for each year thereafter (FAA 2015c:151–152).

As FAA Administrator Michael Huerta has stated, "We have tried to be flexible in writing these rules...We want to maintain today's outstanding level of aviation safety without placing an undue regulatory burden on an emerging industry" (FAA 2015b:2) The unfortunate consequence of their "careful" consideration is that it is taking an excessive amount of time. Businesses are getting especially anxious to legally fly UAVs they already own without having to apply for project-specific COAs. Others are already flying, hoping that loopholes in the current regulations will protect them from any possible litigation.

Loopholes

For those who are operators in the U.S., there are several steps that can be taken in continuing work with UAVs. To operate legally, one can apply for Section 333 exemption or a COA, but most small UAV operators do not have the resources to dedicate to such a process. So, can you fly a UAV in U.S. airspace without a COA or Section 333 exemption? What are the loopholes? I have spoken with several operators, both at non-profit and commercial institutions, who are currently flying their small UAVs in U.S. airspace. Some who are not flying for commercial purposes, academic institutions for example, have suggested that they are flying as hobbyists with "model aircraft" that fit within the FAAs current policies. One operator mentioned that he has flown during commercial projects, but does not charge the client for the generated photographs, thus rendering the service not-for-profit. Others simply fly at their own risk, thinking that the lack of enforcement improves their chances of not being caught.

So, at this time it is a waiting game that will continue for a while, possibly one to two more years. In the meantime, UAV operators want to continue developing new technologies, even if under the radar. Regardless, UAV pilots are in a liminal regulatory stage. UAVs are only going to grow in importance commercially and for archaeological research. Whether the FAA makes any effort to speed up the rule-making process is beyond our control. What cannot be stopped is the desire to take this research to the next level. All we can do at this moment to improve the situation in the near future is to voice our concerns and request fair regulations from the FAA.

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Figure 2. Sean Nāleimaile at Papahana Kuaola in Kaneohe, Hawai'i during the filming of Project KULEANA.

I am currently the Assistant Hawai'i Island Archaeologist for the State Historic Preservation Division-Department of Land and Natural Resources. An enormous part of my job is review and compliance, working to ensure that there is some equity between development and the preservation of our cultural resources. It isn't easy.

I believe that receiving the Arthur C. Parker Scholarship award was vital in awakening my passion and broadening my perspective. This passion and perspective developed in Rapa Nui and were nurtured through my academic, professional, and community relations, and they continue to drive me as I work to fulfill my own *kuleana* to this place and the people of this place called Hawai'i.

BALIÑO, from page 5

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