MANAGEMENT

Who's Who & Whereabouts: an integrated system for reidentifying and monitoring African elephants

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Abstract

Monitoring populations of endangered species is critical to understanding the threats they face and to managing interventions to ensure their long-term survival. Individual recognition further allows for essential studies of life history, home range, population dynamics, social behaviour, and photographic capture-recapture, all of which can make conservation interventions more effective. African elephants (*Loxodonta africana, L. cyclotis*), endangered keystone species, have been subjects of several long-term studies involving individual recognition, yielding critical knowledge for their conservation. Ongoing concern for elephant survival has also led to increased interest in engaging non-scientists in monitoring populations. Tools are therefore needed to easily reidentify individual elephants and to provide user-friendly collection, upload, analysis and sharing of data. We describe the development of the *Elephant Who's Who & Whereabouts*, a relational web-based database (DB) system, for registering, reidentifying and monitoring elephants. We tailored the DB for studying elephants in two populations: Maasai Mara ecosystem, Kenya, and Gorongosa National Park, Mozambique. The main components of the system are: a searchable database (*Who's Who*) of registered adult elephants with administration and user interfaces; a searchable database of observations (*Whereabouts*) including elephant sightings, signs, sick and wounded individuals, and mortalities, with admin and user interfaces; a user interface (*My Observations*) for entering and editing of data; a Smartphone application (*EleApp*) permitting collection and upload of data; a searchable Google-Earth-based Mapping interface with export functionality; a *Features Guide* (photographs and text describing how to identify elephants); a *User Info*. We describe the system's structure, functionality, and ease of use.

Résumé

La surveillance des populations d'espèces menacées est essentielle à la compréhension des dangers qu'elles rencontrent et pour la gestion des interventions mises en place afin d'assurer leur survie à long terme. En outre, la reconnaissance individuelle ouvre la voie à une analyse nécessaire du cycle biologique, du domaine vital, de la dynamique des populations, du comportement social et de la capture-recapture photographique, autant d'éléments qui favorisent une meilleure efficacité des interventions. Les éléphants d'Afrique (*Loxodonta Africana, L. cyclotis*), espèce clé en voie de disparition, ont fait l'objet de plusieurs études de long-terme intégrant la technique de reconnaissance individuelle, qui ont constitué une base de connaissance indispensable à leur protection. Le sujet de la survie des éléphants suscite également un intérêt accru pour l'implication de personnes non-scientifiques dans la surveillance des populations.

Des outils sont donc nécessaires pour une nouvelle identification des éléphants ainsi que pour fournir un environnement facile d'utilisation pour la collecte, le chargement, l'analyse et le partage des données. Nous décrivons ici le développement d'un système de base de données relationnelle en ligne (DB), « *Who's Who & Whereabouts* » (« Qui est qui et où vont-ils ? ») pour la surveillance, la reconnaissance et le recensement des éléphants. Nous avons configuré la base de données en deux catégories de population : l'écosystème Maasai Mara au Kenya et le parc national de Gorongosa au Mozambique. Les principaux éléments de cet outil sont les suivants : deux bases de données consultables avec interface administrateur et utilisateur, l'une répertoriant les éléphants adultes (*Who's who*), l'autre axée sur les observations d'individus, de leurs traces, des sujets malades, blessés, ou morts (*Whereabouts*). On trouve également une interface utilisateur, « My Observations » (*« Mes observations »*), permettant la saisie et la modification de données, une application sur smartphone (*« EleApp »*) pour la collecte et le chargement de données, une interface cartographique (« Mapping ») via Google Earth avec possibilité d'export, un guide des caractéristiques (*« Feature Guide »*) avec photos et textes expliquant comment identifier les éléphants et une information utilisateur (*« User Info »*). Nous détaillons ici la structure du système, ses fonctionnalités et sa simplicité d'utilisation.

Introduction

African elephants (*L. africana and L. cyclotis*) are under increasing threat from habitat loss, human-elephant conflict, civil conflict, and illegal killing (Thouless et al. 2016). Monitoring, the repeated observation of the same population through time using the same protocols, is a critical component of elephant conservation strategies (Blanc et al. 2007, Thouless et al. 2016, CITES MIKE 2021). Monitoring provides methodologically comparable data with which to detect changes in a population and the pressures on it over time, as well as the effectiveness of conservation interventions (Moss et al. 2011; Whitehouse et al. 2001). Near real-time data is especially important to respond to changing threats such as poaching or livestock incursions into protected areas.

Monitoring an elephant population from the ground or air, or through remote sensing, typically involves collecting data such as date, time, location, group size and composition. Data can be captured in the field on laptop computers, hand-held devices such as smartphones, and can include the automatic recording of date, time and precise location data based on built-in Global Positioning System (GPS) technology. Relatively low-cost digital devices increase opportunities to engage non-scientists in data collection. Projects that span large geographic areas and/or are especially labour-intensive can benefit from citizen science, while simultaneously providing opportunities to raise environmental literacy and motivate social change in environmental stewardship.

The emergence of smartphones with built-in GPS technology has led to a burst of publicly available sites permitting the upload of observation data via customizable forms (Magpi Mobile, Movebank, SMART, iNaturalist, Ushahidi crowd mapping platforms). While these off-the-shelf products can be customized for collecting basic data on elephant populations, none of them meet the needs of many biologists who also require an efficient method for identifying the individual elephants they observe and integrating the identified animals with group sightings data.

Monitoring individually known elephants in a population is the gold standard, as this approach yields data on life history events (births, deaths), population structure (age, gender, relatedness), and behavioural data. It is also essential to determine social relationships, measure growth and reproductive success, understand communication, and determine life history parameters, population dynamics (Moss et al. 2011, Goswami et al. 2011) and impacts of poaching (Poole and Granli 2022). Although elephants are easily recognizable, the larger the population the more difficult it becomes to discriminate between individuals. Digital filtering functions (Bedetti et al. 2020) can make reidentifying known individuals easier than manually searching through print-based descriptions and photographs (Moss 1996).

In 2011 we initiated two studies based on individual recognition, one in the Maasai Mara ecosystem, Kenya, and the other in Gorongosa National Park (NP), Mozambique. We created a relational database, the *Elephant Who's Who & Whereabouts*, to house two sets of information from the respective populations to be held in two sub-databases (hereafter DBs): 1) Data

on individually recognized elephants (*Who's Who DB*) and; 2) data on group sightings or "observations" (*Whereabouts DB*). We linked the two DBs via sightings of individually recognized elephants. Each DB was designed with a user interface (referred to as the *Who's Who* and the *Whereabouts*, respectively) and an admin interface (referred to as the *ID Interface* and the *Observation* or *OBS Interface*, respectively).

We built a separate *Who's Who & Whereabouts DB* for each population and developed separate smartphone applications (*EleApp*) to permit the capture and upload of geospatial data from the respective populations. The *Who's Who DB* was populated by the authors, while the *Whereabouts DB* was populated by many individuals, both scientists and others, and administrated by the authors. In the Mara we aimed to involve volunteers, as this was a citizen science initiative. While we designed the *Elephant Who's Who & Whereabouts DB* to function as an integrated method for monitoring a population of individually recognized elephants, the *Who's Who DB* and the *Whereabouts DB* could equally well function as stand-alone tools for identifying elephants in the field or for collecting geospatial data on groups of elephants, respectively. The aim of this paper is to describe the design and functionality of the *Elephant Who's Who & Whereabouts DB* with enough information for others to be able to create similar tools for studying an elephant population.

Methodology

Terms used

Administrator(s): DB-managers (JP, PG) approved data providers/users, verified, corrected and exported data[1].

Admin interface: interface for the managers to administrate the DB.

Observation: a record in the *Whereabouts DB*, which could be a sighting of a group, individuals captured on trail cameras, signs of elephants, sick or wounded individual(s), a mortality.

Register: enter a record of a newly identified elephant in the *Who's Who DB*; give it a unique code number and enter in its attributes.

Reidentify: to match an observed or photographed elephant with one registered in the *Who's Who DB*.

Record: an entry into the DB. In the *Who's Who DB* a record is an elephant; in the *Whereabouts DB* a record is an observation as described above.

Sighting: a record of an elephant or a group of elephants, including those gleaned from trail cameras.

User interface: interface for users to access and query the DB.

Database structure

In 2011 we described the concept and functional design of the relational DB, the *Elephant Who's Who & Whereabouts*, and the smartphone *EleApp* in a comprehensive specification document, which was the basis for coding and design by programmers at Verviant Consulting Services, Kenya. The system consisted of 11 components (Fig. 1).

We created: 1) The *Who's Who DB*, a searchable elephant identification database with 35 tables. 2) An *ID interface* for the authors to register elephants and code in their identifying attributes (see Table 1, 2). 3) A searchable *Who's Who* user interface for querying the registry or reidentifying registered elephants based on their observed attributes (Fig. 2, 3). 4) The *Whereabouts DB* (11 tables), a searchable database of observation events for five types of records (Table 3): Sightings of elephants; records captured from trail cameras; sightings of sick and wounded individuals; signs of elephants; and mortalities. The *Whereabouts DB* included overarching attributes common to each observation event (e.g. date, time, observer, observer type, general area, place name, GPS location) and attributes specific to the record type. We linked the *Whereabouts DB* to the *Who's Who DB* via records of reidentified individuals. 5) *My Observations*, a user

[1]To avoid the possibility that someone might use the database to find elephants with big tusks we had a built-in time lag between observation upload and its online display. We permitted only individuals we knew to use the DB and we required a reasonable written reason for their request.

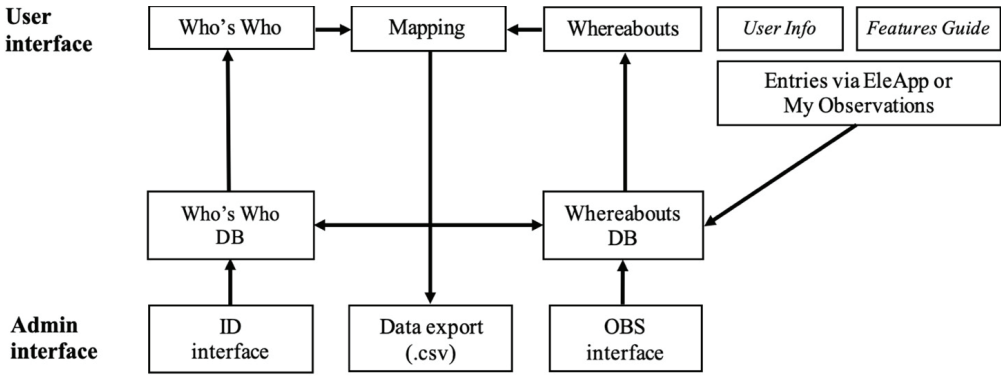


Figure 1. Elephant Who's Who & Whereabouts Database and user information.

interface for computer upload of data by approved users. 6) The *EleApp*, a smartphone application for field data collection and upload that mirrored *My Observations*. 7) An *OBS Interface* for the authors to verify uploaded records. 8) A *Whereabouts* user interface for searching through sightings of elephants. 9) A searchable Google Earth-based *Mapping* interface for geospatial data display and, for approved users, export (.cvs format) of returns from filtered searches. 10) A *Features Guide* with lessons on how to reidentify elephants and illustrations of their characterizing physical attributes. 11) A *User Info* document.

The elephant attributes were developed from those used by the Amboseli Trust for Elephants (ATE) and are common across all African elephant populations (Tables 1, 2). Sightings and Trail Camera Sightings attributes were based on long-term monitoring protocols used by ATE for 50 years (Moss et al. 2011; Table 3). Mortality criteria followed those developed for the Monitoring Illegal Killing of Elephants (MIKE) programme under the Convention on International Trade in Endangered Species (CITES MIKE) (Table 3). Attributes for signs of elephants were developed from our previous work, and we used input from veterinarians to develop criteria for sick and wounded elephants (Table 3). We programmed the DB such that when a record of a dead, sick, or wounded elephant was uploaded, an email with relevant information could be automatically sent to specific recipients (e.g. veterinarian, warden).

The *Mara EleApp* was published on Google Play, while the *Gorongosa EleApp* was distributed by the authors directly to approved users. The *Who's Who & Whereabouts* user interfaces for both Maasai Mara and Gorongosa were accessible via the ElephantVoices website, www.elephantvoices.org, built in a Joomla CMS environment and hosted by www.ciscowebservers.com. Both were password protected.

Results

The Who's Who Database

ID interface

The authors (JP) registered elephants in the *Who's Who DB* via the *ID interface*.[2] Using photographs taken by the authors and other users we registered 1,214 and 396 adult elephants in the Mara and Gorongosa populations, respectively. We populated each record with up to 36 fields of life history and physical attributes (Tables 1, 2) and uploaded up to six annotated photographs (photographer, year) of the face, ears, and tusks (left and right profiles, head-on with ears spread), and special features or alternative views. If we obtained more accurate images, older photographs were archived within the system, thereby keeping IDs accurate and permitting documentation of changes in appearance or the breakage or growth of tusks over time.

Who's Who—The user interface

The *Who's Who* user interface supported two types of queries: Query the registry about the elephant population, and search for an individual under observation to reidentify it.

[2]Mara elephants were registered from 2011-2015 and Gorongosa elephants from 2011-2019

Table 1. Physical attributes in the *Who's Who DB* used to register and reidentify elephants. Illustrations can be found on How to identify African elephants

Sex N=2	Size N=5	Ear right/ left N=28	Ear shape & lobes N=9	Tusks N=21	Body N=4	Trunk/face N=9	Tail N=5
Male	Calf	Completely smooth	Very big ears	No tusks	Head low	One eye blind	Kinky tail
Female	Juvenile	Tiny nicks	Very small ears	One–left	Bump/lump left	Chopped trunk	Short tail
	Small adult	Serrated	Wavy edge	One–right	Bump/lump right	Slit cut trunk	Half tail
	Medium adult	Ragged	Lobes curl outward	Broken left	Permanently lame	Other trunk injury	No tail
	Large adult	2 or more notches	Lobes curve inward	Broken right	Collar	Wart/bump trunk	No tail hairs
		Outstanding notch/tear	Lobes bulge	Equal length		Wart/bump face	
		U-notch	Lobes jut forward	Shorter left		Wrinkled forehead	
		V-notch	Lobes pointed	Shorter right		Pointed forehead	
		Cup-notch	Lobes rounded	Very short			
		Dip-notch		Very long			
		Scoop-notch		Symmetric			
		Square-notch		Higher left			
		Slit from edge		Higher right			
		Finger-flap		Up curved			
		Flap-cut		Straight			
		Unusual notch		Splayed			
		Hole		Convergent			
		2 or more holes		Crossed			
		Slit hole		Skewed			
		Wart/bump		Wonky			
		Prominent veins		Very thick			
		Damaged		Very slender			
		Curtain					
		Flop					
		Droopy					
		Wedge					
		Fold					
		Crinkle					

Table 2. *Who's Who DB* data entry fields coded in to register an elephant via the ID interface (n=number of attributes; Table 1). Dropdown or radio button selections in italics; yr=year, mth=month, wk=week

Name and Photographs	Life-History	Features (see Table 1)
Code	**Sex** (*male, female*)	**Tusk shape and configuration** (n=21)
Name	**Birth year and accuracy** (*within 10, 5, 2 yrs, 6, 1 mth*)	**Right ear** (holes, notches, tears) (n=28)
Home area (if useful)	**Estimated age** (*automatically calculated from birth year*)	**Left ear** (holes, notches, tears) (n=28)
Notes	**Age class** (*0A, 0B, 1A, 1B, 2, 3, 4, 5; calculates from age*)	**Ear shape and lobes** (n=9)
Photo left ear (*date, photographer*)	**Size class** (*large, medium, small adult, juvenile, calf; calculates automatically from age*)	**Trunk and face** (n=8)
Photo right ear (*date, photographer*)	**Mother and accuracy** (*known, good idea, guess, unknown*)	**Body** (n=4)
Photo front (*date, photographer*)	**Family and accuracy** (*known, good idea, guess, unknown*)	**Tail** (n=5)
Photo extra (*date, photographer*)	**Matriarch**	
Photo extra (*date, photographer*)	**Death year and accuracy** (*exact or within 1 wk, within 3 mths, within 1 yr, within 2 yrs, unknown*)	
Photo extra (*date, photographer*)	**Death cause** (*natural, management, illegal*)	
	Motivation (*ivory, bushmeat, conflict, euthanasia, other, unknown*)	
	Death means (*multiple bullets, single bullet, shotgun, poison, spear, arrow, snare, pit trap, other, unknown*)	
	Death reason (*natural injury/ accident, disease, drought, old age, neonatal, predation, other elephant, other, unknown*)	
	Right tusk (*intact, pulled out, chopped out, removed by authorities, naturally absent, unknown*)	
	Left tusk (*intact, pulled out, chopped out, removed by authorities, naturally absent, unknown*)	

Table 3. Whereabouts DB data entry fields: text entry (te), dropdown (dd) menu or radio-button (rb). Dropdown or radio button selections in italics. *Signifies required data

General entry		
Observer (te)*		
Observer type (dd: *researcher, ranger, scout, guide, veterinarian, management, tourist, other*)*		
Date/time (calendar or automatically taken from phone)*		
General area (te)*		
Place name (te)		
Geospatial location in decimal degrees (entered or clicked on map; automatically taken on Smartphone app)*		
Field notes (te)		
Observation type (rb: *sightings, trail cam sightings, sign, mortality*)*		
Sightings and trail cam sightings	**Sick and wounded**	**Mortality**
Group type (dd: *family groups only, family groups with males, males only unknown*)*	**Elephant ID** (te)	**Elephant ID** (te)
Number of individuals (te)*	**Sex** (dd: *male, female, unknown*)	**Sex** (dd: *male, female, unknown*)*
Count accuracy (dd: *exact count, good estimate, guess*)*	**Age sick wounded** (dd: *adult, subadult, juvenile, calf, unknown*)	**Age of elephant at death** (dd: *adult, sub-adult, juvenile, calf, unknown*)*
Families recognized (te)	**Sick type** (dd: *injury, sickness, unknown*)	**Carcass age*** (dd: *fresh–less than 3 weeks, recent–3 weeks to a year, old–greater than 1 year, very old, unknown*)
Names/ID Codes recognized females (te)	**Foraging affected** (rb: *yes, no*)	**Date of death** (select on calendar)
Names/ID Codes recognized males (te)	**Movement affected** (rb: *yes, no*)	**Cause of death** (dd: *natural, management, illegal, other, unknown*)* Once selected brings up relevant death means, motivation (Table 2)
Oestrous female (te and rb: *yes, no*)	**Type of wound** (dd: *abscess, bullet wound, arrow wound, spear wound, snare wire cutting into skin, snare wire loosely attached, chopped off tail, chopped of trunk, lame, predation, tusk wound, other, unknown*)	**Reason for death** (dd: *natural injury/ accident, disease, drought, old age, neonatal, predation, another elephant, other, unknown*)
Musth male (te and rb: *yes, no*)	**Injury status** (dd: *fresh, infected, healing, old, unknown*)	**Status of left and right tusks** (dd: *intact, pulled out, chopped out, removed by authorities, naturally absent, unknown*)*
Sick and wounded (rb: *yes, no*)	**Sign**	**Found by** (dd: *patrol, local community, guide, tourist, scientist, other*)*
	Sign type (rb: *footprints, dung, foraging, rub marks on trees, sounds of elephants*)*	**Specific location** (te)
	Sign age (dd: *fresh–less than 24 hours, recent–1 day up to a week, old–1 week up to a month, very old–more than a month*)*	

a. Query the elephant registry

Query the Elephant Registry allowed users to use life history criteria to search from among all registered elephants living or dead (Fig. 2). A count of the number of animals returned, permitted a user to obtain a demographic report on subsets of the population.

b. Search for an individual

To reidentify an elephant users selected sex and size class (if known) and the most salient physical features of the elephant from among the drop-down menus: tusk shape and configuration; left and right ear holes, notches, and tears; ear shape and size; face and trunk; tail; and body (Table 1, 2).

Users selected multiple attributes under each physical feature, where appropriate, such as under tusks, "one left" and "broken left." The search query used a "combinatorial key" algorithm to simultaneously filter the database by more than one physical attribute such that the following attributes: female + large adult + no tusks + right ear hole + very big ears, returned only those elephants with all these characteristics. The search included a count of the number of animals matching all these characteristics, in this case from Gorongosa, only one (e.g. Fig. 3). The corresponding individuals were listed together with thumbnails of their ID photographs (with mouse hovered over code name) and primary life history information, permitting a quick check for a match. If the individual was not found, an adjustment to the criteria was easily made and another search performed. Clicking on an elephant's code number brought up its digital ID card (Fig. 4) displaying larger photographs; clicking on these enlarged them further. The ID card also included life history information as well as all coded attributes and was printable. Scrolling down below the card revealed basic information from all sightings of the individual.

Functionality of the Who's Who

To test the functionality of the *Who's Who* for reidentifying elephants, we used a Random Number Generator to select 25 adult males and 25 adult females from among the registered Mara elephants. Examining the ID photographs of each individual we performed a search by selecting the most salient and/or unique features and keyed these into the Who's Who user interface and filtered. We noted the number of ID photos available of each elephant, the number of features selected, the number of animals returned and whether the individual was among them. The 50

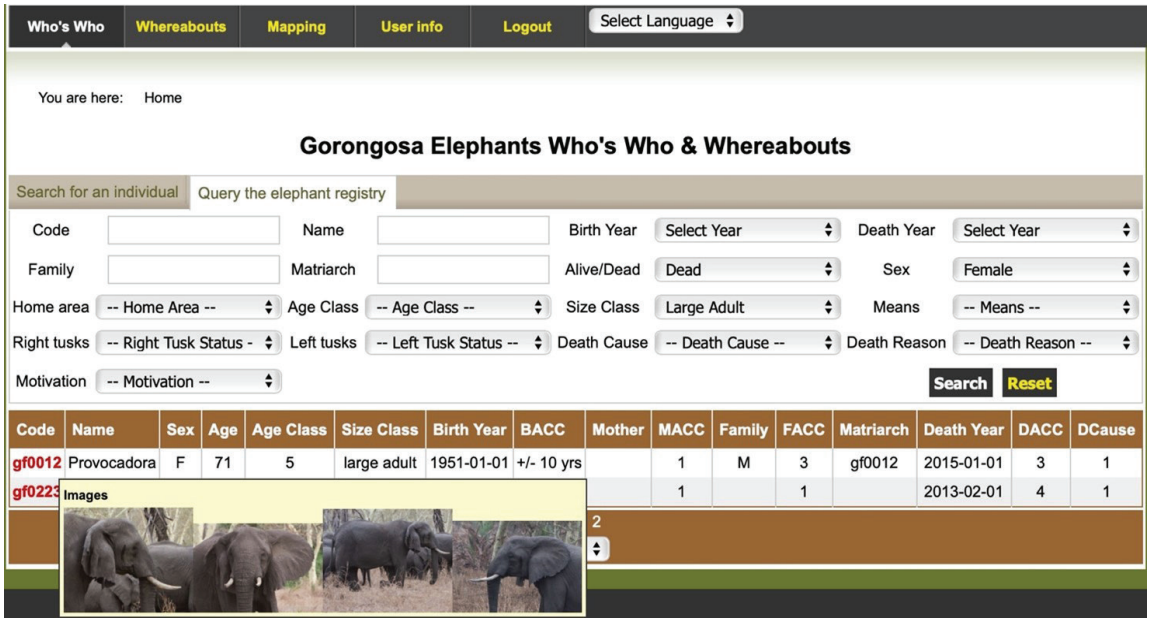


Figure 2. Selections available on Query the Elephant Registry, e.g. Dead, Female, Large Adult; hovering over code gf0012, one of the resulting elephants, shows thumbnails of *Provocadora*.

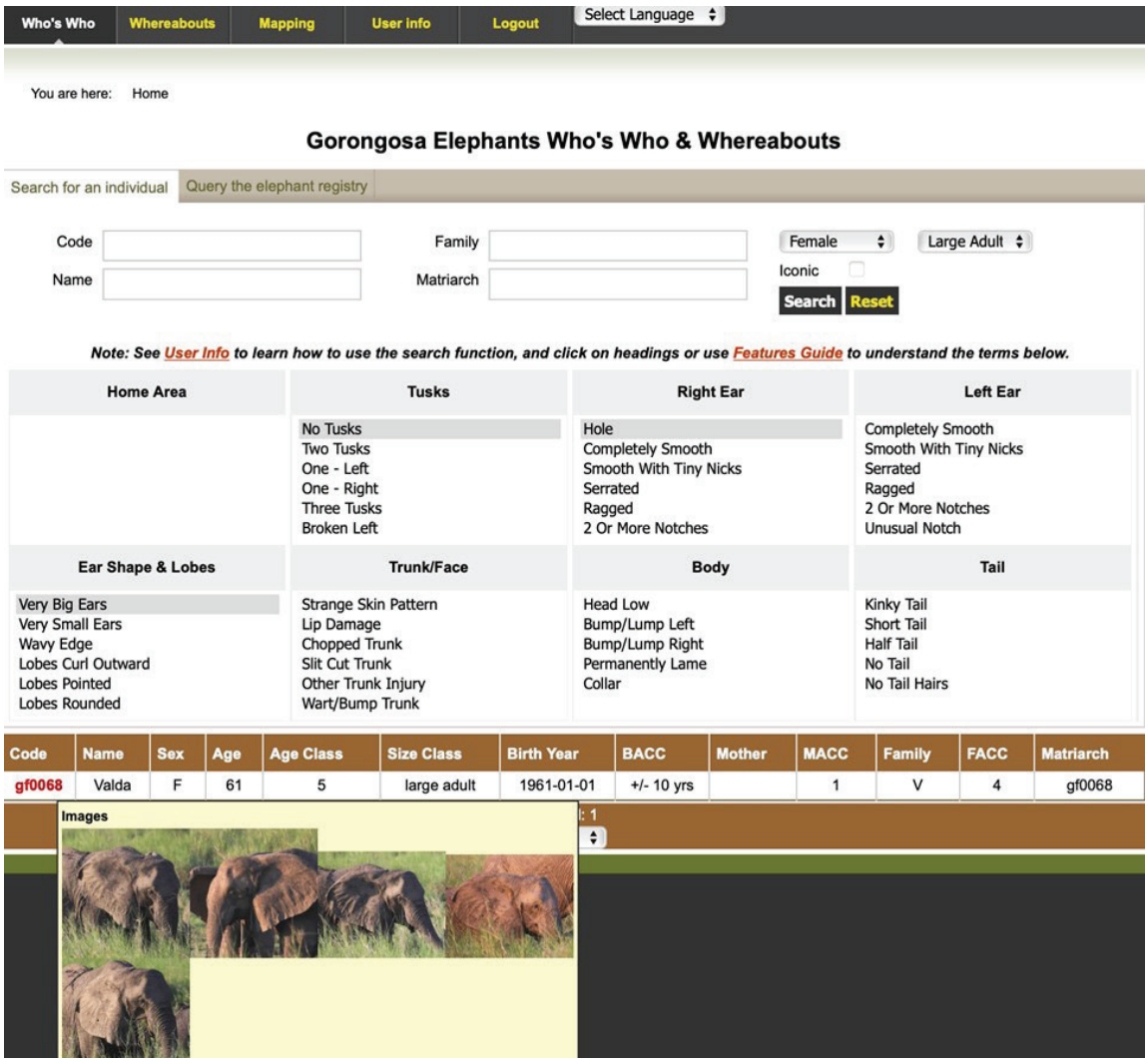


Figure 3. Example of a search on the Gorongosa *Who's Who*. Selecting Large Adult/Female/ Tuskless/Large Ears/Right Ear Hole returns one individual, Valda. Note: there are many more options under the features drop-downs that are not visible in the figure.

ID Card for gf0013

Elephant Details — Add observation | Print ID card

Code	Name	Sex	Age	Age Class	Size Class	Birth Year	BACC	Mother	MACC	Family	FACC	Matriarch
gf0013	Valente	F	56	5	large adult	1966-01-01	+/- 10 yrs		1	M	2	gf0012

Notes

First recorded 2012. She has been seen with gf0012 a few times and looks very similar to her. Could be a sister, perhaps. She is part of the Terrible Trio who charged us. Collared by Dominique in 2018

Home area	Tusks	Right Ear	Left Ear
	Two tusks Higher right	2 or more holes Flap-cut	Scoop-notch 2 or more notches
Ear shape & lobes	**Trunk/Face**	**Body**	**Tail**
Lobes curve inward		Collar	

Photos

Observer	Seen on	General area	Place Name	Group type	Group Size	Females recognized	Males recognized	Field notes
Joyce Poole	01 November 2016		picada 4	Family Group(s) with Adult Males	63	gf0001, gf0013, gf0014, gf0016, gf0017, gf0018, gf0020, gf0021, gf0022, gf0023, gf0024, gf0025, gf0056, gf0058, gf0079, gf0088, gf0164, gf0190	gm0045, gm0057, gm0124, gm0141	Picada 4 we stopped at 250m from the elephants and sat there. We heard vocalisations as if there was a mating but we didn't see one. Then the elephants came toward us. They came to within 5m (Viajante...

Figure 4. Illustration of the individual Valente's digital ID card. Below the card all sightings of her are listed and linked via the observation date. We provide one sighting as an example. Note that her associates are also linked to their respective ID cards.

individuals had a mean of 2.36 (range 1–6) ID photographs. In all but six cases the first search returned a list of individuals that included the sought-after elephant. The average number of animals returned was 5.2 with a range of 1–56; 16 of the 44 successful searches returned only the sought-after individual (Fig. 5).

The Whereabouts database

OBS interface—The admin interface

Only approved users could see or upload data to the *Whereabouts DB*. The authors verified and edited uploaded records via the *OBS Interface*. If, for example, we found a record of an all-male group of 60 elephants (an unlikely sighting) we contacted the observer to verify that he or she intended to select that group type or enter that number. We checked to ensure that the general area selected, or place name entered matched the GPS data acquired. If redundant data were found—such as when two observers uploaded a record of the same individual or group on the same day in the same location, we kept the first or most complete record.

We also checked any uploaded photographs, identified elephants, and added their code numbers to the record. Unknown elephants were registered if the photographs were good enough to clearly distinguish identifying features. If uploaded photographs showed that features of a registered elephant had changed, we updated the record in the *Who's Who DB* and archived

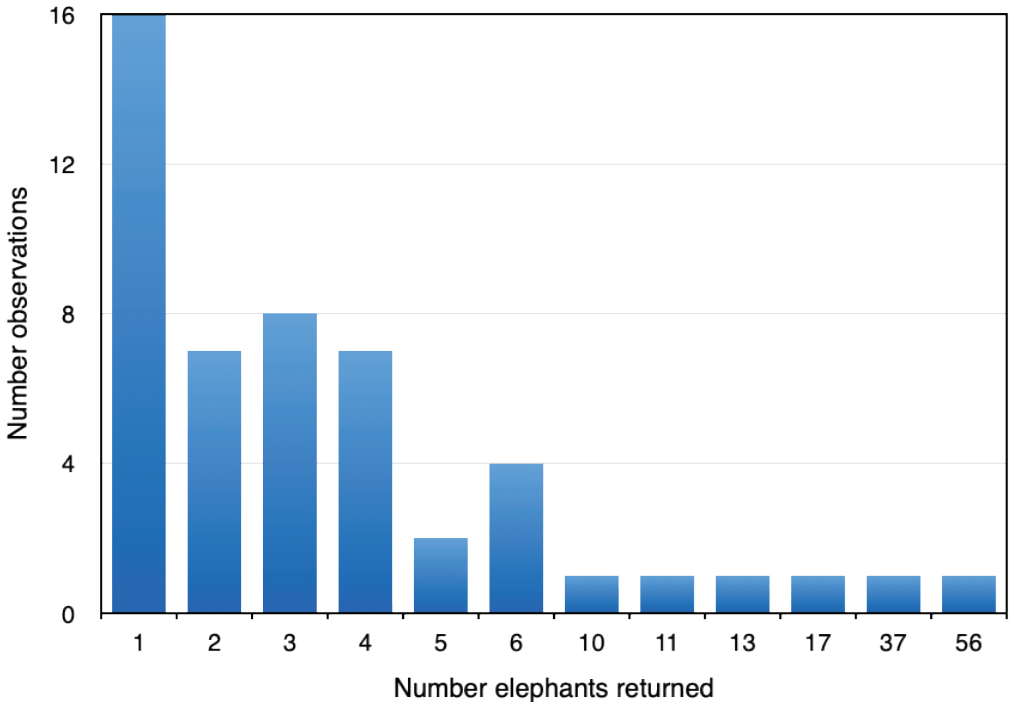


Figure 5. Number elephants returned on 44 successful searches.

the out-of-date photograph.

My Observations—entering, uploading and editing data

My Observations was the web interface to the *Whereabouts DB* where a user could enter, upload, and edit his or her record. Records were either collected with the *EleApp* and uploaded directly (see below) or entered via *My Observations*. General data (Table 3) were entered first and then the type of observation was selected, which prompted a specific sub-set of data entry queries (Table 3). Submitting a record with an elephant ID code or name automatically linked the entry to the ID card(s) of the relevant elephant(s). All required data (* Table 3) had to be entered to save a record. Once saved online, the user could edit or delete the record.

The EleApp smartphone application

The *EleApp* consisted of an easy-to-use form (mirroring the online data entry described above; Fig. 6) for the collection, preliminary storage, and upload of observations to the *Whereabouts DB*. The record date/time and GPS location were automatically acquired from the Smartphone itself. Photographs could be taken within the *EleApp* and be included in the record. Data were saved and uploaded in real-time or uploaded once Internet connectivity was available. The *Gorongosa EleApp* included a bi-lingual (English, Portuguese) interface.

The Whereabouts—The user interface

The *Whereabouts* user interface listed uploaded observations by date and included basic information: Observer, date, time, number of photographs uploaded, general area, place name, females or males recognized and field notes. The date offered a link to the full observation where photographs, GPS coordinates and a map of the location could be seen.

The *Whereabouts* could be queried to produce a report of observations by type, general area, type of observer, elephant group type, and group size range. A search box permitted a free text submission, which allowed a user to search for all observations by a particular observer, elephant name or code, place name or any word that may have been included in the comment field, such as “musth” (Fig. 7).

Table 4. *Who's Who DB* data entry fields coded in to register an elephant via the ID interface (n=number of attributes; Table 1). Dropdown or radio button selections in italics; yr=year, mth=month, wk=week

Group type	Number of records Mara	Number of records Gorongosa
Total	**4,038**	**1,574**
Elephant sightings	**3,073**	**867**
Single males and bull groups	*738*	*350*
Family groups with or without associating males	*2,277*	*485*
Unknown type	*51*	*31*
Trail camera sightings	**-**	**455**
Single males and bull groups	-	193
Family groups with or without associating males	-	250
Unknown type	-	12
Sick and wounded		**37**
Elephant mortalities	**106**	**24**
Elephant signs	**859**	**215**

Number of Records and Participants

By April 2015 the Mara *Whereabouts DB* held 4,000 records collected by 251 individuals and the Gorongosa *Whereabouts DB* held 1,671 records collected by 32 individuals. In addition to ourselves, data contributors included scientists, guides, photographers, rangers, tourists, veterinarians, and members of the local community (Table 4).

The Mapping Interface

The *Mapping* interface included a Google-Earth map with full filtering and export (.csv) functionality that showed the locations of the uploaded observations. Geospatial layers (e.g. conservancy, protected area and forest boundaries, human settlements) were added where available and helpful. Users could filter by time frame, observer, elephant ID code or name, or observation type. By selecting Sighting, Trail Cam Sighting, Sign, or Mortality offered full selection and filtering possibilities under each type. Hovering over a single observation revealed a link to the record in the Whereabouts user interface (Fig. 8). Administrators could export filtered results as a .csv file for further analysis or to share with collaborators.

Features Guide: How to identify African elephants

The *Who's Who & Whereabouts* section on www.elephantvoices.org included a Features Guide on How to identify African elephants with illustrative photographs and written descriptions of the physical attributes used (Fig. 9). The guide included eight sections: How to (1) sex; and (2) age African elephants; how to use characteristics of the (3) tusks; (4) ear notches, tears and holes; (5) ear lobe size and shape; (6) trunk and face; (7) body; and (8) tail to identify individuals.

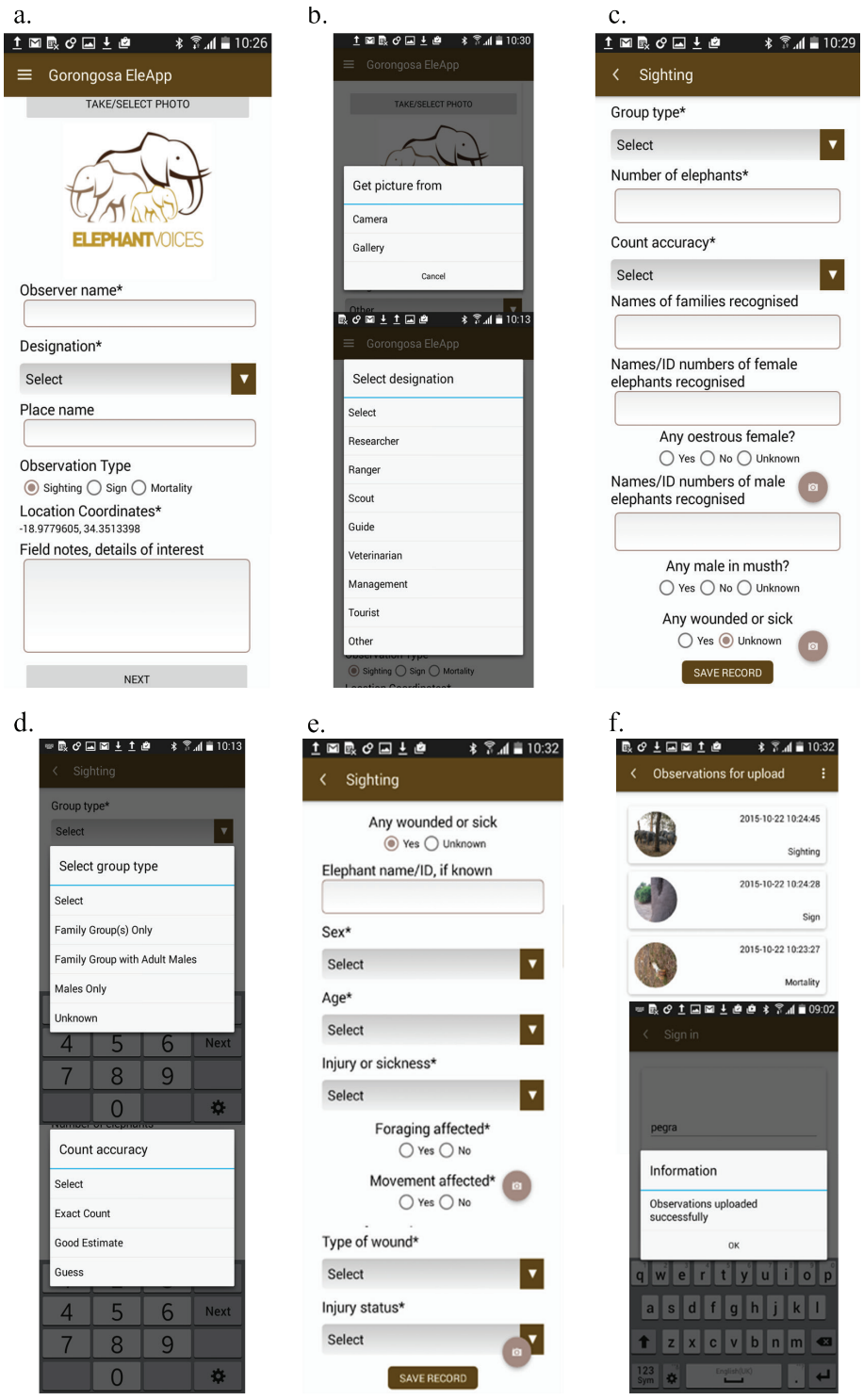
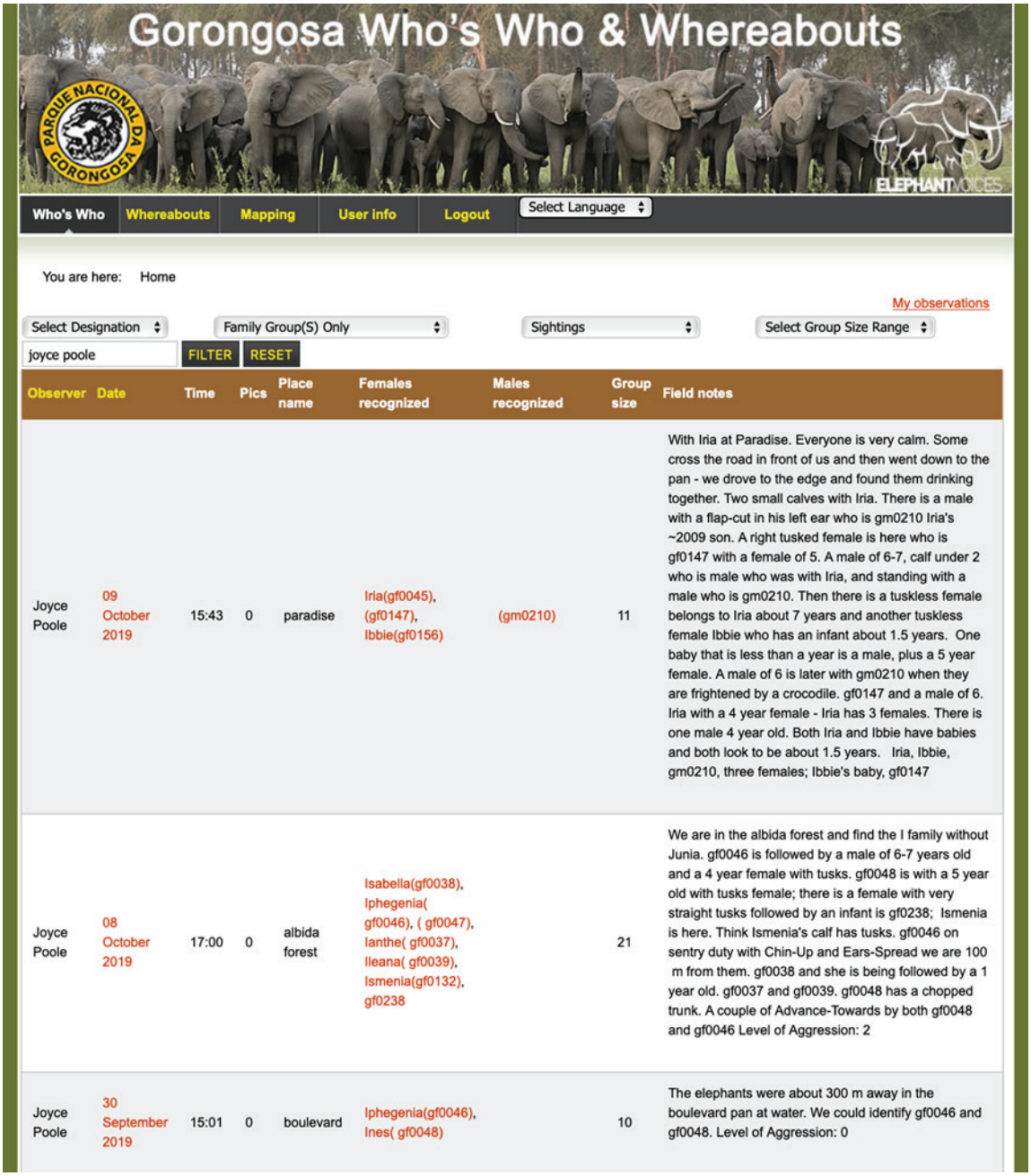


Figure 6. Screenshots a–f taken from the *EleApp* (as seen when a user scrolled through entering data), include the main entry (a, c and e) and upload (f) pages, some of the dropdown selections (e.g. b and d), and illustrate the ease of entering elephant sightings data. Date, time and location were taken automatically from the Smartphone. Entries marked with an * must be completed to upload.



Observer	Date	Time	Pics	Place name	Females recognized	Males recognized	Group size	Field notes
Joyce Poole	09 October 2019	15:43	0	paradise	Iria(gf0045), (gf0147), Ibbie(gf0156)	(gm0210)	11	With Iria at Paradise. Everyone is very calm. Some cross the road in front of us and then went down to the pan - we drove to the edge and found them drinking together. Two small calves with Iria. There is a male with a flap-cut in his left ear who is gm0210 Iria's ~2009 son. A right tusked female is here who is gf0147 with a female of 5. A male of 6-7, calf under 2 who is male who was with Iria, and standing with a male who is gm0210. Then there is a tuskless female belongs to Iria about 7 years and another tuskless female Ibbie who has an infant about 1.5 years. One baby that is less than a year is a male, plus a 5 year female. A male of 6 is later with gm0210 when they are frightened by a crocodile. gf0147 and a male of 6. Iria with a 4 year female - Iria has 3 females. There is one male 4 year old. Both Iria and Ibbie have babies and both look to be about 1.5 years. Iria, Ibbie, gm0210, three females; Ibbie's baby, gf0147
Joyce Poole	08 October 2019	17:00	0	albida forest	Isabella(gf0038), Iphegenia(gf0046), (gf0047), Ianthe(gf0037), Ileana(gf0039), Ismenia(gf0132), gf0238		21	We are in the albida forest and find the I family without Junia. gf0046 is followed by a male of 6-7 years old and a 4 year female with tusks. gf0048 is with a 5 year old with tusks female; there is a female with very straight tusks followed by an infant is gf0238; Ismenia is here. Think Ismenia's calf has tusks. gf0046 on sentry duty with Chin-Up and Ears-Spread we are 100 m from them. gf0038 and she is being followed by a 1 year old. gf0037 and gf0039. gf0048 has a chopped trunk. A couple of Advance-Towards by both gf0048 and gf0046 Level of Aggression: 2
Joyce Poole	30 September 2019	15:01	0	boulevard	Iphegenia(gf0046), Ines(gf0048)		10	The elephants were about 300 m away in the boulevard pan at water. We could identify gf0046 and gf0048. Level of Aggression: 0

Figure 7. The Whereabouts user interface showing a few records when filtered for "Sightings" of "Family Groups Only" by "Researcher" Joyce Poole.

Figure 8. The Gorongosa Mapping Interface filtered for sightings of family groups with associating adult males.

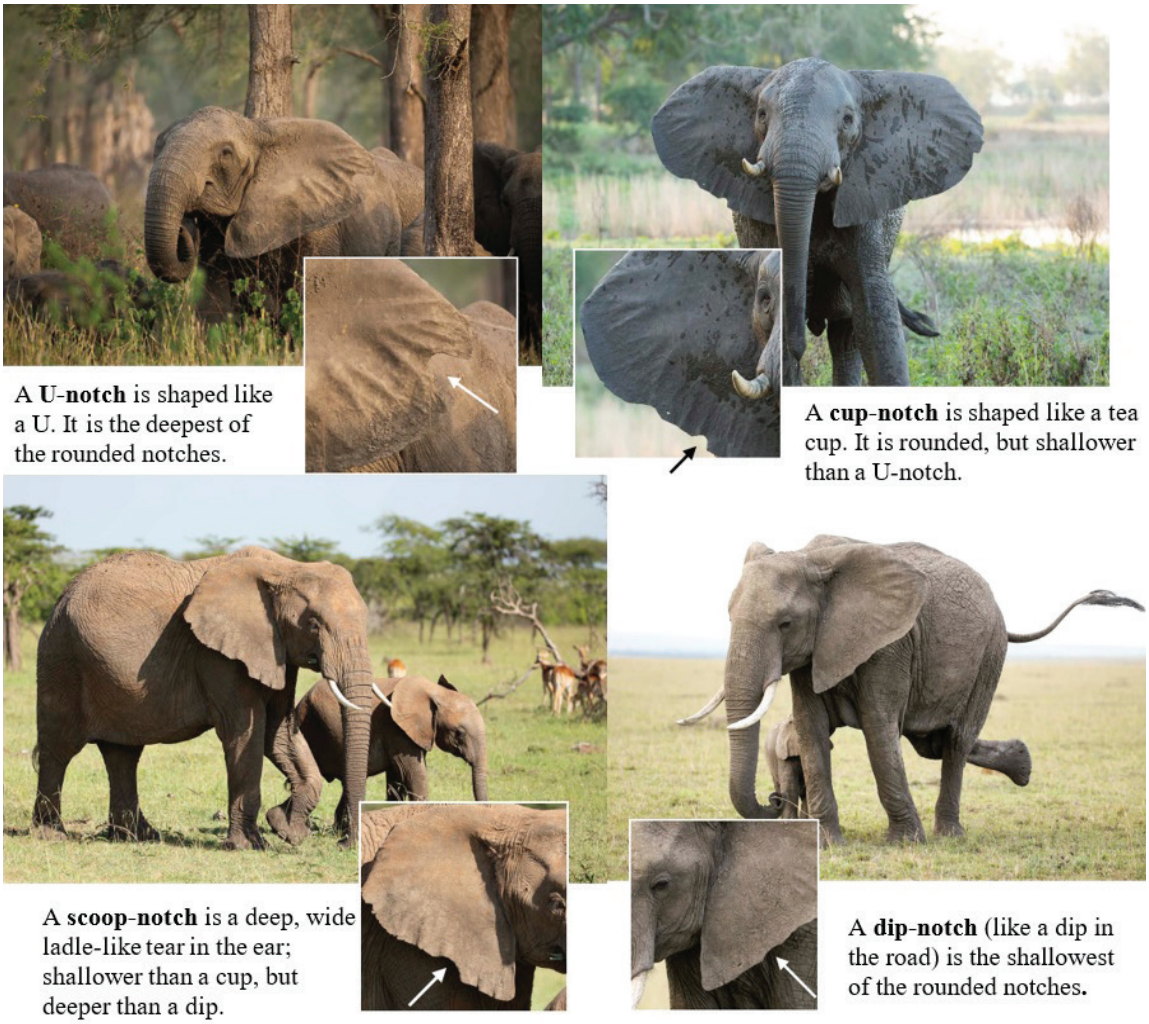


Figure 9. How to identify elephants on www.elephantvoices.org offers illustrative and written descriptions of all the attributes we used to identify elephants. Here, for example, are the rounded notches U, cup, scoop and dip shape. (*All images © ElephantVoices*)

Discussion

In this study we designed, built, and deployed a set of digital tools for individual registration, reidentification and monitoring of elephants. The combined effort of specialists and others yielded an extensive dataset of individual elephants, their families, associations, mean group size and distribution for both the Mara and Gorongosa populations. Filtered searches from the *Who's Who & Whereabouts* and *Mapping* interfaces yielded data for reports to wildlife authorities (Poole et al. 2015) and scientific publications (Gaynor et al. 2021; Campbell-Staton et al. 2021; Poole and Granli 2022).

Computer-aided image-recognition (pattern-matching) or machine learning software has been developed to quicken the matching process between an observed and registered individual for a few species that have distinct contours, spots or stripes (e.g. cheetahs, zebras, giraffes, tigers, sharks, seals, whales) allowing discrimination between individuals (Bergur-Wolf et al. 2017; Bolger et al. 2012). Attempts to develop an automated system for recognition of elephants have met with limited success because elephant skin does not exhibit a salient pattern and because skin wrinkle patterns and ear notches take on different shapes when viewed or photographed from different angles. Bedetti et al. (2020) describe a code-based reidentification system (SEEK; *Pachyderm* Vol. 61) for non-experts that uses a basic software application to search a database of known elephants for potential matches based on a code that combines age, sex, and the location of basic ear attributes of an observed elephant. The potential matches can then be checked against photographic records. Others have developed and tested automated reidentification approaches using computer vision algorithms for multi-curve matching to identify individuals through the contours of ears (Ardovini et al. 2008; Weideman et al. 2020), but these still require refinement. Most recently Kultis et al. (2021) developed a semi-automated hybrid system, ElephantBook, that relies on both computer vision and manual matching of physical attributes (SEEK), showing promising results for use by untrained observers, but requires the user to upload photographs to match an individual.

For observers with some elephant experience, the *Who's Who* offers a quick, intuitive, and reliable search function with immediate photographic returns that contains easily visible life history and social relationship data that makes reidentification simple. While our DB was web-based, an offline version on a tablet would provide an extremely efficient field tool. Computer and especially cloud-based data storage minimizes the risk of critical ID cards being lost, damaged, or stolen.

There is, undoubtedly, a degree of subjectivity inherent in classifying the features of elephants, for example, whether ears are defined as "very big" or "very small" or whether a notch is a "dip", "scoop", "cup" or "U." The size of elephant ears and tusks differ by individual as well as by population, thus what is considered big or small, long or short will also be influenced by local variation.

Furthermore, since the features of an elephant that stand out to an observer will vary from person to person, all salient characteristics must be coded in. For example, if an elephant has a **U-notch** and a **flap-cut** in the left ear, both plus **two or more notches** should be coded in for that ear. Likewise, if one feature might be confused for another (e.g. a **scoop** versus a **dip**) both should be coded. The key is to select only the most salient/least ambiguous features in a search. If too many individuals are returned, additional features can then be added to narrow the search. If no match is found after the resulting thumbnails are scanned, changes can be made to the selection.

The technique utilized by SEEK aims to avoid subjectivity by noting only whether a notch (of any type) occurred in upper, middle, or lower section of the left or right ear. Earlier versions of our technique also incorporated notch location, but we found that it created more ambiguity, as without accurate measurement it was often difficult to quickly "eyeball" in which third of the ear a notch was located.

While populating a *Who's Who DB* is a time-consuming job for a skilled person, once done it is relatively easy to keep updated. The *Who's Who* combinatorial key significantly reduces the time it takes to match an observed elephant with one in the database, compared to the process of searching through possibly hundreds of ID cards. Combined with the Features Guide, new researchers could learn to reidentify elephants without expert assistance. The *Who's Who* has the added benefit that life-history data and associations are stored together

with an individual's identifying characteristics, so that once an easily recognizable elephant is reidentified family members or regular associates can also easily be recognized.

Furthermore, our experience confirms that the *Who's Who & Whereabouts Database*, together with the *EleApp*, can be used by minimally trained citizen scientists to effectively contribute meaningful results to a larger effort to monitor an elephant population. Identifying elephants takes both patience, time and experience. In our projects most citizen scientists collected data that did not include individual identification but still provided valuable data on group size, type and location. There were, however, always a few highly dedicated people who learned to distinguish one elephant from another, or submitted photographs to us, and thus contributed valuable sightings of known elephants.

Collecting mortality data is a critical component of monitoring an elephant population. We modelled the collection of mortality data on the MIKE system so that it could be comparable to data from other populations or, if collected in a MIKE site, could contribute to MIKE data. Elephant deaths must be reported to the responsible wildlife authorities and, if collected by a citizen scientist, must be verified on site by a trained research officer.

The *Who's Who & Whereabouts Database* and *EleApp* provided a reliable, user-friendly, and productive way of building up comprehensive information on an elephant population. The data entry tools were adopted by a range of participants with different skill levels and motivations including scientists, guides, rangers, and other professionals, as well as by volunteers and others. Furthermore, tracking data from collars could also easily be integrated in the database.

Depending on the requirements of a study, the *Who's Who* and *Whereabouts DBs* could be used as stand-alone offline tools.

When we prepared the databases for our Mara and Gorongosa research we did not set out to build an off-the-shelf solution for others. This was primarily due to challenges related to customization, programming language, software, and hosting environment. We hope, however, that the structure, characteristics, menus and additional content described in this document will be useful to others who may wish to replicate the database or aspects of it.

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