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Thermal Drone Technology Used to Capture Thermoregulation in Wild Sumatran Elephants

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ABSTRACT

Drone technology plays a critical role in supporting conservation efforts for endangered species, not only in terms of species monitoring within various landscapes, but also potentially when applied to behavioral studies to investigate interaction patterns and response to environmental change. We tested a thermal drone to investigate thermoregulation and surface temperature of wild Sumatran elephants in the lowland tropical forest of Jambi, Indonesia. Thermoregulation data was obtained using RGB images and videos, while temperature values were measured from thermal images (R-JPEG) extracted into TIFF equipped with pixel temperature. We detected a visual thermoregulation mechanism known as mud bathing. Our study demonstrated that the trunk functions to draw mud and throw it onto the head, back, and stomach, the tail functions to distribute the mud to all parts of the back of the body, while the ears flapped to keep head temperature cool. Our measurements showed that the surface temperature of Sumatran elephants is between 28.9-30.3°C. The head had a relatively lower temperature than other body parts. This study also revealed that the environmental humidity variable significantly affects the elephant's temperature rise. The use of drone technology for future behavioral studies is recommended as it accurately provides high quality data and can be widely used in any type of terrain.

1. Introduction

Monitoring species body temperature (T_b) plays an important role in physiological parameters, thus providing insight into thermoregulation study, physiology and behavioral responses towards environmental changes, which can guide efforts to conserve endangered wildlife (Yang *et al.* 2020). The most common process used in monitoring T_b, is invasive and necessitates direct contact, (e.g., Thomas 2017 for elephants; Satyaningtijas *et al.* 2019 for dugong; Yang *et al.* 2020 for crocodile lizard; Giannetto *et al.* 2021 for cattle; and Easterwood and Cohen 2023 for horses). In some wildlife species, invasive methods have been carried out by inserting temperature-sensitive data loggers (model mlog T1C) into the body through anaesthesia and surgery (Lubbe 2013); the resulting impact requires post-operative recovery which has led to species mortality (Aquarone *et al.* 2015; McCafferty *et al.* 2017). This process is time consuming, costly, and challenging to apply to many individuals.

Drone technology has been developed to support conservation activities and aid wildlife monitoring, producing good quality image data, quickly detecting the presence of species under canopy, performing a stable platform, which is unobtrusive and maneuverable (Rahman and Rahman 2021). This has made it suitable for morphometric studies, behavioral observations, abundance, and demographics (Wich and Koh 2018). Drone imagery data can be applied in modeling biodiversity at species level, which is helpful for understanding and predicting the condition of a

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species in the future (Reddy 2021). Drone imagery significantly reduces bias and improves accuracy (Lee *et al.* 2019). Drones surveillance equipped with RGB and thermal infra-red cameras (TIR) has an ultimate feature in detecting species from birds to large mammals within the landscape (Wich and Koh 2018). Previous study showed that the success rate of TIR in detecting wildlife was 73.2%, while RGB was 67.2% (Brunton *et al.* 2020).

Thermal imaging is a valid and effective non-invasive technology used for wildlife monitoring (Nääs *et al.* 2014). The use of TIR for wildlife monitoring is growing as TIR sensor technology advances down to the size of drones, which cover a wide range of applications, along with its considerably economical device resulting in more affordable prices (Rahman and Setiawan 2020). Initial studies measuring surface temperature (T_s) using TIR sensors, include the Hainan gibbon, recorded at temperatures between 27-31°C, and howler monkey at 27°C (Kays *et al.* 2018; Zhang *et al.* 2020). Meanwhile, temperatures for larger mammals like the Javan deer ranged between 26.3-43.7°C, and water buffalo temperatures ranged from 25.1-39°C (Rahman *et al.* 2021).

The Sumatran elephant (*Elephas maximus* Sumatranus) is a protected species recognized within the IUCN Red List as Critically Endangered (Gopala *et al.* 2011). Successful conservation strategies could be improved by modeling the prediction of behavioral responses to adverse effects of environmental change, for example, mammals that are likely migrating to unprotected areas as a response to climate change (Miller *et al.* 2013; Condro *et al.* 2021; LaDue *et al.* 2022). Most research on Sumatran elephants relates to human conflict issues (Berliani *et al.* 2016). Nevertheless, information regarding environmental changes that impact behavioral response is still limited. Species observation towards behavior including the mechanism of thermoregulation, is substantial in maintaining the growth and survival rate of a species, for example in the case of environmental temperature changes which may lead to stress and affect animal welfare and productivity (Sevegnani *et al.* 2016).

Drone thermal imagery is used not only to detect the presence of species under the canopy, or calculate populations, but can also be used as a new method in studying specific behavior. This study aims to: (1) measure T_s without body contact (non-invasive); (2) measure environmental parameters influence towards T_s; (3) monitor behavioral response toward drones at various altitudes; (4) evaluate the use of various camera angle's for monitoring Sumatran elephant behavior. Monitoring thermoregulation of wild Sumatran elephants using drones has never been attempted, and it is possibly expected to produce baseline data for conservation efforts. Therefore, here we investigate thermoregulation behavior of Sumatran elephants by using a thermal drone in the lowland tropical forest ecosystem of Sumatra, Indonesia to support conservation management.

2. Materials and Methods

2.1. Research Areas

This research was conducted in November 2022 in the Bukit Tigapuluh Landscape, Jambi Province (1°10'50"–1°20'50" S, 102°20'30"–102°42'00" E; Figure 1). The area of research covers 50.097 ha, at an elevation of 55 to 169 m above sea level with varied topography from lowlands, valleys and hills. The vegetation types are dominated by primary forest, secondary forest, monoculture production forest (rubber and eucalyptus), oil palm plantation, and other functional areas (community-owned land).

2.2. Field Data Collection

Thermal image data was captured using a DJI Matrice 300 RTK drone, supported by DJI Enterprise Zenmuse H20 Series multi-sensor camera, consisting of a zoom camera, wide camera and thermal camera (H20T). The Zenmuse H20T Thermal Camera uses an Uncooled Vanadium Oxide (Vox) Microbolom sensor, a type of resistor used as a detector in a thermal camera that covers a large surface area and good thermal insulation. Thermal images taken using the Zenmuse H20T are stored in R-JPEG format attaching data and temperature information.

We conducted 14 drone flights from noon to evening in various habitats to assess factors that impacted surveillance operations. All flights were carried out according to the SOP of Civil Aviation Authority from the Indonesian Ministry of Transportation. Before the drone survey was attempted, we checked all location coordinates obtained from the GPS collars, which are equipped with a radio transmitter and attached to the wild elephants, as an initial guide to obtain the elephants' position and to track their movements. Arriving at the location indicated by the GPS collars,

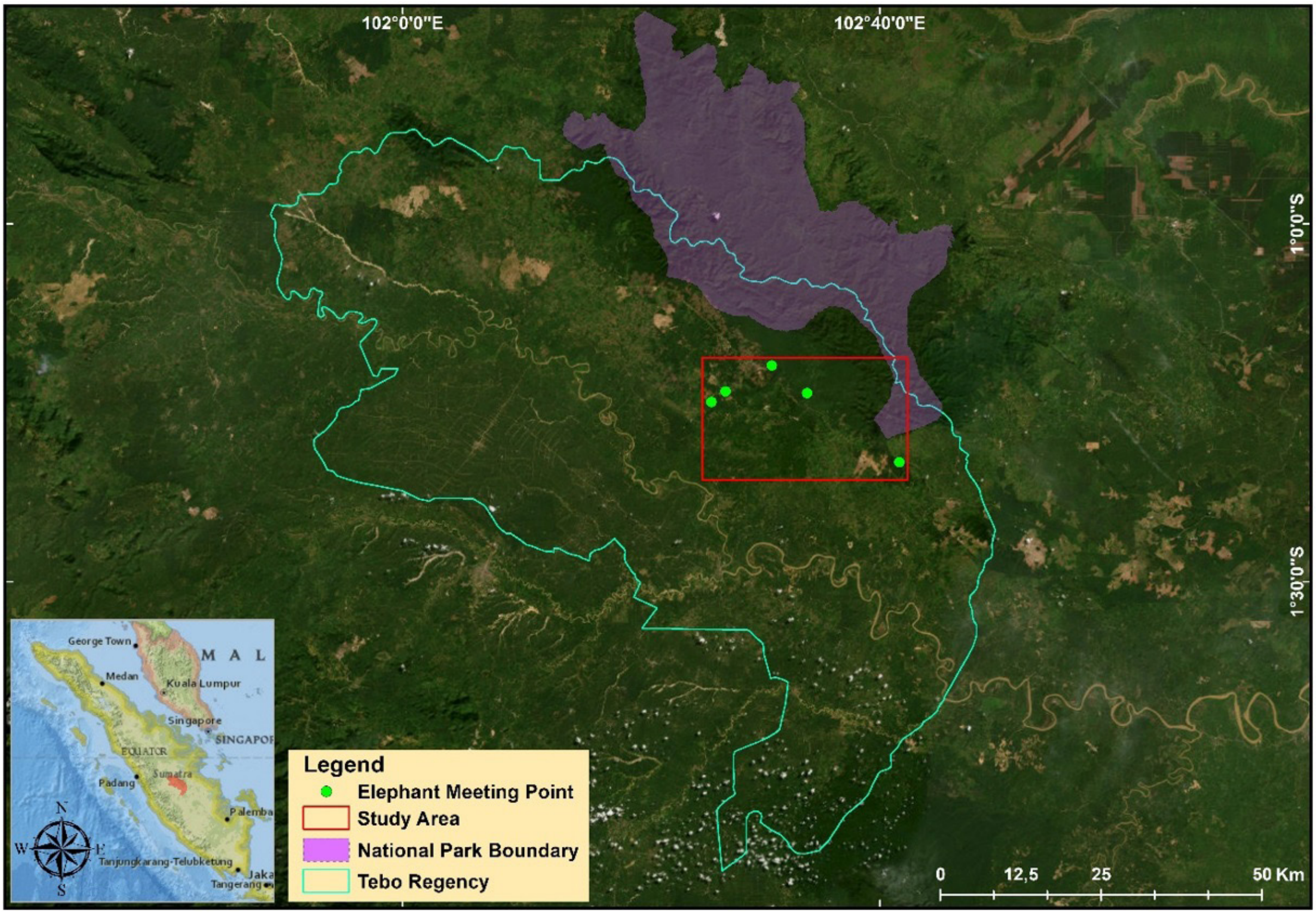

Figure 1. Research area map

wild elephants were not automatically visible as they are actively mobile animals in closed canopy areas. Radio telemetry signals were therefore used to locate the final position of the wild elephants. The drone was launched 100–200 m from the focal animal. We observed a total of 34 wild elephants within three groups at different locations and times. The first group consisted of five elephants, the second group consisted of 12 elephants, and the third group totalled 17 elephants. Minimum altitude of each flight was set to 70 m to minimize sound disturbance emitted by drone that would affect the elephants. The device later activated all three modes (RGB camera, thermal camera, and video) to focus on capturing behavioral and thermal data. We repeated the same pattern at each level with a total average flight time of 35 minutes.

2.3. Image Processing

Only few images of elephants captured by RGB camera were used as data sources. Several elephants caught on camera were not completely visible as they were hidden or covered by a canopy, thus, it was necessary to select complete image from the shape of the head and body. After the selection process, the individuals were counted and marked with serial numbers, based on their herd, using GIMP 2.10.34 software (https://www.gimp.org). The video format to support monitoring thermoregulation behavior, was run by using Windows Media Player (https://support.microsoft.com). Identification of thermoregulation behavior was carried out manually and visually by sight. Focal areas were the head, back and abdomen, where the process of thermoregulation behavior could be indicated visually by determining the surface of the skin, which was either covered by mud or not. This process would be the basic step for calculating the temperature in thermal images.

Thermal images from the DJI H20T camera were analyzed using the DJI Thermal Analysis Tool (https://www.dji.com), to indicate any facts affecting the parameters of humidity and reflected temperature on thermal temperature value of elephants. The temperature changes on surface were recorded based on changes in humidity values at every 5% increase, ranging from 40 to 100%, and based on changes in reflected temperature values at every 5°C ranging at 10 to 40°C. DJI Thermal Analysis Tool software simplified the changing of environmental parameter values. Nevertheless, this software could only calculate temperature values with full image sizes and did not compatibly support the process of calculating the pixel temperature values for each coordinate. R-JPEG files must therefore be converted to TIFF format with Anaconda3 software (https://www.anaconda.com) and Visual Studio Code 1.75.1 (https://code.visualstudio.com) using a python script in DJI Thermal SDK package (https://www.dji.com) and Exiftool (https://exiftool.org). The image analysis process is presented in Figure 2.

2.4. Statistical Analysis

To obtain accurate temperature data, it was necessary to perform a calibration based on environmental parameter values (Table 1). Pixel temperature measurement was applied using QGIS 3.28.3 (https://www.qgis.org), focused on 10 points on the head, 15 points on the back and abdomen with mud baths, 15 points on the back and abdomen without mud baths, and 80 points on the environmental temperature around the object (Figure 3). Furthermore, the dataset consisting 1.600 thermal pixels was divided into four sections (head, mud bath, non-mud bath, ambient temperature).

Table 1. Calibration of environmental parameter values for pixel thermal calculations

Parameters	Group 1	Group 2	Group 3	Source
Distance (m)	78.5	75.6	99.8	Drone altitude
Emissivity	0.98	0.98	0.98	Mole *et al.* 2016
Humidity (%)	85.75	94.12	84.19	NASA (.gov)
Reflected temperature (°C)	26.09	24.93	26.67	NASA (.gov)

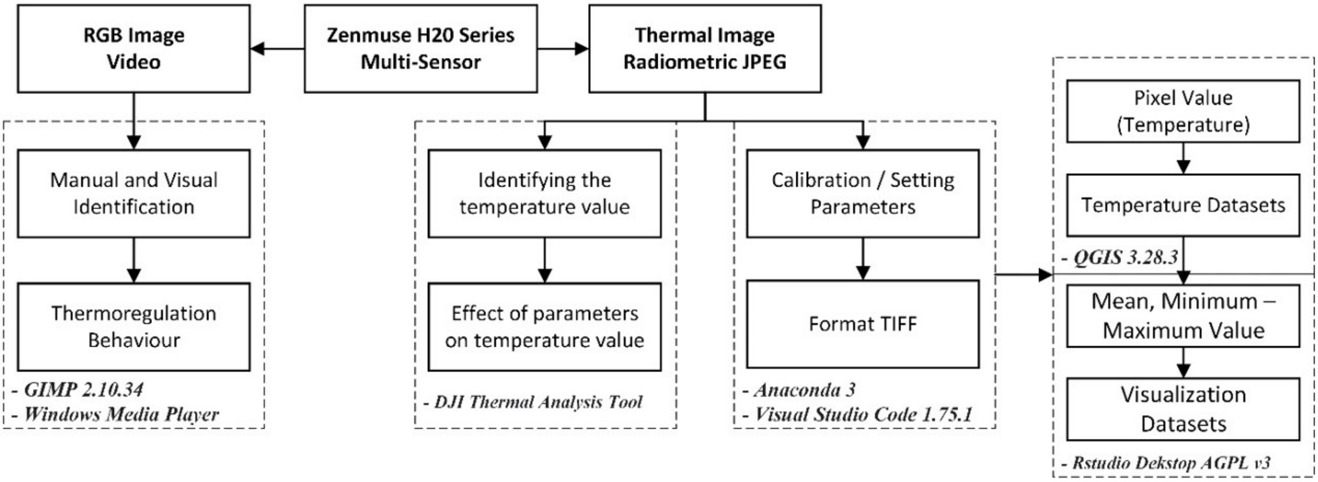

Figure 2. Methodological framework in detecting thermoregulatory behavior and T_s values using multi-sensor drones

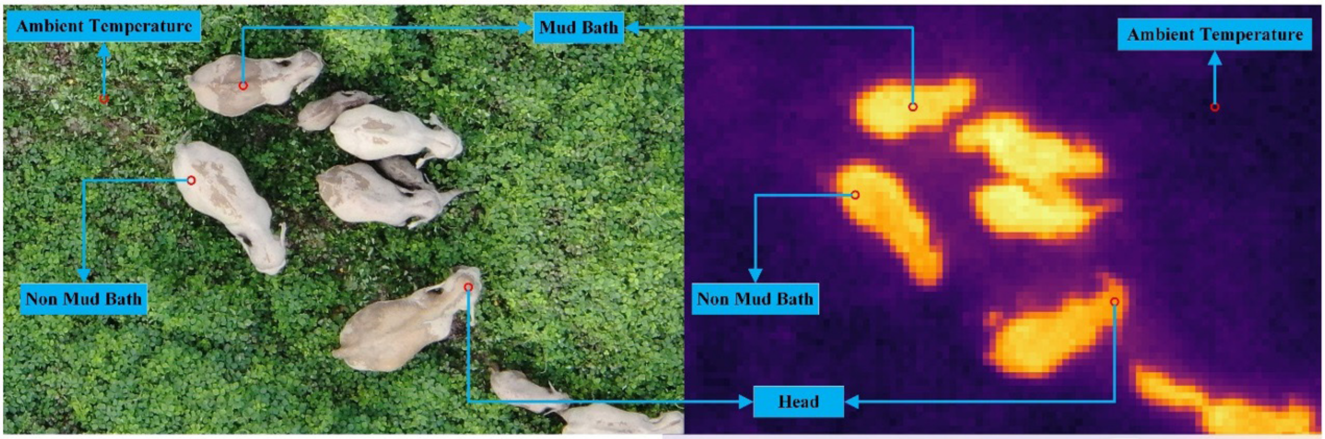

Figure 3. Thermal temperature measurements on the head, mud bath, non-mud bath, and ambient temperature

Pixel thermal values were analyzed using RStudio Desktop (https://posit.co).

3. Results

3.1. Detectability of Wild Sumatran Elephants

Determining the time of the observation contributed significantly to the success of detecting the presence of elephants. This was based on rapidly increasing temperatures after sunrise, which, within lowland forest rose between 11:00–14:00. At 13:00 the temperature of tree branches was 40.8°C, the leaves in the canopy were 36.4°C, while the shade under the tree was around 31°C. As a result, ambient temperature (T_a) and elephant temperature was defined as similar and hence challenging to compare visually with a thermal sensor. Consequently, observations in this study began at 15:00, when the solar radiation was considerably lower and T_a became cooler (Figure 4).

The position of camera angle on the gimbal performed an important role in detecting the presence of elephants under dense canopy-covered forest. Gimbal pitch degree angle which was positioned at -90° experienced difficulties in detecting elephants under the trees. Elephants could be detected at -30° to -70° as camera's view could penetrate through the trees from the side, not from above. In addition, the detectability factor of elephants was triggered by drone altitude. When the drone approached at an altitude of 100 m AGL, some elephants would respond with a trumpet-like roar as a sign of danger, but other elephants showed no change in behavior. Elephants would observe the surrounding situation and when they found no visible threat, they would remain calm. In this situation, the drone was slowly lowered to 70 m AGL to optimize the observation and monitoring results.

3.2. Thermoregulation Behavior

Elephant activities were properly observed in the afternoon as the temperature decreased and elephants emerged into an open area. We attempted a series of trial shots using different camera angles (Figure 5). Capturing elephant activity applied between a -30° to -50° angle at an altitude of 70 m AGL. These conditions allowed the observer to see individuals from a side position to obtain optimal data compared to a camera angle set at -90°.

Figure 4. Detection of an elephant under the canopy with a 100 m agl height, using a wide camera, zoom camera and thermal camera

Figure 5. Observation of behavior using various camera angles

We recorded the mud bathing phenomenon, which is known as thermoregulation behavior. From the recorded image data, the mechanism of mud baths in elephants was carried out using three body parts: trunk, tail and ears. The trunk took mud and threw it over the top of the head, back and stomach, the tail was used to spread the mud to all parts of the back of the body, while their ears flapped vigorously, aiming to keep the head temperature cooler. The calculations in the video image show that out of 10 elephants in five minutes, the average ear flaps were 175 times at 25-26.6°C (Figure 6).

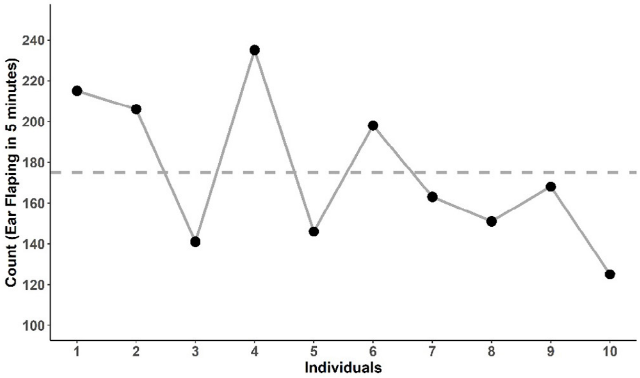

Figure 6. Ear flapping rate on 10 elephants for 5 minutes span at T_a between 24.93-26.6°C

3.3. The Effect of Humidity and Reflected Temperature on Surface Temperature

The intensity of infrared radiation can be affected by the surface temperature of hot objects around it; therefore, it is necessary to calculate how the environmental parameters affect temperature value on a thermal image. We carried out sensitivity tests on two parameters of humidity and reflected temperature, we did not include the distance and emissivity parameters in this test. Considering that drone distance to the observed target had the same value, i.e., >25 m, if the target distance exceeds 25 m, the distance parameter is set to the 25 m position. If it exceeds 25 m, the temperature measurement accuracy will decrease. According to several sources, the emissivity parameter on the surface of the elephant's skin has a value of 0.98 and in all processes this sensitivity test uses an emissivity value of 0.98 and a distance value of >25 m.

In humidity and reflected temperature tests, measurements were made at three thermal points on 34 elephants. The results show that the humidity parameter has a significant effect on the elephant's thermal temperature value and based on the linear equation, the humidity value is inversely proportional to the thermal temperature value. When humidity value increases, thermal temperature value will decrease, and vice versa. Meanwhile, the reflected temperature value test did not significantly affect elephant's thermal temperature. Each time it increased by 5°C, thermal temperature value decreased by 0.1-0.2°C, meaning that reflected temperature did not significantly affect the species with higher temperature value (Figure 7).

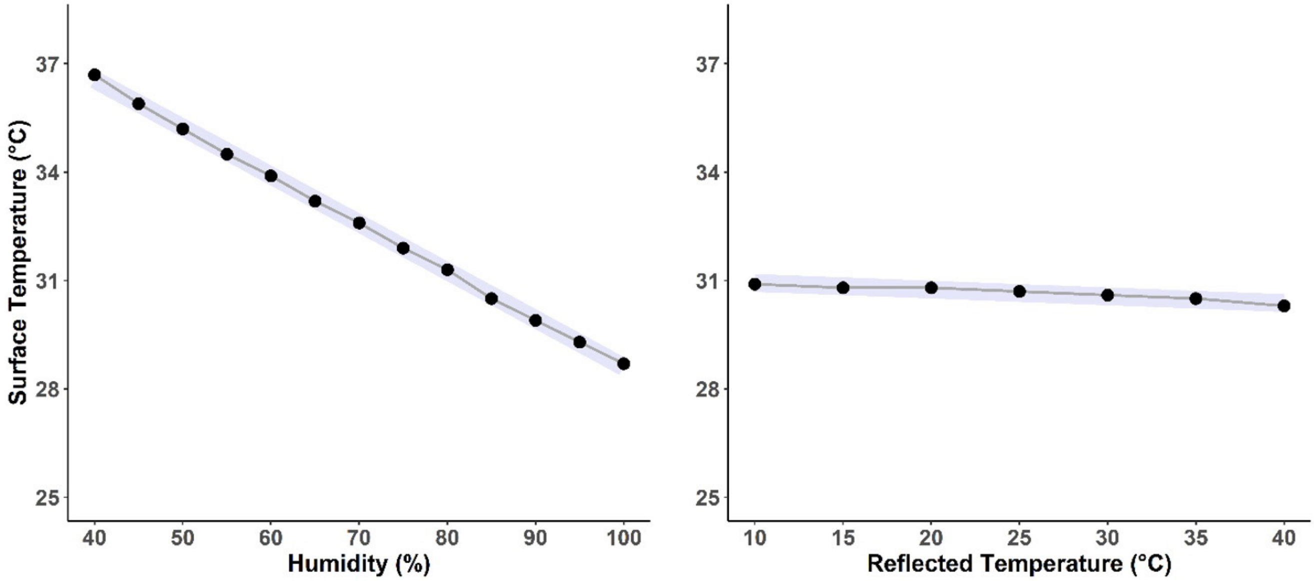

Figure 7. Effect of humidity and reflected temperature on the value of T_s

3.4. Surface Temperature

In capturing thermal data, the multi-sensor camera was positioned at -90° and it was perpendicular to the bottom, thus there was no bias in thermal image gradation. The thermal image was captured when the elephant spread into open areas, unobstructed by vegetation. DJI H20T thermal camera captures of thermal images indicated good results and the color composition of disparate temperature values looked solid. The results of T_s measurements on thermal pixel stated dissimilar T_s on the head and body parts in those individuals having taken a mud bath, and the body parts of those not taking a mud bath. The results for the 3 groups consisting of 34 individuals have consistent values even though the observations were made at different times and locations. The head had a relatively lower surface temperature than other body parts such as the back and stomach, while the mud bath body had a lower temperature than body parts that were not bathed in mud. T_s of the head had an average value of 28.4-29.5°C, the body parts with mud baths ranged between 28.7-29.8°C, the body parts not bathed in mud ranged between 29.9-30.7°C, while the temperature value of environment was lower than the temperature of an elephant with a difference of >4°C (Figure 8).

4. Discussion

This study took place in lowland tropical forest with dense canopy cover. From morning to noon, the vegetation has potential to interfere with TIR data collection due to a temperature rise in the canopy forest. When the temperature rises, elephants move faster and rest under the canopy to reduce the metabolic heat system (Chrétien *et al.* 2016; Mole *et al.* 2016; Kays *et al.* 2018). When the study was conducted T_a during the day, was around 32.5°C, while T_a in the afternoon was 23.8°C, and the evening was the optimal detection time for elephants. In these conditions, objects and the environment contrast making the thermal image of the animal more viable (Rahman and Setiawan 2020). In this study, data collection was carried out by focusing on the height of the drone so that elephants became familiar and unconcerned with the presence and noise of drones. The objective is to minimize reactions and disturbance to the target individuals during the observation (Christie *et al.* 2016), however the drones can be lowered slowly to 70 m AGL for optimal image capture.

From the images captured, it could be seen that Sumatran elephants performed a thermoregulation

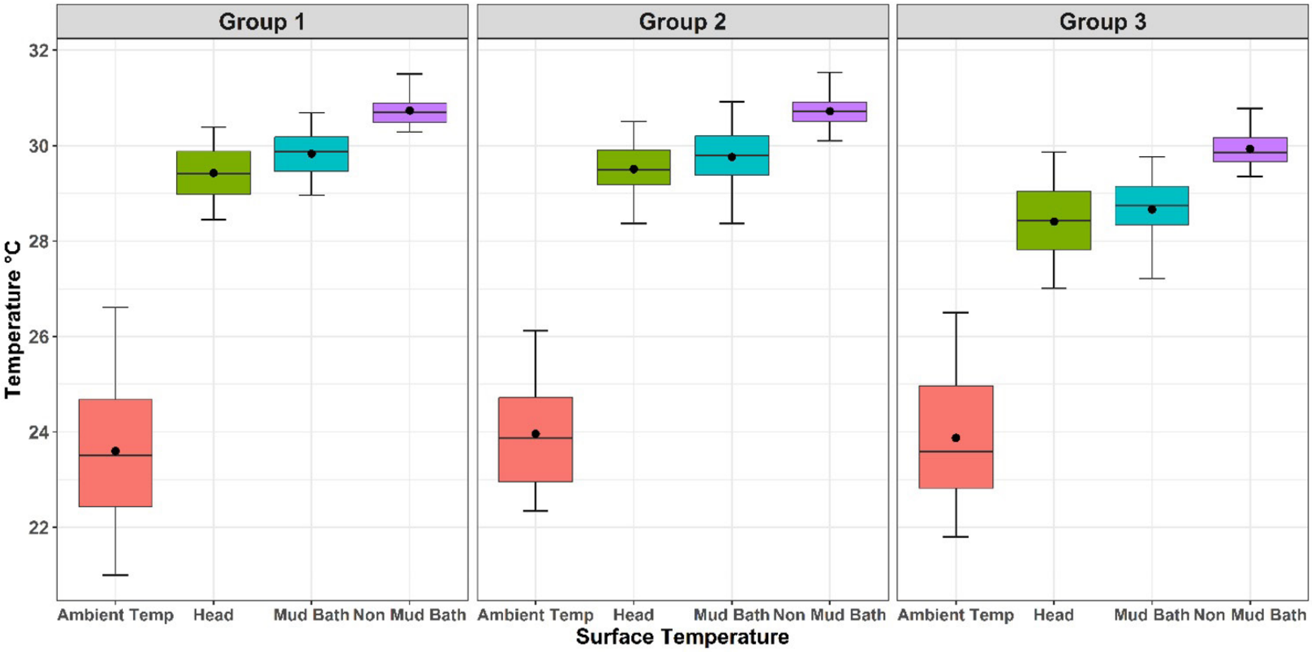

Figure 8. Differences in elephant T_s values during the thermoregulation mechanism between the head, mud bath, non mud bath and ambient temperature values

mechanism by taking a mud bath. Several individuals were still seen taking mud baths at 18:35 in the afternoon towards evening. Based on our results of measurements from three groups of elephants, it is known that T_s in those who took a mud bath and $< T_s$ in those who did not take a mud bath, had disparate temperatures between 0.9-1.2°C. This finding indicated that mud baths function to keep T_b cooler, and these results are aligned with previous research by Domínguez-Oliva *et al.* (2022) which revealed that mud bath behavior functions to regulate T_b. In addition to the mud baths, we recorded ear flapping behavior in all observed individuals. Ear flapping is one of the thermoregulatory behaviors influenced by Ta, and the frequency of moving ears will increase along with the rising of T_a (Athurupana *et al.* 2015). From the results of video image measurements, Sumatran elephants flapped their ears between 125-235 times/5 minutes in full rather than partial movement. This ear movement causes the head T_s to be cooler than the rest of the body (Figure 6). The calculation of ear movement frequency in our study was greater than the results of research by Vanitha and Baskaran (2010) and Athurupana *et al.* (2015) who recorded the frequency of ear flapping between 6-10 times/minute in *ex-situ* habitat. The thermoregulation mechanism in the Sumatran elephants that we observed was generally similar to the thermoregulation mechanism in the African elephant (Mole *et al.* 2016).

T_s of the Sumatran elephant had a value range of 27-31.7°C, which is lower than T_b of Thai elephants which was measured using feeding telemeters, in which thermometer capsules were fed into elephants to obtain a temperature measurement with a value of temperature ranging between 35.73-36.88°C (Weissenböck *et al.* 2010), and measurements using the deep rectal method with a value of temperature 36.2°C (Thomas 2017). There are differences in the values of T_s and T_b, but this condition is normal and supported by research done by Piccione *et al.* (2013) that stated the fact in endothermic animals the value of $T_s < T_b$. As validation, we measured T_s of human hands with results between 30.2-32°C (Figure 9). This value is similar to Lee's research (2018) which measured the temperature of human hands using a digital thermometer with results at 32.6°C. The temperature value generated through thermal images is valid, and results from the T_s of Sumatran elephants obtained in our study can be used as a reference value. Referring to the results obtained in this study, the use of drones supports a new method of observing Sumatran elephant behavior in natural habitat. The advantages of using drones in this study were having a multi-sensor camera that is capable of producing high-resolution images, thus it is easy to

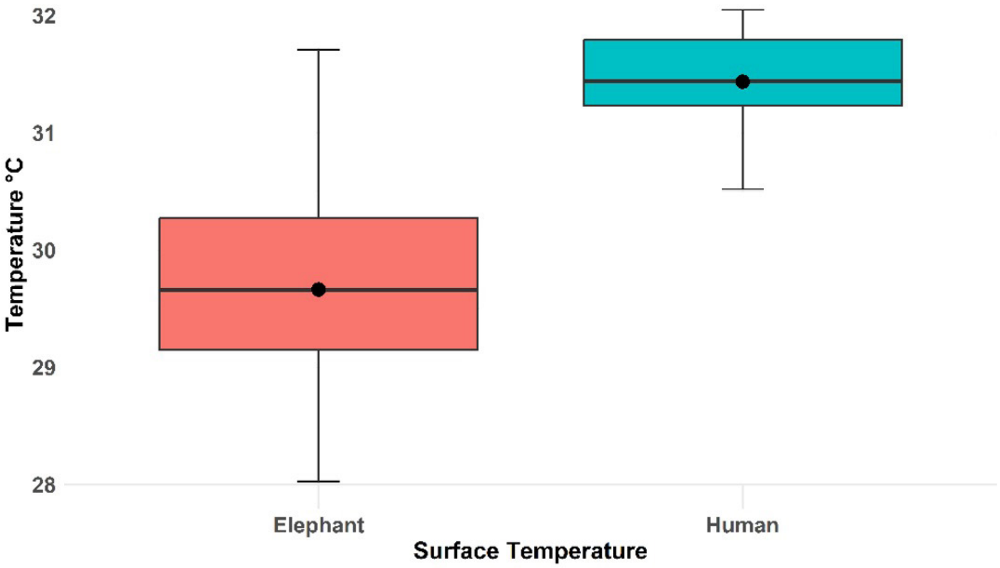

Figure 9. Comparison of the average Ts values of elephants and human

identify targets quickly and accurately, to minimize bias, capable of a long flight duration (35 minutes), and safe for observers and the focal animals. The use of drone multi-sensor in monitoring behavior and measuring surface temperature is recommended to be applied for future research on other tropical rainforest species for example: Sumatran rhinoceros, Sumatran tiger, Asian tapir, and other large mammal species.

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