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# Performance of unmanned aerial vehicle with thermal imaging, camera trap, and transect survey for monitoring of wildlife

**D A Rahman[1,2], A A A F Rahman[2]**

[1] Department of Forest Resources Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University), IPB Dramaga Bogor 16680 Indonesia
[2] Tropical Biodiversity Conservation Program, Faculty of Forestry and Environment, IPB University, IPB Dramaga Bogor 16680 Indonesia

E-mail: dede.auliarahman@gmail.com

**Abstract**. Reliable monitoring to obtain ecological data on species is required for effective wildlife management and conservation. However, few monitoring methods are satisfactory in terms of accuracy of the wildlife data produced and cost-effectiveness. Several methods are developed in the last few decades such as camera traps, unmanned aerial vehicles (UAVs) with thermal infrared (TIR) imaging may have great potential as a tool for wildlife surveys. We assessed the performance of the camera trap, UAVs-TIR, and traditional ground-based transects survey to the monitoring of wildlife in the IPB University Campus. Camera traps provide the highest number of wildlife records (54 for 22,080 camera days) and allow the identification of several species. Transect survey provides poor records and the most time consuming (24 records for 1,380 h). UAVs-TIR was quite successful in detecting wild animals in the canopy of trees that were not detected by camera traps and transects survey (20 records for 2,208 h of fieldwork). Camera traps and UAVs-TIR are both expensive but they support the fieldwork and provide interesting and much data for further analysis. The use of camera traps and UAVs-TIR simultaneously improves the detection of terrestrial and canopy animals that are often overlooked by the ground observer.

## 1. Introduction

Limited access, rugged terrain, and dense canopy cover of tropical rainforests make this ecosystem one of the least explored habitats until now. In tropical rainforests, surveys of small to large body size of wildlife populations using classical sampling methods are very challenging [1,2]. The walkways and canopy crane in recent decades have been the solution for botanists, entomologists, and conservationists in monitoring species richness and biodiversity contained in natural tropical rainforest in Indonesia. Thus, most of the work in wildlife monitoring activities, both for recording terrestrial and arboreal animals, has been carried out by observers on land, observing around or sticking their necks upwards to record data from animals that inhabit tree canopies [3]. Periodic wildlife monitoring is needed to measure the risk of extinction of specific species and evaluate the conservation value of forests [4], transect traditional ground-based is one approach that is still used in wildlife monitoring activities. However, ground-based survey techniques require extensive effort, losing small animals, cryptic and elusive, and even almost never or difficult to monitor nocturnal species in tropical forests with dense forest cover [5, 6]. Moreover, technically there are binding assumptions in the use of this method, whereby measuring the distance from the observer to the target animal must be accurate and the initial location of animals detected to be recorded precisely [7]. Animals with low detection rates, which are either rare and/or elusive and have a pattern of active nocturnally and live in tropical rainforests with dense forest cover, are difficult to meet the assumptions of this method. Since the early 1990s, started by [8], the technique of using a remote triggered photographic camera unit has become popular in Indonesia [9]. This method has been shown to be efficient for monitoring cryptic and elusive terrestrial animals in tropical rainforests [10-13]. Not only terrestrial fauna, recently, comprehensive data for arboreal animals are obtained also through the installation of camera traps in the field, but is still limited to a certain geographic scale due to the time consuming and effort required to harvest camera trapping data in the trees (climbing and checking cameras) [5,14].

In the last decade, the use of unmanned aerial vehicles (UAVs) in wildlife research and their management activities has been an increase rapidly in the number [15,16]. More advanced technology, autonomous capabilities, ease of use, diversity of platforms and components, lower costs, wide use for multiple purposes, and relaxed regulatory restrictions in some countries regarding the use of unmanned aerial vehicle technology have contributed to the increased use of this technology for wildlife monitoring activities [17,18]. Species that are very sensitive to ground survey activities, the use of UAVs is very suitable and works well for monitoring, research and management of these kinds of species. Recently, UAV imagery can be obtained at a relatively low cost and easily, while the detection of wildlife in open habitats [19-21] and covered in tree canopies [16,22] under various sampling regimes is possible with the increased resolution of cameras. In some other cases, signs of wildlife such as nests, burrows, tracks, etc, can be identified using UAVs technology [23-25]. Furthermore, current UAV technology is equipped with imaging sensors, such as RGB (Red, Green, and Blue) and high-resolution thermal cameras, offering the advantage of collecting data that can be retrieved repeatedly for various purposes and various detection techniques [26,27].

In the end, the selection of wildlife monitoring methods will greatly affect the quality, accuracy, precision, and completeness of the results of a study [6,28]. Considering the availability of resources and the most advantageous use of techniques based on a balance between the negative and positive characteristics of each appropriate method in relation to survey limitations and constraints is an essential and critical point in wildlife research activities. Apart from the various field survey methods commonly used in wildlife monitoring activities, an assessment of the efficiency of the method in survey activities can be attributed to the use of resources, in terms of financial and human involvement. Apart from setting clear goals, [29] states that in a wildlife research activity, the availability of budget and time and trade-offs between the two constraints must be considered and tested, including the possibility to adding the resources and extending the time needed to accomplish the goals set in monitoring activities.

The use of appropriate monitoring tools and methods is needed to support wildlife conservation efforts. This study was aimed to evaluate the efficiency of three survey methods: unmanned aerial vehicles with thermal infrared (UAVs-TIR), camera trapping, and transect sampling in terms of the resulting detection rate (1) and of financial needs and human costs (2). We test the hypothesis that the UAVs-TIR provides the best tradeoff between the data produced, cost, and survey effort.

## 2. Methods

### *2.1. Study area*

The use of tools and methods was evaluated in several tree density classes at IPB University, Indonesia. The study area is dominated by flat terrain with a total area of approximately 267 ha. Surrounded by built-up areas, the IPB University campus still leaves less than 40% of its area as a forest with various types of plants and different tree density classes. Some of the dominant tree families including Bignoniaceae (African tulip *Spathodea campanulata*), Euphorbiaceae (rubber tree *Hevea brasiliensis*), Fabaceae (white albizia *Paraserianthes falcataria*), Meliaceae (mahogany *Swietenia macrophylla*), and Moraceae (breadfruit *Artocarpus altilis*). Meanwhile, some of the common mammals found in the study area are from the family of Cercopithecidae (long-tailed macaque *Macaca fascicularis*), Herpestidae (Javan Mongoose *Herpestes javanica*), Hystricidae (Malayan porcupine *Hystrix brachyura*), Manidae (Pangolin *Manis javanica*), and Viverridae (Asian palm civets *Paradoxurus hermaphroditus*), as well as several species of bats, rodents, and squirrels. The area is also inhabited by a large number of birds, herpetofauna (amphibians and reptiles), and butterflies.

### *2.2. Sampling location*

Sampling locations were selected on the basis of the degree of tree density. The analysis was conducted using satellite image (satellite image-based), the tree density is expressed in several classes: low tree density, medium tree density, high tree density. For accuracy and collected ground truth assessment, the distances between classes are changed to the form below: class 1 (High Tree density=HTD; > 0.387), class 2 (Middle Tree Density=MTD; 0.291-0.387), class 3 (Low Tree Density=LTD; 0.190-0.290), class 4 (Grass Land=GL; 0.097-0.190), class 5 (Bare soil=Bs; ≤ 0.097) (figure 1).

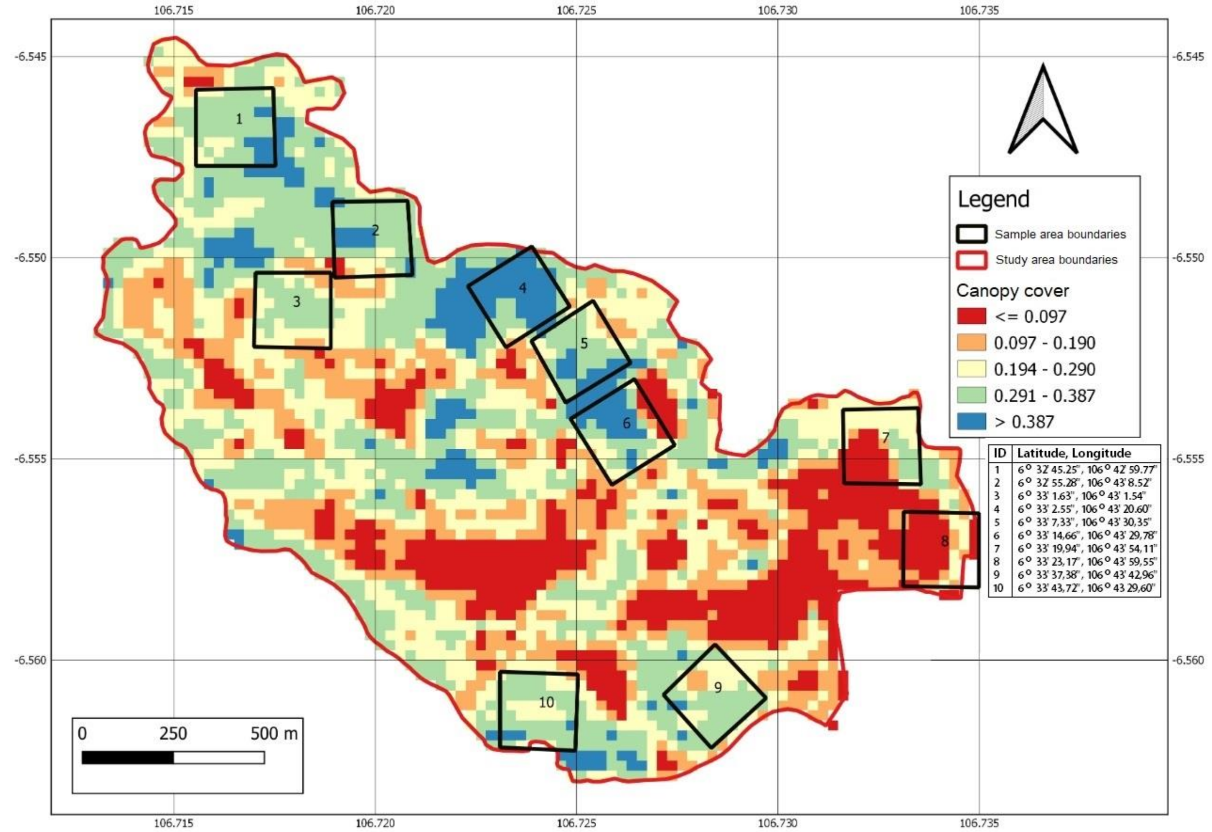


**Figure 1**. Blackline polygon as the location of square plots in the study area, placed at the five tree density classes representing the land cover condition of the IPB University campus.

The sampling location was divided into 10 grids (each grid=0.004 km$^2$) using a Geographic Information System (ArcGIS 10.5.1). From July to September 2020, we conducted a survey with three different methods at each of the sampling locations, first, we used UAVs-TIR technology (DJI Mavic 2 Enterprise Dual with FLIR). This tool is equipped with two types of cameras, a standard camera and a camera with an infrared thermal sensor. The heat between objects recorded by UAVs can be distinguished with FLIR MSX (multispectral dynamic imaging) which has a light spectrum that can be easily seen. We used the 640 × 360-pixel resolution of the nonradiometric thermal infrared camera embedded in the UAVs technology (FLIR Vue Pro 640). Mission Planner (Mission Planner Version 1.3, http://ardupilot.org/planner/, accessed June 22nd, 2020) was used to program the flight path of UAVs. To get a precise and repeatable flight at the fixed height (altitude above ground level, hereinafter referred to AGL) an integrated terrain following feature was used. For the screen showing the operation of both systems, we used the Apple 7.9" iPad (128GB, Wi-Fi + 4G LTE).

Before the flight, the thermal sensors are internally calibrated with a precision of 0.05°C (<50 mk) and the flight plan is made identical. On each flight, the camera is aligned perpendicular to the planned flight path and facing down vertically to get the widest possible view. In our study, a total of 20 flights was carried out with 1 flight in the morning and 1 flight in the afternoon (each hour of flight varies between 20-25 minutes), which is entirely started a half-hour before sunrise and sunset. The average temperature in the whole flight during the study time was 20°C in the morning and 25°C in the afternoon. Flights performed with a height of 50 m AGL (± 2.5 m), which gives a broad horizontal view of 42-m with a resolution of 7-cm ground sample distance. UAVs flew in a route from east to west with an average speed of approximately 8.5-11 m s -1. In this flight, a total of 10 parallel transects with a line length of 4 km per grid (figure 2).

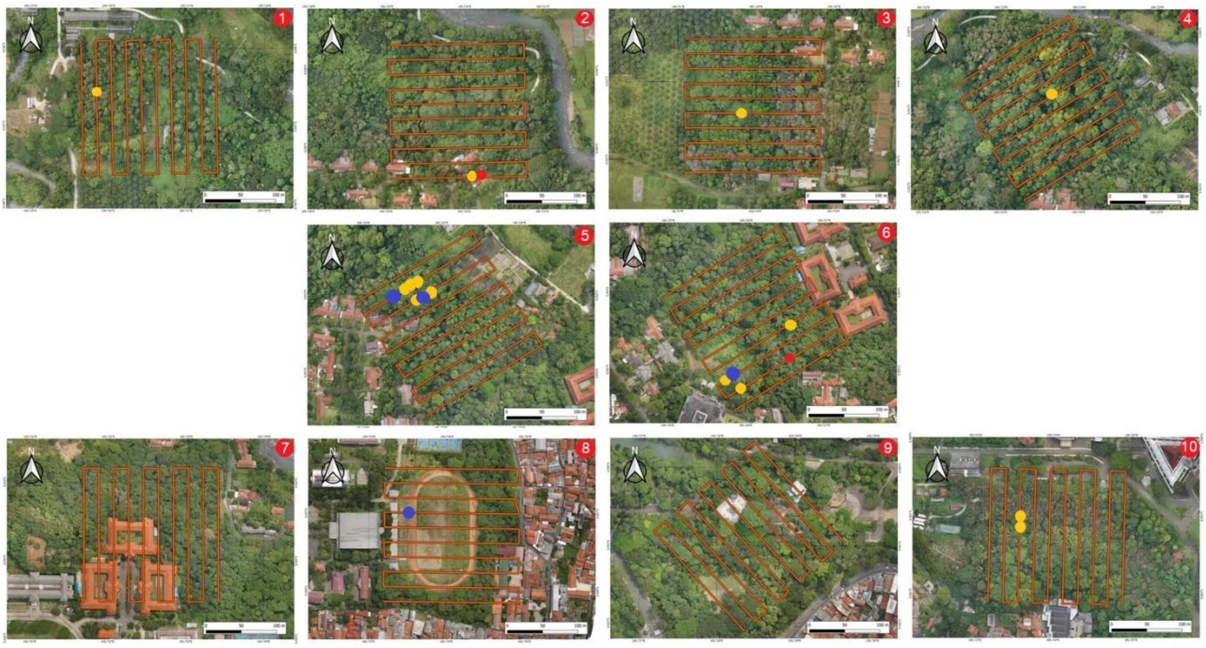

**Figure 2**. The planned UAV flight paths and transects on each grid indicate with red lines. Colored dots (red dots = detection in July; yellow dots = detection in August; purple dots = detection in September) indicate marked wild animal observations.

Within each grid, we also defined one camera trap. We installed a total of 10 digital Bushnell Trophy Cam with a working system based on a heat sensor/passive infrared motion. Camera traps are operated in video mode with a duration of one-minute and one-minute video per trigger. Camera traps are placed at a height of 30-50 cm above the ground to record animals with various body sizes [6,13]. All species capture by camera traps were grouped and identified as squamates and amphibians [30], birds [31], and mammals [32]. Camera traps installed in the field are checked every 30 days to harvest the data produced, replace batteries and memory cards, or replace camera traps if they are malfunction.

Apart from collecting data with UAVs-TIR and camera traps, on each grid, we also take data on sample four permanent transect along 0.4 km. Occurrence data of animals on transects were collected by walking four or six times in the time period from July to September 2020. Data collection was carried out in five monitoring periods with 3-h monitoring activities in each period, with details of the period I: started from 06:00 to 09:00; period II: from 11:00 to 14:00; period III: from 16:00 to 19:00; period IV: from 21:00 to 24:00; and period V: from 02:00 to 05:00. Monitoring of animals in limited light conditions was carried out with the aid of night-vision thermal imaging binocular. Observer bias was reduced by involving two observers in one survey activity. A total of 40 transects were used in monitoring activities with this sampling design.

### *2.3. Data analysis*

To compare the detection rates for each method, we used the number of animal detections per month. We calculated the relative abundance indices (RAIu) for wildlife data were capture by UAVs-TIR as:

$$RAIu = \frac{\text{Total number of sighted wild animals}}{\text{number of aircraft flight path x repetitions}} \text{ x } 100$$

while the relative abundance indices (RAIc) for the camera trap data were expressed as [33]:

$$RAIc = \frac{\text{Sum of all independent photographs}}{\text{total number of camera days}} \text{ x } 100$$

Consecutive photographs of the same species with a distance of more than 0.5 hours are considered independent photos [34]. While for the survey transect data, the relative abundance indices (RAIt) were calculated by:

$$RAIt = \frac{\text{Total number of sighted wild animals}}{\text{number of transect x repetitions}} \text{ x } 100$$

To determine the efficiency of the three wildlife monitoring methods, we also calculated the cost of each method for a 30-day survey (optimal time interval for replacing battery and memory card in camera traps) and for a 3-month survey (the duration that fulfills the closed population assumptions). For camera trapping, a total of 5 days per month is allocated for the researcher's work in the field with details of 1 day for installing the camera and 1 day for checking or removing the camera, and 3 days for collecting data or interpreting photos captured by camera traps. For UAVs-TIR and transect surveys, field research activities are carried out every day to collect data so that it takes 30 working days for researchers. Meanwhile, to prepare flight routes and transects for each of these methods, the field assistant takes 2 days and 5 days respectively to complete their works. Costs are classified as additional fixed and variable expenses for each method. Compass, global positioning system tool, computer, etc. were included as fixed costs which did not change during the study period. Since these costs are almost the same for each method they are excluded from the calculation. Batteries and memory cards, camera trapping devices are included as variable expenses for camera trapping. For Unmanned Aerial Vehicles, it consists of UAV-TIR and iPad, while for transect sampling consists of range finder and binocular. For each method, the daily allowance for researchers and field assistants were also calculated based on the days they work in the field. Costs are calculated based on local currency (real) and then converted to American dollars that apply internationally (exchange rates are using the average in the period of July-September 2020: 10,000 IDR ≈ US$ 0.680).

## 3. Results and discussion

### *3.1. Comparative efficiency of three survey methods*

In this study, a total of 2,208 h, 22,080 h (920 trap days), and 1,380 h were collected from the survey using UAVs-TIR, camera trapping, and transect sampling, respectively. A total of 28 species of wild animals including humans were recorded in 27 genera in this whole study.

In a survey using camera traps, a total of 312 photos (31.2 per camera trap) were exposed, showing the diversity of wildlife in the study area with findings of 2 insects (0.64%), 7 squamates (2.24%), 2 birds (0.64%), 4 domestic mammals (1.28%) and 35 wild animals (11.15%), and 4 humans (1.28%; table 1). Most of the photographs did not show any animal captured (82.69%). From the 14 identified species, the long-tailed monkey (*Macaca fascicularis*) was the animal with the highest frequency of being captured by camera traps (n = 18 photographs) and was captured in almost all sample locations. Furthermore, other mammal species that are captured by camera traps are Javan treeshrew (*Tupaia javanica*; n = 8), East Indian brown skink (*Eutropis multifasciata*; n = 6), humans (n = 4), domestic cat (*Felis catus*; n = 3), domestic dog (*Canis lupus familiaris*; n = 1), and 9 species were photographed less than 15 times. RAIc were 0.41, 0.32, and 3.93 for July, August, and September, respectively. The number of photographs increases with the length of time the camera traps are installed, low in the initial period of installation, and continues to increase with a peak in mid-August.

Through UAVs-TIR, we could identify long-tailed macaque, Javan deer (*Rusa timorensis*), Javan treeshrew and crested serpent eagles (*Spilornis cheela*) (Total 20 records). While through transect sampling, a total of 24 records was detected: mammals (n = 4; 16.67%) and humans (n = 1; 4.17%), birds (n = 18; 75%), squamates (n = 1; 4.17%) and insects (n = 2; 8.33%). We record the activity of bird vocalizations five times in the sampling transects, but the dense vegetation density makes it difficult to find an individual directly. Compared to the two other methods, wildlife detection using camera traps was significantly higher (UAVs-TIR: $\chi 2 = 1.824$; df = 1; $p < 0.001$ and transect sampling: $\chi 2 = 0.417$; df = 1; $p < 0.05$) (table 1).

**Table 1**. The relative abundance of wildlife in July-September by three survey methods at IPB University Campus, Indonesia (RAIu and RAIc: Relative abundance index for UAVs-TIR and camera trapping, respectively, RAIt: Relative abundance index for transect sampling).

| Period of survey | UAVs-TIR | | Camera trapping | | Transect sampling | |
|---|---|---|---|---|---|---|
| | Number of sightings | RAIu | Number of photographs | RAIc | Number of sightings | RAIt |
| July | 2 | 1.25 | 18 | 6 | 8 | 4 |
| August | 14 | 8.75 | 31 | 10.33 | 6 | 3 |
| September | 4 | 2.50 | 5 | 1.67 | 10 | 5 |

Camera traps provide the most numerous and accurate records of terrestrial mammal species and allow the identification of species or individuals that have certain characteristics. A study by [35] found that camera traps were best in detecting occurrence, identifying wildlife at the species level, and investigating in detail the species of large mammals when compared to surveys using a track plot. Camera traps can provide faster information that can be the basis for rapid assessment of the conservation status of wildlife especially in rare mammal species under all environmental conditions, either in open areas or in areas with very dense vegetation when compared to track surveys and line transect census [36]. Another study showed extreme results in the monitoring of the Critically Endangered Bawean deer (*Axis kuhlii*), where the camera trap data provide a very significant difference in the number of animal detection when compared with transect survey [6]. Monitoring and recording animals 24 hours a day is an advantage of camera trap technology [13]. Different types of animals in different taxa and activity patterns (diurnal, crepuscular, and nocturnal) have the same chance of being capture by this tool [6]. Camera traps have been proven to be effective in producing a variety of data including the presence and absence of species in an area [37], demographic parameters and life history [38], activity patterns [9], reproductive status [12], and predation [39] which are very relevant for the study of the size, population dynamics, and population trends with deep learning analysis [40].

In contrast to the camera trapping, The main difficulty in monitoring wildlife with UAVs-TIR and transect sampling is potential errors in identifying species, especially when the object is located in dense vegetation [18]. Moreover, UAVs-TIR can only detect the presence of a few species in the study area. These results might be explained by both the rarity of the species and their small size. UAVs-TIR with low resolution is perhaps the most limiting of the three methods. In addition, this also depends on the field conditions in the sample plots, which are generally determined by two main factors, i.e. the type of vegetation, and the climate condition which can cause large variations in detection results [16]. UAVs-TIR has been extensively studied in temperate climates with their coniferous forests [41] or tropical areas with vegetation types such as savanna [42], where this technique works well in both conditions. Two problems with using UAVs-TIR in tropical rainforests are the dense vegetation cover and extreme wind conditions during the rainy season. Monitoring using the UAVs-TIR conducted in the dry season will provide a better detection rate and be able to describe the condition of the number of species in the area. Our study suggests that this monitoring tool can be an adjunct to camera traps, as it records several species of animals in three locations where no videos were taken by camera traps.

Meanwhile, for transect surveys, the competence of surveyors is an important factor in the success of monitoring activities. The ability to identify species from existing markers and estimate observer-animal distances quickly and precisely in dense vegetation presents its own challenges and requires heavy fieldwork [43]. The ability of the observer will determine the degree of bias, observations made by an untrained and inexperienced person can lead to misidentification of the species, less sensitivity in sensing the presence of the species, etc. In addition to these factors, the efficiency of monitoring by transect surveys greatly depends on weather conditions. Heavy rainfall and strong wind conditions can cause the animal to be inactive which could potentially obscure the study results. At last, transect surveys may not be reliable for monitoring cryptic, elusive, or rare species because of their low detection rates and so samples are not large enough to be analyzed further.

### *3.2. Limitations of UAVs-TIR and camera trapping*

Unmanned aerial vehicles and camera traps are equipped with infrared detection, although both tools work differently, they are equipped with cameras that can detect heat or movement from animals. The performance of these two devices decreases with increasing ambient temperature [6]. When the ambient temperature is higher than the animal's body temperature, for example in UAVs-TIR, the thermal sensor that works is less than optimal because of the difficulty in distinguishing objects from their environmental background. Therefore, based on the results of the study, it seems that higher detection occurs when the ambient temperature in the surrounding areas is lower than the animal's body temperature which prevalently occurs in the morning or evening [16, 41]. Meanwhile, the sensitivity of camera traps may be disrupted due to leaf shaking or falling branches during rain, which is an important problem that commonly occurs in tropical rainforests.

In a monitoring activity using camera traps, the risk of losing the camera as a result of being stolen, disturbed, or destroyed by both humans and animals passing must be taken into account. So backing up additional camera traps is necessary to secure the predefined sampling design and to obtain the expected data. The risk of losing trap cameras is usually higher when trap cameras are placed in locations close to central areas of human activity. Installing an explanatory notice about camera traps installed in an area in most cases can reduce theft cases, as well as notifying local security forces to participate in securing camera traps installed in the field. In addition, completing a camera trap with a padlock or other safety device can be part of the effort to secure this tool. In our research activities, camera traps are placed in an area far away from human activities to reduce the possibility of theft by outsiders who enter the campus area secretly.

### *3.3. Budget comparison*

The calculation of daily costs of variable expenses for a 30-day and a 3-month surveys were, respectively, US$ 594 and US$ 281.33 for UAVs-TIR, US$ 93.6 and US$ 42 for camera trapping, and US$ 249.1 and US$ 166.37 for transect survey (table 2). In terms of time-consuming by researcher and field assistant, the last two methods gave similar results in that time spent in the field was longer than camera trapping (30 + 15 days vs. 10 + 6 days for the 3-month survey).

The cost of trap cameras in the initial period is high, then decreases over time because the camera can be operated and/or be used in other research projects for a longer period of time, besides that the travel/setting costs and people get lower in the accumulated time. The same duration of fieldwork without the constant need for researchers in the field is a major advantage of using camera traps for wildlife monitoring activities, as the camera traps can work automatically and be placed for several days or even in several months in the fields. Meanwhile, the use of UAVs-TIR and sampling by transect survey requires daily field visits. The daily costs of monitoring using UAVs-TIR were highest for the 30-day survey followed by the survey transect, while for the 92-day survey, the daily cost of the survey was much lower and more efficient on camera trap (US $ 42 per day vs. US $ 167–282) compared UAVs-TIR and transect survey, respectively. In evaluating methods of wildlife recording, researchers agree that methods with more accurate results, even if they are more expensive, are best for studies over a long period or when studies are different but can use the same primary field tool.

**Table 2**. Calculation of variable expenses (in US$) for a 30-day and a 3-month surveys in wildlife monitoring at the IPB University Campus, Indonesia, using three methods.

| Method | Item | Variable expenses unit value | 30-day survey quantity | Total | 3-month survey quantity | Total |
|---|---|---|---|---|---|---|
| UAVs-TIR | Drone DJI Mavic 2 Enterprise Dual with FLIR | 4,225 | 1 | 4,225 | 1 | 4,225 |
| | Apple 7.9" iPad (128GB, Wi-Fi + 4G LTE) | 615 | 1 | 615 | 1 | 615 |
| | Researcher's per diem | 100 | 10 days | 1,000 | 30 | 3,000 |
| | Field assistant's per diem | 50 | 2 days | 100 | 6 | 600 |
| Total | | | | 5,940 | | 8,440 |
| Per-day cost | | | | 594 | | 281.33 |
| Camera trapping | Camera traps | 213 | 10 | 2,130 | 10 | 2,130 |
| | Memory cards | 5 | 10 | 50 | 10 | 50 |
| | Batteries | 0.35 | 80 | 28 | 240 | 84 |
| | Researcher's per diem | 100 | 5 days | 500 | 10 days | 1,000 |
| | Field assistant's per diem | 50 | 2 days | 100 | 6 days | 300 |
| Total | | | | 2,808 | | 3,564 |
| Per-day cost | | | | 93.6 | | 42 |
| Transect survey | Range finder | 268 | 1 | 268 | 1 | 268 |
| | Binocular monarch | 354 | 1 | 354 | 1 | 354 |
| | Night vision binocular scout | 512 | 1 | 619 | 1 | 619 |
| | Researcher's per diem | 100 | 10 days | 1,000 | 30 | 3,000 |
| | Field assistant's per diem | 50 | 5 days | 250 | 15 | 750 |
| Total | | | | 2,491 | | 4,991 |
| Per-day cost | | | | 249.1 | | 166.37 |

## 4. Conclusion

As it is obvious from this study, camera traps are reliable and standardized monitoring tools that are very useful in formulating species management and conservation programs. Whilst, UAVs is a new technology that has recently been developed for wildlife monitoring activities with various challenges and limitations in their use. During our testing, an important issue in the use of this technology is to find a way to maximize the detection function of the tool and identify an animal's objects recorded by a low-resolution thermal camera. However, our study found that this technology performs well in various tree density classes. In the future, this technology is very promising for use in ecological research activities, particularly for monitoring wildlife in tropical rainforests in Indonesia. As a stand-alone monitoring tool, somewhile the use of each tool is less representative of the findings of species present in a survey area. The use of two or more monitoring tools and survey methods increases the scope of the assessment of the fauna community in an area. A combination of two or more methods can be complementary and always give data with better quality, especially for monitoring the cryptic, elusive, or rare species. Using camera traps and small size UAVs with high thermal resolution (≥ 1,024 × 768) has the potential to be a solution for obtaining comprehensive data of wildlife.

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