Remote Ecological Monitoring with Smartphones and Tasker

Therese Donovan,* Cathleen Balantic, Jonathan Katz, Mark Massar, Randy Knutson, Kara Duh, Peter Jones, Keith Epstein, Julien Lacasse-Roger, João Dias

T. Donovan
U.S. Geological Survey, Vermont Cooperative Fish and Wildlife Research Unit, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, Vermont 05405

C. Balantic, J. Katz
Vermont Cooperative Fish and Wildlife Research Unit, 302 Aiken Center, 81 Carrigan Drive, University of Vermont, Burlington, Vermont 05405

Present address for C. Balantic: National Park Service, Natural Sounds and Night Skies Division, 1201 Oakridge Dr. Suite 100 Fort Collins, Colorado 80525

M. Massar
Bureau of Land Management, California Desert District, 1201 Bird Center Dr., Palm Springs, California 92262

R. Knutson, K. Duh
Indiana Dunes National Park, 1100 N. Mineral Springs Rd, Porter, Indiana 46304

P. Jones
South Burlington, Vermont 05403

K. Epstein
Forecast LLC, South Burlington, Vermont 05403

J. Lacasse-Roger
Digipom Inc., 8815 Avenue du Parc, Suite 402, Montréal, Quebec H2N 1Y7

J. Dias
KITXOO, Unipessoal Lda., Lisbon, Portugal

Abstract

Researchers have increasingly used autonomous monitoring units to record animal sounds, track phenology with timed photographs, and snap images when triggered by motion. We piloted the use of smartphones to monitor wildlife in the Riverside East Solar Energy Zone (California) and at Indiana Dunes National Park (Indiana). For both efforts, we established remote autonomous monitoring stations in which we housed an Android smartphone in a weather-proof box mounted to a pole and powered by solar panels. We connected each smartphone to a Google account, and the smartphone received its recording/photo schedule daily via a Google Calendar connection when in data transmission mode. Phones were automated by Tasker, an Android application for automating cell phone tasks. We describe a simple approach that could be adopted by others who wish to use nonproprietary methods of data collection and analysis.

Keywords: acoustic monitoring; AMMonitor; automated ecological monitoring; camera trapping; cell phones; cellular network; smartphones

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Autonomous Monitoring with Smartphones  
T. Donovan et al.

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* Corresponding author: tdonovan@uvm.edu

**Introduction**

In the past decade, researchers have increasingly used autonomous monitoring units (AMUs) to track ecological units of monitoring and management interest (August et al. 2015; Burton et al. 2015). Such units can record animal sounds from several hundred meters away, take timed photographs to track phenology, and act as camera traps that snap images when triggered by motion. The practice of using AMUs to monitor wildlife species has grown immensely in the past decade, with monitoring projects that target birds (Furnas and Callas 2015), bats (Zamora-Gutierrez et al. 2016), elephants (Wrege et al. 2017), wolves (Root-Gutteridge et al. 2014), primates (Heinicke et al. 2015), amphibians (Brauer et al. 2016), insects (Newson et al. 2017), and marine mammals (Raven Pro 2014).

Many proprietary AMUs use store-on-board technology, where units are deployed and collect data on a preprogrammed schedule, and data are later retrieved by a human. Such AMUs offer many benefits. They can be deployed in the field for long periods of time to collect large amounts of data, such as audio recordings and photos. Moreover, having a record of audio and photo data allows researchers to carefully verify and analyze species identifications or other research targets a posteriori (Hobson et al. 2002; Willi et al. 2019).

However, store-on-board approaches can create a time lag between data collection and analysis. Monitoring plays a key role in adaptive management because it establishes the present state of the ecological system of interest, providing natural resource managers with a benchmark from which to base management decisions (Williams et al. 2009). For time-sensitive decision-making, rapid collection and delivery of monitoring files may narrow the gap between data collection, scientific discovery, and on-the-ground natural resource management.

Furthermore, store-on-board approaches follow a preprogrammed monitoring schedule. However, as noted by Thompson (2004), a one-size-fits-all sampling schedule may be unsuccessful at capturing all species of interest. The efficiency of data collection may be enhanced if AMUs are capable of receiving directions about when to collect future monitoring data, permitting a temporally adaptive sampling framework (Balantic and Donovan 2019a). For example, if a target species that is vocally active in the morning was already “captured” by a device at a given location, a change in the monitoring schedule may maximize the probability of capturing other, yet-undetected, targets.

Smartphone-based ecological monitoring offers a potential alternative to the store-on-board monitoring paradigm; smartphones can send remotely collected audio, photo, or other data over the cellular network for expedient analysis and are inherently positioned to receive frequent external instructions about when to conduct future monitoring. In this paper, we describe two prototype approaches for using smartphones as nonproprietary AMUs. Although smartphone-based monitoring is prohibitive in remote areas with limited cell phone coverage, virtually any smartphone can be modified into an AMU where cellular or Wi-Fi coverage is available.

**Methods**

**Overview**

We prototyped two smartphone AMU designs, the “California design” and the “Indiana design”, according to where our pilot studies were located. The California design focused on acoustic monitoring only, while the Indiana design included both acoustic and photographic monitoring. Both designs involved establishing remote (unstaffed) monitoring stations, and both used an Android smartphone and external microphone stored in a weather-proof box mounted to a pole and powered by solar panels. Microphones were configured to capture sounds in the normal range of human hearing. Each smartphone was connected to a Google account and received its recording/photo schedule daily via a Google Calendar connection when in data transmission mode. Phones were automated by Tasker (2018), an application for Android that performs “tasks” (sets of actions, such as taking a recording or picture, turning on airplane mode, or syncing files to the cloud and then removing them from the phone) based on “contexts” (application, time, date, location, event, or gesture triggers). Monitoring files (audio and/or photos) were collected based on Tasker instructions (Text S1, Supplemental Material) and were sent directly to a centralized cloud-based account daily.

**California design**

The California design focused on acoustic monitoring within the Bureau of Land Management’s Riverside East Solar Energy Zone, a 599-km² area in southern California...
designated for utility-scale solar renewable energy development. Due to abundant sunshine within the Solar Energy Zone, the AMUs did not require an external backup battery. All components of the California design are detailed in Text S2 (project management and smartphone setup; Supplemental Material), Text S3 (Tasker XML; Supplemental Material), and Text S4 (station design; Supplemental Material).

For the California design, the AMU was a modified Android smartphone (2015 second generation Motorola Moto E model XT1527) with a 5.0.2 or 5.1 Lollipop Android operating system) secured within a black weather-proof Pelican case (model 1120) and attached to an external 10-watt Aleko solar panel for power (Figure 1, top panel). We connected the solar panel’s power cable to a voltage regulator that stepped the voltage down to accommodate the smartphone’s 5-V requirement. We attached each smartphone to a tip-ring-ring-sleeve cable that connected through the Pelican case to an external omnidirectional electret condenser microphone (JLI-61A, JLI Electronics). Once assembled, we attached each unit to a U-post 1.83 m aboveground. As a pilot study, we deployed AMUs nonrandomly at 16 spatially independent sites within the Solar Energy Zone.
to record songbirds and amphibians. We collected data from March 2016 to May 2017.

Ambient temperatures at the desert field site can exceed 48°C in the summer, and we anticipated that devices would automatically turn off to avoid overheating within the microclimate of a black protective case. In preliminary testing, baking smartphones in a conventional oven yielded the insight that the devices consistently shut off when the internal temperature exceeded approximately 68°C. At the time of development, the smartphones required that the power button be physically pressed by a human to turn back on after shutting down from a drained battery or overheating, rendering an AMU unfit for monitoring. To avoid this situation, we used a “boot on power” firmware modification so that the smartphones would autonomously turn back on when they were capable of doing so.

We created a Tasker profile to automate each phone’s operation (Text S3, Supplemental Material). Typically, phones operated in airplane mode to minimize power and cellular data usage. We used the Easy Voice Recorder Pro app (Digipom 2016) to schedule recordings, which allowed us to use Tasker to trigger recordings based on schedules entered in each phone’s Google Calendar (Text S1, Supplemental Material). In total, we scheduled each unit to take nine 1-min recordings per day, recording in Waveform Audio File (WAV) format at a sampling rate of 44.1 kHz. We collected recordings in airplane mode to prevent electromagnetic interference. Each day, the phones connected to the cellular data network daily for two 40-min windows to transmit collected recordings over the network. We used the Tasker-enabled app Dropsync Pro (MetaCtrl, Prague, Czech Republic) to sync files to a Dropbox account and, once synced, purge files on the phones.

**Indiana design**

The Indiana design expanded the type of data collected, including audio data, timed photographs, and motion-triggered photographs. To avoid modifying the smartphone firmware, we did not use a boot-on-power modification in this design. Monitoring occurred within the Indiana Dunes National Park, part of the U.S. National Park Service system and located at the southern end of Lake Michigan, which greatly affects the Park’s weather. Summers are warm and humid, with high temperatures of generally ~30°C and low temperatures of ~18°C. Highs in winter are ~0°C with low temperatures ~5°C. Hours of sunshine are dependent on weather and season, necessitating a backup battery to ensure that phones did not turn off. All components of the Indiana design are summarized in Texts S5–S7.

The AMU was a Samsung S9 (model SM-G960U with a 10.2.1 Android operating system) secured within a polycarbonate enclosure with knockouts (Polycase model SK-21) that permitted sealed connections to an external microphone (YouMic Lavalier microphone) and two external 10-watt solar panels (Renogy monocrystalline 12 V) for power (Figure 1, bottom). We connected the solar panel’s power cable to a Society of Automotive Engineers (SAE) converter and used an SAE to Universal Serial Bus (USB) stepdown to step down the voltage (Motopower MP0609 3.1-amp Motorcycle USB charger SAE to USB adapter). We connected the USB stepdown to a battery pack (Voltaic Systems V44 Always On External Battery Pack with dual USB ports, 12 000 mAh), which in turn powered the phone. Once assembled, we attached each unit to a steel square sign post ~1.8 m aboveground. We deployed the AMUs at 21 spatially separated, nonrandom monitoring locations chosen by National Park biologists in an attempt to record target songbirds and amphibians of interest. We collected data from May 21 to October 19, 2019.

In addition, we deployed phones at three “temporary” stations that operated on battery charge only (Figure 1, bottom). Temporary stations did not include the solar panel. Rather, we fully charged the phones and connected them to a fully charged battery pack (Voltaic Systems V44 Always On External Battery Pack with dual USB ports, 12 000 mAh) before deployment. We attached the polycarbonate case to a portable sign stand or to a wooden post, where the phones collected data for ~10 d before power was depleted.

We created a Tasker profile to automate each phone’s monitoring tasks (Text S6, Supplemental Material). We undertook a recording sampling schedule of 1-min recordings taken every hour 24 h a day. As with the California design, we used the Easy Voice Recorder Pro app (Digipom 2016) to collect Waveform Audio File recordings (sampling rate of 44.1 kHz) as triggered through a Google Calendar setting. In addition to audio monitoring, we scheduled hourly photographs during daylight hours, hypothesizing that long-term monitoring conducted in this fashion might yield compelling insights about the timing of phenological events, depending on whether stations could be positioned with a view toward indicative vegetation. The phone’s camera captured timed images, which were triggered by the phone’s Google Calendar entries, and stored the images in Joint Photographic Group (JPG) format.

At the three battery-powered temporary stations, we explored whether smartphones could act as camera traps, collecting images that are triggered by motion. We used the Motion Detector app (Emparador Tools) for this purpose, which is Tasker enabled. Motion-triggered tests were carried out between June 25 and September 30, 2019, at three temporary monitoring stations (Kemil, Inland Marsh Overlook, and Pollinator). We scheduled 205 15-min motion capture trials at various times of the day. The Pollinator station had 179 scheduled capture trials and was also deployed with much higher trigger sensitivity (i.e., photos would be triggered by very minimal movement). The other two stations (Kemil and Inland Marsh Overlook) had 11 and 15 sunset-based...
motion capture trials, respectively, and were deployed with medium sensitivity (i.e., a more substantial degree of disturbance to the camera field would be required to trigger a photo being taken).

Each day, the phones connected to the cellular data network for four 15-min windows to transmit collected monitoring files over the network. Additionally, a phone performance log was transmitted along with the monitoring files. We developed a Tasker task that produced a performance log 5 min before the time of transmission. The performance log allowed us to monitor the phone itself, including ambient temperature, battery level, battery temperature, cellular signal, data usage, and other statistics, all of which were used in troubleshooting (Text S1, Supplemental Material). We used the Tasker-enabled app Autosync for Google Drive (MetaCtrl) to sync files to a Google Drive account and, once synced, purged files on the phones.

**Results**

The cost per AMU in the California design was approximately US$128 per unit in 2015 plus an additional $100 per phone and $28 per phone per month for a pooled AT&T cellular data plan. This pooled plan allowed each phone to use an average of 1.5 GB of data per month (Table 1). The cost per AMU in the Indiana design was approximately $400 per unit in 2019 (Table 1) plus an additional $0.99 per phone and $1,300 per month for a pooled 2-GB AT&T cellular data plan used throughout the duration of the monitoring project.

As a broad, coarse-grain analysis of performance, we looked at the period from September 1 to September 30 for both pilot programs in their respective monitoring years, at which point both pilot deployment methodologies had been fairly stabilized. For the California project,

<table>
<thead>
<tr>
<th>Component and item</th>
<th>Need</th>
<th>Price per unit ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>California design</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1120 Pelican case</td>
<td>1</td>
<td>21.95</td>
</tr>
<tr>
<td>5-V 1-A switching fixed regulator</td>
<td>1</td>
<td>15.00</td>
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<tr>
<td>Short (6” A/MicroB) USB cords (connects phone to power cable)</td>
<td>1</td>
<td>1.85</td>
</tr>
<tr>
<td>Long (3.00/914.4 mm) USB cords (connects power cable to solar conXall)</td>
<td>1</td>
<td>0.95</td>
</tr>
<tr>
<td>conXall Inline SKT (connects external microphone on inside of box)</td>
<td>1</td>
<td>3.99</td>
</tr>
<tr>
<td>conXall PNL MNT PN (connects external microphone on outside of box)</td>
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<td>2.55</td>
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<tr>
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<td>3.24</td>
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<td>conXall inline PN (connects power cable on inside of box)</td>
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<td>3.46</td>
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<td>Foam microphone windscreens</td>
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<td>TRRS audio cable</td>
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<td>1.85</td>
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<tr>
<td>Power</td>
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<tr>
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<td>Total</td>
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<td>7.50</td>
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<td></td>
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<tr>
<td>YouMic</td>
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<td>11.99</td>
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<td>4.82</td>
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<td></td>
<td></td>
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<tr>
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<tr>
<td>Solar arm</td>
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<td>MC4-SAE 4-ft extension cables</td>
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</table>

a Text. Abbreviations: SAE = Society of Automotive Engineers; TRRS = tip-ring-ring-sleeve; USB = Universal Serial Bus.
in the period from September 1 to September 30, 2016, we scheduled each phone to take nine recordings per day (30 d × 9 recordings/d = 270 recordings expected from each AMU). The 14 devices actively deployed during this time delivered 74% of their expected recordings (Figure 2a), varying from phones that delivered 98% of expected recordings to phones that only delivered 8% of their expected recordings (minimum = 8.1%, first quartile = 83.7%, median = 91.3%, mean = 78.9%, third quartile = 94.9%, maximum = 98.1%). Performance variations were largely attributable to variations in deployment length and cellular signal strength at the monitoring site, although we were not able to clearly determine the cause of failure for the two low-performing devices.

For the Indiana project, in the period from September 1 to September 30, 2019, we scheduled each phone to take 24 recordings per day (30 d × 24 recordings/d = 720 recordings expected from each monitoring location during this period). We collected a total of 7 295 audio files (Figure 2b). The 16 devices actively deployed during this time delivered 63% of their expected recordings, varying from phones that delivered 79% to 6% (minimum = 6.2%, first quartile = 64.4%, median = 71.2%, mean = 63.3%, third quartile = 73.8%, maximum = 79.2%). The Tasker phone logs enabled us to diagnose some causes of failure. Three phones had overheating issues during this time and turned off, dragging the average down (Figure 2c). Other devices failed to deliver scheduled recordings for known or unknown reasons.

We took a total of 366 timed photographs between May 23 and July 5, 2019, at the 16 monitoring stations, creating a time series of images (Figure 3). Due to inconsistent scheduling of timed photographic events, we were unable to fully evaluate files collected versus received.

From the 205 scheduled motion-trigger trials, 1 756 triggered photographs were delivered to the cloud. All of the triggered photos were from the “Pollinator” station, which was positioned near a group of flowering plants to explore the possibility of using smartphone-based motion capture for pollinators (Figure 4).

Discussion

Amid increasing advances in telecommunications and wireless infrastructure, smartphone-based ecological monitoring may provide a creative option for addressing challenges in wildlife conservation and management. Herein, we have illustrated two frameworks for the hardware and data collection side of smartphone-based ecological monitoring; we do not address the ensuing challenges of data management and analysis of autonomously collected files. In our own work, we used the R package AMMonitor for data management and analysis (Balantic and Donovan 2020), which enabled us to investigate practical scientific questions about temporally adaptive sampling (Balantic and Donovan 2019a), machine learning for automated acoustic wildlife detection (Balantic and Donovan 2019b), and dynamic occupancy models using acoustic data (Balantic and Donovan 2019c). However, files delivered from smartphone-based AMUs could be analyzed with a variety of software methods depending on the research question. For example, audio files might be analyzed with widely used proprietary methods, such as RavenPro (Charif et al. 2010) or Kaleidoscope (Wildlife Acoustics 2016), with free R packages, such as monitoR (Katz et al. 2016) or warbleR (Araya-Salas and Smith-Visdauur 2017), or with the Automated Remote Biodiversity Monitoring Network (ARBIMON; Sieve Analytics, San Juan, Puerto Rico) (Aide et al. 2013), which provides cloud storage, data management, and computing for analysis of audio files. An array of data management and analysis options also exists for photo data (Young et al. 2018), including the Wildlife Insights: Camera Trap Data Network (Ahumada et al. 2020).

Wildlife monitoring with smartphones

Our efforts have been informed and inspired by previous smartphone-based autonomous monitoring efforts. For example, McKown et al. (2012) used smartphones to monitor remote seabird colonies, and Aide et al. (2013) used smartphones to collect and send 1-min recordings every 10 min, where files were analyzed in near real time with the ARBIMON platform. Both the McKown et al. (2012) and Aide et al. (2013) efforts had a substantial data collection and analysis infrastructure that we could not match. Without such an infrastructure in place, we sought a simple, inexpensive alternative that could be configured and operated by a very small research team that did not rely on proprietary platforms. Tasker was our low-cost solution. In both the Indiana and California efforts, the total cost of apps was less than $20. Tasker can work with any contemporary Android model, is in active development, has an active community forum, and several excellent tutorials for getting started (see Text S1 for a brief introduction, Supplemental Material). We did not encounter any challenges with Tasker per se; the only glitches were due to incorrect settings that we rectified once understood. With nearly endless smartphone configurations, the main challenge was ensuring that we configured the apps correctly to meet our monitoring needs along with the sheer amount of time it took to configure each monitoring smartphone.

Tasker obviated the need to build a dedicated cell phone app for wildlife monitoring in our two pilot study areas. However, dedicated apps have many benefits; they can reach a wide user group, enable efficient and accurate data collection, and permit data storage/upload to an online data repository (Teacher et al. 2013). For example, the highly successful iPlover app was developed for the purpose of citizen-based monitoring of piping plovers Charadrius melodus throughout the U.S. Atlantic coast (Thieler et al. 2016; Zeigler et al. 2017). The ARBIMON Touch app was similarly designed to work with the ARBIMON II bioacoustics analysis platform, and there are numerous other ecologically minded apps that facilitate data collection, crowdsourcing, education, and collaboration (Teacher et al. 2013).
Figure 2. (a) Fraction of scheduled recordings from September 1 to September 30, 2016, that were delivered to Dropbox using the California design implemented in the Riverside East Solar Energy Zone, California. We scheduled each phone to take nine recordings per day (30 d × 9 recordings/d = 270 total). (b) Fraction of scheduled recordings from September 1 to September 30, 2019, that were delivered to Google Drive using the Indiana design implemented at Indiana Dunes National Park, Indiana. (c) Variation in individual phone performance at Indiana Dunes National Park from September 1 to September 30, 2019. We scheduled each phone to take 24 recordings per day (30 d × 24 recordings/d = 720 total).
However, there may be some benefits to the Tasker approach we ultimately used. Android phone and app development are in a constant state of flux, and as operating systems change, the reliant apps may break. The main benefit of the Tasker approach is that it is easy to learn, use, and update. Tasker projects can be updated and maintained into the future by biologists without Java coding expertise, especially if a monitoring program makes use of a single smartphone model. Further, it is possible to turn a Tasker project into a stand-alone app (Android Package [APK] files) with the Tasker App Factory app (Crafty Apps EU). However, if multiple smartphone models or operating systems are used, a dedicated app, such as iPlover, may be more desirable so that the graphical user interface will work across devices.

**Comparison of the prototypes**

Comparisons between the two prototype approaches are difficult because nearly every aspect differed between them. With abundant sunshine, no battery was required in the California design, and, in general, files were delivered as expected. Cellular data coverage was the most limiting factor, and sites with spotty coverage had the lowest success rate. The main
drawback to the California design was the required setup, which involved soldering, drilling, and modifying the smartphone firmware. If units failed, we could not service them easily in the field. We were concerned about overheating and used a boot-on-power firmware modification, which required “rooting” the phones (i.e., overriding the phone manufacturer’s and mobile network operator’s software limitations). Rooting a phone potentially voids the phone’s warranty and can leave the device open to malware attacks. We are unsure how often the boot-on-power feature was used, although it was likely a critical feature in a desert where average high temperatures routinely exceed 38°C in 4 months of the year. However, because we were not using the phone’s camera in California, we could tuck the monitoring box snugly behind the solar panel to provide shaded protection.

The Indiana design was more complex than the California design mainly due to required backup power. We used solar panels as the primary power generation source, but could have explored battery-powered solutions as well (e.g., a rechargeable motorcycle battery), which, in hindsight, would have been cheaper. The Indiana design benefitted from a no-root solution and used more Tasker triggers that allowed us to track each smartphone’s battery, temperature, data usage, and other statistics. The plug-and-play station design enabled a relatively pain-free setup, and we could exchange parts quickly with other parts should they fail. The main drawback to the Indiana design was unforeseen overheating of boxes exposed to full sunlight, which zeroed the fraction of files delivered until we could switch out the phone. Because we deployed the Indiana phones for camera monitoring as well as acoustic monitoring, many boxes were exposed to full sun. The simplest solution to overheating was to secure a large, plastic flower pot holder over the box to provide some shade (Figure 1g). We did not attempt to insulate the polycarbonate boxes, but insulated lockable plastic junction boxes with knockouts would have been preferable to our selected model.

Conclusion

Ecological monitoring with automated devices has increased rapidly in recent years, with a large variety of smartphone apps dedicated to this purpose. Here, we explored how Tasker can be used to operate a smartphone-based ecological monitoring program that offers an alternative to the store-on-board paradigm. Our simple approach could be adopted and modified by others who wish to use nonproprietary methods of data collection that enable data transmission over a cellular or Wi-Fi network.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Text S1.** Automating smartphones with Tasker and AutoInput tutorial developed in 2020.

Found at DOI: https://doi.org/10.3996/JFWM-20-071.S1 (6.61 MB PDF).

**Text S2.** California smartphone setup for the Riverside East Solar Energy Zone smartphone monitoring effort (Bureau of Land Management, California). We deployed smartphone-based autonomous monitoring units at 16 sites and collected data from March 2016 to May 2017 with a focus solely on collecting audio data.

Found at DOI: https://doi.org/10.3996/JFWM-20-071.S2 (5.49 MB PDF).

**Text S3.** Tasker XML file used to automate smartphones for the Riverside East Solar Energy Zone smartphone monitoring effort (Bureau of Land Management, California). We deployed smartphone-based autonomous monitoring units at 16 sites and collected data from March 2016 to May 2017 with a focus solely on collecting audio data.

Found at DOI: https://doi.org/10.3996/JFWM-20-071.S3 (53 KB XML).

**Text S4.** California smartphone monitoring station design for the Riverside East Solar Energy Zone smartphone monitoring effort (Bureau of Land Management, California). We deployed smartphone-based autonomous monitoring units at 16 sites and collected data from March 2016 to May 2017 with a focus solely on collecting audio data.

Found at DOI: https://doi.org/10.3996/JFWM-20-071.S4 (11.05 MB PDF).

**Text S5.** Indiana smartphone setup for the Indiana Dunes National Park smartphone monitoring effort (National Park Service, Indiana). We deployed smartphone-based autonomous monitoring units at 21 sites and collected data from May 2019 to October 2019 with a focus on expanding the type of data collected, including audio data, timed photographs, and motion-triggered photographs.


**Text S6.** Tasker XML file used to automate smartphones for the Indiana Dunes National Park smartphone monitoring effort (National Park Service, Indiana). We deployed smartphone-based autonomous monitoring units at 21 sites and collected data from May to October 2019 with a focus on expanding the type of data collected, including audio data, timed photographs, and motion-triggered photographs.

Found at DOI: https://doi.org/10.3996/JFWM-20-071.S6 (180 KB XML).

**Text S7.** Indiana smartphone monitoring station design for the Indiana Dunes National Park smartphone
monitoring effort (National Park Service, Indiana). We deployed smartphone-based autonomous monitoring units at 21 sites and collected data from May to October 2019 with a focus on expanding the type of data collected, including audio data, timed photographs, and motion-triggered photographs.

Found at DOI: https://doi.org/10.3996/JFWM-20-071.S7 (21.75 MB PDF).

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