Day and night camera trap video is effective for identifying wild Asian elephants

Sasha Montero-De La Torre[1], Sarah L. Jacobson[1,2], Marnoch Yindee[3]*, Joshua M. Plotnik[1,2]*

[1] Department of Psychology, Hunter College, City University of New York, New York, NY

[2] Cognitive and Comparative Psychology Program, Graduate Center, City University of New York, New York, NY

[3] Akkhraratchakumari Veterinary College, Walailak University, Thasala, Nakhon Si Thammarat, Thailand

*** Correspondence:**
Corresponding Authors
drfungy2000@yahoo.com; Joshua.Plotnik@gmail.com

Abstract

Camera traps provide a virtual window into the natural world of wild animals, as they provide a noninvasive way to capture anatomical and behavioral information. Regular monitoring of wild populations through the collection of behavioral and demographic data is critical for the conservation of endangered species like the Asian elephant (*Elephas maximus*). Identifying individual elephants can contribute to our understanding of social dynamics and foraging behavior in this species. Wild elephants can be distinguished using a variety of different morphological traits: variations in ear and tail morphology, body scars and tumors, and tusk presence, shape, and length. However, to our knowledge, there is little explanation in the literature about how remote camera trapping can be used to systematically identify elephants. Thus, this study set out to provide a template for how to provide this information using physical characteristics identified from day and night video footage collected remotely in the Salakpra Wildlife Sanctuary in Thailand between February 2019 and January 2020. We identified 24 morphological characteristics that can be used to identify individual Asian elephants. Using 33 camera traps spread across the protected area within the sanctuary as well as crop fields along its periphery, 107 Asian elephants were identified, for the first time in Thailand, using 475 total day and night videos. In the identified population, there were 72 adults, 11 sub-adults, 20 juveniles, and 4 infants. We predicted that the morphological traits would aid in reliably identifying these individuals with a low probability of misidentification. The results indicated that there were low probabilities of misidentification between elephants in the population using camera traps, and that the elephants in this study were reliably identified. These low probabilities of misidentification are comparable to a previous study using photographic data that were collected through direct observations of wild Asian elephants. This study suggests that the use of day and night video camera trapping can be an important tool for the long-term monitoring of wild Asian elephant behavior, especially in habitats where direct observations may be difficult. This work has important implications for the study of wildlife behavior using remote methods, as well as for endangered species conservation.

Keywords: *Elephas maximus*[1], camera traps[2], remote sensing[3], elephant behavior[4], human-elephant conflict[5].

1 Introduction

In the past several decades, camera trapping (using remote motion-activated cameras to collect photos and videos) has been a popular technique to study elusive and rare species with direct implications for conservation (Griffiths & van Schaik, 1993a; Foster & Harmsen, 2011; Mohd-Azalan & Lading, 2006). Camera traps are beneficial because they are able to capture image snapshots and video recordings while being minimally invasive and without the need for a human operator (Griffiths & van Schaik, 1993a; Swinnen et al., 2014). These remote video recordings are essential because they can capture animal movement, activity patterns, and behaviors (Swinnen et al., 2014; Caravaggi et al, 2017; Hegglin et al., 2004; Stevens & Serfass, 2005; MacCarthy et al, 2006) that may not otherwise be observable due to the species living in dense habitats (Griffiths & van Schaik, 1993a; Foster & Harmsen, 2011). The use of remote camera traps is a great option for observing wild Asian elephants (*Elephas maximus*) that may otherwise be impossible to observe within a dense forested habitat. The camera trap as a remote data collection tool enables us to better understand relationships between individuals and to assess environmental factors that may impact animal behavior (Caravaggi et al., 2017; Sanderson & Trolle, 2005; Mohd-Azalan & Lading, 2006; Tobler et al., 2008).

Camera trap technology has improved to a level where high-quality videos can be recorded remotely that capture significant information about animal movement and activity patterns over long periods of time (Hegglin et al., 2004; Stevens & Serfass, 2005; MacCarthy et al, 2006). While camera traps can be very useful at the population-level for documenting the occurrence of particular species (Silveira et al., 2003; Trolle, 2003), and to quantify activity patterns (van Schaik & Griffiths, 1996; Gómez et al., 2005), in order to use them to study behavior across landscapes or assess individual variation in risk-taking behavior in human-wildlife conflict, a method of tracking and identifying individual animals is crucial. This involves determining what key features and characteristics make an individual unique when comparing it to others within a population. The present study uses existing animal identification methodologies to identify physical and behavioral characteristics that are unique to individual elephants and to use this information to create an identification database for one landscape in Thailand. Previous studies on the identification of individual animals using camera-trap photography have mainly focused on spotted and striped carnivores with naturally-occurring markings (Karanth, 1995; Karanth & Nichols, 1998; Kelly, 2003). These markings are a well-recognized tool in the field for identifying animals due to individual variation in physically unique features like stripes, or unusual markings like scars (Pennycuick, 1978; Lehner, 1996; Harrison, 2016). However, looking at natural markings in animals that do not have distinct coat patterns is more labor intensive and problematic in terms of reliability (Goswami et al., 2012). For species without coat patterns, researchers have looked at a combination of characteristics such as skin folds, the presence of scars, ear nicks, horn length and shape, tubercles on the rump, and tail length (Laurie, 1978; Morgan-Davies, 1996).

Elephants, for example, are typically distinguished using a variety of different morphological features such as variations in their ear and tail morphology, body scars and tumors, spine shape, cuts and bumps, and tusk shape and size when present (Douglas-Hamilton & Douglas-Hamilton, 1975; Sukumar, 1989; Moss, 1996; Goswami et al., 2007; Fernando et al., 2011; Goswami et al., 2012; de Silva et al., 2013; Vidya et al., 2014). Goswami and colleagues (2007) identified male Asian elephants in India using a system of identifiable characteristics. For this first study in a male elephant population, the authors found that they could use a combination of 16 different traits to reliably identify individual elephants (Goswami et al., 2007). Goswami and colleagues (2012) later assessed different groupings of these traits to determine that "fixed morphological traits" (those which were unlikely to change over the course of a few years) were the most reliable for identification and in estimating population size. In another study, Vidya and colleagues (2014) used a combination of 22 traits to identify 223 individual elephants, including females. Some of the traits they highlighted were ear top fold, nicks and tears, tusk traits and warts/wounds in males, and tail traits in females. This study demonstrated the success of identifying individuals of both sexes through a combination of physical traits alone and that these traits could be used for capture-recapture methods over time (Vidya et al., 2014). Capture-recapture uses a primary and secondary sampling period at different points in time to estimate a local population's size and demographics (Karanth & Nichols, 1998; Foster & Harmsen, 2012; Chaiyarat et al., 2015). This previous work to identify individual elephants, however, used photographs taken at multiple angles from research vehicles, and thus whether remote-sensing photography or videography can be as useful for similar identification of elephants is not yet known.

The use of camera traps can contribute positively to our growing knowledge about human-elephant conflict (HEC), an increasing threat to the conservation of Asian elephants. HEC occurs as available habitat for elephants becomes more fragmented, bringing elephants into closer proximity to human development. One frequent result is conflict caused by elephants foraging on high-quality foods grown in agricultural areas, or "crop raiding" (Menon & Tiwari, 2019). Research that identifies the individuals that frequently enter crop fields and how they behave in human-dominated landscapes could inform HEC mitigation and elephant conservation in the future (Mumby & Plotnik, 2018). The first step towards this goal is to identify individuals within a population to then understand their behavior and movement through the landscape. The current study focuses on identifying individual Asian elephants within and around the Salakpra Wildlife Sanctuary in Kanchanaburi, Thailand. This sanctuary is just one part of a larger protected area called the Western Forest Complex (WEFCOM). Salakpra is an integral part of this large complex as it supports about 17.5% of WEFCOM's elephant population (Mitchell et al., 2013). Previous research has estimated the population in Salakpra to be between 180-200 using camera trap photos (Chaiyarat et al., 2015) and genetic analysis (Siripunkaw and Kongrit, 2005), but the population is now estimated to range from 250-300 (DNP, 2017). As one of the primary breeding populations in Thailand (Mitchell et al., 2013), it is important to identify individuals within the sanctuary to better understand the demographic composition of the population and as an initial step in beginning to study individual variation in behavior and between-group social dynamics. The area surrounding Salakpra also experiences frequent and intense crop raiding (van de Water & Matteson, 2018), thus it is also important to identify how and whether elephants move between the sanctuary and the bordering villages.

Our primary objective in this study was to determine the effectiveness of camera trapping to identify individual Asian elephants in the Salakpra Wildlife Sanctuary, in Kanchanaburi, Thailand. In addition to building on previous studies that have used a variety of methodologies to identify elephants from photographs, our research team's interest in collecting behavioral data on wild elephants presented a unique opportunity to assess the effectiveness of the video function on camera traps to identify individual animals. In the present study, we used a list of 24 physical characteristics adapted from Goswami et al. (2007), Vidya et al. (2014), and de Silva et al. (2013) to test whether remote camera trap footage collected during the day and at night can be used to identify Asian elephants across a diverse landscape. This identification methodology is an important step towards understanding wild Asian elephant behavior at both individual and group levels by using efficient and non-invasive camera trapping technology. Identifying individual elephants can assist in better understanding social demographics in herds (Vidya & Sukumar, 2005; de Silva et al., 2011), facilitating behavioral observations to understand foraging behavior (Clapham et al., 2012), and contributing to our overall understanding of the individual elephant's impact on human-elephant conflict (Mumby & Plotnik, 2018).

2 Methods

2.1 Study Area

We began studying elephant behavior in January, 2019 in the Salakpra Wildlife Sanctuary, a protected area in Kanchanaburi, Thailand, in collaboration with the Thai Department of National Parks, Wildlife and Plant Conservation (DNP), which manages it. Salakpra is approximately 970 km^2 and is located within the 18,000 km^2 Western Forest Complex (WEFCOM - Mitchell et al., 2013). It is a unique protected area in that it is completely closed to tourists and permission is required to enter the Sanctuary. Data were collected from four different locations: Kaeng Kaeb (KK) and Khao Seua (KS) located within the protected area, and Tha Manao (TMN) and Mae Plasoi (MPS) located along the periphery of the protected area near crop fields (Figure 1). KK and KS are identified as ranger stations within the protected area of Salakpra where, except for park ranger patrols, human activity is at a minimum. TMN and MPS are villages (specifically, crop fields along the Sanctuary's outside border) where chances of human-elephant interactions are high. The Sanctuary contains areas of mixed deciduous forests (60%), dry dipterocarp forest (30%), and disturbed land (10%) (Chaiyarat et al., 2015). Crop fields mainly consist of corn, pumpkin, sugar cane and cassava.

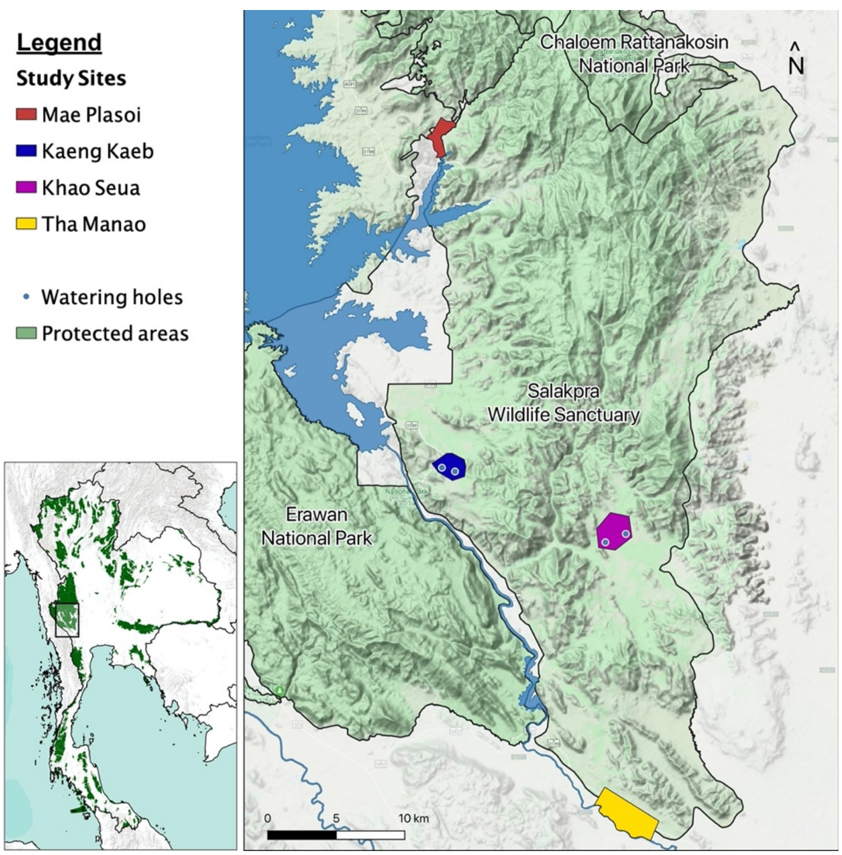

Figure 1. *Map of the study areas inside the Salakpra Wildlife Sanctuary.*

2.2 Permission

This study was approved by the Hunter College Institutional Animal Care and Use Committee (JP-Elephant Behavior 5/21), and permission was granted to collect data in Salakpra Wildlife Sanctuary by the National Research Council of Thailand and the Thai Department of National Parks, Wildlife and Plant Conservation.

2.3 Camera Traps

The videos analyzed in this study were recorded between February, 2019 and January, 2020. There were a total of 34 Browning Spec Ops Advantage remote-sensing cameras set-up throughout the four sites: eight in KK, 11 in KS, six in TMN, and eight in MPS. One camera went missing from the MPS area in September, 2019 resulting in a final total of 33 camera traps. In the protected area, cameras were installed around watering holes and salt licks; on the periphery of the protected area, they were installed around crop fields and on pathways frequented by elephants. Camera traps were motion activated and set with a fast trigger (0.4 seconds) to capture 20-second high resolution video (30 frames/second) from up to ~25 m away when triggered. Videos were taken using natural light during the day and built-in infrared light at night. The cameras recorded the time, date and temperature during each recorded clip, which was automatically saved to SD cards collected periodically.

2.4 Identifying Individual Elephants

In this study, there were 24 physical characteristics (Supplementary Table 1) chosen to identify individual elephants adapted from Vidya et al. (2014), de Silva et al. (2013), and Goswami et al. (2007), and re-defined to our specifications (see the 'characteristics' section below). Video clips of 20-sec duration from all four sites were first scanned and flagged for further investigation using VLC media player (version 3.0.10). In order for videos to be flagged, elephants must have been visible and identifiable, meaning more than two characteristics were distinguishable (i.e., ear folds, tears, tail length, etc.). During a second round of investigation, flagged videos were opened and stopped at the point where the elephant features were most clearly visible.

Once an elephant was chosen, another video with the same elephant was found, primarily using videos from the same location (sanctuary or crop fields). However, in some rare instances, elephants were found to have traveled between locations (e.g., KK to KS). These videos were used to match the same characteristics, on a different date to qualify the viewed elephant as a unique individual (Figure 2). This process used the flagged videos first to see if any matched to the individual in question or not. If not, we investigated videos that were previously not flagged to find a match. This method was similar to capture-recapture methods used to identify individual elephants in previous studies (Goswami et al. 2007, 2019), with a significant deviation. Because our study is an ongoing, long-term project focused on elephant behavior, we did not employ common capture-recapture methods nor did we go through all of the footage at this initial stage. Instead, since the purpose of the current study was to conduct an analysis of the effectiveness of video camera trap data for identifying individual elephants, we selected footage where elephants were easily observable. In the near future, we will identify as many of the elephants in the landscape as possible using these video data.

Figure 2. *Day and night snapshots of three elephants showing the variable quality of video. Figure 2A was an adult male that was distinguished by the one grown out tusk and tears on the bottom of the right ear. In the night shot of the same elephant (Figure 2B), we were able to make out the top ear folds more clearly. Figure 2C shows an adult female with two offspring behind her, visible with her*

at night as well (Figure 2D). This female had an especially large tear on the right ear which is distinguishable in both shots. Pigmentation on the ears and body was sometimes visible in night videos, as can be seen with this elephant.

Once an elephant was identified, he or she was then entered into an AirTable cloud-based database (San Francisco, USA) with a unique ID, screenshots, and associated characteristics. Characteristics were used to specify each area of an elephants' body that could be described with different trait state options or specific features of that characteristic. For example, a characteristic such as *back shape* might have a trait state option such as *humped* to describe the characteristic. *N/A* was used when these areas of the body were not visible due to video quality or elephant body position. Video clips were continuously associated with each elephant in the database to record additional individual characteristics or previously unobservable trait states, as well as to monitor its movement patterns between study areas. When a new individual was found in different video files, we repeated this process to document it. Male and female adult and sub-adult elephants were identified. If a female that was identified was observed with juveniles or infants in two separate instances, the offspring were characterized and linked to the accompanying female(s).

2.5 Characteristics

2.5.1 Age

During this study, we categorized elephants into four age classes (represented by letters A-D). All relative height differences and estimated age ranges were adapted from de Silva et al. (2011). When solitary bulls were observed, they were coded as adults (A), as they tend to leave their natal herd once mature (Sukumar, 1989; Fernando & Lande, 2000). In social groups, adult females were distinguished by enlarged breasts, if they were observable, or the presence of calves with them (de Silva et al., 2011) (Supplementary Table 2). Although the present study utilized age as a characteristic, the age classes mentioned are only estimates based on the trait state definitions; we were not able to determine the exact age of individuals.

2.5.2 Body Condition

To determine the body conditions of each individual, we assessed the pelvic, shoulder, and back bones as elephants moved in a video. Body condition definitions were adapted from Fernando et al. (2009) and simplified to three categories (Supplementary Table 3). The backbone was also used as an indicator of body condition (Wemmer et al., 2006).

2.5.3 Tusks/ Tushes

We categorized whether the individual had either tusks or tushes (incisors that are much smaller and thinner than tusks) (Kurt et al., 1995). In Asian elephants, only males have tusks – although not all do – while both males and females can have tushes (i.e., short tusk-like protrusions from the top of the mouth), but again, not all do (Sukumar, 1989; Kurt et al., 1995; Chelliah & Sukumar, 2013). When tusks were present, tusk symmetry, arrangement, and angle were recorded accordingly (Table 1). Tusk symmetry was categorized based on whether the tusk length was symmetrical. Tusk arrangement was categorized based on the tusk growth direction of both tusks compared to each other. Tusk angle was categorized as the direction of the tusks in reference to a horizontal plane. Tusk angle was best determined with side views of the elephant, with the trunk's position used to help guide the decision (Figure 3).

Table 1| *Tusk characteristics and trait state definitions*

Tusks/Tushes	Trait State Definitions	Examples
Presence of Tusks	*Both*: when an elephant had both of their tusks or tushes	Figures 3B-D
	Right only: when an elephant only had a right tusk or tush	Figure 3A
	Left only: when an elephant only had a left tusk or tush	
	None: when there were no tusks or tushes present for males or tushes present for females. If *none* was provided, the other tusk characteristics did not apply	
Tusk Symmetry	*Even*: when tusks were growing at an even rate	Figure 3D
	Uneven: when tusks were growing at an uneven rate or when one was broken (one tusk may be longer or shorter than the other)	Figure 3A, 3C
Tusk Arrangement	*Parallel*: tusks growing at the same angle, straight out, and pointing forward.	
	Splayed: tusks pointed outward (not parallel) from each other	Figure 3D
	Convergent: tusks growing out but inward, potentially resulting in tusks crossing over each other	Figure 3C
Tusk Angle	*Straight ahead*: tusks growing out parallel to a horizontal plane	Figure 3C, 3E

	Intermediate: tusks directed diagonally and not straight (parallel) or down (perpendicular)	
	Pointed down: tusks growing downward, perpendicular to the horizontal plane	Figure 3B

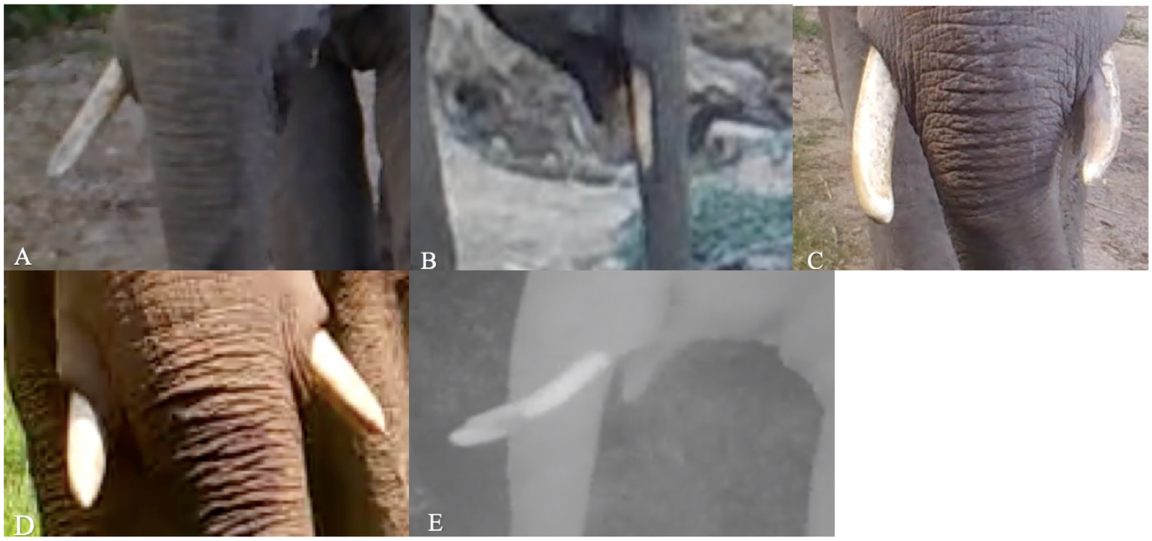

Figure 3. *Visual representation of some of the tusk arrangements (Table 1 for detailed definitions/descriptions of each type of arrangement).*

2.5.4 Ear Characteristics

Characteristics of the ear were categorized for the right and left ear separately. Also, top folds and side folds (labeled as primary and secondary fold in de Silva et al. (2013), respectively) were considered separate characteristics in this study. The top ear fold was determined by what degree the top ear was folded for both sides. The side folds of each ear were categorized by the way each side fold lays, with only 2 options. The bottom of the ear or the ear lobes were described by their angular shape (Figure 4). Other characteristics of the ears (ear tears, holes and depigmentation) were also categorized when possible (Table 2). The presence and location of ear tears and holes were categorized from the top to bottom of the ear, based on the area with the most tears or holes. If there were any other tears or holes along the ear, they were added as a note in the database.

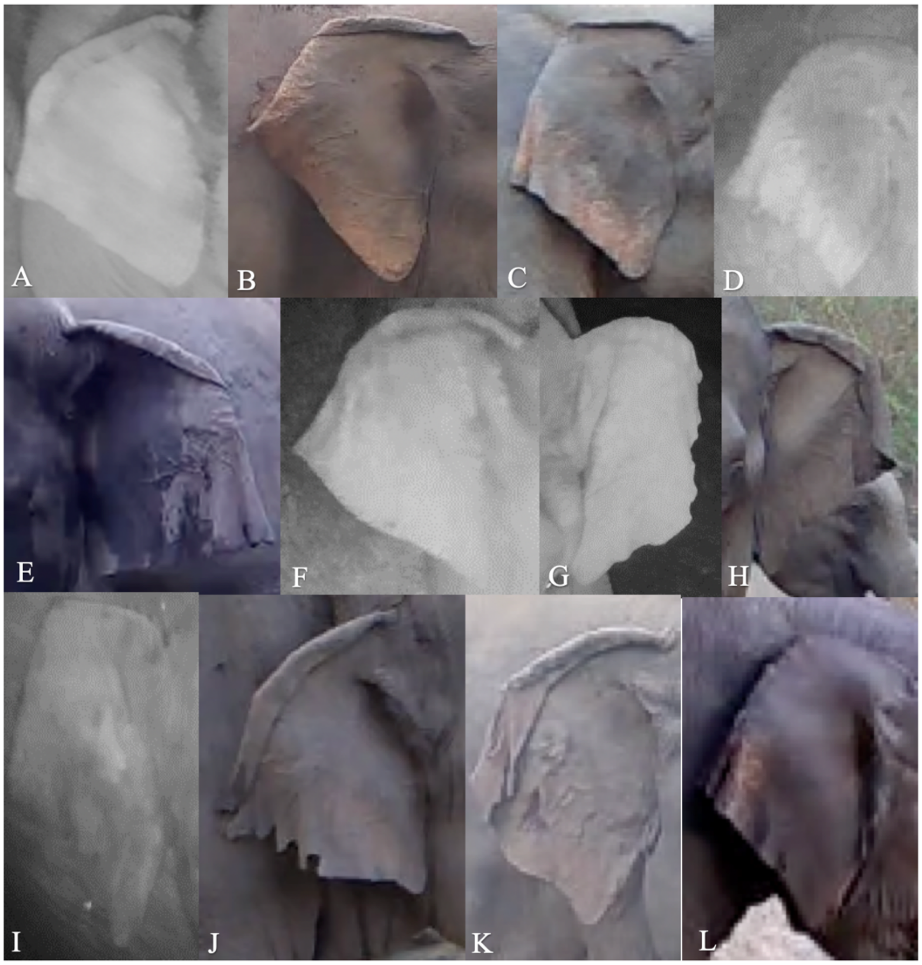

Figure 4. *Visual representation of some of the ear characteristics seen during the day and night, see Table 2 for trait state descriptions for A-L*

Table 2| *Ear characteristics and trait state definitions*

Ear Characteristics	**Trait State Definitions**	**Examples**
Ear top fold	*None:* when there was no true curve (fold) visible	Figure 4I
	Forward slightly: where the top of the ear was folded at an almost 90-degree angle	Figure 4C
	Forward rolling fold: where the top of the ear was folded like a "wave" and we were able to still see the ear under the fold	Figures 4A, 4E, 4F
	Forward flat fold: where the top of the ear was folded so you cannot see under the fold for the majority of the ear	Figures 4B, 4G, 4H, 4J, 4K
	Backward: where the ear curved back at any angle	Figure 4L
Ear side fold	*Forward:* where the side of the ear was folded forward at any angle and degree	Figures 4A, 4F, 4H, 4J, 4K
	Backward: where the side of the ear was folded backward at any angle and degree	Figures 4B-E,4I, 4L
Ear lobe shape	*L-angular:* where the ear lobe blended in with the ear and created a wide angle	Figure 4E
	V-acute: where the ear lobe was pointed at the bottom, to form an acute angle	Figures 4C, 4D, 4H-L

	U-rounded: where the ear lobe was more rounded than pointy	Figures 4A-B
Ear tears/holes	*None:* no visible tear or hole seen	Figures 4A, 4C, 4D
	At side fold: tears or holes were visible on the side folds	Figures 4J, 4K
	Before side fold: tears or holes were visible in between the top and side fold	
	After side fold: tears or holes were visible between the side fold and where the bottom of the ear meets the head	Figures 4G, 4J
	On top fold: tears or holes on the top of the ear	Figure 4J
Ear Depigmentation	*Present-slight:* where discoloration was seen in less than half of the ear, beginning from the bottom portion of the ear going upwards/inwards, and if little to no depigmentation was seen on the back of the ear	Figure 4L
	Present-prominent: where discoloration was seen in more than half of the ear, beginning from the bottom portion of the ear going inwards and if the majority of the back of the ear was depigmented	Figures 4B, 4C

2.5.5 Back Characteristics

Back shape of each individual was organized into three categories (Figure 5 & Table 3). 'Concave back' was not observed in this study, but because it was observed in the population studied by Vidya et al. (2014) in India, it was included as a possible category.

Figure 5. *Visual representation of the prominent back shapes, see Table 3 for trait state descriptions for A, B, & C*

Table 3. *Back shape characteristics and trait state definitions*

Back Characteristics	Trait State Definitions	Examples
Back Shape	*Flat:* where the majority of the back was more or less a straight line	Figure 5B, 5C
	Concave: where the back dipped in the center	
	Humped: where the back was elevated, primarily in the middle, but humps can occur throughout the back as well	Figure 5A

2.5.6 Tail Characteristics

There were two different tail characteristics used to identify the elephants: tail length and brush type (Figure 6 & Table 4). Tail length was categorized based on the length of the tail from the rump to the tip of the tail, not including the 'tail brush' or hair. The tail-brush type was described based on the length and location of the tail hair, with the latter being on the anterior (side closest to the body), posterior (side farthest from the body), or both sides of the tail.

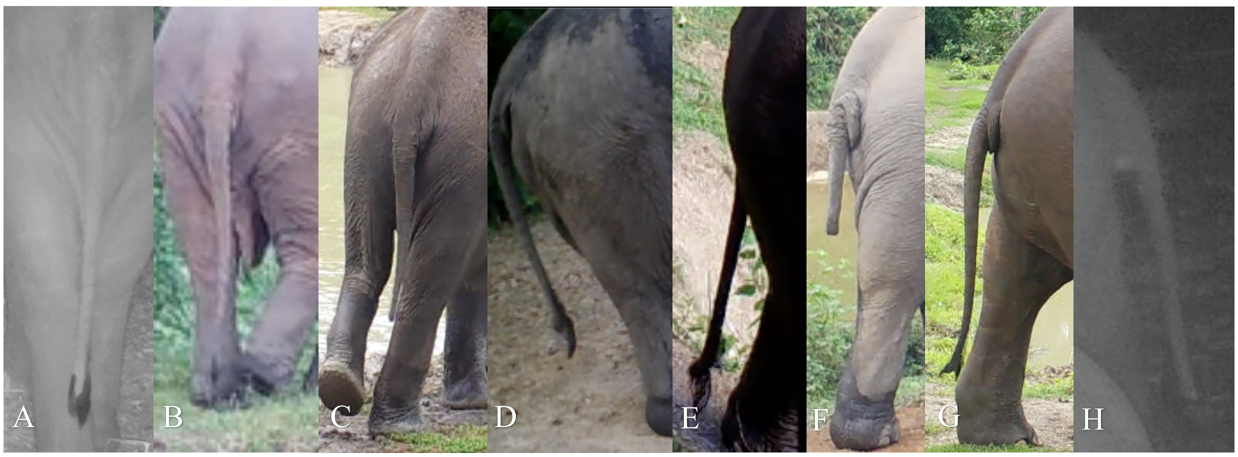

Figure 6. *Visual representations of tail length and brush type characteristics, see Table 4 for trait state descriptions for A-H*

Table 4. *Tail characteristics and trait state definitions*

Tail Characteristics	Trait State Definitions	Examples
Tail Length	*Stump (above abdomen):* a short and stubby tail that ended above the abdomen	Figure 6F
	Below genitals: above knee: a tail that extended between the genital area and above the knee	Figure 6D
	Below knee, above ankle: a tail that extended anywhere between the knee and the ankle	Figure 6A, 6G
	At knee: a tail that extended around the back of the knee	Figure 6C
	At ankle: a tail that extended to the ankle (before the leg becomes wider, forming the foot pad)	Figure 6B
Brush Type	*No hair:* there was no visible hair on the end of the tail	Figure 6C, 6F
	Short anterior: hair stubble, not long enough to naturally curve, on the side closest to the body	
	Short posterior: hair stubble, not long enough to naturally curve, on the side farthest from the body	
	Short both: hair stubble on both sides of the tail	
	Short anterior, normal posterior: hair stubble on the side closest to the body and normal hair length on the side farthest from the body	

	Normal anterior, short posterior: normal hair length on the side closest to the body and short/stubble hair on the side farthest from the body	
	Normal anterior: tail hair that is long enough to form its natural curve on the side closest to the body	Figure 6D, 6E, 6H
	Normal posterior: tail hair that is long enough to form its natural curve on the side farthest from the body	
	Normal both: tail hair that is long enough to form its natural curve on both sides of the tail	Figure 6A, 6B, 6G

2.5.7 Depigmentation on body

This section only categorized if and where there was depigmentation on other parts of the elephant, other than the ears (Supplementary Table 4). Supplementary Figure 1 shows an example of an elephant with depigmentation on both the body and trunk.

2.6 Statistical Analysis

All data were recorded and analyzed in Microsoft Excel 2016. Using Goswami and colleagues (2012)'s misidentification calculation, the likelihood of the human-run identification process resulting in the misidentification of two different individual Asian elephants with similar morphological traits was determined by calculating the maximum probability squared ($p_{\max}^2$). It is important to note that for the current study, we used this calculation to determine the probability of misidentification between easily visible elephants in our subset. It is our understanding that in Goswami et al. (2012), each video was treated as a potential new elephant using a capture-recapture methodology. In our study, to determine the maximum probability, the sighting frequency of each trait state option per characteristic was calculated. For example, the most common trait state for *Left ear lobe shape* is a *v-acute* ear lobe shape which was observed in 63.89% of all adult elephant sightings. Once the most common trait frequencies were calculated, they were ranked from the most to least commonly occurring morphological characteristics and trait states. If there was more than one characteristic and trait state option that occurred the same number of times in the populations, the first occurring characteristic as listed in the ID protocol was put first into the ranking followed by the next on the list. For example, if *L ear top fold, Body condition*, and *R ear top fold* all had a trait state that occurred 22 times, they would be put into the ranking in this order: *Body condition, L ear top fold, R ear top fold*, as this corresponds to their order in the characteristic list. The characteristic list order on the datasheet was arranged for capturing information from the front of an elephants' body to the back. However, characteristics that were seen from the whole elephant like *sex* and *body condition* were placed at the front of this order.

Exploratory statistical tests were used to determine whether characteristics were independent from each other. Independence in this case means that the traits of one characteristic cannot be predicted from the traits of another characteristic. Chi-square or Fisher exact tests were used to calculate whether the number of individuals with each combination of traits corresponded to the assumption of independence between those traits. As was the case in Goswami et al. (2012), many pairs of characteristics were not independent from one another. If traits are independent, then the probability of a combination of traits would be equal to the product of their individual probabilities. However, because of non-independence, a conditional probability calculation is more appropriate as it does not assume independence. Therefore, to estimate the probability that an individual possessed the most commonly occurring combination of traits ($p_{\max}$), conditional probabilities were calculated by moving successively down the trait frequency ranking.

In the present study, when computing p_{max}, we first calculated the probability, p(A), of the most frequent trait state for *presence of tusks/tushes*. Next, we looked at the probability of *back shape's* p(B) most frequent trait state occurring, when *presence of tusks/tushes* most frequent trait state occurred. Moving down the ranking, the next characteristic (*L ear hole*) and its most frequent trait state option were put into the calculation for the probability of the *L ear hole*'s p(C) most frequent trait state taking place, given the *presence of tusk/tushes* most frequent trait and *back shape's* most frequent trait. This process continued until the number of elephants with the combination of characteristics reached one (Table 5). The probability values were then squared to obtain the value for the probability of any two individuals showing the exact combination of morphological features (p_{max}^2) (Goswami et al., 2012).

3 Results

From the videos collected between February 2019 and January 2020, there were a total of 107 elephants identified using 24 physical characteristics and their trait state options in both day and night camera trap videos. These elephants were identified across a total of 475 videos. Of those elephants, 72 were identified as adults, 11 were identified as sub-adults, 20 were identified as juveniles, and four were identified as infants. For this study, only the 72 adults in 363 videos were used for the calculation of p_{max}^2, because determining elephant sex is more definitive when the elephants are sexually mature (Sukumar, 1989; Fernando & Lande, 2000). Therefore, the age class characteristic was excluded from calculations. In the calculation of p_{max}^2 the number of elephants included in the conditional probabilities decreased to zero on the 20th characteristic (Table 5). With the inclusion of 19 characteristics and their most frequent trait, p_{max}^2 = .006 for this sample (Table 5).

Table 5| *Elephant count and calculation results for* p_{max}^2 *for all adult elephants (n=72), including most to least common characteristic and trait state option*

Ranked Characteristics	**Majority Trait State**	**Number of elephants with trait**	**Proportion**	**Number of elephants with combination**	p_{max}	p_{max}^2
Presence of tusks/tushes	None	63	0.875	63		
Back shape	Humped	63	0.875	54	0.857	0.735
L ear hole	None	61	0.847	46	0.745	0.556
Tail length	Below knee, above ankle	58	0.8556	35	0.652	0.425
L ear side fold	Backward	56	0.778	29	0.618	0.381
R ear hole	None	56	0.778	23	0.517	0.268
R ear side fold	Backward	55	0.764	23	0.618	0.381
R ear depigmentation	Present-Prominent	53	0.736	17	0.382	0.146
Sex	Male	52	0.722	11	0.400	0.160

Depigmentation on body	Both	52	0.722	10	0.348	0.121
Body Condition	1	49	0.681	8	0.320	0.102
L ear depigmentation	Present-Prominent	48	0.66	8	0.348	0.121
R ear lobe shape	V-acute	47	0.653	5	0.200	0.040
L ear lobe shape	V-acute	46	0.639	5	0.348	0.121
Brush type	Normal both	42	0.583	4	0.160	0.026
R ear tear	At side fold	37	0.514	2	0.174	0.030
L ear top fold	Forward rolling fold	31	0.431	2	0.160	0.026
R ear top fold	Forward rolling fold	31	0.431	2	0.174	0.030
L ear tear	At side fold	29	0.403	1	0.080	0.006
Tusk Symmetry	Uneven	5	0.069	0	0	0
R tusk angle	Straight ahead	5	0.069	-	-	-
L tusk angle	Straight ahead	4	0.054	-	-	-
Tusk arrangement	N/A	3	0.042	-	-	-

A similar calculation for p_{max}^2 was conducted for the sample consisting of only male (N=52), and then only female elephants (N=20). However, in contrast to the previous calculation for the entire sample, when calculating p_{max}^2 for males, only 22 characteristics were included in the calculation (the characteristic of sex was excluded). When performing the conditional probability calculation for males, characteristics and their most frequent trait states were established in most common to least common order. After including 18 characteristics, the number of elephants with the same combination reached one (Table 6), signaling that no elephants remained, and thus no additional calculations were needed. With the inclusion of 18 characteristics and their most frequent trait, p_{max}^2 =.011 for the sample of male elephants.

382 Table 6| *Elephant count and calculation results for p_{max}^2 for adult male elephants (n=52), including*
383 *most to least common characteristic and trait state option*

Ranked Characteristics	Majority Trait State	Number of elephants with trait	Proportion	Number of elephants with combination	p_{max}	p_{max}^2
Back shape	Humped	46	0.885	46		
Presence of tusks	None	43	0.827	37	0.804	0.647
L ear hold	None	42	0.808	30	0.717	0.514
Tail length	Below knee, above ankle	42	0.808	23	0.617	0.380
Depigmentation on body	Both	41	0.788	18	0.561	0.315
L ear side fold	Backward	40	0.769	16	0.548	0.300
R ear depigmentation	Present-Prominent	38	0.731	12	0.421	0.177
R ear side fold	Backward	37	0.712	12	0.548	0.300
R ear hole	None	37	0.712	10	0.351	0.123
L ear depigmentation	Present-Prominent	33	0.635	10	0.548	0.300
Body Condition	1	31	0.596	8	0.281	0.079
R ear lobe shape	V-acute	31	0.596	5	0.343	0.117
L ear lobe shape	V-acute	29	0.558	5	0.281	0.079
R ear tear	At side fold	29	0.558	3	0.206	0.042
Brush type	Normal both	28	0.538	2	0.187	0.035
R ear top fold	Forward rolling fold	24	0.462	2	0.206	0.042
L ear top fold	Forward rolling fold	23	0.442	2	0.187	0.035
L ear tear	At side fold	23	0.442	1	0.103	0.011
Tusk Symmetry	Uneven	5	0.096	0	0	0
R tusk angle	Straight ahead	5	0.096	-	-	-
L tusk angle	Straight ahead	4	0.077	-	-	-
Tusk arrangement	N/A	3	0.058	-	-	-

384

When performing the conditional probability calculation for females, we only included 18 characteristics, as opposed to the 22 characteristics for males, because we excluded tusk characteristics. Using the same procedure as the previous two calculations, the number of elephants decreased to one after including 16 characteristics (Table 7). With the inclusion of 16 characteristics and their most frequent trait, $p_{\max}^2 = .048$ for the sample of female elephants. Table 5, Table 6 and Table 7 illustrate how $p_{\max}$ and $p_{\max}^2$, with the addition of each characteristic and their most frequent trait state, decreased or stayed the same depending on the number of elephants that showed each combination.

Table 7| *Elephant count and calculation results for p_{max}^2 for adult female elephants (n=20), including most to least most common characteristic and trait state option*

Ranked Characteristics	Majority Trait State	Number of elephants with trait	Proportion	Number of elephants with combination	p_{max}	p_{max}^2
Presence of tusks/tushes	None	20	1.00	20		
L ear hole	None	19	0.95	19	0.950	0.903
R ear hole	None	19	0.95	18	0.947	0.898
Body Condition	1	18	0.90	16	0.844	0.713
R ear side fold	Backward	18	0.90	15	0.888	0.789
Back shape	Humped	17	0.85	13	0.732	0.536
L ear lobe shape	V-acute	17	0.85	10	0.683	0.467
L ear side fold	Backward	16	0.80	9	0.659	0.434
R ear lobe shape	V-acute	16	0.80	8	0.683	0.467
Tail length	Below knee, above ankle	16	0.80	8	0.585	0.343
L ear depigmentation	Present-Prominent	15	0.75	5	0.427	0.182
R ear depigmentation	Present-Prominent	15	0.75	5	0.585	0.343
Brush type	Normal both	14	0.70	4	0.342	0.117
L ear tear	None	11	0.55	2	0.439	0.193
Depigmentation on body	Both	11	0.55	2	0.228	0.052

R ear tear	None	10	0.50	1	0.220	0.048
L ear top fold	Forward rolling fold	8	0.40	0	0	0
R ear top fold	Forward slightly	8	0.40	-	-	-

4 Discussion

The current study aimed to determine whether camera trap videos can be used to reliably identify individual Asian elephants. We used day and night videos to identify a total of 107 individual elephants. We calculated the probability of two individuals having the same characteristic combinations for 72 identified adult elephants within the population.

This study was successful in evaluating whether individual Asian elephants could be reliably identified. We used 19 out of 24 morphological characteristics (excluding age and four tusk characteristics) to reliably identify 72 elephants. This result was comparable to previous studies that systematically identified Asian elephants in photographs taken from research vehicles using similar combinations of these characteristics (Goswami et al., 2007; Vidya et al. 2014; de Silva et al., 2013). Goswami et al. (2012) used a combination of 20 characteristics, similar to the current study, to obtain a p_{max}^2 = .010 for a sample of only adult male Asian elephants. The results obtained in Goswami et al. (2012) were comparable to the results of the current study; we found a p_{max}^2 of .006 when considering all adult elephants, and a value of .011 when only considering adult males. Goswami and colleagues (2012) were able to achieve lower probabilities of misidentification for adult males (p_{max}^2 = .008 and p_{max}^2 = .005) than we were in our study based on a number of specific traits. These traits (termed characteristics in our study) included: presence of tusks, tusk arrangement, angle, length, thickness, ear damage, and earlobe shape. For the current study, tusk characteristics are listed towards the end of Table 5 and Table 6 specifically because they were the least frequently occurring characteristics in our population. However, *presence of tusks/tushes* was usually an important characteristic since most of our study population did not have tusks or tushes. It is likely that Goswami and colleagues were able to achieve this lower probability using tusk characteristics because their population had more tusked males. In the present study, we also investigated the probability of misidentifying adult female elephants ($p_{\max}^2$ = .048). There may be a higher probability of misidentification for females because there were fewer females in this subset, therefore only showcasing a small amount of trait combinations within the study population. The calculation could not go further than the 16th characteristic (Table 7).

Overall, the $p_{\max}^2$ results for all adult elephants, only male elephants, and only female elephants, illustrate that there were low probabilities of misidentification between elephants in the population and that the elephants in this study were reliably identified. These results were important because they were very similar to previous studies that used photographs taken during direct observations to identify individual Asian elephants (Goswami et al., 2007; Goswami et al., 2012). This suggests that camera trap videos captured during the day and night were successful in capturing characteristics to reliably identify Asian elephants, even given their limitations as stationary cameras without the ability to zoom in for detail. This is a promising first step in understanding elephant behavior in this population and their movement between the Salakpra Wildlife Sanctuary and the crop fields along its perimeter.

Previous studies identified between 150-220 individuals total living in this landscape (Siripunkaw and Kongrit, 2005; Chaiyarat et al., 2015). Because we have not yet identified the entire population, a comparison of the saliency of particular characteristics for identification purposes would be premature. The overall goal of this study was to identify as many elephants as possible and to determine how many characteristics were needed to reliably do so; thus, we did not randomly sample from the available footage. In order to compare the efficacy of using particular characteristics and traits across time of day, sex and location, the majority of the elephants in this landscape will need to be identified.

4.1 Implications

The current study contributes to our understanding of how different technological methods can be used to identify individual Asian elephants (Goswami et al., 2007; Vidya et al. 2014; de Silva et al., 2013; Fernando et al., 2009; Fernando et al., 2011), and provides a guide for identifying them using day and night camera trap videos. This hopefully can encourage researchers in other Asian elephant ranges to employ camera trap technology to systematically identify individuals in their local populations, especially where direct observations in the environment are challenging. As more researchers conduct research at the individual-, rather than just the population-level, they can better monitor elephant movement and activity while also characterizing variation in behavior patterns between elephants (e.g., Rees, 2009; Horback et al., 2012; Sitompul et al., 2013; Horback et al., 2014).

Practically speaking, the database of individual elephants created for the present study can and will be compiled into a guide and provided to Sanctuary park rangers and local farmers as a reference for the elephants located in the area. Since frequent crop raiding has been observed around Salakpra (van de Water & Matteson, 2018), individual identification may provide insight into how particular elephants are interacting with humans in the area (e.g., Cook et al., 2015; Goswami et al., 2015). Identifying information about elephants that frequently forage on crops could also aid in targeting HEC mitigation strategies at the individual level, a potentially more effective strategy that takes elephant behavior and personality into account (Mumby & Plotnik, 2018). More targeted strategies may help farmers manage their time as they direct their efforts towards specific individuals they can identify within their own crop fields.

Identifying individuals is also crucially important for understanding individual variation in elephant behavior more generally. Remarkably, we know very little about wild Asian elephant behavior and how elephants adapt to rapid, human-generated environmental change (de Silva et al., 2011; Fernando et al., 2009; Fernando et al., 2011; Vidya & Sukumar, 2005; Sukumar, 1990). The current study helps form a foundation for future research in this area. Our own work aims to use the individual identification of wild Asian elephants to assess differences in personality and cognition, not only as a means to help in their conservation, but also as a method for understanding how flexibility in behavior facilitates adaptations to anthropogenic change (Mumby & Plotnik, 2018).

4.2 Limitations

In previous studies on Asian elephant identification, researchers followed the elephants in vehicles and captured photos from various angles in-person (Goswami et al., 2007; Vidya et al., 2014). This may have allowed the researchers to obtain a more comprehensive or individually-directed data set. Camera traps are beneficial for studying animals in the wild because they are a non-invasive method to observe individuals and their behavior (Swinnen, et al., 2014). However, we were limited in our ability to collect morphological data using stationary camera traps, as the elephant's voluntary approach toward and movement around the cameras could be an obstacle for collecting data on all the characteristics and trait states for each elephant.

The camera angle was another limitation for using camera traps in identification. While it could be beneficial for capturing some characteristics of the elephant in the frame, this benefit was dependent on the elephant's distance from the camera. Some videos only captured ears, backs, and tails, while other videos did not capture backs, tail length or ear top folds. Camera traps deployed in the field were typically put up in a high place and were stationary for a long period of time. The only way to change the view would be to manually move the direction of the camera, and this was usually done infrequently due to their installation in remote areas. Overall, these limitations increased the frequency of data points where the elephant could not be identified due to a lack of observable characteristics.

Collecting identification data from night videos was another challenge. During the night, when the infrared light was illuminated, characteristics like ear folds would sometimes blend in with the color of the ear, obscuring the shape and folds, making it difficult to identify the trait state. Even with some traits obscured, there were typically others visible that allowed for identification of the elephant. In the future, we would like to determine the traits that are best identified in night videos compared to videos taken during the day.

While there are limitations for using camera traps to identify individual elephants, they did allow us to take multiple screenshots from video as the elephant moved around the camera (and did so at a close proximity that would not easily be possible with a handheld personal camera). Thus, the lack of a human presence during data collection, which certainly would negatively impact the elephants' behavior, could help offset the limitations camera trapping poses to individual identification.

4.3 Conclusion

In the current study, 72 adult elephants were reliably identified through camera trap videos based on the misidentification probability calculation (p_{max}^2) and using 19 of the 24 possible morphological characteristics (Supplementary Table 1). While these characteristics were derived from previous Asian elephant identification studies (Goswami et al., 2007; Vidya et al. 2014; de Silva et al., 2013), this is the first known study to use these characteristics for elephants in Thailand, and to do so using remote sensing camera traps. The present study also indicates that camera trap videos are reliable in capturing characteristics to identify individual Asian elephants. Overall, we hope these results will help inform the use of camera traps in the wild to study individual elephants, demographics and population dynamics and behavior. Camera traps, and video data collected from them in particular, provide a unique opportunity to record animal behavior over a cumulatively long period of time without the negative impacts posed by human presence or interference while filming. This is particularly relevant for the relatively new study of conservation behavior (the use of animal behavior research in conservation practice) and the application of animal behavior research to human-wildlife conflict. For elephants in particular, understanding individual differences in elephant behavior and how elephants make decisions about risk have important implications for mitigating human-elephant conflict from the elephants' perspective. This decision-making process and differences in how elephants behave in and around human-dominated landscapes can best be observed from a relatively unbiased viewpoint. We believe that remote sensing camera traps present a unique and exciting avenue for collecting such data, and encourage scientists interested in wildlife behavior and its application to conservation to consider their use as remote video-recording devices in their own work.

5 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

6 Author Contributions

SM organized the data, created the database for identifying elephants, ran the analyses and drafted the manuscript. SJ designed the study, collected data, supervised data analysis, trained SM on coding procedures, reviewed the identification criteria, and revised the manuscript. MY assisted with data collection and camera trapping in the field, provided research and logistical support in Thailand and revised the manuscript. JP designed the study, initiated and oversaw data collection, reviewed identification criteria and data analysis, and revised the manuscript.

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