CHAPTER 9

Mobile data collection apps

Edward McLester and Alex K. Piel

9.1 Introduction

To effectively inform conservation strategies, it is of fundamental importance to understand the biology of the organism or system that is to be conserved. Given the pervasiveness of biodiversity crises around the globe, there is a need for large data sets across wide spatial and temporal scales (Sutherland et al., 2004; Schwartz et al., 2018). Building larger data sets and efficiently transforming data to conservation action increasingly requires innovation of data collection methods (Marvin et al., 2016; Marshall et al., 2018). How, then, can we make use of modern technology to quickly and reliably convert our observations to an analysable, storable format when faced with the logistical, financial, and environmental constraints that field researchers encounter?

At their most basic, traditional methods of data collection by hand rely on pen and paper. This simplicity is not a fault in itself—rather, recording data by hand allows unlimited flexibility to change data collection protocols on the fly, to include any number of ad libitum observations, and is universally implementable across all study sites and budgets. Pen and paper are inexpensive and can be complemented by any number of other tools (e.g. Global Navigation Satellite System [GNSS] units; cameras; audio and video recorders) as needed. Nonetheless, the most obvious disadvantages to data collection by hand are the lack of (1) standardization, (2) automation, and (3) integration, in the workflow (Marshall et al., 2018). First, variability in legibility may reduce data reliability.

Moreover, handwritten data may be harder to standardize and maintain interindividual reliability given propensity for spelling mistakes or user-specific languages (Verma et al., 2016). Even with training, data collectors may vary in their coding or abbreviations, especially when recording unusual or rare events that are not clearly specified in the data collection protocol. Second, transcribing and storing the data for analysis must be done manually—or at least, using an additional step such as processing with handwriting recognition software—which is a labour-intensive process and may introduce errors that require more time to correct (McDonald & Johnson, 2014). Similarly, recording observations is entirely dependent on the observer's writing speed, which will also vary substantially depending on the environment (e.g. in inclement weather). Third, pen and paper can be difficult to integrate into workflows that require other devices—for example, GNSS coordinates and image filenames or timestamps must be copied or coded from the corresponding device at the point of capture. As well as being slower, each such additional step in the workflow introduces a greater susceptibility to unintentional errors by the observer. Depending on observer training and the protocol complexity, this may lead to substantial interobserver variation in the order of steps taken to record each observation (Figure 9.1).

Technological methods are designed to automate some or all parts of the data collection workflow, thereby increasing standardization of data collection across users and reducing opportunities for

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-GPS(C053) SWALA-1-(J) (SE~50
[MO, J]
-GPS(C055) CHOO YA PONGO-1-AGE1
[MO, J]
-GPS(C056) SB7 [HT 1m] [MO, J]
-GPS(057) SB8 [HT 1m] [mfuo, B]
—x—
BLOWFLY TRAPDAY PK/JL 08/10/2013
-GPS(C001) PONGO-2-(D1, J1)-(W~25m)
-GPS(C002) BLOWFLY TRAP(BT1-M) (Mp)
[MO, KALI]
-GPS(C003) Mansusuwa-(Chupa 2)
[MFUO, KALI]
-GPS(C004)(BT2-Mp) [MO, KALI]
-GPS(C005)(BT3-Mp) [mfuo, B]
-GPS(C006)(BT4-Mp) [MO, J]
-GPS(C007) PONGO-2 (J1, m1)(E~35m)
[MO, J] -GPS(C008)(BT5-Mp)[MO, J]

BT DAY PK/JL 09/10/2013
-GPS(C009)(BT6-Mp)[MO, J]
-GPS(C010)(BT7-Mp)[MO, J]
TRANSECT Mp=(5868.9m)
-GPS(C011) SOKWE-1(J)(W~30m)
[MO, J]
-GPS(C012) SAUTI YA SOKWE-2 (N~100m)
[MO, KIASI]
-GPS(C013) SOKWE-7(V2-J2-M1-D1)
(N~60m)[MO, J]
-GPS(C014) NYANI-2 (D1, M1)[MO, J]
(W~30m)
-GPS(C015)(BT1-J)[MO, J]
-GPS(C016) NYANI-1(D)(N~35m)
[MO, B]
-GPS(C017)(BT2-J)[MO, J]
-GPS(C018) CHOO YA KOLONGO-1
AGE2-[MO, KIASI]

kona tandara 9 male 2 female 4 watoto 3 mita
125 toka sisi na distance mita 0 toka transect, sehe
mu ya (mbuga juu) kambu na kona ya tatu, saa=
12:18 GPS= 027 transect work) wamekimbia (south).

Tumefika sehemu ya (mbuga) juu hakuna kitu kona
ya tatu, sehemu ya (mbuga juu) Saa=12:29 GPS= 028
transect work) Mpanda road.

Tumeona Choo 1 age 2 kwa kolongo, mita 0 toka transect
Saa=12:52 GPS= 029 sehemu ya mbuga juu-mawe tok
a balabala, mpanda road. na tumeona Ngedere 8 mo
ja male nyingine 7 (female) mita 14.25 toka sisi dis
tance mita 0 toka transect. wapo juu kwa miti wame
tuona wakakimbia (South). (transect work)

Tumefika sehemu ya (mbuga mlima katikati-mawe)
kona ya nne, hakuna kitu, Saa=13:15 GPS= 030
tembea) transect work) (Mpanda road).

Tumefika sehemu ya (mbuga juu-majani) hakuna kitu
Sehemu ya kambu na msitu funga, Saa= 14:47 GPS=
031 (transect works) (kona ya tano)

Tumefika sehemu ya (myombo mlima katikati) na
mawe, kona ya sita, hakuna kitu saa=15:14 GPS=032
transect works) kambu na bonde (west)
transect, Sehemu ya myombo Juu, hakuna kitu, Saa=16:09 GPS=033

MASOKWE (WORKS) 30/07/2010
SHEDY/BUSOTI
Tumefika sehemu ya (myombo mlima katikati) hakuna
kitu (tembea) Saa=6:56 GPS= 034 (Masokwe works) tunak
wenda kusikiliza masokwe mapolomoko kubwa leo.

Tumefika sehemu kwa kusikiliza masokwe Mapolomoko
area, hakuna kitu, sehemu ya (myombo mlima kali)
Saa= 7:15. GPS= 035 bado kusikia sauti, (masokwe works)

Tumesikia sauti kwa masokwe (2) sehemu ya (mlima
kali myombo) mita 572 toka sisi, wao wapo kambu
na microphone kwa mnumba, Saa=9:19 GPS= 036.

Tumesikia Sauti kwa masokwe (3) sehemu ya mlima
kali myombo) mita 580 toka sisi wao wapo palepale
kwa mara ya kwanza, tumesikia Saa= 9:34 GPS= 037

Tumesikia Sauti kwa masokwe 1 sehemu ya (mlima
kali myombo) mita 578 toka sisi, wao wapo tena sehe
mu sawasawa, tunafuata wao, . Saa= 9:40 GPS= 038

Tumeona vitanda 3 age 1, lakini Choo amekaukia
sana, kwenye mti wa Kabamba #1, mita 3.60 toka
9, 4.11, 6.34 toka njia mita 8½, 7, 11 juu, sehemu ya
mlima kali myombo) Saa=10:06 GPS= 039 Masokwe

Tumeona vitanda 2 age 1 na yeye Choo, kavu sana, kwen
mti wa kabamba #1 toka sisi, mita 7.25) 6.74 di
mita 13½, 14, juu) sehemu ya (Kabamba Chini) map

Figure 9.1 Examples of handwritten notebooks used to record behavioural and ecological data (see 9.4 Case Study). Note contrasting handwriting styles and legibility between the two users. The small and finite amount of writing space also means long details or corrections to mistakes do not always fit into predefined columns, giving potential for confusion during transcription. Longer notes are written out in full (rather than abbreviated or as shorthand) and may require time to translate if data are to be analysed as part of international collaborations (credits: AP).

user error (Newman et al., 2012). In the early 2000s, personal digital assistants (PDA) running proprietary operating systems (e.g. Palm OS or Windows Mobile-based devices) provided alternative hardware to collecting data by hand. As discussed by Waddle et al. (2003), however, these devices were generally expensive, slow to process large data sets, and could only back up data by downloading to a computer—leaving them susceptible to data loss if damaged beforehand. The inclusion of sensors such as GNSS or cameras was also limited, meaning expensive, bulky setups comprising multiple pieces of equipment were usually required for specific tasks beyond entering written observations (e.g. see the PDA-GPS combinations described by Diefenbach et al., 2002 and Marshall et al., 2018).

The emergence of the smartphone in the last decade has provided a considerable increase in the accessibility of alternatives to collecting data by hand. Mobile phones have transitioned from devices designed primarily for calling and messaging to all-in-one computing solutions, complete with multiple cameras; WiFi, GNSS, and Bluetooth capability, accelerometers, and processors and onboard storage capable of running software in line with desktop computers (Aanensen et al., 2009; Snaddon et al., 2013; Berger-Tal & Lahoz-Monfort, 2018). A similar trend can be seen with the (re)introduction of the tablet computer in 2010, with tablet models including both low-end media consumption devices, and high-end devices marketed as replacements for traditional laptop computers. USB charging is ubiquitous in smartphones and tablets, allowing devices to be powered from a range of sources (e.g. AC and DC power systems; portable power banks; laptops and desktop computers).

The popularity of these devices has led to a substantial demand for both hardware and software. Their expansion has been especially significant in developing countries where, in addition to communication, these devices provide solutions for otherwise missing or inaccessible infrastructure (e.g. banking; healthcare—Pimm et al., 2015). Most importantly for financially constrained researchers, this user uptake has led to a range of models and prices suitable for almost all budgets. While these starting costs can still appear prohibitive compared to the cost of pen and paper, evidence indicates short-term costs from purchasing devices and apps, as well as time costs from training team members, can be offset by savings in paid time once researchers have been familiarized with a digitized data collection protocol. For example, Leisher (2014) reviewed three surveys of local communities overseen by The Nature Conservancy in South Africa and Tanzania (20102011; paper-based) and Kenya (2013; iPad-based). The authors found that the time taken to complete a survey was also significantly shorter when using tablets, allowing data collectors to complete more surveys per work hour.

Moreover, the cost per survey (i.e. survey materials and paid working hours for pre-analysis data cleaning) was significantly lower for the tablet-based study, despite a higher initial cost of purchasing six iPads compared to printing paper forms, in line with two similar studies (Zhang et al., 2012; King et al., 2013; reviewed in Leisher, 2014). Specifically, the tablet-based survey exhibited a substantially lower number of data entry errors that required time to correct compared with the handwritten surveys. In a comparison of handwritten and app-based capture-mark-recapture protocols, Bateman et al., (2013) also found that the data entry was significantly quicker (up to twice as fast) and the number of data entry errors was significantly lower (by almost a third) in the app-based protocol, regardless of which protocol researchers were given to use first.

The technological advances that have made their way into current smartphones and tablets mean that the potential for these consumer devices to be powerful and accessible tools for scientific researchers has now been realized in just a matter of years. As such, the rapid pace at which mobile computing has and continues to evolve means updates on available hardware and software, as well as applications of these devices in conservation science, are warranted.

9.2 New technology

9.2.1 Data collection hardware

Given that efficient implementation of data collection software depends equally on the device it is running on as the software itself, it is worth briefly reviewing current mobile hardware that supports data collection software applications (usually shortened to 'apps' in the context of mobile devices). The sheer range of devices currently available and the continuous rates at which new devices are released mean that a review of all smartphone and tablet models suitable for data collection is beyond this chapter's scope. Instead, here we briefly summarize key features that are likely to be of importance when choosing a data collection device. This is especially pertinent when discussing the use of consumer-orientated devices for data collection, given that the features that are likely to be of interest for field researchers are often not advertised by manufacturers (or at least, not with scientific research in mind).

9.2.1.1 WiFi, cellular, and satellite (GNSS) connectivity

WiFi (wireless LAN) connectivity is ubiquitous among modern smartphones and tablets, with higher-end models supporting 5 GHz band connectivity from some routers that offer greater bandwidth than the usual 2.4 GHz band. WiFi is a universally compatible standard worldwide and includes compatibility with mobile satellite internet hotspots (e.g. see services from Iridium, Inmarsat, and Thuraya). In addition to internet connectivity via a wireless router, WiFi compatibility also enables local data transfer from WiFi-enabled peripherals such as digital cameras, camera traps, and memory cards without the need for cables or additional accessories.

Unlike smartphones, cellular connectivity is a key difference between tablet models that otherwise resemble smartphones concerning usability and functionality, save for the larger form factor. Most tablets are offered in cellular (accepting SIM cards) and non-cellular ('WiFi only') models. Cellular connectivity in either a smartphone or a tablet may be useful to take advantage of developing projects such as Loon, which aims to expand cellular internet access to otherwise inaccessible locations using networks of balloons that provide internet connectivity through either direct cellular service signals or via proprietary receivers by users on the ground. In Kenya, Loon was first deployed commercially in 2020, with an initial service range spanning 50,000 km^2 which provided network access through cellular 4G service to thousands of households that previously had only sporadic cellular internet access[1]. Otherwise, non-cellular tablets models are usually substantially cheaper than equivalent cellular models. Given that cellular internet service can usually be shared relatively easily from a single internet-connected device using mobile tethering or WiFi hotspots, cost savings can be made by choosing non-cellular tablets, compared with either cellular tablets or smartphones.

GNSS coordinates often comprise an important element of field observations. Integration of GNSS antennae into small form factor mobile devices is common, given everyday applications (e.g. driving navigation aids), and provides a useful alternative to bulkier external USB-connected GNSS peripherals for laptops, for example. While 'GPS' usually refers to the United States owned and operated NAVSTAR GPS network that offers global coverage, some devices support supplementation from additional regional GNSS networks (satellite-based augmentation system—SBAS) for more reliable fixes. Examples of SBAS support on consumer smartphones and tablets include compatibility with the GLONASS (Russia), QZSS (Japan), BeiDou (China), GAGAN (India), and Galileo (European Union) systems. In addition, support for assisted GNSS (e.g. A-GPS) means using a cellular signal to assist with GNSS triangulation, which can reduce battery use. First introduced in Android smartphones in 2018, dual-frequency GNSS support, which increases triangulation accuracy (e.g. minimum 30 cm cf. typical ~5 m for single frequency) by supporting connectivity to two frequencies rather than a single frequency from each satellite, should become more widespread in future devices. Unfortunately, predicting GNSS signal accuracy and reliability from a device's specifications alone can be difficult, not least because information concerning GNSS connectivity is often vague or missing in manufacturer descriptions. Instead, several apps can report details of GNSS fixes, such as accuracy in metres, number and positions of triangulating satellites, and SBAS availability (e.g. GPS Status & Toolbox and GPSTest for Android; GPS Diagnostic: Satellite Test for iOS).

Bluetooth connectivity is also a common, if not universal, feature that enables both connection to external peripherals and wireless data transfer. In the first instance, peripherals can include GNSS receivers—which may supplement or provide more accurate fixes than the internal GNSS—keyboards, mice, and styluses for data entry, or speakers and headphones for playback experiments, for example. In the second instance, similar to local WiFi, Bluetooth data transfer also means that data can be extracted from compatible sources—e.g. Kestrel and HOBO weather stations—in the field without the

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[1] https://www.nytimes.com/2020/07/07/world/africa/google-loon-balloon-kenya.html

need for additional expensive or bulky proprietary accessories.

9.2.1.2 Battery life

Device battery life (usually specified in milliamp hours [mAh] for smartphones and tablets) is almost always an important consideration for researchers in field environments where power is expensive or only available sporadically. Fortunately, as applications of mobile devices in everyday life have increased, similar demands from consumers have made battery life in mobile devices a competitive selling point. As such, many mobile devices come equipped with batteries designed to last for a full day's worth of work and media consumption. Most data collection apps require very little computing power to run. Besides, low-end devices with minimum-spec and low-power processors are usually sufficient. As such, the battery lives of these devices can match or exceed those advertised to consumers if multitasking is kept to a minimum. Battery life can also be increased by lower screen resolutions and brightness and limiting WiFi, cellular network, GNSS, and Bluetooth uptimes. As a rough starting point, in these author's experience, a fully charged battery of $\geq$3500mAh on a 7-inch Android tablet (ASUS ZenPad Z370C) is sufficient for 1–13 hours' data collection (15-minute interval form filling; regular map-viewing and note-taking; continuous GNSS signal; medium screen brightness at 1280×800 resolution; n = daily for 13 months).

Most mobile devices charge using USB connections via micro B and type C ports. Adapters for either port to AC or DC power outlets are readily available. Low amperage USB charging works particularly well with DC outputs from solar power systems often used in remote field environments because it does not require inefficient AC-DC inverters. Additionally, a wide range of small, portable rechargeable battery banks are available to easily pair with devices to extend battery life or provide extra recharges in the field. Battery banks with capacities ranging from 5000–30,000mAh are relatively inexpensive (<£50) to purchase. Portable battery banks are usually recharged by USB, although some variants can be charged directly by integrated solar panels. Larger battery banks (2–5 kg; 50,000–120,000 mAh; consider maximum mAh permitted onboard by airlines when purchasing) are available that include integrated AC-DC inverters and that can be recharged continuously using mains electricity or external solar panels.

Where solar power is not viable, thermoelectric generators may be an alternative. For example, the Hatsuden Nabe 'pan charger wonder pot' (Japan[2]) and PowerPot V (USA) are cooking pans that use residual energy from boiling water to power a DC or USB output (7–30 watts). Low wattage models can charge a smartphone in ca. 3–5 hours and may be useful in field environments where open fires are used for cooking. An early 2-watt Hatsuden Nabe was used successfully by Vitos et al. (2013b) to charge mobile devices during a community forest monitoring scheme in the Republic of Congo, where solar power was limited by dense canopy cover in the rainforest. Although the Hatsuden Nabe and PowerPot V appear to no longer be in manufacture, similar thermoelectric products or relatively inexpensive DIY equivalents may be worth exploring.

9.2.1.3 Ruggedness and protection in the field

The relative expense and fragility of electronic devices compared to pen and paper methods means minimizing risk of breakdown or damage is a primary concern for researchers. For mid- to high-end smartphone models, protection from accidental damage or weather is often a selling point for everyday consumers and therefore advertised clearly. Protection is usually quantified through Ingress Protection Ratings that comprise two digits (e.g. 'IP68'): the first indicating dust-proofing (scale 0–6 where 6 is completely dust-tight) and the second indicating water damage resistance (scale 0–9 where 9 is protected against high-pressure water or steam jets). Screens made of Corning's Gorilla Glass, or similar alternatives to regular glass, should afford better protection against cracks and scratches.

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[2] Produced by Japan's TES New Energy (website: https://web.archive.org/web/20140927084216/ http://tes-ne.com/English/pot; since defunct).

Some budget and low-end devices are made of materials that may actually be more durable than more expensive fragile high-end devices (e.g. plastic cf. glass). Similarly, the popularity of many devices means that a large selection of manufacturer or cheaper third-party accessories are typically available, including soft covers, hard cases, screen protectors, and waterproof bags. Pairing cheaper, lower- or non-certified devices with appropriate accessories may afford a similar level of protection to certified devices at a cost saving.

Several manufacturers also offer specialized heavy-duty, 'rugged' smartphone and tablet models (e.g. Cat, Plum, AGM, Doogee, and Blackview for smartphones; Panasonic and Getac for tablets). These devices include outdoors-orientated features such as armoured casing for protection against drops, higher grades of shock-proofing and water-submersion, and larger batteries for extended use in the absence of power. Some of these devices are priced similarly to regular, non-rugged models, usually because the rugged features eschew otherwise expensive flagship features, such as screen and camera quality. For even more effective protection, but a typically higher cost than regular devices, some manufacturers (e.g. Panasonic; Getac; Trimble) offer tablets and laptops built around industry- and military-grade specifications. These specialist devices may also offer similarly high-specification features not otherwise found on consumer devices, such as high power GNSS antennae, external keyboards, barcode readers, and long-lasting, hot-swappable batteries. Note that such purpose-built devices may be restricted to old or otherwise deprecated versions of mobile operating systems to ensure compatibility with proprietary features, which may cause compatibility issues with data collection apps designed for modern consumer devices.

9.2.1.4 Operating system and app availability

The operating system is the software run by a device that performs baseline system functions, facilitates user input, and allows applications and other software to be installed. Operating systems may be strictly tied to hardware, usually in line with specific manufacturers. Among mobile devices, the two most common operating systems are Android[3] and Apple's iOS.[4] Android is an open-source, Linux-based software developed primarily by Google and found on devices from a range of manufacturers in addition to Google (e.g. Samsung, Huawei, Motorola). In contrast, iOS is proprietary software and is included only on Apple-manufactured devices (i.e. iPhones and iPads[5]).

While the features offered by Android and iOS are broadly comparable, a handful of caveats warrant mentioning. Most significantly, although many apps are available for both operating systems, some apps are only available for one or the other—therefore, app compatibility is extremely important to consider when investing in new devices. In both operating systems, apps are typically installed from the app stores (Google Play Store in Android, and the App Store in iOS[6]). In Android, however, apps obtained from other sources can also be installed manually using their respective standalone executable .apk files (the equivalent of a .msi file in Microsoft Windows), by copying them onto the device and navigating to them using a file explorer app. This allows for Android apps to be backed up or transferred locally and installed in the absence of an internet connection.

Being at least partially open-source software, many Android devices from manufacturers other than Google come preinstalled with the manufacturer's own apps, features, and aesthetics that add an extra layer of software to the underlying operating system. While occasionally useful, this so-called bloatware can often slow performance, reduce battery life, and add unnecessary distractions to what is usually otherwise required by researchers to be an efficient, functional device. It is generally worth

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[3] Hereafter, 'Android' (a trademark of Google) refers to the most common consumer devices that run Android alongside Google's software suite, which includes the Google Play Store for downloading apps (in contrast to non-Google Android forks, such as Amazon's Fire OS, for which app availability and compatibility may vary).

[4] Microsoft's Windows 10 Mobile being deprecated as of 2019; but see Windows 10 and Windows 10X for tablets (e.g. Microsoft's own Surface line) and dual-screen devices, respectively. See also Huawei's Harmony OS, which may emerge as a large market share in the near future.

[5] Hereafter, 'iOS' refers to both iOS and iPadOS.

[6] Unreferenced apps named in this chapter are available from the corresponding app store at the time of writing.

checking the extent to which unnecessary apps can be hidden, disabled, or uninstalled to provide the most streamlined, foolproof, and distraction-free workflow for the end-user. This is particularly pertinent for devices that are to be used by users who may not have worked with mobile devices before (e.g. see Stevens et al., 2013 for an example of a streamlined Android user interface designed for citizen science data collection).

In contrast, devices sold directly by Google typically run more streamlined and recently released stock versions of Android .[7] iOS devices also avoid the risks of manufacturer customization because they are always produced by Apple, and therefore do not include any other manufacturer's own content. However, this restriction does mean that users who prefer apps compatible only with iOS will find a more limited range of devices and price points from which to choose. The cost of Apple and Google's own devices are usually significantly higher than third-party manufacturer Android devices, the latter of which can often provide similar enough features to suffice for conservation research at a substantial cost saving, depending on researcher needs.

9.2.2 Data collection software

A review of every mobile data collection app is a daunting endeavour. A cursory search online reveals an array of software designed to facilitate mobile data collection for a variety of devices, tasks, or study species. The number of useful and deployable apps decreases quickly, however, when deprecated apps (i.e. apps that are no longer regularly updated) are excluded. We consider deprecation to be an important factor because the fast rate at which new devices and operating system versions are released means that loss of compatibility can quickly become an issue if apps are not regularly updated at the same rate (Teacher et al., 2013). A lack of recent development does not necessarily eliminate the usefulness of an app or exclude functionality, but it does mean that without developer support, functionality and troubleshooting are not guaranteed and may require trial-and-error to discover whether app features do or do not work on certain devices (see 9.7).

As such, given our intent for this chapter to retain relevance for current and near-future applications, we present a non-exhaustive list of data collection apps in active development with applications across conservation science. Specifically, we focused on apps that: (1) support broad functionality for use in data collection in conservation science; (2) are in active development at the time of writing; (3) run on either Android and/or iOS, given these will most likely continue to be the market-leading operating systems;[8] and (4) do not require additional specialized hardware. We also did not test apps that fit these criteria but only offer commercial price tiers that are unlikely to be accessible to solo users (i.e. >$100 USD per month[9]).

9.2.2.1 App accessibility

We identified 11 apps that fitted our criteria for recommendation in this chapter, with some caveats (Table 9.1). Of these, five apps run only on Android; two run only on iOS; and four are compatible with both operating systems. While most of these apps are proprietary software, some are built around an existing file format for data collection. For example, XLSForms[10] is an open-source standard for coding data collection questionnaires in Microsoft Excel .xls or .xlsx files or, if preferred, a graphical wrapper (e.g. ODK Build) that once converted into finalized XForm .xml files using online or offline tools are compatible with several different apps and services. Allowing multiple apps to be developed using a single standard means that users have a choice

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[7] See also devices by HMD's Nokia and Lenovo's Motorola, two manufacturers currently producing devices with close-to-stock versions of Android.

[8] Examples of apps that did not fit our criteria: *Ant-App* (Ahmed et al., 2014); *DORIS* (cited in Teacher et al., 2013); *Mongoose 2000* (Marshall et al., 2018); *Prim8* (McDonald & Johnson, 2014); *The Observer XT* (Zimmerman et al., 2009). Further lists of apps for ecological data collection are curated by Emiolio Bruna at http://www.brunalab.org/apps (see Marvin et al., 2016) and reviewed in Andrachuk et al. (2019) and Aitkenhead et al. (2014—for examples of environmental monitoring using specific mobile device sensors).

[9] For example: *CommCare* (https://www.dimagi.com/commcare); *ArcGIS Survey123* (https://survey123. arcgis.com/); *SurveyCTO* (https://www.surveycto.com); *Secure Data Kit* (https://www.securedatakit.com).

[10] https://www.xlsform.org/en; https://www.opendatakit.org/xlsform

Table 9.1 A comparison of current mobile apps for general purpose data collection as of July 2020. Parentheses indicate where additional apps or software are required to make use of features not otherwise directly integrated. Data export options refer to .csv output file type, unless otherwise stated

					Data collection				Data export				
Author/ Service	**Mobile app**	**Operating system**	**Form creation software**	**Cost**	**GNSS coordinates**	**Photo/ video**	**Audio**	**Drawing/ handwriting**	**Export offline (file type notes)**	**Export via SMS**	**Export to online cloud via internet**	**Cloud service**	**Website**
Open Data Kit (ODK)	ODK Collect	Android[1]	Microsoft Excel (XLSForms standard)	Free	Yes	Yes	Yes	Yes	Yes (.xml; .csv via ODK Briefcase[7])	No	Yes (also including .kml; .json)	Google Drive; custom server (local or third-party including Google Compute Engine, Amazon Web Services) using ODK Aggregate	opendatakit.org
Ona	ODK Collect	Android[1]	Microsoft Excel (XLSForms standard)	Free; paid tiers (monthly subscription)	Yes	Yes	Yes	Yes	Yes (.xml; .csv via ODK Briefcase[7])	No	Yes (also including .xlsx; .kml; .json)	Fully integrated; Google Drive; custom server (local or third-party including Amazon Web Services) using proprietary service	ona.io
DataWinners	DataWinners	Android[2]	Microsoft Excel (XLSForms standard); Proprietary software (online via browser)	Free (one year); paid tiers (annual subscription)	Yes	Yes	Yes	Yes	Yes (.xml; .csv via ODK Briefcase[7])	Yes, to online cloud (not compatible with app)	Yes	Fully integrated	datawinners.com

Kobo Toolbox	KoBoCollect	Android [1]	Microsoft Excel (XLSForms standard); Proprietary software (online via browser)	Free	Yes	Yes	Yes	Yes	Yes (.xml; .csv via ODK Briefcase [7])	No	Yes (also .xlsx)	Fully integrated	kobotoolbox.org
CyberTracker	CyberTracker	Android [3]	Proprietary desktop software (offline)	Free	Yes	Yes	Yes	Yes	Yes (also including .xlsx; .kml; .xml; .html)	No	Yes	Custom server (local or third-party) using FTP	cybertracker.org
Fulcrum	Fulcrum Mobile Data Collector	Android; iOS	Proprietary software (online via browser)	Paid tiers (monthly/annual subscription)	Yes	Yes	Yes	Yes	No	No	Yes (also including .xslx; .sql; .sqlite)	Fully integrated	fulcrumapp.com
Imperial College, London	EpiCollect5	Android; iOS	Proprietary software (online via browser)	Free	Yes	Yes	Yes	No	No	No	Yes	Fully integrated	five.epicollect.net
HanDBase	HanDBase Database Manager	Android [2]; iOS	Proprietary desktop software (offline) [6]; In-app	One-off	Yes	Yes	No	Yes	Yes	No	No	-	ddhsoftware.com
FileMaker	FileMaker Go	iOS	Proprietary desktop software (offline)	One-off; paid cloud service (monthly/annual subscription)	Yes	Yes	Yes	Yes	Yes (also .xlsx)	No	Yes (via FileMaker Cloud or FileMaker Server)	Fully integrated using FileMaker Cloud; custom server (local or third-party) using FileMaker Server	filemaker.com/products/filemaker-go

continued

Table 9.1 *Continued*

					Data collection				Data export				
Author/ Service	**Mobile app**	**Operating system**	**Form creation software**	**Cost**	**GNSS coordinates**	**Photo/ video**	**Audio**	**Drawing/ handwriting**	**Export offline (file type notes)**	**Export via SMS**	**Export to online cloud via internet**	**Cloud service**	**Website**
Damien Caillaud/ Dian Fossey Gorilla Fund International	Animal Observer[8]	iOS[4]	Proprietary desktop software (offline via R)	Free	Yes	Yes	Yes	No	Yes (.csv via iTunes; R)	No	Yes (as .dat; .csv via R)	Custom server (local or third-party) using FTP	fosseyfund.github.io/AOToolBox
Ross et al. (2016)	ZooMonitor[8]	Android; iOS[5]	Proprietary software (online via browser)	Free (for accredited organizations); paid tiers (annual subscription)	No (user-defined coordinates only)	No	No	No	No	No	Yes	Fully integrated	zoomonitor.org/home
Newton-Fisher (2012)	Animal Behaviour Pro	iOS	Microsoft Excel; In-app	One-off	No	No	No	No	Yes	No	No	-	kar.kent.ac.uk/44,969
Stevens et al. (2013); Extreme Citizen Science group, University College London	Sapelli Collector	Android	Proprietary desktop software (offline)	Free	Yes	Yes	Yes	No	Yes (also .xml)	Yes, to offline device also running app	Yes	Custom server (local or third-party) using GeoKey	sapelli.org

[1] iOS supported using Enketo via browser.

[2] Android app is deprecated.

[3] Manual (offline) install only (.apk installer provided by desktop software).

[4] iPad only.

[5] iOS and Android supported using web app via browser.

[6] Desktop software is deprecated.

[7] ODK Briefcase is Java-based desktop software for Windows, macOS, and Linux.

[8] Designed specifically for behavioural data collection.

of apps and price tiers that—thanks to inter-app compatibility—can be switched between as budgets allow: from free pricing for those willing to build and collate forms, apps, and optionally cloud servers; to paid subscriptions for services that conveniently integrate these features into a single, all-in-one solution.

9.2.2.2 Software features

The apps that we identified as having the most flexible customization, and therefore the broadest applications, generally follow a similar format. Users populate a form with questions in various formats (e.g. text boxes; multiple-choice; record GNSS coordinates; capture photo using device camera) and media that can be displayed as part of questions or answers (e.g. images; video; audio), which can encompass multiple pages, loops, and repeats. Apps designed more specifically for behavioural data (e.g. Animal Observer; Animal Behaviour Pro) generally had formats more closely divided into data collected as part of focal follows, scans, or ad libitum observations. In the case of Zoo Monitor, some aspects of data collection were more tightly constrained for use in captive environments (e.g. eschewing capturing GNSS coordinates for pinpointing a location on a predefined map by eye). However, we felt enough customization was possible in other questions for the app to be recommendable for broader use cases.

9.2.2.3 Data export and storage

Almost all reviewed apps (Table 9.1) support offline export of data as spreadsheets, although saving these spreadsheets directly onto the mobile device was only possible in some proprietary apps. Instead, for all of the apps using the XLSForms standard, local export requires using separate desktop software. Exporting data to a cloud server—either an existing server provided by the user, or one provided as a part of an integrated service—was a feature available in almost all of the apps we reviewed, and in the case of Fulcrum, is currently the only option for exporting data. Of particular note were the options included in DataWinners and Sapelli Collector service to transfer data using SMS. In the case of DataWinners, this method of sending data is not cross-compatible with forms filled in and submitted using the app; however, we felt it noteworthy given the advantage of being able to exploit weak cellular service in remote areas that may support SMS service but not suffice for internet data service.

9.2.2.4 'DIY' versus integrated services

A distinction can be drawn between standalone apps—either free or requiring a one-time purchase—and apps included as part of more complete packages and mainly paid for by subscription. For example, commonly used apps such as ODK Collect and CyberTracker, or heavily animal behaviour-focused apps such as Animal Behaviour Pro and Animal Observer, provide a front-end for data collection. These apps may require other software or customization (and therefore potentially some technical knowledge) to set up an entire workflow that includes collating data from multiple users in a single (e.g. cloud) database, for example. As such, these apps may be especially useful in modular or 'DIY' workflows (Vitos et al., 2013a), in which flexibility and customization of software are desired or required (e.g. to meet prerequisites, such as the particular type of smartphone or tablet on which data will be collected, or cloud server/service to which data must be exported).

On the other hand, services such as FileMaker, Fulcrum, and Ona include data collection apps, cloud storage, and additional features, such as proprietary form-building software and data analytics, that are integrated into a single package. These services may suit researchers who require an 'oven-ready' workflow for data collection that can be quickly deployed to multiple users with little technical knowledge, and may be willing to pay subscription prices for the convenience of an all-in-one service. In addition, for users who require rapid analyses of data or prefer to eschew exporting data for analysis in separate software, some integrated services include some analytical features in their software. For example, FileMaker, Fulcrum, and Ona allow users to visualize heatmaps of collected form locations, generate PDF summary reports, and create various charts, respectively, directly within their software. These analytical features are generally missing or less fleshed-out in standalone apps designed foremost for data collection, which require users to export data for analysis in other software (e.g. Microsoft Excel; R; QGIS).

9.3 Applications

The variety of hardware and software features in current mobile devices can facilitate a wide range of conservation science applications. This section reviews several broad functionalities and discusses the advantages of digitizing workflows in each case.

Several of the apps we reviewed (Table 9.1) have been used in conservation projects, particularly those with the broadest customization and functionality (e.g. Open Data Kit- and XLSForms-based apps and CyberTracker). Mobile data collection apps are often adopted as direct substitutes for pen and paper methods, but the amount of data that can be recorded and the speed at which it can be organized and transmitted to a central database mean that data collection protocols can quickly be expanded to supersede what is possible by hand. For example, rangers at the Djelk Indigenous Protected Area, Australia, used CyberTracker in place of paper forms and GNSS units to increase monitoring efficiency of feral wildlife, vegetation infestations, and prescribed vegetation burning (Ansell & Koenig, 2011; reviewed in Liebenberg et al., 2017). ODK Collect has been used for a similar purpose in several conservation projects. For example, The Jane Goodall Institute trained forest scouts to use the app to monitor chimpanzee presence and deforestation (Chapter 2). ODK Collect was used in a community forest monitoring scheme in Vietnam, whereby community members could complete questionnaires and record details, including photographic and video evidence, of illegal activities (Pratihast et al., 2012). The same app was also used in Brazil to run a community-based monitoring scheme of fisheries production to assess impacts of environmental change on catch quality (Oviedo & Bursztyn 2017). In the latter two cases, using a mobile app to delegate data collection to local communities resulted in data that were of comparable accuracy and reliability to expert or government data and were less expensive to collect.

The speed at which data can be transferred from individual devices for collation in a database, especially where the internet is available to update cloud databases online, means near real-time monitoring is possible. For example, KoBoCollect was used by community informants to report observations of human–wildlife conflict (e.g. crop-raiding and property damage by elephants in Tanzania) that allow authorities to identify problem individuals more quickly and mitigate future conflicts (Le Bel et al., 2016). The authors note that the app provides a more reliable and efficient upgrade to both pen and paper and a system of coded SMS messages that relayed observations to authorities (Le Bel et al., 2014). CyberTracker is used by rangers in South African national parks to monitor anti-poaching efforts based on data collected during patrols (Liebenberg et al., 2017). Similarly, ForestLink, an Open Data Kit-based app developed for the Rainforest Foundation UK, is used for real-time monitoring of illegal deforestation and community threats in several locations across Africa and the Americas. Data are uploaded to a central database using low-power (e.g. Rapsberry Pi-based) modems that transmits data using a satellite uplink, negating the need for cellular or internet connectivity. Alerts can then be quickly delegated to ground teams for investigation in person (Rainforest Foundation UK, 2019).

Mobile devices and apps provide opportunities for integration with other technological platforms. In Uganda, mobile devices are used during patrols by forest rangers in tandem with the Global Forest Watch platform, a system that analyses satellite imagery to detect forest loss and alert rangers on the ground who can investigate and verify breaches of regulations (Weisse et al., 2017; see Chapter 2).

Mobile devices are a core component of protected area management desktop software, such as Vulcan's EarthRanger and ESRI's ArcGIS for Protected Area Management (PAM), which collate data collected with mobile devices in order to provide rapid or real-time monitoring of events within protected areas (e.g. wildlife sightings, illegal activities, and enforcement). Both EarthRanger and

ArcGIS for PAM are compatible with proprietary and third-party data collection apps, such as CyberTracker. In the case of EarthRanger, alerts can also be transmitted from a central computer to mobile devices (e.g. carried by rangers on patrol) using WhatsApp or SMS. Similarly, the Spatial Monitoring and Reporting Tool (SMART) mobile and desktop software is a widely used conservation monitoring and management tool. Data can be collected using mobile devices (using a third-party app, such as CyberTracker, or using SMART's own app, which is itself based on CyberTracker) and collated for overview and analysis in the SMART desktop program. SMART is detailed in full in Chapter 9.

9.3.1 Behavioural data collection

Behavioural data directly inform our understanding of species ecology and are therefore important considerations for conservation strategies that need to accurately reflect how animals use their environment and interact with other organisms, including humans (Sutherland, 1998). Behavioural data protocols usually comprise some combination of focal follows, scans, and ad libitum observations, which usually need to be collected alongside data from external devices such as location coordinates, timestamps, and image or audio captures. These data must be recorded relatively quickly to accurately reflect an animal's behaviour at a given point in time and to minimize wasting time that may be needed to collect data for other protocols (Marshall et al., 2018). Speed of data collection is likely to be limited by the nature of the study species (e.g. small, fast-moving, arboreal, or flying animals that are difficult to observe) and by adverse field conditions (e.g. poor weather or tough terrain). Furthermore, as discussed in Section 9.1, one of the major disadvantages of data collection with pen and paper is the lack of integration between a handwritten datasheet and other pieces of equipment such as GNSS units, cameras, and sound recorders, which can result in a slow, disjointed workflow, and more opportunities for user error.

Mobile apps are particularly well-suited for behavioural data collection because they support the fast input of complex protocols without compromising the amount or resolution of data recorded, which may occur if otherwise handwritten qualitative observations are reduced to code or shorthand (Bateman et al., 2013). For example, forms made with XLSForms support loops for repeated observations, conditional statements that display questions or pages depending on answers to previous questions or forms, and restrictions that prevent users forgetting to answer certain questions. Apps designed specifically for behavioural data (e.g. Animal Observer; Animal Behaviour Pro—Table 9.1) can also include useful features such as countdowns and reminders for scans, and pre-made templates to match group- and individual-level protocols that speed up form customization. Moreover, the use of onboard or external (e.g. via Bluetooth or WiFi) hardware features, including GNSS, cameras, and microphones functions, are integrated into almost all data collection apps (e.g. see Table 9.1). In many cases, timestamps or GNSS coordinates can be recorded automatically at a given stage in the protocol, avoiding any user input—and potentially mistaken or missing entries—altogether.

9.3.2 Citizen science and community engagement

In addition to data collected by researchers in the field, the popularity of smartphones as consumer devices means that collecting data through the general public ('citizen science'—reviewed in Graham et al., 2011) is now easier than ever and increasingly integrated into long-term projects (e.g. Rafiq et al., 2019). For fully integrated services, forms can be built using provided tools or templates and shared publicly with other users through a website or app (e.g. EpiCollect5—Table 9.1). For even wider dissemination, mobile apps can be built from the ground up and distributed through app marketplaces, where they can also be more easily discovered by or marketed to new users. By making apps publicly available to so many potential users through just a handful of standardized app marketplaces, apps can be adopted for extremely short-term projects with little prior notice needed for users. For example, wildlife tourism experiences can encourage users to download apps at the start of tours to report observations (e.g. see Whale Trails,[11] an Android and iOS app designed for whale watchers to record humpback whale GNSS tracks—Meynecke, 2014). For long-term citizen science projects that require a large number of users to collect sufficient data, mobile apps may be better suited to attracting and retaining users because they can be easily integrated into a format that appeals to a wider array of demographics and personal interests, such as interactive games (Bowser et al., 2013; Kim et al., 2013).

Mobile apps can also help facilitate data collection protocols that are designed with specific local communities in mind. Specifically, touch-screen devices with large screens can make user input more intuitive than handwritten methods because of the ease of displaying different media types to users, such as images, video, or audio to users. This can increase accessibility for a data collection protocol, even for users who may not have experience with smartphones or tablets. In turn, user enjoyment is likely to be greater, which is an important factor in motivating users to continue collecting data for citizen science projects (Kim et al., 2013). For example, Sapelli Collector was used in developing questionnaires with graphic interfaces based on input from local communities in Cameroon, which were suitable by communities with high rates of illiteracy for reporting observations of local wildlife crime (Stevens et al., 2013). CyberTracker and the XLSForms standard also support icons or pictures as replacements for text throughout questionnaires (e.g. multichoice answers). In the case of CyberTracker, a key use case has been the recording of indirect evidence of animal presence (e.g. prints), for which an icon-based interface is especially intuitive for non-literate users (reviewed in Liebenberg et al., 2017). Similarly, Vitos et al. (2013b) took advantage of the open-source code for ODK Collect to remove all text from the app to streamline the interface for non-literate users during community data collection in the Republic of Congo.

9.3.3 Mobile geographic information systems (GIS) and participatory mapping

Several GIS are available as mobile apps. Mobile-only GIS apps include SWMaps and Locus GIS for Android (free) and GIS Pro for iOS (paid). An Android port of the free and open-source QGIS was under development but is deprecated at the time of writing (as alternatives for viewing QGIS projects on mobile, see Input by Lutra Consulting for Android and iOS and QField for QGIS for Android). For direct spatial data collection, ODK Collect supports some spatial data question types (e.g. tracing of lines and polygons; see also GeoODK for Android and ArcGIS Survey123 included in ESRI's paid ArcGIS suite—footnote 7).

Mobile GIS apps provide similar functionality as desktop software for displaying, annotating, and in some cases analysing, vector (e.g. shapefiles) and raster data. An advantage of displaying spatial data on a mobile device is that the device GNSS location can be displayed in real time as an overlay, similar to conventional mapping apps (e.g. Google Maps; Apple Maps). As such, researchers can quickly and easily create fully customizable and navigable maps for any location for which pre-existing spatial data is available. These maps allow researchers to identify and plan routes to sites of interest (e.g. transect or sampling locations), avoid geographic hazards, and more quickly familiarize themselves with new study sites—especially important given that data collection is often tightly constrained by time available for fieldwork.

In addition to navigation, mobile GIS can be used to collect data directly. Location tracks may be recorded for a given time or distance intervals for later analysis, which is a similar functionality to that found in standalone GNSS units. We also note that running a GIS app that continuously acquires a GNSS fix even when minimized is one effective way of reducing GNSS triangulation times in other apps (e.g. data collection apps that record GNSS coordinates—Table 9.1) because the fix should already be available.

Mobile GIS are also useful tools in participatory mapping that collate spatially explicit data and knowledge from local communities (see Chapter 2). Issues such as land rights and vegetation usage may

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[11] Likely deprecated—see *Whale Track* for Android for a similar example in active development.

involve input from many community members, for which digital maps can provide useful sandboxes for drawing and discussing user-identified landscape features in relation to various spatial data, such as boundaries or disputed areas. Previous studies, such as those focusing on community practices and forest use in Ecuador (Delgado-Aguilar et al., 2017) and Suriname (Ramirez-Gomez et al., 2016), have used paper or hard copies of maps when interviewing or creating maps with local communities, which then require scanning and georeferencing for analysis in desktop GIS. Mobile GIS may provide effective alternatives to paper maps, particularly in areas where spatial data are already available for creating custom maps that correspond to interview questions (McCall et al., 2016; see also Pacha, 2015).

9.3.4 Mobile devices as multipurpose tools

As mentioned in Section 9.1, the transition of smartphones and tablets into devices capable of rivalling desktop computer functionality means that there are many applications of these devices for field researchers in addition to recording observational data. It is impossible to review every use of the multitude of apps currently available for Android and iOS (which number in the millions for each operating system), but here we highlight some of the more common applications that can supplement primary data collection.

The popularity of mobile devices combined with the current operating system duopoly means that integration with an Android or iOS app over Bluetooth or WiFi has become a common standard for connectivity, as evidenced by the number of 'smart'-branded everyday products now available. App connectivity has also become standardized for certain equipment of use to conservation researchers. For example, several Kestrel and HOBO weather stations can be configured and data collected from using the free Kestrel LiNK and HOBOmobile apps, both of which are available for Android and iOS (Figure 9.2). Mobile devices are not only smaller and lighter to carry to remote locations than laptops—particularly specialized rugged models—that are usually used in conjunction with these stations, but if already being used for data collection, can remove the need to purchase other devices specifically for this purpose. For digital cameras, some camera manufacturers (e.g. Canon Camera Connect and WirelessMobileUtility by Nikon, for Android and iOS) provide apps for certain digital camera models that add remote control functionality. Outside of proprietary apps, USB on-the-go technology is a connection standard for mobile devices that supports connectivity to a wide array of generic USB peripherals, such as flash drives and SD card readers that can benefit camera trap users (see also WiFi-enabled SD cards that enable wireless transfer of photos to mobile devices, camera compatibility permitting).

Many of the more generic apps bundled with most mobile devices are also useful for researchers as digital alternatives to pen and paper. Apps for recording text range from simple note-taking to mobile equivalents of desktop office suites (e.g. Microsoft Office, Polaris Office, and WPS Office for Android and iOS, all of which have free tiers). Some office suites also include PDF readers as alternatives to standalone equivalents such as Adobe Acrobat Reader—all of which can be used to refer to documents such as protocol instructions or published articles without the need for hard copies. Drawing or sketching apps can be useful where language or illiteracy can impede verbal communication. Image galleries provide a system to organize animal or plant IDs that can be examined at high resolutions in the field. While most variants of Android and iOS come bundled with basic gallery and file manager apps, third-party alternatives that allow detailed browsing by nested folder structures (e.g. Simple Gallery Pro; F-Stop Gallery Pro; FX File Explorer for Android) can be useful for organizing large photo catalogues by study group and subject, for example. Internet-permitting folders of images can also be synced with a single cloud service account to allow a manager or other user to update the database on multiple devices remotely and with one action (e.g. Microsoft OneDrive and Dropbox for Android and iOS, which offer 2–5 GB of free storage with paid tiers thereafter and allow files to be updated when online and subsequently accessed offline). Audio recorder apps allow for spoken data collection (see

Figure 9.2 Kestrel Drop 1 temperature logger connected wirelessly to a Motorola Moto E (2014) Android smartphone via Bluetooth and the Kestrel LiNK app. Universal standards for Bluetooth and WiFi wireless connectivity mean consumer smartphones and tablets are increasingly compatible with data recording loggers and sensors. In this case, wireless connectivity means the logger can be positioned several metres high in a tree while still allowing users to remotely adjust settings, observe measurements in real-time, and export data to comma separated spreadsheets (.csv files; credit: EM).

also speech-to-text apps, such as the free Otter Voice Notes for Android and iOS, that can transcribe spoken notes in real-time), while media players can be used for audio playback experiments using Bluetooth connectivity or through 3.5 mm wired output. Where the cellular network is available, SMS or free internet messaging apps (e.g. WhatsApp) can be cheaper and more intuitive replacements for two-way radio communication, especially in difficult field conditions where referring to a written message can be integral to avoiding miscommunication.

9.4 Case study: from paper to digital data collection for primate conservation at the Issa Valley, western Tanzania

Historically, behavioural data collection on wild animal presence, ecology, and behaviour has been relatively labour intensive, not just in data collection but also in storage, transfer, and transcription. Researchers at the Issa Valley, western Tanzania, began a long-term study of primate community ecology in 2008 (the Greater Mahale Ecosystem and Conservation [GMERC] Project—Piel et al., 2018). The project began with two foreign researchers and two local field staff. Field staff had varying literacy and writing abilities. Data collection was in Swahili and began by documenting all evidence of wildlife and human disturbance. With only four data collectors, attempts to standardize the documentation of these events were initially relatively straightforward. For example, data were collected in Rite in the Rain data books, which were converted to grid cells to remind assistants which information to record. Each staff member was allocated two days/month to transcribe data from books to data sheets, which could then be more easily transcribed (a second time) to an electronic format for eventual analysis.

Besides the obvious challenges of protecting paper against the elements, especially keeping data dry through rain, there were additional obstacles to handwritten data collection. Despite attempts at standardization, variability in data records persisted. For example, spellings of wildlife names changed both within and between data collectors. Thus, collectors began developing individually specific abbreviations for recording observations. Due to variation in literacy, important ad libitum observations of animal behaviour went either unrecorded or were reduced to short narratives with details omitted due to the time taken and space available on paper to write down observations. This issue was especially pertinent given the nature of such ecological work. Anticipating everything that occurs in the natural world is naturally impossible and often requires rapid or continuous recording of observations, otherwise key details may be missed. Finally, time spent transcribing data from books was considerable (ca. half a workday per week for each staff member).

Additional data were collected as the project expanded in scope, especially on animal behaviour. In a matter of months, researchers and local field staff had habituated two troops of baboons (*Papio cynocephalus*; Johnson et al., 2015) and another of red-tailed monkeys (*Cercopithecus ascanius*; McLester et al., 2019), which later fissioned into two daughter troops, while habituation of a focal chimpanzee (*Pan troglodytes schweinfurthii*) community continued. The project hired additional staff, and protocols quickly transformed from recording opportunistic encounters of wildlife and people to detailed behavioural observations (e.g. dawn to dusk 5-minute focal follows of individual animals). Researchers and assistants collected an increasingly wide range of data, including dietary diversity, social interactions, and activity budgets. As protocols expanded, data collection increasingly required large amounts of reference information to which researchers needed to refer, such as plant species names, individual identities of animal group members, and behavioural ethograms. In particular, mammal diversity monitoring conducted with line transects required research staff to be familiar with information on perpendicular and observational distances, flight responses, and the age, type, and location of snares. Increasingly, assistants would also encounter people who were illegally in the forest. A database on this growing threat was built, requiring data collection on human activity, the village of origin, and duration in the forest, which necessitated additional flexibility in the number and complexity of questions recorded per observation.

As the complexity of data collection protocols and the number of collectors grew, the time allocated for training, data transcription, and resolving confusion concerning spelling and nomenclature also increased. More personnel meant that more data could be collected, but also led to an increased need for quicker collation and transcription or digitization for eventual analysis. Assistants soon required one day per week to keep up with transcription demands. With a team of eight assistants, this time budget eventually led to the time equivalent of multiple months spent on transcribing data books to paper databases. More time still was subsequently spent by management staff entering those paper data onto a computer spreadsheet.

In 2013, the project replaced paper data collection with a digital data collection protocol (Figure 9.3). Assistants and researchers were provided with an Android tablet each and trained on its use. At the time, smartphones were not widely used in Tanzania, yet assistants still only needed a matter of days to familiarize themselves with the tablets. The ability to enlarge the font, the predictability of the questions, and the restricted choices all made for ease of use. Interobserver training lasted only a few weeks before assistants were comfortably and consistently recording digital data.

Open Data Kit (Table 9.1), using the free ODK Collect app and an online ODK Aggregate cloud server hosted on Google Cloud Platform, was introduced as the primary platform for data collection. While data are stored locally on tablets and can be exported, weak cellular internet service is available in some areas of the study site and means staff can upload data to the server on a ca. weekly basis. For most of the project's data collection, form file sizes are extremely small ($\leq$2 kilobytes) because protocols do not include recording media such as photos or videos. As such, uploading forms (usually <5 megabytes total per week) can be a fast and typically inexpensive process that can be instigated using smartphone mobile hotspots. The process was made faster still with the introduction of a satellite internet connection in 2015. The server currently hosts >100,000 records from 50 data protocols at a monthly cost of ca. $\leq$\$2USD.

The transition to digital data collection has resulted in tangible benefits. By uploading data to a cloud server, project directors can view, download, and back up data remotely, indirectly increasing accessibility to data for collaborators and funders. Furthermore, ODK Aggregate allows permissions to be set for individual users. Management staff and researchers can be provided with limited access to the server to upload new protocols and verify data have uploaded successfully, reducing the need to contact and work through a single administrator (in this case, the project directors) each time.

Digital entry has eliminated most legibility issues and freed up time previously spent transcribing handwritten data. Limited, custom selections have

Figure 9.3 GMERC Project staff members Mlela Juma (top) and Sadiki Abeid, Mashaka Alimas, Shedrack Lukas (bottom) use Google Nexus 7 Android tablets running ODK Collect to record observations of chimpanzee vocalizations and phenological data, respectively, in miombo woodland (credits: EM; Christian Howell/GMERC).

greatly improved standardization of observations, particularly through multiple-choice questions and requirements that avoid skipping questions accidentally. Similarly, automatic background data collection, such as date and time stamps and GPS coordinates, have also reduced mistakes or gaps in data sets. Technological issues have also been relatively straightforward to identify and resolve because project directors and collaborators can view or be sent large numbers of data files easily by email or other cloud services, either from the study site itself or using stronger internet connections available in nearby villages and towns. Researchers and students can create, test, and familiarize themselves with data collection protocols in advance of fieldwork using the variety of XLSForms tools available online (Table 9.1).

At the Issa Valley, most costs of shifting to digital data collection have related to hardware. Even budget tablets are relatively expensive compared to pen and paper, and they are not as water-resistant as waterproof stationery. Tablets do get dropped and damaged accidentally, as can happen with any handheld device. Some issues such as incorrect time zones in device settings have led to later problems with behaviour or chronology reconstruction during data cleaning, although these have been relatively straightforward to rectify.

The other primary cost–benefit ratio relates to time; specifically, the time spent training staff in a new technology compared to time spent transcribing handwritten data. While all field sites vary in individual circumstances, it can be a worthwhile transition if time is more valuable than money. In the case of the Issa Valley, assistants now spend more time in the field, where their skills of behavioural observation, plant identification, and threat detection are used daily, and they no longer spend many hours each month transforming those data for later, remotely conducted analyses. That such a transition adds to a project fiscal budget was an acceptable cost to improving data standardization, streamlining the path from observation to analysis, and applying people's skills where they are most appropriate.

9.5 Limitations/Constraints

Although there is a focus on customization in many data collection apps, including those reviewed earlier, app choice can still be a limiting factor if compatibility and/or functionality do not meet a researcher's use case. While developing an app from scratch is the most effective way to ensure that an app functions exactly as required, this may not be an option for a majority of users who do not have the required technical knowledge to do so themselves, or time to find a collaborator who does (see Teacher et al., 2013, who provide a detailed walkthrough of the app-building process for researchers). As such, users may find themselves with a potentially convoluted workflow that relies on multiple apps or platforms, limiting the degree to which switching to a digital workflow will streamline data collection. Similarly, complex workflows may be more time-consuming to train staff or team members in, particularly those who do not already have experience with the hardware being used.

Logistically, as with any electronic device, power requirements can be a limitation. First, device battery life will always be a limiting factor for day-to-day use and will vary depending on battery capacity and usage intensity. Second, and more fundamentally, is the need for a power source to recharge devices. While the range of battery capacities and charging methods available (e.g. USB through AC, DC, or external battery/power bank) can alleviate this requirement to a certain degree, in remote field sites power may be limited or inconsistently available to the extent that electronic data collection is restricted to a small number of devices or not simply not feasible. Similarly, a lack of internet connection can restrict opportunities to send and store data remotely from a field site, although there is almost always an offline alternative for saving data locally (Table 9.1).

Hardware or software failure can result in data loss on any device. While backups are faster to make electronically, storage for digitized data on multiple external drives can become expensive depending on the storage capacity required and the type of drive used (e.g. solid-state drives are more expensive than hard drives, but also more reliable due to the absence of moving parts). For online cloud-based storage, expenses can be incurred either through subscriptions for the cloud service, or through the cost of obtaining an internet connection in remote locations (e.g. via satellite internet). In both cases, however, these issues are equally intrinsic to data collected by hand. Paper records can also be accidentally misplaced or destroyed and are arguably more difficult to back up and store without using an electronic device. Moreover, analogue data will need to be transcribed to a digital format at some point in the workflow in order to be analysed, which means any such benefit to collecting and keeping data in an analogue format is likely to be cancelled out by the time and/or financial costs of digitizing data (see 9.1).

9.6 Social impact/privacy

Digitizing data collection usually requires third-party software and almost always the use of third-party hardware. As such, maintaining data confidentiality will always depend on the extent to which hardware, software, and cloud storage providers can or will protect researcher data.

Regulations governing how manufacturers are obliged to protect user data differ between countries or region. Personal data protection in the European Union is mandated by the General Data Protection Regulation in the European Union, which differs from the United States, for example, where data protection laws vary between states. Researchers using third-party cloud services (e.g. Google Cloud Platform or Amazon Web Services) to store or transfer data should remain informed of where their data will be located throughout the process and how its storage will be regulated. For example, the Google Cloud Platform service for hosting cloud storage (among other uses) offers users a choice of country for server location. Alternatively, researchers in need of the strictest encryption should avoid outsourcing storage to third parties and instead use a personal home server, particularly one with an open-source operating system (e.g. see Ubuntu and Linux Mint as useful introductions to Debian Linux, and Manjaro as an introduction to Arch Linux). Depending on the researcher's needs, a low-power device may suffice to minimize running costs for home servers that run continuously (e.g. see Raspberry Pi and Intel NUC devices as starting points).

Researchers that collate data collected by other users with apps (e.g. citizen science projects) also have a responsibility to protect the data collectors' confidentiality (Bowser et al., 2014). Data that may be used for research purposes can also reflect personal information (e.g. GNSS locations; photographs that may inadvertently include individuals). As such, researchers should make clear to data collectors how and where the data will be stored, and which steps have been taken in line with appropriate legal frameworks to mitigate unintended uses (e.g. allowing data collectors to delete any data after submission; establishing strict schedules for how long data will be stored; deleting personally identifiable details from stored data—reviewed in Bowser et al., 2014).

9.7 Future directions

The distinction between mobile and desktop hardware and software is quickly becoming narrower. Each annual iteration of manufacturer flagship devices raises the bar for computing and graphics power, storage capacity, and connectivity to peripherals that mobile devices can support. As such, for many users, smartphones and certainly tablets now facilitate a level of productivity that would previously have been confined to desktop or laptop computers. Desktop software can be more effectively duplicated on mobile devices and several new form factors, including devices with foldable or dual screens (see the Samsung Galaxy Fold and Microsoft Surface Neo devices, for example) should further expand the opportunities for porting desktop workflows to mobile devices when they become available in lower-end devices with less exclusive prices. For conservation researchers, this means that stages in a workflow can be carried out on mobile devices in the field, allowing faster analysis and communication of data and, ideally, action based on those results.

The fast pace at which software and hardware are constantly evolving, and the wide range of applications needed by conservation researchers present a problem for standardizing software. More generalized apps can be improved and updated for new hardware faster by larger development teams, but inevitably will not be suitable for every protocol or study species/system. While building an app from the ground up and disseminating it are cornerstones of both Android and iOS, data collection software built by a small team designed to support a single project is less likely to see user uptake outside of the authors and is more likely to quickly depreciate (Teacher et al., 2013). We clearly observed this effect while reviewing currently available apps for this chapter, during which we identified many apps that did not fit our relatively broad criteria for inclusion in Table 9.1. These instances highlighted the degree to which apps are frequently developed for a very specific study species or system, released publicly—sometimes with media exposure or a dedicated journal article—and then no longer updated outside of a very short timeframe, or even at all. It could be argued that an app that suits at least one user's protocols for a single project can still be considered a success. Given the initial time costs of disseminating equipment and training users when switching to a digital data collection platform—especially for large teams—it can be inefficient for researchers to change data collection software at frequent intervals. Alongside the need to update and maintain apps in line with continuous advances in hardware and software, there is, therefore, a need for potential app developers to balance specific functionality against how much time can be committed to supporting a relatively small number of end-users in the future. As an alternative, researchers may consider adopting a platform that uses an open-source standard (e.g. XLSForms—see Table 9.1; 9.2.2), given that these apps benefit from larger user-bases that can provide technical support, greater flexibility for complex workflows, and less reliance on proprietary technology that may become deprecated at short notice.

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