Ivosevic et al. Journal of Ecology and Environment (2017) 41:12
DOI 10.1186/s41610-017-0028-1

Journal of Ecology and Environment

SHORT COMMUNICATION

Open Access

Monitoring butterflies with an unmanned aerial vehicle: current possibilities and future potentials

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Abstract

The world of technology is pleasantly evolving to a stage where small robotic aid may be used to ease the work of researchers, and to one day bring more accurate results than the current human abilities allow. In the research field of species monitoring in biology, unmanned aerial vehicles (UAVs) have begun to play an important role in how research is approached, analyzed, and then applied for further investigation, particularly by focusing on a single species. This paper uses data that has been collected from June to October 2015, to demonstrate how the innovative idea of using UAVs to monitor a particular species will bring a positive development in conservation research, and what it was able to achieve in this research field so far. More precisely, we examine the potential of UAVs to take center stage in future research, as well as their current accuracy. This paper describes the use of the commercially available Phantom 2 Vision+ for the detection, assessment, and monitoring of the butterfly species *Libythea celtis*, demonstrating how it can help the monitoring of butterflies and how it could be developed for even more adventurous and detailed research in the future.

Keywords: Butterfly, Monitoring, Phantom 2 Vision+, Unmanned aerial vehicle (UAV)

Introduction

The development of technological advancements in the last decade has revolutionized the way that ecology has been researched, and has also broadened its impact on the world. This is true for many other scientific disciplines, but it has a prominent effect on ecology due to its importance and ability to conserve the ever changing environment that affects many species. Remotely controlled robots, unmanned aerial vehicles (UAVs) in particular, have not only revolutionized data acquisition for abiotic parameters but also for exploring inaccessible areas and observing animals in their natural habitats (Grémillet et al. 2012). The multiple acts of monitoring the current plant and animal species, as well as searching for those that have not been discovered yet, is a very difficult task, and one that demands a team of highly skilled researchers in order to be carried out correctly (Millennium Ecosystem Assessment 2005). So far, the current availabilities in technologies have not provided a method fast enough to collect the vast amount of data that is continuously needed in order to provide reliable research for all species—until the idea of the UAV presented itself.

Unmanned aerial vehicles (UAVs) have enjoyed a rapid boost in usage and development in the field of environmental data collection and adaptability in various disciplines. This is largely due to the fact that their technological advancement has included miniature sensors, faster movement, and great agility, especially when deployed in low altitudes (Laliberte et al. 2010). The continuing advancement in technology promises tailored systems implemented with micro-sensors operating with extraordinary precision (Watts et al. 2012). Perhaps one of the most important contributions that have been made by UAVs is their ability to require minimal pilot training and to be equipped with various cameras, a built-in accelerometer, a gyroscope, a GPS system, and other sensors that are valuable to the collection of data. No other technological advancement to date has been able to combine so many different techniques into a single system. This study will effectively show that even

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the smallest of creatures such as the butterfly can be effectively monitored with a UAV.

Assessing the abundance of species is a fundamental and inevitable requirement in ecology and conservation. The population of butterflies is a vital bio-indicator for measuring environmental changes and habitat status (Van Swaay et al. 2012). Tracking the variation in butterfly population density poses contributions to entomological research, such as biodiversity monitoring and species conservation. Changes in butterfly numbers are sampled mainly through their regular counts on fixed routes, known as transects, and often through the mark-recapture method. However, because of the fragility of the species, using this traditional method on butterflies is likely to cause them a lot more harm and may also change their behavior after release (Henry et al. 2015). Most adopted butterfly-monitoring protocols rely on counts along transects or fixed routes (Pollard walks) to generate information on the availability of species and their richness and abundance. According to more detailed recent studies and references regarding butterfly monitoring methodologies, it can be concluded that the results and accuracy of count-based methods depend heavily on the ecology and behavior of the target species and the habitat type in which surveys are taken (Pellet et al. 2012).

Snout butterflies (Nymphalidae: Libytheinae) have unique morphological characteristics among the groups of Lepidoptera (Hao et al. 2012). *Libythea celtis* or Nettle-tree butterfly (Fig. 1) is a species of the subfamily Libytheinae. It is recorded in Southern Europe, Northern Africa, and Asia, and their larvae generally feed on leaves of *Celtis* (Celtidaceae). The species has several striking physical features, most notably the unusually long labial snout-like palpus that looks like the petiole of a dead leaf, offering an excellent camouflage when the butterfly is taking a rest, and its gently widening rather than club-shaped antennae and the hump on the hindwing, breaking up the outline. (Hao et al. 2012; Guypadfield 2015). *L. celtis* hibernates in the extreme heat of August, not re-emerging until the first warm days of spring, hence their flight time is late June to August and March after hibernation (Kaygin Toper et al. 2006).

Materials and methods

Aircraft

Unmanned aerial vehicles rely heavily on their inertial measurement unit (IMU) in order to collect data. This is possible because UAVs at high altitudes are able to regulate their height and position simultaneously with the use of their three-axis accelerometer and gyroscopes from their Global Positioning System (GPS) (Floreano and Wood 2015).

The Phantom 2 Vision+, from the DJI Company, is an aircraft that contents all the necessary components for immediate take off and is equipped with a high quality camera, which shoots photos at 14 megapixels and full HD video at 1080 and 720p/60fps. It also has the ability to tilt the camera as you fly, creating unique angles. Camera settings include picture quality, ISO, exposure compensation, white balance, and capture format, and can be adjusted through the VISION app. The Wi-Fi range extender can support the Wi-Fi connection from a remote control to the aircraft at a distance of up to 700 m (NZ Camera 2015). The removable 4-GB micro SD card allows the storage and preservation of data collection. We replaced the existing micro SD card with a 32-GB micro SD card to ensure sufficient data storage.

Study site description

Research location was placed in Sobaeksan which was designated as the 18th national park in Korea on December 14, 1987 (Korea National Park Service 2015). More precisely, our study area was placed in Namcheon valley, on the Danyang flow into the Namhangang River.

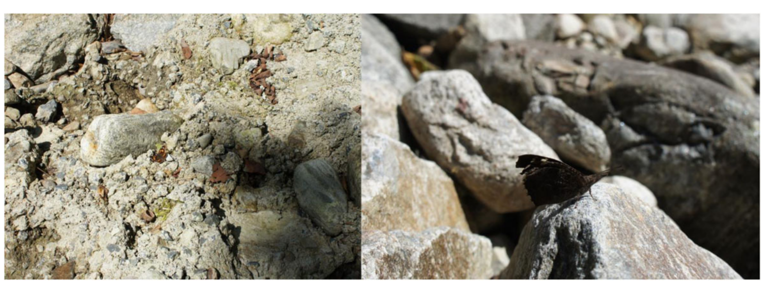

Fig. 1 *Libythea celtis* captured with Sony NEX-5 camera in the designated study site. Using hand-held camera, it is possible to spot and determine the target species of the butterflies. This particular study used the Nettle-tree butterfly as the test subject, to discover whether or not small UAVs have the potential to become the main method of accurately monitoring butterflies in as many aspects of their life as possible. The collected results will then be analyzed and used in order to provide a starting point for future research and as a method by which UAVs can be developed to fit a bigger and better purpose as data collectors. We discuss strengths and weaknesses of methods used in this research and give our recommendations and conclusions based on the experience, and biological and ecological background knowledge

A total area of 4×4 m^2 was allocated as study site. The UAV was hovered at an altitude of 4 m covering the target area (Fig. 2), which was the ideal environment for the *L. celtis* that enjoys rocky slopes surrounded by *Celtis*. The natural coverage of tree branches and shrubs is the perfect environment for this species, although it did present a few drawbacks for the research team. Namely, the shadow cast by small rocks and the river flow caused interferences and difficulties in distinction due to their camouflage abilities and size. However, it is precisely these shrubs and slopes which the *L. celtis* needs for survival and which have become endangered due to human interference and urbanization. Habitat preferences of *L. celtis* include rocky shrub-filled slopes and rubbles by slow flowing streams (Pyrgus 2015).

UAV-aided sampling method

Sampling methods in terms of flight sessions were carried out in the period of June to October 2015. A total of 21 flights were conducted in repeated surveys (once a week), without preconceptions of expected results. Each flight utilized all of the UAV's flight abilities in order to record as much information as possible on the target species of butterflies, the flight pattern, and their density in the chosen area. The Phantom 2 Vision+ was used as the primary monitoring tool, surveying the area and taking video records of the butterflies in duration of 5 min each. The length of the video shots was sometimes determined and adapted according to the weather conditions and constructive works in the study site. This particular butterfly is very well camouflaged in its current habitat, and their movements would be a lot easier to track in a shorter span of time than in a longer one.

Because of the small size of the area that was being monitored, as well as the surrounding natural environment, we came to the conclusion that the safest way to monitor the species, and one which would provide the least disturbance, would be to hover the UAV above the butterflies. Additionally, this flight pattern would keep the vehicle much more stable, which would then provide an easier means to count the butterflies that were captured at the time. The UAV would hover at the same point for 5 min, but during the flight we would change and adjust the camera angles in order to record the current swarm of butterflies within the study site. We have hovered our UAV at an optimum altitude of 4 m so as to be close enough to spot butterflies, but not too close so as to disturb them. We targeted on one particular study area, and performed point count, instead of a transect method, for butterfly population, as this method fitted the need to assess the ability of UAV for butterfly monitoring with minimal parameters to be accounted for. Each flight was specially authorized by the government authorities of Korea, and care was at all times taken that the natural habitat would not be disturbed in any way.

As is the case with all new types of research, this one was also affected by some of the most frequent disturbances that are associated with studies conducted in nature. Namely, the weather conditions that we had no control over would have an effect on both the UAV and the butterflies accordingly. The UAV would need to be flown much more carefully in windy conditions and would be impossible to use in case of rain. Likewise, the butterflies would not appear in nearly as many numbers once the weather took a turn for the worse. Additionally,

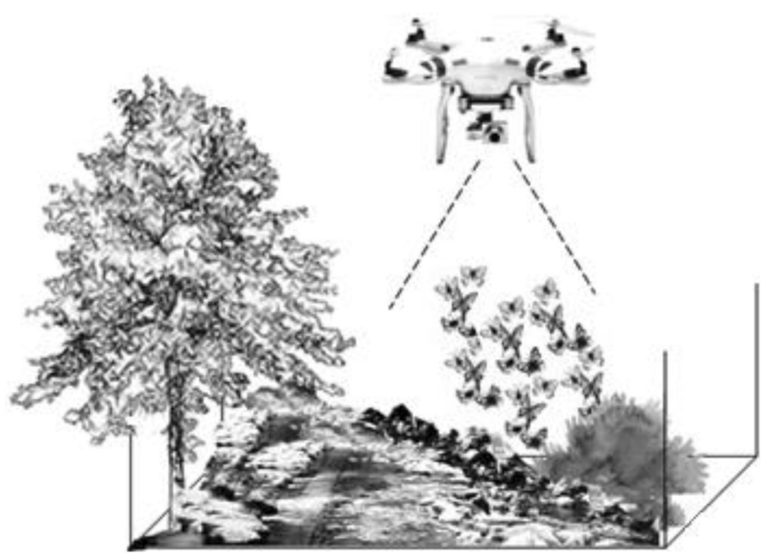

Fig. 2 Survey area. The graphical scheme is given for better visual representation and understanding the study site dimensions and the UAV position during the period of recording. UAV is hovering above the study site and recording the swarm of butterflies

a few instances of reconstruction work in the park were also a cause of a disturbed research period. The park is a very popular tourist destination, so we would have to stop filming in case other people were present. This was done both to ensure the safety of the tourists and also because the butterflies were automatically affected by their presence and would leave the designated area, leaving us with nothing to record. However, we were still able to make the most of our time available and to collect enough data to be able to come to an objective conclusion pertaining to the topic of the research aim.

Data processing and analysis

Each flight's data was transferred from a micro SD card to a standard computer. Every video recorded was reviewed in VLC player after slowing it down four times. The videos were analyzed in detail for three parameters, namely: entry count, left count, and re-entry count. The study site was divided into six imaginary quadrants for better investigation of the parameters (Fig. 3). Entry count is incremented when a new butterfly enters the study site (Fig. 4a). Left count is incremented when a butterfly is not spotted within 3 s in the same quadrant (Fig. 4b). Re-entry count is incremented when a butterfly is spotted again in the same quadrant within 3 s (Fig. 5). The video was rewound or looped several times to verify the viability of an instance before the count was affirmed. Re-playability has proven to be a major asset in using UAVs as monitoring equipment for butterfly monitoring.

Results

The most significant moments in our research were when we were able to capture a swarm of butterflies on three occasions, June 4th, June 10th, and June 18th. This was the first time where it became apparent that our methods of data collection were valuable and perhaps most importantly that the use of a UAV would indeed be the base for outstanding results for the future of ecological research. We listed down our parameters and results in Table 1.

At the end of the 5 min, there were no butterflies left within the capture frame. The total count was calculated as re-entry count subtracted from entry count. The count error was calculated using the following formula:

$$\%_{\text{error}} = \left|\frac{{}^{\#}\text{Left} - {}^{\#}\text{Total\_count}}{{}^{\#}\text{Total\_count}}\right| * 100 \qquad (1)$$

According to Jeon et al. (2012), the species *L. celtis* has been classified as a dominant species in March and April, with its reappearance after estivation time in August and September. Despite our eagerness to continuously monitor butterfly populations from beginning of August to October, the butterflies appeared only two times in a comparatively small number. Out of reach, flying outside the study area, a few butterfly individuals were not recorded by the UAV, but were only taken by hand-held camera or phone camera device. In terms of butterfly count, the UAV data was able to show that the number of butterflies in that particular area was a lot smaller than it was in the past. The reasons for such a reduction in numbers would need to be additionally analyzed in order to give an accurate account of the situation, and it would also allow for more detailed plans of future UAV flights, which would now be able to focus on a specific aspect of monitoring a species. This study did not take into account the effect of wind turbulence, from the UAV, on the behavior of the butterfly species. The altitude of 4 m might not significantly alter the population count from the study site as the butterflies adapted to the constant wind quickly. Detailed effect of wind turbulence on behavior of butterflies requires future dedicated research studies. It is notable to say that

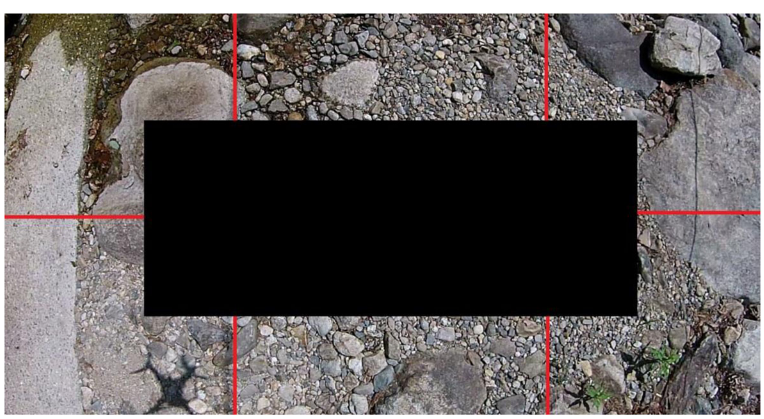

Fig. 3 Study site quadrants. During the process of butterfly counting, the study site area covered by the UAV's camera is divided into six imaginary quadrants for better investigation of the parameters

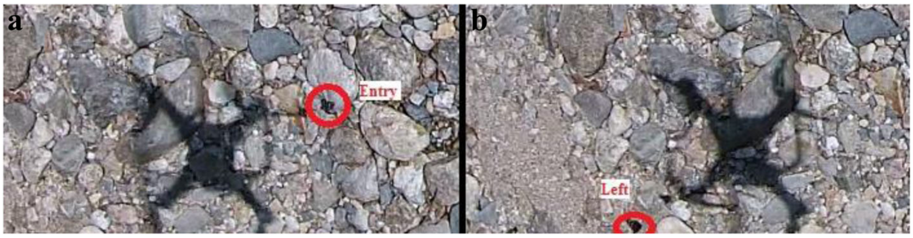

Fig. 4 Entry count and left count: **a** Butterfly entering the survey area recorded by the UAV. **b** Butterfly leaving the survey area recorded by the UAV

we assigned a small study site to test the feasibility of UAV technology in monitoring and it is quite easy to cover larger areas due to its portability. It is evident that UAV can be a powerful tool to monitor butterflies in the upcoming years.

The most difficult achievement in this type of data collection was counting the number of butterflies when they were in their greatest numbers. Not only was it difficult to count them individually in order to determine their number but it was also difficult to come to a final conclusion on how these results should be judged, since there is very little previous research that deals with the topic. Simply because a butterfly was not spotted by the UAV in that particular area does not mean that it did not make an appearance. In fact, traditional survey counting methods showed that the butterflies were present more or less through the whole survey period with the highest number of butterflies in June. Also, time intervals set up for monitoring were considerably shorter with the UAV than for the conventional method, which resulted in a smaller count number.

Discussion

Conventional methods used in the past were indeed useful in their own might and have provided us with an abundance of information to use in our research. However, with the fast changing image of our world and its technology, we must stay up to date with all of the latest advancements and possibilities if we are to keep our mark as valuable researchers and contributors to the conservation effort. Among many other things, the UAV also allows for ease of access in areas where it is either impossible or very dangerous for humans to enter on their own. This has not only insured the safety of the researchers, but it has also allowed for much lesser interruptions of the butterfly species.

It is our hope that our results will provide inspirational development both to future researchers on the same topic and to companies that build the UAVs. The best way for this research to be improved is if both the developers and conductors come together to create the apt machine for data monitoring in the wild.

The dangers and insecurities that present themselves whenever research is carried out in the wild are a valid reason to hope for a new approach to data collection, where the presence of humans will be minimized. Not only are UAVs more accurate in their data collection, but they are also much better able to cover terrains that are sometimes dangerous or impossible to do with basic capabilities of humans.

UAVs have the ability to become a much more affordable and versatile way of monitoring both species and the environment. Future developments of this kind of research would allow for specially trained personnel to handle the flight patterns of UAVs, while the actual data analysis could be carried out by specially trained researchers and contractors who provide the remote sensing software for counting of the species (Rango et al. 2006). An additional improvement we focus on is the camera's ability to record most of the details of the target species' movements. This is essential so as to track the butterfly species effectively, either manually or by

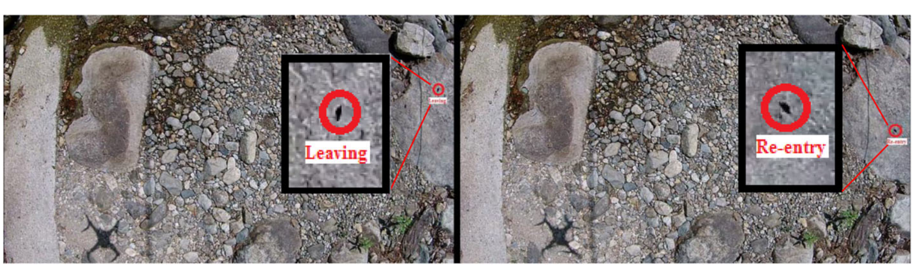

Fig. 5 Re-entry count. Re-entry count represents the number of butterfly individuals which are leaving the study site and reappearing within the time period of 3 s

Table 1 Results of counting procedure

Date	Entry	Left	Re-entry	Total count	% Error
04.06.2015	87	57	29	58	−1.72414
10.06.2015	15	9	3	12	−25
18.06.2015	9	7	1	8	−12.5

using well-calibrated object-tracking algorithms coded for the specific use. High shutter speed, slow-motion cameras can detect butterfly movements more precisely by capturing many more pictures per second than conventional cameras. With current enhancement in high definition recording, it is evident that in the near future, we can track the movements of butterflies with high precision. Although it would be completely unrealistic to say that UAVs will have the ability to completely replace researchers in the near future (Breckenridge and Dakins 2011), the one thing that we certainly can be sure about is that they will have the ability to improve the way we conduct research.

The aim of this research was to discover whether or not it is beneficial to continue our research into the world of UAVs and whether or not we should introduce them as regular members of conservation. The results, although there have been some difficulties, have shown that we have indeed discovered fantastic use for drones in biology, as well as in many other life and environmental sciences.

As with any other new innovative technique, there are certainly areas that can still be worked on and developed, and this is also true for the UAV. However, the benefits that it has shown in the current achievement are more than enough reason to continue with this research and to develop it into a leading method of conservation.

Abbreviations
UAV: Unmanned aerial vehicle; UAVs: Unmanned aerial vehicles

Acknowledgements
This subject is supported by the Korea Ministry of Environment (MOE) as "Public Technology Program based on Environmental Policy (2014000210003)".

Availability of data and materials
Not applicable.

Authors' contributions
BI analyzed and interpreted the image data of the butterflies and was one of the major contributors in writing the manuscript. YH mainly collected all the image data of the butterflies with UAVs and processed the data to analyze and also one of the major contributors in writing the manuscript. OK mainly designed this work and revised the paper totally. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Received: 28 November 2016 Accepted: 16 February 2017
Published online: 14 March 2017

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