CHAPTER 5: MAPPING IN PRACTICE

FAINE GREENWOOD

This chapter discusses several pioneering efforts that have been using drones to create community and cadastral maps, among other types. Drones are especially useful for mapping small areas or doing projects that were too minor to be budgeted for in the past. Inexpensive to operate and easy to learn how to use, drones permit organizations and individuals to easily gather aerial data. “You don’t have one major government department sitting in the capital city and rotting away because they can’t do anything, because the scale of the economy never justified doing any mapping,” says Walter Volkmann of Micro Aerial Projects, a drone company based in Florida. “Now you have local capacity.”[1]

Indonesian geographer and drone pilot Irendra Radjawali uses unmanned aerial vehicles in his work with the indigenous Dayak people of Borneo. He is training them to use UAVs and to utilize UAV imagery to defend themselves against illegal land use and corporate land-grabbing, a common problem in Southeast Asia.[2] “If you have to sit together with decision-makers at any level, you need more than rhetoric,” he explains. “You need arguments, and building arguments needs data first. And that means methods of collecting the data, analyzing the data.”

With his assistance, the Dayaks have successfully used UAV imagery to challenge in court a mining company engaged in environmentally damaging activities, a success Radjawali hopes to replicate with his new network of Community Drones schools. “The idea of making the schools,” Radjawali says, “is not only to teach them how to make drones, but also to understand what the products of the drones are, how they can understand the maps. The drone is just part of the process.”[3]

Gregor MacLennan, the program director for Digital Democracy, a group based in Oakland, Calif., has helped Guyana’s Wapishana people use a drone to monitor their ancestral territory. “Our aim beyond the drone work is developing a toolbox of tech that can help different communities address the challenges they’re facing with land rights and resources … not just training people to use the drone, but building the community structure necessary to manage something like that, the training required to help people use the images,” he says.[4] “There’s an awful lot more than just buying the drone.”

COMMUNITY MAPPING

Community mapping is a form of participatory mapping that encourages community members to make their own spatial representations of their own land, in a way that makes sense to them. What is to be mapped may cover a wide range of categories, from plots of land to fields of crops to sites of particular spiritual and historical importance. Unlike with top-down mapping, in which authorities decide which space belongs to whom and how space ought to be

Chad Hill flies a custom-built drone at the Feifa archeeological site in Jordan as part of his research for the “Follow the Pots” project. Image courtesy Morag Kersel/Follow the Pots.

used, community members make their own assessments in a participatory and cooperative fashion.

In this approach, the involvement of community members in the UAV flight and mapping process is of paramount importance; they will not be able to make very good use of the tool if no one explains to them how it works. The best practitioners in the UAV mapping field make an effort to collect their data in a transparent and open way, explaining their motivations and their intentions as they proceed.

Today's UAV technology, combined with the photogrammetric processing software and computer vision tools that are now widely available, has made this collaborative process among community members, governments, and aid organizations easier than ever before. The Dayaks face regular challenges to their land rights from resource extraction companies, such as bauxite miners and palm oil growers. Radjawali works with the Dayaks via the Swandiri Institute, an Indonesian organization dedicated to researching the political ecology and social impacts of environmental change. Community Drones, the network of schools that Radjawali and the Swandiri Institute have opened, teaches villagers how to document their land holdings, how to gather photographic evidence of illegal use of their land by interlopers, and how to adjudicate community land disputes.

In April 2014, Radjawali used a homemade tricopter UAV to map 30 hectares of land that Dayaks in the West Kalimantan province's Sanggau Regency said had been damaged by a bauxite mine. The UAV was equipped with a Canon PowerShot SX260 camera with a focal length between 4.5 and 25 mm, and was flown autonomously using the APM flight controller and Mission Planner software.

To map 30 hectares, Radjawali flew the UAV at 250 meters above ground level, shooting about 240 photographs at a pixel resolution of 9 cm. The images were processed in the VisualSFM open-source photogrammetry software, which stitched them together into a high-resolution map, a process that took roughly an hour. Radjawali used the Canon SX260's GPS for georeferencing, as well as using his Magellan eXplorist 310 GPS unit to collect ground control points.

The resulting map showed a desert where a small lake used to be; illegal bauxite washing (a step in extracting aluminum from bauxite ore) had depleted the lake's water. The mining activity was conducted outside of a concession area designated for the purpose, another violation. Dayak representatives were able to use the resulting aerial photographs as evidence in a court case against the mining company, which the Dayaks would eventually win, ending the mining operation.[5]

Meanwhile, in Guyana, MacLennan has been working with the Wapishana[6] to monitor a savannah and rainforest territory totaling 7 million acres. MacLennan taught a Wapishana monitoring team how to build two fixed-wing UAVs: one for flight practice and one capable of autonomous flight. They used this second UAV to shoot imagery of the forest and the illegal mining activity that goes on within it. MacLennan has worked with the Wapishana since 2008, helping them create the local monitoring team to build maps to support their ancestral land claim. They currently hold legal title to only about 20 percent of that claim, he says.

The territory claimed by the Wapishana, who number about 7,000 individuals, is mineral-rich and has attracted the attention of wildcat gold miners who cut away the forest and pollute water sources during their excavations. While these activities are illegal, local government authorities often look the other way, preferring to pocket the money the miners give them. Some Wapishana also profit from the mining industry, MacLennan says. They believe that the income it generates outweighs the damage done to the environment.

Beyond the immediate threat of illegal mining, the Wapishana also needed an inexpensive way to make maps of their villages and their holdings, which could be used to negotiate property

Irendra Radjawali

Bauxite mining on the banks of the Kapuas River, which runs through the Indonesian portion of the island of Borneo.

lines, the equal use of resources, and other basic community functions. Satellite imagery was too low in resolution and prone to cloud cover for their needs, so MacLennan and the Wapishana hit upon the idea of using a drone.

MacLennan, new to the UAV world, had intended to build the drone (an FX61 fixed-wing) himself before he arrived in Guyana in the fall of 2014, but he ran out of time. Instead, he built the UAV with the monitoring team, an experience he soon realized was very valuable for everyone involved. “There’s a lot of issues with anyone going in and flying a drone over your village. … The fact that it was their drone, that they built themselves, really changed the dynamic,” MacLennan says. “Their sense of owning the tech, it being theirs, would have been different if this had been a case of ‘We got this great tech from the gringos, and they taught us how to use it.’”

Already accustomed to repairing motorbikes and boat motors, the Wapishana quickly took to drone building, MacLennan says. He worked with them on flight training, and then they began to fly mapping missions, shooting images and video with a GoPro camera. They were able to shoot enough images to create a map, and as of June 2015, MacLennan was working with a trial version of the Pix4D software to process the images into an orthophoto, an aerial photograph geometrically corrected to have a uniform scale, thus making it usable as a map. The monitoring team planned to present the orthophoto at a large Wapishana tribal meeting scheduled for July of 2015.

The initial experiments with the drone, as is often the case with this new technology, did not always go smoothly. Both landing and takeoff with the drone were difficult due to the dense vegetation of the Wapishana’s territory. MacLennan hopes to address this problem during his next trip to Guyana at the end of 2015, perhaps by building a fixed-wing plane light enough to crash without being too badly damaged. The UAV’s link to the radio control broke just as MacLennan was leaving, and although he managed to get it repaired by the manufacturer and sent back, he had been unable as of June 2015 to connect with his Wapishana colleagues on Skype to walk them through the repair process.

“I see the drone project as an experiment, an amazing new tech which is exciting, but it’s not entirely clear how it can be used,” MacLennan says. “One way we found very quickly, is that it gets people in the press and funders really excited. But the second part is: What does it actually change on the ground?” MacLennan hopes to start similar Digital Democracy drone-mapping experiments in Peru.

In neighboring Suriname, meanwhile, the GISsat company has used UAVs to create a number of geographic products for indigenous communities there. These include projects to monitor logging, conduct an inventory of housing facilities for village planning, and create orthophoto maps that the village board and local nongovernmental organizations can incorporate into their work. In a presentation about its work at a 2013 conference,[7] GISsat emphasized the importance of working with traditional authorities to get an “entrance pass” into the region, and involving the local community to support ground activities, such as collecting ground control points. Using a Trimble Gatewing X100 fixed-wing UAV, GISsat was able to map 0.95 square kilometers of an indigenous-controlled area, with a total flight time of 38 minutes.

CADASTRAL MAPPING

Cadastral mapping is the spatial representation of cadastre records, which, per a definition by the U.N. Food and Agriculture Organization, are “records showing the extent, value and ownership (or other basis for use or occupancy) of land.”[8] Of course, cadastral maps and community maps are not mutually exclusive categories. However, cadastral maps usually must adhere to a government standard of ground resolution and design. UAVs could be used by state authorities to update cadastral maps without community involvement; however, we focus our discussion on cadastral mapping using UAVs in collaboration with local communities.

Cadastral maps are often unavailable or very out of date in the developing world, a situation that often has the worst impact on indigenous and poor people. [9] Without adequate legal proof of land ownership, they are vulnerable to having their land “grabbed,” to seeing the natural resources they rely on exploited by outside players without adequate remuneration, and to becoming embroiled in confusing property disputes.

The Land Alliance, a nonprofit dedicated to the study of land issues, has recently begun experimenting with UAVs for cadastral mapping in Peru, where many thousands of people lack land title.[10] It emphasizes an approach in which government policy is linked to geospatial data and community participation, using the UAV’s ability to quickly gather aerial information to permit a more real-time mapping process. Landowners are actively involved in planning, marking the boundaries of land parcels so that they are visible from the air, and reviewing and verifying the resulting information. Per the Land Alliance,[11] regional government representatives are also intimately involved in the process, helping to resolve disputes and mediate the process.

Walter Volkmann of Micro Aerial Projects recently completed a World Bank-funded mapping project in Albania, one of the least developed countries in Europe.[12] After the People’s Socialist Republic of Albania was officially dissolved in 1992 after parliamentary elections, the country embarked on a large-scale property privatization effort. Many observers considered this effort to be corrupt and largely for the benefit of people with political connections—the privatization efforts were carried out with inadequate access to information and with a lack of transparency.[13]

Albania introduced a computerized land administration system in 2012, based on international standards, but only 20 percent of the nation’s properties are currently covered in the database, while almost 80 percent are covered only by paper maps that are of insufficient quality to be used in the database. Volkmann's project was intended as a pilot test of a UAV-based method of cadastral mapping that could be used both to support land registration efforts and to improve geospatial data that already existed.

While there are existing high-resolution orthophotos of Albania, covering the entire country, the imagery dates from 2007. Lower-resolution imagery from Google Earth, which dates to 2012, is inadequate for the task of identifying and defining property boundaries, as is required in a cadastral survey. The UAV was able to fill this coverage gap, generating high-resolution, up-to-date imagery that could be used immediately. Volkmann and his colleagues tested their UAV mapping system in three locations: an agricultural area called Fushe Milot, a dense urban area known as Komuna Farke, and a strip of the Elbasan national highway, all in the general vicinity of Tirana, Albania's capital. The Elbasan highway site and the Fushe Milot site were chosen as examples of how UAV imagery can provide useful information for infrastructure development and management. Plans for a new highway and a new water pipeline would route them through areas where land ownership is unclear—an information deficit the drone-mapping project was meant to help close.

The team used a custom-built UAV equipped with a Samsung NX1000 camera and 16mm lens, with the intent of keeping costs low and thus accessible to residents of a developing country. They flew their mapping UAV 75 meters above the ground at the Fushe Milot and Elbasan highway sites, and at 50 meters at the urban test site at Komuna Farke. The flights were designed so there would be 80 percent forward overlap and 70 percent side overlap of images, which resulted in large data sets and long processing times.

The mapping process itself did not take the team very long. In Volkmann's report for the World Bank, he said it took a total of three hours to carry out field surveying for the Fushe Milot site, greatly reduced from the three to four weeks such a survey would have taken in the past. To cover 23 hectares at the Fushe Milot site with a ground sampling distance (GSD) of 1.8 cm, the UAV required four flights of about 10 minutes in length.

However, processing the data took many hours, Volkmann reported, and it proved to be the limiting factor of the exercise. It took 48 hours for Volkmann to produce a 1.8 cm-resolution digital orthophoto of the Fushe Milot site using Agisoft PhotoScan software, with a positional accuracy of under 10 cm. A week after the aerial survey, the team was able to show this orthophoto to local landowners, who were asked to define the boundaries of their property.

This process was a success: "In approximately 3 hours we were able to define the boundaries of 29 property parcels on the orthophoto," Volkmann wrote.[14] The UAV maps were overlaid onto scanned images of the existing and out-of-date paper registration index maps, which made the differences between the two clearly visible.

ENVIRONMENTAL & CONSERVATION MAPPING

UAV technology is already finding wide adoption among scientists and conservationists around the world, who have embraced its low cost and relative ease of use. Such efforts are discussed in detail in Chapter 7.

ARCHAEOLOGICAL MAPPING

Archaeologists have been early adopters of UAV technology, embracing it as an easy-to-use and inexpensive alternative to the pricey manned aerial surveys and often cloud-obscured satellite data they used to rely on. Archaeological researchers currently use UAVs for initial surveys of areas with suspected historical sites, georeferenced 3D mapping, aerial thermography, and site monitoring, among other applications. The Digital Archaeological Record[15] has an excellent collection of papers describing archaeological UAV use cases, some of which we will describe here.

UAVs show potential in the arena of architectural cultural heritage reconstruction, making it easier to make digital "copies" of important buildings and sites[16]—data that will virtually preserve them if these irreplaceable historic sites are destroyed or damaged in the future. Archaeologists in Peru, as described in Chapter 9, have begun using UAVs to produce detailed 3D images of historical sites around the country. These can then be stored in a database and used for further research, as well as to assess the risk of damage or destruction involving places particularly at risk.

Today's inexpensive and programmable UAVs have made aerial thermography, the practice of using thermal cameras to detect hidden archaeological sites, considerably easier than it was in the past. While researchers have experimented with thermal imagery collected from manned aircraft, kites, and even a manned powered parachute, the use of UAVs has become more attractive because of their precision and ability to fly in relatively rough conditions. This was demonstrated by a 2013 study in New Mexico[17] carried out by researchers from the University of Arkansas and the University of North Florida.

The researchers used a CineStar 8 UAV equipped with a FLIR thermal camera to search for surface and subsurface cultural remains at an archaeological site known as Blue J, in northwestern New Mexico near the famous Chaco Canyon. The ancestral Pueblo site consists of around 60 households spread over 2 square kilometers. It has been thoroughly covered with deposits of sand and dirt, making it difficult for archaeologists to detect where other structures might have been when the site was occupied. Thermal cameras are able to discriminate between different materials due to the different ways they interact with thermal infrared radiation at different times of day, and can produce images that show the location of structures invisible or almost invisible to the naked eye. Thermal cameras like the FLIR Tau 2 LWIR that the researchers used have become small enough to be mounted on a drone capable of carrying a reasonably heavy payload, such as the eight-armed CineStar, which can lift 4.4 pounds.


A three-dimensional map of Antiochia ad Cragum, a research site in the village of Güney on Turkey's south coast.

Using CineStar's proprietary mission-planning software, the archaeologists flew five surveys at the site, with an average flight time of 11 minutes from takeoff to touchdown. The researchers used Agisoft PhotoScan software to create both color and thermal ortho-imagery, which was georeferenced using ground control points taken at the site.

The researchers found that the thermal imagery showed almost all of the archaeological features discovered previously by a more traditional ground survey, as well as a number of features that had not been detected before. In their conclusion, the archaeologists wrote that the UAV "offers a means to collect and process thermal imagery over very large areas extremely rapidly, which is perhaps its greatest advantage."[18]

Archaeologists Austin "Chad" Hill and Dr. Morag Kersel of the interdisciplinary "Follow the Pots" project[19] are using UAVs to monitor looting at the Early Bronze Age sites of Bab adh-Dhra`, en-Naqa, and Fifa in Jordan. The UAV flights are part of a planned five-year study of how people loot, sell, and collect pottery from the estimated nearly 10,000 graves in the area, which have been looted for decades.[20]

Hill and Kersel hope their research will allow them to literally "follow the pots" from where they were initially collected, tracing the artifacts' journey from looters to middlemen to dealers, all the way to the final buyer. They also hope that their multi-year project will help assess government and police efforts to protect the sites, as well as the efficiency of local outreach programs, guards, fences, and other efforts to end the looting. UAV imagery has given them a low-cost way of documenting changes at the sites on a yearly basis.

Kersel, an assistant professor at DePaul University, and Hill, a researcher at the University of Connecticut, have used both multi-rotor UAVs and a fixed-wing UAV to gather three-dimensional aerial imagery, which they have collected since 2013 at approximately the same time each year.

BEN KREIMER

The UAV project came about after the researchers had experienced trouble obtaining adequate aerial imagery of their study sites, finding that each manned flight would cost them as much as $2,000.[21] Kersel and Hill realized that UAVs could bring down their costs and allow them to conduct aerial surveys as often as they wanted to, and Hill—a childhood RC enthusiast—began to build a mapping platform, keeping the costs down and allowing him to fix the aircraft himself if needed.

The UAVs, Hill explained in an interview, are used to gather high-resolution 3D data of the Bronze Age sites once a year, which is then properly georeferenced and processed with a GIS system. The researchers look for signs of new looting at the sites, which can be easily compared with the information gathered from previous years.

"With the difference analysis of GIS data, we can analyze how the shape of the land has changed from year to year with a high degree of accuracy—with the looting events at the site, with negative change where ditches have been dug, where the soil has been thrown up around the new pit," Hill explains.

When in the field, Hill walks below the UAV while carrying a Nexus7 tablet running the DroidPlanner autonomous flight-planning software, enabling him to keep the drone within his line of sight at all times. Hill tends to fly his UAVs at about 60 meters off the ground, with the Skywalker FPV plane typically flying for 25 to 30 minutes.

The researchers use the onboard GPS from a Canon S100 camera for initial georeferencing, then use precisely surveyed Total Station GPS ground control points to georeference the aerial data with Agisoft PhotoScan Pro.

Hill is a believer in his DIY drone solution: "It's better to buy lower-end stuff that you expect to have problems with, because you'll have problems with any equipment," he explains. Since the UAV project began in 2013, Hill says, the high-resolution and three-dimensional imagery gathered by the UAVs has enabled the researchers to document 37 new looting pits. "We've been able to document changes in the site we wouldn't have been able to detect with a satellite," he says.

GEOMORPHOLOGICAL MAPPING

Geologists also have begun using drones to make maps. Geomorphological maps are maps that describe terrain based on its geological features.[22] Christopher Hackney and Alexander Clayton of the University of Southampton in England used a small Quest 200 fixed-wing UAV to map a series of moraines in the foreland* of Skaftafellsjokull, a glacier in Iceland. They are seeking to understand how the geological features have been shaped by the climate. "These features are located in a topographically constrained region which does not easily facilitate high resolution mapping with terrestrial laser scanning, Lidar or satellite radar mapping,"[23] they wrote. Hackney and Clayton discuss other geological drone mapping efforts to monitor soil erosion in Morocco, landslides in the French Alps, gully evolution in South African grasslands, and Fountain Glacier in Canada.[24]

* The foreland of a glacier is the area immediately in front of the ice's current extent.

Hackney and Clayton mention that some UAVs have been equipped with LIDAR— a remote sensing technology using lasers to measure altitude†—but that "the current suite of LIDAR sensors which may be deployed on UAVs are less high powered than traditional LIDARS and have a higher signal-to-noise ratio."[25] They speculate that LIDAR may in the future enable greater surface detail to be obtained than at present, but for now they recommend photogrammetric techniques that create 3D models from overlapping camera images, like those described in the previous chapter.

CONCLUSION

This description of drone mapping efforts is naturally not exhaustive. Indeed, given the rapid growth in drone use, no exhaustive listing is possible. Nevertheless, for a diversity of examples beyond those described in this chapter, consult a database that New America is continually updating, available online at: drones.newamerica.org. §

† LIDAR measures the distance from the drone to features on the ground; if the absolute position of the drone is known from GPS measurements, the LIDAR thus measures the altitude of ground features.

ENDNOTES

1 Walter Volkmann, interview with the author, May 22, 2015.

2 Faine Greenwood, "Drones to the Rescue," *Future Tense* (blog) *Slate*, June 3, 2015, http://www.slate.com/articles/technology/future_tense/2015/06/community_drones_helps_indonesia_s_dayaks_protect_their_land.html.

3 Irendra Radjawali, interview with the author, May 2015.

4 Gregor MacLennan, interview with the author, June 18 2015.

5 Amanda Siddharta, et al., "Drones and the Environment," Tempo English, May 5, 2015, http://magz.tempo.co/konten/2015/05/05/OUT/30020/Drones-and-the-Environment/37/15.

6 Gregor MacLennan, "We Built a Drone," *Digital Democracy*, December 19, 2014, https://www.digital-democracy.org/blog/we-built-a-drone/.

7 GISsat, Stef De Ridder, and Egbert Moerland, "Social mapping of tribal communities using UAV technology in Suriname," (paper presented at the 2013 Esri International User Conference, San Diego, CA, July 8-12, 2013), http://proceedings.esri.com/library/userconf/proc13/papers/840_92.pdf.

8 Bernard O. Binns, "Cadastral Maps," in Cadastral Surveys and Records of Rights in Land, revised by Peter F. Dale (Rome: Food and Agriculture Organization of the United Nations, 1995), http://www.fao.org/docrep/006/v4860e/v4860e03.htm.

9 "The Law of the Land," Geospatial World, April 2014, http://geospatialworld.net/Magazine/MArticleView.aspx?aid=30962.

10 Land Alliance, "Developing, Testing and Refining a Technology and Participatory Driven Approach for Land Titling in Rural Peru," Land Alliance, http://thelandalliance.org/wp-content/uploads/2015/01/UAV-based-participatory-electronic-formalization-Concept-Paper-modified-for-use-on-Land-Alliance-Website-copy.pdf.

11 Ibid.

12 This section is derived from Grenville Barnes, Walter Volkmann, Romeo Sherko, Kathrine Kelm, "Drones for Peace: Part 1 of 2: Design and Testing of a UAV-based Cadastral Surveying and Mapping Methodology in Albania," (paper presented at the Annual World Bank Conference on Land and Poverty, –Washington, DC, March 24-27, 2014), http://www.fao.org/fileadmin/user_upload/nr/land_tenure/UAS_paper_1_01.pdf; Kathrine Kelm, Rumyana Tonchovska, and Walter Volkmann, "Drones for Peace: Part II: Fast and Inexpensive Spatial Data Capture for Multi-Purpose Use," (paper presented at the Annual World Bank Conference on Land and Poverty, –Washington, DC, March 24-27, 2014), http://www.fao.org/fileadmin/user_upload/nr/land_tenure/UAS_paper_2_01.pdf; and Walter Volkmann, interview with the author, May 22, 2015.

13 Adri Nurellari, “The Corrupted Process of Privatization in Albania,” (paper presented at the 10th International Anti-Corruption Conference, Prague, Czech Republic, October 7-11, 2001), http://www.10iacc.org/content.phtml?documents=300&art=48.

14 Barnes, Volkmann, Sherko, and Kelm, “Drones for Peace: Part II: Fast and Inexpensive Spatial Data Capture for Multi-Purpose Use.”

15 “Archaeological Applications of Unmanned Aerial Systems (Drones),” The Digital Archaeological Record, 2015, http://core.tdar.org/collection/29462/archaeological-applications-of-unmanned-aerial-systems-drones.

16 M. Bolognesi, A. Furini, V. Russo, A. Pellegrinelli, and P. Russo, “Testing The Low-Cost RPAS Potential in 3D Cultural Heritage Reconstruction,” *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-5/W4 (2015), http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-5-W4/229/2015/isprsarchives-XL-5-W4-229-2015.pdf.

17 Jesse Casana, John Kantner, Adam Wiewel, and Jackson Cothren, “Archaeological aerial thermography: a case study at the Chaco-era Blue J community, New Mexico,” *Journal of Archaeological Science* 45 (2014): 207-219.

18 Ibid.

19 “Follow the Pots Project,” Follow the Pots, http://followthepotsproject.org.

20 Erik Ofgang, “UConn Researcher Uses Drones to Track Looting in Middle East,” *Connecticut Magazine*, April 14 2015, http://www.connecticutmag.com/Blog/Connecticut-Today/April-2015/UConn-Researcher-Uses-Drones-to-Track-Looting-in-Middle-East/.

21 Austin “Chad” Hill, interview with the author, May 5, 2015.

22 Michael P. Bishop, L. Allan James, John F. Shroder Jr., and Stephen J. Walsh, “Geospatial technologies and digital geomorphological mapping: Concepts, issues and research,” *Geomorphology* 137, no. 1 (2012): 5-26.

23 Christopher Hackney and Alexander Clayton “Unmanned Aerial Vehicles (Uavs) and Their Application in Geomorphic Mapping,” in *Geomorphological Techniques*, eds. Lucy Clarke and Jo Nield (British Society for Geomorphology, 2015), 6.

24 Ibid., 2.

25 Ibid., 5.