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*Tools and Technology*

# Mobile Application for Wildlife Capture–Mark–Recapture Data Collection and Query

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**ABSTRACT** Capture–mark–recapture (CMR) approaches are often used in the management and conservation of wildlife species and effective approaches to estimate populations rely on accurate data-collection techniques. Unfortunately, sampling errors can arise at several steps in the CMR process. We designed and applied a mobile application (app) for field-collected data from a CMR study on herpetofauna. Entering data into a digital format in the field using the mobile application eliminated timely steps to process handwritten data sheets and double-checking data entries. Applications were developed for mobile devices on the iOS and Android operating systems. Both platforms have similar user interactions via data entry on a touch screen using pre-programmed fields, checkboxes, drop-down menus, and keypad entry. Our mobile application includes features to insure collection of all measurements in the field through pop-up messages and can proof entries for valid formats. The application can assign unique numbers to newly captured individuals by querying the database for unused codes and eliminates the potential to assign 2 individuals with the same unique code. Technicians can query a database to view histories of previously captured animals from the field. During a 2-month project, we estimated that using the mobile application instead of manual data entry and proofing via data sheets reduced our total project time by 10%. To our knowledge, this is the first application developed for mobile devices for biologists using CMR techniques and could be developed for use in other areas of field data collection. 

**KEY WORDS** capture–mark–release (CMR), data collection, data entry error, data proofing, database, field methods, mobile devices, web application.

Capture–mark–recapture (CMR) methods are often used in the management and conservation of wildlife species to estimate populations and survival (Seber 1982). Effective approaches to estimate populations rely on accurate data-collection techniques and assumptions such as unique marks remain with the animal (Pollock 1982, Seber 1982). Unfortunately, we have found that sampling errors can arise at several steps in the process, including when sampling data in the field, during data recording, and in the process of data entry. For example, during some CMR studies that rely on technicians to record an animal's unique code on a data sheet, the potential exists to accidentally assign one unique mark to >1 individual, thus creating 2 animals with the same unique code. Some researchers follow established protocols to reduce data errors by implementing error-checking methods, such as comparing duplicate entries of the same data (Brown and Austen 1996, Zhang and Hu 1998, Barchard and Pace 2008) or by one technician reading data entered to a second technician, who compares values to an original data sheet (Kawado et al. 2003).

Although there is limited evidence documenting the benefits of data-proofing methods in wildlife biology, Johnson et al. (2009) found that double-checking fisheries data reduced errors compared with single-data-entry methods. An evaluation of fisheries data found that abundance estimates from single-data-entry were different from estimates from data that had undergone proofing; however, the magnitude of difference was small (Johnson et al. 2009). Scientists within the medical field have evaluated data-entry errors and the implications of errors in assessing clinical trial results. For example, data entered without a proofing step had error rates of 0.34% and 0.66% (Kawado et al. 2003, Büchele et al. 2005).

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In addition to the ramifications of overlooked data errors, wildlife biologists must also balance considerations for the efficiency of data collection and proofing. Nearly all scientists are limited by time and funding available to complete a given project. Therefore, time spent double-checking entered data diverts resources from other research activities, such as additional field sampling and data collection (Johnson et al. 2009). However, failing to eliminate data errors could compromise research results and misdirect management recommendations.

Scientists have used small hand-held computers and personal digital assistants (PDAs) to enter field data directly into a digital format, thus eliminating paper data sheets and post-sampling data-entry and proofing steps (Green 2001, Fletcher et al. 2003, Ice 2004). However, PDA technology is being replaced by mobile devices. Smart phones and tablets have become the preferred digital platform (Au 2012). Researchers can now use mobile devices anywhere and anytime, even without being connected to the Internet, for a multitude of purposes (Tarasewich 2003). As mobile devices and other small-sized electronics become available and affordable, field researchers have the potential to reduce data errors with customizable user-interfaces and to increase time-savings by entering data as a digital format during field sampling. For example, Aanensen et al. (2009) developed a mobile application (app) to enter and store epidemiology data on a mobile device and send data to a central web database.

Here, we describe the first mobile wildlife application to collect field data and query capture-history information. Our mobile application was developed by computing undergraduate and Master's graduate student developers from Arizona State University (ASU; Mesa, AZ), Polytechnic campus. We tested our mobile application in the field and compared the mobile application with traditional data recording via data sheets and data entry techniques with human subjects.

The objective of our study was to determine the effectiveness of mobile applications in CMR field research. Using an existing data set, we quantified the types of data entry errors and the duration for data entry and data proofing. We used undergraduate student subjects to compare the duration of data recording and data entry, and the frequency of errors between the mobile application and traditional (paper) techniques. Finally, we field-tested the mobile application using existing mark–recapture studies on herpetofauna.

# METHODS

## Field Data Collection

We collected CMR data from June through July, in 2010, 2011, and 2012 as part of a long-term study (Bateman et al. 2010). We captured lizards using traps at sites along the Virgin River in Nevada and Arizona, USA (Bateman and Ostoja 2012). Trapped lizards were identified to species, weighed, measured, sexed, individually marked with a unique toe-clip (Waichman 1992) and released at point of capture.

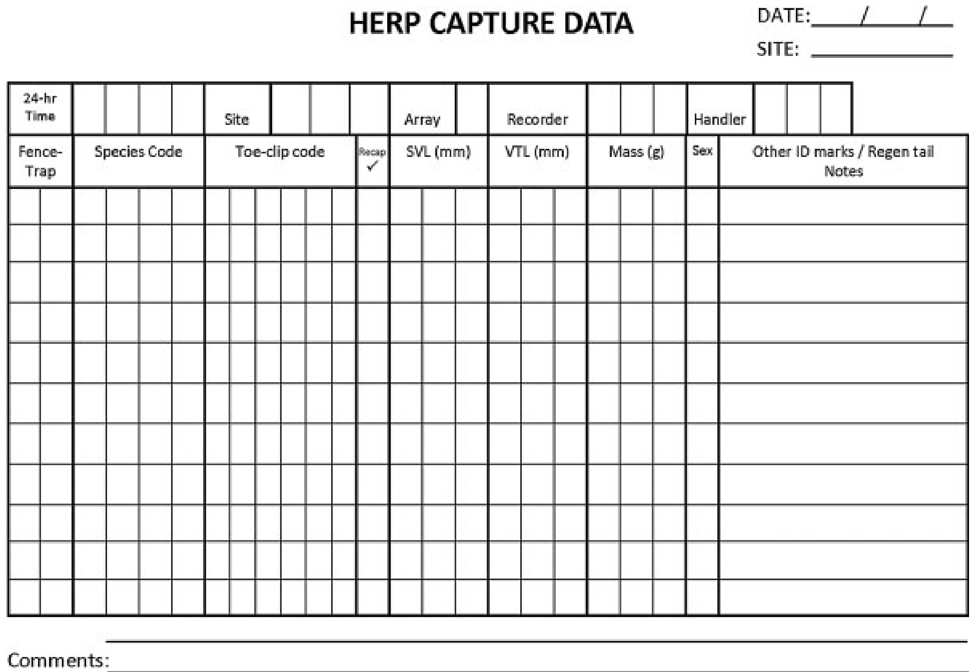
Typical of large projects, several technicians processed animals, recorded data in the field on a data sheet (Fig. 1), entered data into a Microsoft Excel (Microsoft Corp., Redmond, WA) spreadsheet, and proofed data entries. Types of data recorded on data sheets included species code, toe-clip code, snout-to-vent length, vent-to-tail length, mass, sex, and notes of animal condition (Table 1). A list of unique toe-clip codes was generated for each species at each site. When an unmarked lizard was captured, a technician referred to a list of available codes (Waichman 1992). After a toe-clip code was assigned to an animal, the technician crossed out the code and recorded the date of use. These were standard data-collection and data-entry methods used prior to the development of the mobile application. Animal-handling activities were approved by ASU Institutional Animal Care and Use Committee (protocol no. 12-1254R).

## Data Entry and Proofing

To quantify types of errors that occur during data entry, we used identified errors from the 2010 and 2011 Virgin River database. Technicians entered data into a Microsoft Excel spreadsheet formatted to resemble field data sheets (Fig. 1). Capture events for each individual animal were entered by a single technician and included morphometric and location data (Table 1). Proofing data entailed a technician viewing the data in the Microsoft Excel spreadsheet and comparing with the handwritten data sheet. Proofing data occurred during separate time intervals from data entry and, when possible, technicians proofed data they themselves did not enter. When an error was discovered during proofing, the technician used the highlight tool in Microsoft Excel to identify the cell and correct the value.

To quantify the duration of data entry and proofing, participants were recruited from a junior–senior undergraduate class (i.e., Vertebrate Zoology) at ASU in which wildlife biology is a covered content area. Only participants who gave consent to have their performance included as part of the overall study were included in analyses. As a class exercise, students were given verbal and visual instructions of how to enter data into a Microsoft Excel spreadsheet. Students were provided copies of data sheets from records from the long-term herpetofauna study described previously. Students were divided into 2 groups. One group entered data for approximately 20 animal captures and then left the classroom. The second group of students proofed data entered by the first group of students. Discovered errors were highlighted in Excel by participants. We recorded the time required for each student to enter or proof data. This allowed us to quantify the time required for data entry and proofing. Technicians were also timed during data entry and proofing during the herpetofauna project in 2011. Research activities were approved by ASU Human Subjects Committee (protocol no. 1112007241).

To estimate time required for entering and proofing data for a reasonable number of animals captured for one summer field season (e.g., 1,000 captures, such as are often encountered in our Virgin River project), we used Equation (1). We calculated the total time required to enter


HERP CAPTURE DATA

DATE: ___/___/___
SITE: ___________

| 24-hr Time | Site | Array | Recorder | Handler |
|---|---|---|---|---|

| Fence-Trap | Species Code | Toe-clip code | Recap ✓ | SVL (mm) | VTL (mm) | Mass (g) | Sex | Other ID marks / Regen tail Notes |
|---|---|---|---|---|---|---|---|---|

Comments:

**Figure 1.** Example field data sheet used to record captures and morphometric data for individual amphibians and reptiles. Modified from sheet originally designed by A. Chung-MacCoubrey. Data fields and types of data are defined in Table 1.

data for 1,000 captures ($T_{(\text{total})}$) as

$$T_{(\text{total})} = T_{(\text{data entry/20 caps})} + T_{(\text{data proof/20 caps})} \times \left(\frac{1,000}{20}\right) \quad (1)$$

## Comparing Mobile and Traditional Methodologies

We provided undergraduate students (i.e., from Vertebrate Zoology class) with 40 min of verbal and visual instruction on data recording and data entry methods. We instructed students in how to enter data from herpetofauna species using traditional (paper data sheets) methods and using a mobile application installed on a smartphone. For the traditional method, students entered data from 3 animals on a data sheet (Fig. 1) and then entered those written data into an Excel spreadsheet. Students recorded the time they began data entry on the data sheet and recorded the time they completed data entry in Excel. Students also recorded data on Android smartphones (Motorola Droid; Motorola, Inc., Schaumburg, IL) with the application already installed and connected to Wi-Fi (Fig. 2). The application automatically recorded the start time and students recorded the time they synced the device with the database—this indicated that recorded data on the device were sent to the online database (Fig. 3). Students used flashcards to represent known values of lizard and amphibian species and used a different set of flashcards for each method.

We compared time (to record data and enter into a database) and frequency of errors between the traditional and mobile application methods. Because the same students tested both data entry methods, it was possible that students could have performed faster on the second technique (attributable to experience). We used a split-plot analysis of variance (repeated-measures ANOVA) to compare within-subjects factors (type: mobile vs. traditional method) and between-subjects factors (order: whether the student collected data first with the mobile device, second with traditional data sheet or first using traditional data sheet, second with mobile device).

## Field-Testing Mobile Application

To determine the effectiveness of the mobile application technique compared with traditional (data sheet) data collection, we used the mobile application during 2 research projects. We collected herpetofauna data from September 2011 to March 2012 using the mobile application at field sites established on the Phoenix–Mesa Gateway Airport (hereafter, Gateway), in Arizona. We also collected data from May to July 2012 using the mobile application along our Virgin River study in Nevada. Lizards were captured in trapping arrays and processed using methods described previously. Technicians tested mobile apps for 2 platforms on 2 devices—a Motorola Droid with Android version 2.3.3 (US$150, used) and an Apple iTouch third-generation iOS (US$230, new; Apple, Inc., Cupertino, CA).

Prior to each use, devices were synced with the database via a Wi-Fi connection (Fig. 3). This updated any changes from previously captured animals. The database was stored on each mobile device; therefore, when a previously marked animal was recaptured, technicians could view the animal's capture history. Technicians could double-check that the animal captured in the field matched the history from previous captures.

Data were added to the database through multiple mobile devices from the field and also through the web application from a computer (see online Appendix A). Upon returning

**Table 1.** Definition of field data collected on data sheets or collected via a mobile application (app) during field research on herpetofauna. A graphical user interface (GUI) allows a user to interact with the mobile device via a touch screen. The application was developed to reduce data-entry errors, such as allowing only specific types of data or by alerting the user of missing values ([a]) with a pop-up message. The application is synced to the database, so it can display capture histories of specific individual animals ([b]).

| Data field | Definition | Entry type | GUI on app | Error checking |
|---|---|---|---|---|
| Date | Calendar day | Date | No action by user | Populated by app |
| Time | Time of sampling | Time | No action by user | Populated by app |
| Site | Site location name | Text | Drop-down menu | Pre-filled site codes[a] |
| Array | No. of trap array | Alpha-numeric | Drop-down menu | Pre-filled array numbers[a] |
| Recorder | Initials of tech recording data | Text | Type via touch keyboard | Two or three letters required[a] |
| Handler | Initials of tech measuring animals | Text | Type via touch keyboard | Two or three letters required[a] |
| Fence-trap | Trap location where animal was captured | Categorical | Drop-down menu or select image | Select trap location from image of trap array[a] |
| Species code | Four-letter genus and species | Text | Drop-down menu | Lists only species encountered in study[a] |
| Toe-clip code | Unique toe-clip | Alpha-numeric | Drop-down menu or select image | Select code from image of lizard with numbered toes[a] |
| Recap | Animal is a recapture | Text | Checkbox | If unchecked, app will suggest next unused toe-clip. Unchecked allows user to enter toe-clip |
| SVL | Animal snout-to-vent length | Numerical | Select numbers for key pad | Numbers only, no text permitted |
| VTL | Animal vent-to-tail length | Numerical | Select numbers for key pad | Numbers only, no text permitted |
| OTL | Animal original tail length if regenerated tail | Numerical | Select numbers for key pad | Numbers only, no text permitted |
| Mass | Animal wt | Numerical | Select numbers for key pad | Numbers only, no text permitted |
| Hatchling | Animal is a neonate | Categorical | Checkbox | Default is unchecked, user selects if neonate |
| Sex | Animal sex | Categorical | Drop-down menu | Pre-filled with male, female, unknown[a] |
| Dead | Animal is dead in trap | Categorical | Checkbox | Default is unchecked, user checks if dead |
| Comments | Short notes on condition of animal | Text | Type via touch keyboard | NA |
| History[b] | Date and morphometric data on individual animal | Text | Viewable in table format | No editing allowed |

from the field, technicians synced mobile devices with the database on a server via a Wi-Fi connection. The database was created with SQLite3 and was accessed through a Ruby on Rails web application. The web application outputs data from the database into a user-readable format that appears similar to the Microsoft Excel spreadsheet already in use for data entry. The web application allows data from the database to be manipulated for corrections (Appendix A in Supplementary Information) and to be exported as a .CSV file. The produced .CSV file can be imported into Microsoft Excel and Access or any other data-manipulation program that supports this format.

# RESULTS

## Data Errors and Time to Record Data

During 2 field seasons, we recorded 2,119 capture events. Of those, 77 capture events contained errors (error rate of 3.6%) for single data entry. Errors were detected during data-proofing steps and number of errors per capture event ranged from 0 to 5. There were 3 occasions where entire capture events were missing. The most frequent type of error occurred when technicians neglected to record whether an animal was alive or dead (i.e., data field was left blank). The second most frequent error occurred when technicians entered an incorrect unique toe-clip code as a typo. Other errors included incorrect species code, incorrect location, incorrect or blank sex, incorrect measurements, and incorrect or blank live–dead category.

Time to enter data for 20 animal captures did not differ between experienced technicians and mostly inexperienced undergraduate students ($t_{21} = -1.87$, $P = 0.075$). The mean calculated time necessary for manual data entry and proofing combined for 20 capture events was 28.4 min (SE = 1.6, $n = 16$) or 1.4 min/capture event for undergraduate students and 23.2 min (SE = 1.9, $n = 7$) or 1.2 min/capture event for technicians. Student subjects in the second class group took an average of 11.5 min (SE = 0.9, $n = 11$) to proof data entered by the first group.

To determine the time required to enter and proof data (Equation 1), we defined $T_{(\text{data entry/20 caps})} = 25$ min and $T_{(\text{data proof/20 caps})} = 11$ min. We estimated total time to enter and proof data for 1,000 captures (or one summer field season) to be approximately 30 hr.

## Comparison of Data-Entry Methods

We compared paired samples from 32 biology undergraduate students entering data using traditional methods and mobile

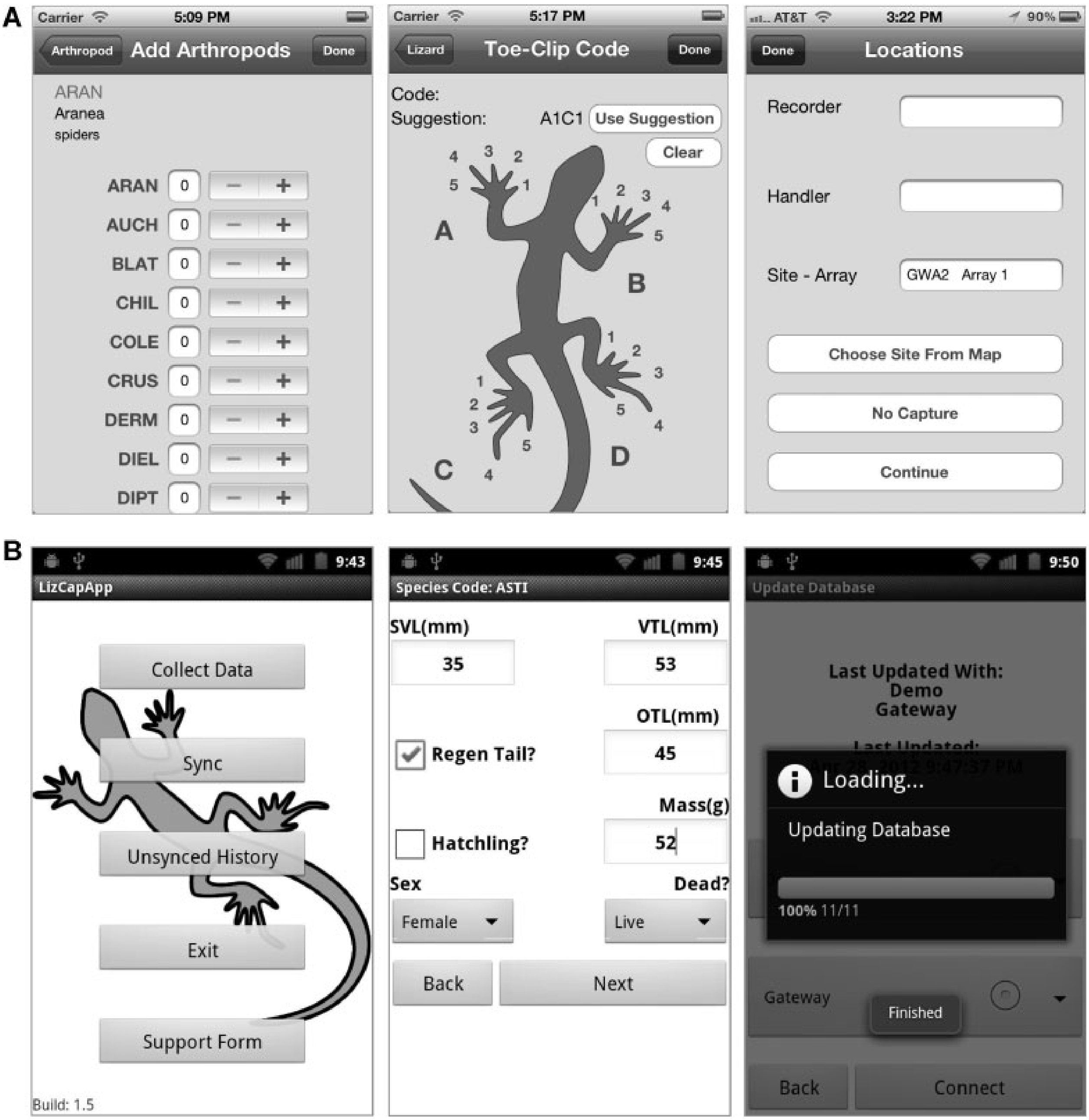



**Figure 2.** Examples of screen shots from mobile applications for the (A) iOS platform and (B) Android platform developed for data recording and syncing used in herpetofauna field research. After data are recorded by technicians, data are synced to an online database via a Wi-Fi connection. Data fields and types of data are defined in Table 1.

devices (students entered 3 capture events/method). Compared with traditional data-entry methods, students recorded and entered data 50% faster using the mobile application ($F_{1,30} = 140.27$, $P > 0.0001$; Fig. 4A). Compared with traditional data-entry methods, students had 32% fewer errors using the mobile application ($F_{1,30} = 7.88$, $P = 0.011$; Fig. 4B). The order of data entry method (using the mobile device first or using traditional methods first) did not improve the time or reduce data errors (time, $F_{1,30} = 0.70$, $P = 0.408$; errors, $F_{1,30} = 0.007$, $P = 0.933$). Types of errors that occurred using the traditional method but were absent from the mobile application testing included blank values, incorrect study site, incorrect species code, and incorrect measurement data.

## Field-Testing Mobile Application

During the period of field testing the mobile application on the Gateway project, we collected data on 424 animal captures. We encountered 6 occasions when the mobile application suggested a toe-clip code different from our list of available unique codes. Upon further investigation, in all occasions a technician neglected to cross off a code on the

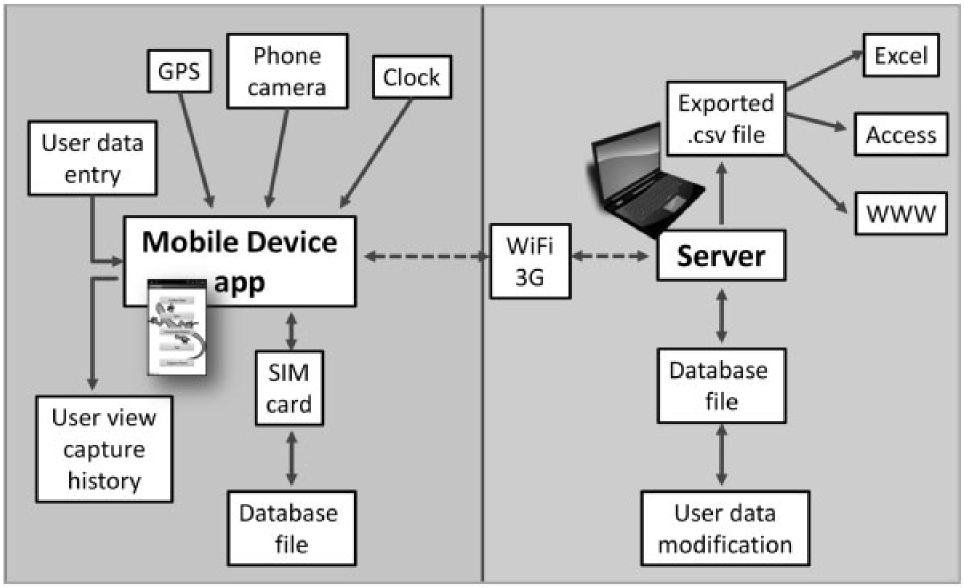



**Figure 3.** Schematic showing the flow of data collected in the field (left panel) on a mobile device to a database housed on a server and accessed back in the lab (right panel). Arrows indicate the direction of data flow from generation to storage or viewing and dashed lines indicate data transfer via a wireless signal. Note that photo capture and Global Positioning System (GPS) location data are future features to be developed in our application.

data sheet after assigning a new toe-clip to an animal. The mobile application correctly suggested the next available toe-clip and prevented the technician from assigning the same unique code to 2 individual animals. During field testing the mobile application on the Virgin River project, the application was used to collect data on 327 animal captures. The application performed as expected and resulted in no loss of capture data. We experienced a force close (i.e., application crashed) on one occasion when the user entered an incorrect format for mass.

## DISCUSSION

We found that using a mobile application to collect field data was a viable option for recording and entering data. Our results show that our mobile application performed without loss of data, increased the opportunity of catching marking errors (via data queries), and was significantly faster at transforming field-collected data to a database. Data-proofing steps built in to the application (Table 1) allowed for consistent data collection from one technician to another by reducing ambiguity with pre-populated drop-down menus, prohibited omitting data by not allowing a user to proceed if specific fields were missing data, and reduced the risk of assigning unique codes to >1 individual during animal marking. Unique code errors were further reduced by eliminating typos during data entry in Microsoft Excel from the auto-correct function (e.g., Excel would auto-fill toe-clip codes based upon previous entries). The benefit of having capture histories available on the application allows technicians to ensure that marked animals match their histories. For example on the Gateway project, on 6 occasions we were able to correct the sex of an adult animal first captured as a hatchling when determining the sex was difficult. On the Virgin River project, on 2 occasions we captured a lizard that had been captured every year for 4 years. One benefit of viewing capture histories from the field is to ensure that the captured animal matches its history. For example, if an animal has an incorrect mark, the mark can be corrected when the animal is 'in the hand' instead of finding an error after the fact when viewing data back at the lab. Similarly, any inconsistencies in the database can be identified in the field and corrected.

Wildlife and ecological projects are increasing in complexity, duration, and scale to discover broad-scale trends and patterns by organizations such as the Long-Term Ecological Research Network, National Center for Ecological Analysis and Synthesis, and National Ecological Observatory Network, and by many natural resource agencies (i.e., U.S. Geological Survey and U.S. Forest Service). For these entities, it will become increasing critical to manage data collection in a consistent and robust fashion across their networks (Michener et al. 1997, Jones et al. 2006).

By eliminating the time required for data entry and proofing, development of our mobile application could potentially free-up significant time in field-based research. This application has eliminated manual data entry and proofing steps in our herpetofauna projects. Based upon our human-subject and field tests, using the mobile application can reduce nearly 1 work week of time (assuming a 2.5-month sampling period with 1,000 capture events). For large-scale projects, the time saved could be used to collect additional samples in new locations and process more animal captures during a project. For smaller projects, feasibility is also an important consideration.

There are potential disadvantages to using a mobile application as a primary data-entry system. There exists a possibility of a unit losing data as a result of a dead battery, overheating, or being dropped. However, losing data from a

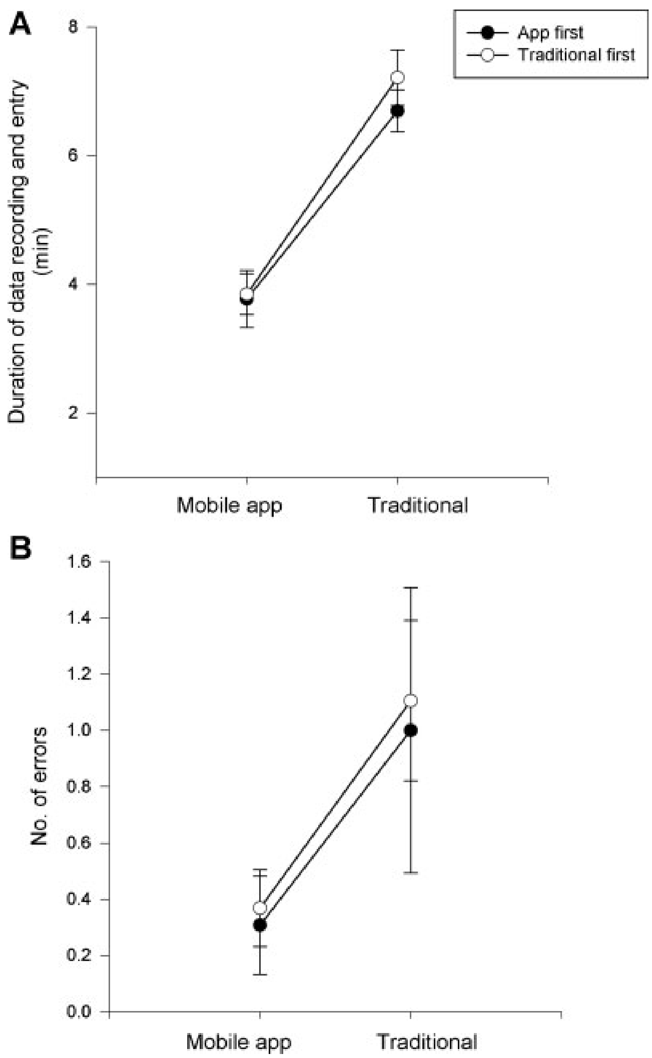



**Figure 4.** Mean (±SE) duration (measured in sec) of data recording and entry into a database using 2 data-entry methods (A) and mean (±SE) number of errors per person per method (B). Subjects ($n = 31$) entered data for 3 herpetofauna species from flashcards using traditional (data sheet) and mobile application methods. Subjects entered data using traditional methods by recording data on a data sheet (Fig. 1) and then transcribing data into an Excel database. Subjects also entered data using a mobile application by recording data on an Android smartphone and then syncing entered data with an online database.

dead battery is a remote possibility for Android devices because data can be stored on a removable memory card (not available on the iOS devices). Processing time can cause delays in the field for any project relying on electronics and technology. For example during a fisheries project, processing speeds decreased as the amount of memory available on a PDA device decreased, causing the field crew to spend more time to process a captured fish (Johnson et al. 2009). The processing capability of mobile devices such as Android phones and tablets and iTouch and iPhones is far superior to the processing speeds of PDA devices (Tarasewich 2003). Other disadvantages of mobile devices could be the mechanism of data entry. For example, some of our student respondents felt the size of the QWERTY keyboard and touch screen were too small for data entry. Although, Sears and Zha (2003) found that smaller keyboards of mobile devices did not significantly increase data-entry time or lead to more data errors compared with larger keyboards. In the field, we used cases with protective membranes to protect the screen from dust and moisture, which may interfere with the touch screen sensitivity.

Overall, applications on mobile devices can be used in the field for data collection and query during CMR studies. The main benefit of the application is the amount of time saved by eliminating transcribing data into a database. Although most of our student subjects were novice users, our results show that users have fewer errors using mobile applications compared with manual data-entry methods. Because mobile applications can have disadvantages that affect their ease of use, we recommend training technicians on data entry and syncing methods. We suggest that backup methods, such as carrying an additional mobile device or data sheets, can reduce potential problems during data collection.

### Future Directions

Because many biologists have little understanding of sophisticated computer programming to develop their own mobile application, our aim is to develop a web-interface for biology users to customize their own application (such as CyberTracker.org). Development of mobile applications that can be customizable by each user could provide consistency across projects using several technicians over multiple locations. Our application utilizes many of the types of data that are typical of wildlife field projects (e.g., text or categorical fields, measured data, count data, and location information); therefore, there is the possibility for expansion to other taxa. We have the potential to adapt our application to any CMR project by allowing users to customize specific data types and data fields. For example, instead of capture histories tied to a specific toe-clip combination, a user could record color leg-band combinations for birds, numbers of metal ear tags for rodents, or radio frequencies or passive integrated transponder tags for telemetered animals. Our intent for dissemination of the customizable application would be via open-source venues such as iTunes (Apple, Inc.) or Google Play (Google, Inc., Mountain View, CA).

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## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Figure of mobile database schema and description of data flow through relational tables. Photos of technicians entering data on smart phone and tablet via mobile application.