Journal of Environmental Science and Engineering A 12 (2023) 139-150
doi:10.17265/2162-5298/2023.04.003

VTOL UAVs for Forest Monitoring and Management via Remote Sensing: A Case Study in Khao Yai National Park, Thailand

Cattleya Delmaire, Charnvit Munikanond and Settapong Malisuwan

Institute of Earth Science and Sustainable Development (IESSD), Asia Aviation Academy (AAA), King Mongkut's Institute of Technology Ladkrabang (KMITL), Prince of Chumphon Campus, Chumphon 86160, Thailand

Abstract: The utilization of UAVs (Unmanned Aerial Vehicles) has experienced a remarkable upsurge in various industries, including forestry. Their capacity to expeditiously and effectively cover large tracts of land has resulted in their widespread adoption as a valuable forest management and monitoring tool. The versatility of UAVs extends to their capability to perform quick and efficient surveys of large areas, inventory of tree species, and monitoring of forest health. This research paper reports on the successful utilization of VTOL (Vertical Takeoff and Landing) UAV that was designed and built at the IESSD (Institute of Earth Science and Sustainable Development) located in the AAA (Asia Aviation Academy) at KMITL (King Mongkut's Institute of Technology Ladkrabang) Prince of Chumphon Campus, Thailand. The VTOL UAV is employed for resource and environmental missions, as well as forest monitoring by using remote sensing technology. VTOL UAVs are used for aerial surveillance to conduct air photography, data collection, and processing for resource and environmental missions. This research paper presents a comprehensive analysis of the areas at risk of deforestation and forest encroachment in a particular region of Khao Yai National Park in Thailand, highlighting the potential for the resulting photographs to inform evidence-based decision-making and facilitate sustainable forest management practices. This study offers recommendations to develop VTOL UAVs remote sensing capabilities and mitigate deforestation and forest encroachment in Khao Yai National Park.

Key words: VTOL, UAVs, remote sensing, deforestation, forest encroachment.

1. Introduction

In recent years, UAVs (Unmanned Aerial Vehicles) have gained widespread attention and recognition as a valuable research tool. The remarkable progress in microelectronics and battery technology has resulted in the development of low-cost drones, leading to their increasing popularity in research applications [1]. UAVs provide numerous benefits, including on-demand remote sensing, flexible temporal and spatial capabilities, high accuracy, reduced costs, and labor, and lowered human risk. Additionally, the availability of advanced image processing technology has enabled greater information extraction from drone-captured imagery. For instance, photogrammetry facilitates the conversion of 2D images into 3D models of the earth. This technique allows for the measurement of tree heights, delineation of tree crowns, and other crucial information about forests [2].

Currently, there is a growing demand for UAVs with VTOL (Vertical Takeoff and Landing) capabilities. VTOL technology has been developed by combining the advantages of both multicopters and fixed-wing aircraft. Although multicopters can perform VTOL, their rotary wing rotor cannot exceed the velocity of sound. VTOL, on the other hand, can achieve high-speed VTOL and can be utilized for a variety of purposes, including high-resolution photography for forest monitoring and management, water surveillance, traffic surveillance, accident site assessment, and

Corresponding author: Cattleya Delmaire, MA in European Studies, researcher, research fields: sustainable development.

military escort operations. This study aims to analyze the current level of VTOL technologies and their global trends [3, 4]. In addition, over the past few years, there has been a growing interest in the utilization of VTOL UAVs for remote sensing purposes because this technology has found applications in a variety of fields, including urban planning, engineering monitoring, and ecological research [5]. Its potential uses are unlimited, and the range of applications is continually expanding.

The following section outlines the research methodology employed in this study to accomplish the research objectives. By leveraging the capabilities of VTOL UAVs equipped with various sensors and remote sensing technology, the research aims to contribute to the optimization of forest management practices and promote evidence-based decision-making for sustainable resource management.

2. Research Methodology

The research methodology employed in this study follows a systematic approach to assess the potential applications of VTOL UAV-based remote sensing in forest monitoring and management. The workflow consists of several key stages, each serving a specific purpose in data acquisition, processing, and analysis.

2.1 Sensor Selection and Calibration

The first step involves selecting suitable sensors to be mounted on the VTOL UAV platform based on the remote sensing tasks at hand. These sensors may include high-resolution digital cameras, multispectral cameras, thermal cameras, and LiDAR (Light Detection and Ranging) sensors. Additionally, calibration of the sensors is essential to determine their spatial relationship and remove geometric distortions caused by cameras.

2.2 Mission Planning and Design

The success of the UAV-based remote sensing missions relies on careful mission planning. Factors such as topography, weather conditions, and lighting in the study area are considered to design an optimal mission plan. Key flight parameters, including flight path, altitude, image waypoints, speed, camera settings, and exposure time, are meticulously planned to ensure data overlaps, full coverage, and high-quality data acquisition.

2.3 Data Collection and Pre-processing

With the mission plan in place, the VTOL UAV autonomously collects remote sensing data based on the flight parameters. The collected data are then subjected to pre-processing to ensure its suitability for further analysis. Pre-processing tasks may include camera distortion correction, image color adjustment, noise elimination, vignetting and blur removal.

2.4 Aerial Triangulation and 3D Reconstruction

Aerial triangulation, also known as structure from motion, is performed to recover camera poses and 3D structures (sparse point clouds) from the image sequences. GPS (Global Positioning System) and inertial measurement unit data are used to initialize the camera position and orientation for each image, and image matching is employed to estimate camera poses. Tie-points are generated, and connection relationships among images are established. Bundle adjustment is then utilized to optimize camera positions and orientations, leading to the derivation of 3D structures.

2.5 DSM (Digital Surface Model)

Using the oriented images, dense point clouds or DSM is derived through dense image matching. DSM provides a detailed representation of the terrain surface, which, when combined with surface reconstruction and texture mapping, yields a comprehensive 3D model of the scene. Furthermore, orthophotos are generated to eliminate geometric distortions and provide a seamless, orthorectified mosaic at the desired resolution.

2.6 Image Interpretation and Application

With orthophotos and 3D models at hand, image interpretation is performed to gain insights into the scene, including image/scene classification, object extraction, and change detection. The interpretation results are then applied to various applications, such as thematic mapping, precision agriculture, and disaster monitoring.

In this research, VTOL UAVs are equipped with various sensors, including visible light cameras, multispectral cameras, thermal cameras, and LiDAR technology, to capture detailed aerial imagery of forests. These sensors enable the extraction of valuable information about tree health, species composition, forest density, and overall forest structure. The data collected by VTOL UAVs with high temporal and spatial resolution are processed and analyzed using the outlined workflow, enabling evidence-based decision-making for sustainable forest management practices.

The subsequent sections of this paper will delve into specific applications of VTOL UAV-based remote sensing in forest monitoring and management, utilizing a case study conducted in Khao Yai National Park, Thailand. This case study aims to analyze areas at risk of deforestation and forest encroachment in the park, providing valuable insights for conservation efforts and effective land-use planning. Additionally, the research will explore the potential of remote sensing technology for precision forestry applications, ultimately contributing to the optimization of forest management practices and supporting sustainable resource management.

3. UAV-Based Remote Sensing for Forest Management

VTOL UAVs have become increasingly popular in recent years, and there are several trends that are shaping the development of these vehicles [6, 7].

(1) Miniaturization

Advances in miniaturization technology have led to the development of smaller and more compact VTOL UAVs. These smaller UAVs are easier to transport and deploy, and can be used in a wide range of applications, including military, civilian, and commercial.

(2) Increased Payload Capacity

As VTOL UAVs become more advanced, they are able to carry heavier payloads, such as high-resolution cameras, sensors, and other equipment. This makes them more versatile and useful for a wide range of applications, including aerial mapping, surveillance, and inspection.

(3) Longer Flight Times

Advances in battery technology have led to longer flight times for VTOL UAVs. This is a significant advantage, as longer flight times allow for more data to be collected and analyzed, and enable UAVs to cover larger areas.

(4) Autonomy

There is a growing trend towards developing autonomous VTOL UAVs, which are capable of operating without human intervention. These UAVs can be programmed to perform specific tasks, such as aerial mapping or inspection, and can operate safely and efficiently in a variety of environments.

(5) Hybrid Designs

There is increasing interest in developing hybrid VTOL UAVs, which combine the advantages of fixed-wing and rotorcraft UAVs. These hybrid UAVs are capable of VTOL, but can also fly horizontally like a fixed-wing aircraft, allowing them to cover greater distances and operate in a wider range of environments.

The comprehensive development process of the VTOL UAV is depicted in Fig. 1 [6].

Fig. 2 illustrates a body frame design layout of the VTOL UAVs in this research at RDC-UAVs.

The current global threat posed by climate change has raised concerns about the sustainability of various land surface systems, including agriculture and forestry [8]. In this context, remote sensing plays a critical role in monitoring these resources to develop effective agroforestry systems. Traditional remote sensing technologies, including satellite and manned aircraft platforms, have seen significant improvements in terms of their spatial, spectral, and temporal resolutions [9]. However, the advantages offered by UAVs, such as

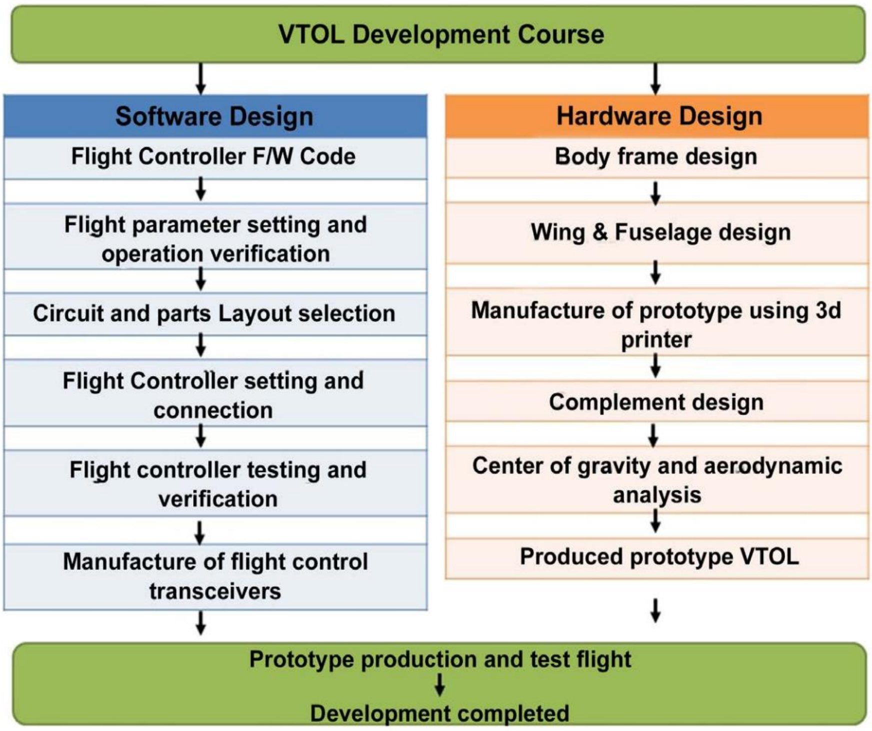

Fig. 1 Development process of the VTOL UAV [6].

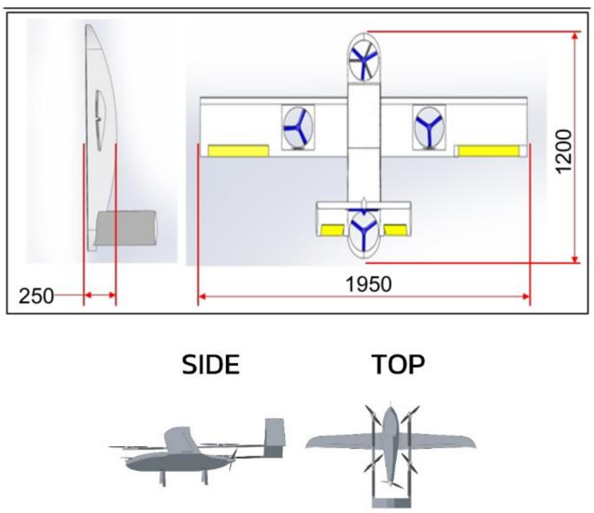

Fig. 2 Body frame design layout of the VTOL UAVs.

their high spatial and temporal resolutions, flexibility, and lower operational costs, make them a viable alternative to traditional remote sensing platforms. Moreover, UAVs can plan data acquisition campaigns, avoid unfavorable weather conditions, and provide data available on demand. Furthermore, UAVs can be used in real-time operations, further enhancing their utility in forest management [5].

This paper focuses specifically on some of the potential and novel applications of VTOL UAV-based remote sensing in forest monitoring and management. It should be noted that the design and building of the VTOL UAV for this mission is not the focus of this paper. However, we acknowledge that other mature or long-standing applications, such as precision agriculture, coastal and polar monitoring, disaster and emergency monitoring, and atmospheric monitoring, exist but are not addressed in this paper. The paper is structured into several sections including an Introduction, which provides an overview of the research topic and objectives. The subsequent section discusses the UAV and its application in resource and environmental missions, followed by a Case Study that presents aerial photography of the areas at risk of deforestation and forest encroachment in Khao Yai National Park, while the Recommendations section offers potential solutions for forest management. Lastly, the Conclusion summarizes the findings and highlights the significance of the study.

UAVs equipped with high-resolution cameras or multispectral sensors can capture detailed aerial imagery of forests. This imagery can provide valuable information about tree health, species composition, forest density, and overall forest structure. It can help identify areas of concern, such as diseased or stressed trees, invasive species encroachment, or signs of insect infestations. Forest management is an area where remote sensing technologies are being developed and optimized, and their relevance for decision support is becoming increasingly crucial for forestry managers, policymakers, and researchers. Remote sensing technology provides data at different resolutions, including space, spectral band, and time, which enables forest modeling under different conditions and for various management purposes, such as economics, monitoring, conservation, and restoration. Compared to traditional field-based inventories, remote sensing platforms offer the advantage of providing full coverage of forest areas, which provides data on many primary forestry parameters. This full coverage is often guaranteed by remote sensing platforms, unlike traditional field-based inventories [10]. Remote sensing platforms have shown their potential to provide reliable and accurate data for forest management. However, there is still a need for full optimization of remote sensing platforms, especially in forest management applications. The optimization of remote sensing technology in forestry can enhance the accuracy and precision of forest models, leading to better management decisions and outcomes.

Remote sensing applications have shown great potential in forestry management. However, the requirements for high temporal resolution in remote sensing applications for forestry present a challenge [11]. The traditional airborne and spaceborne remote sensing platforms provide spatial and temporal resolutions that are usually not appropriate for achieving regional or local forestry objectives. Although aircraft platforms offer more appropriate spatial scales, regular time-series monitoring can be costly [12]. Additionally, remote sensing data acquired from manned aircraft and satellite platforms are vulnerable to information loss and degradation caused by cloudy sky conditions that attenuate electromagnetic waves [13].

UAVs are suitable for real-time applications, and their flexibility of use and increasing applicability have created many opportunities for practical forestry, facilitating and improving field data collection in terms of temporal and spatial accuracy [14]. UAVs have emerged as a promising technological tool for precision forestry applications due to their high spatial resolution, quick turnaround times, and lower operational costs [15]. Recent advancements in UAV technology, along with computer vision and related research topics, have provided many opportunities for practical forestry by enhancing field data collection in terms of temporal and spatial accuracy.

The workflow of UAV-based remote sensing involves several stages [16]. First, suitable UAV platforms and remote-sensing sensors are selected according to the remote-sensing tasks. It is essential to calibrate all the hardware, including cameras and multi-sensor combinations, to determine the spatial relationship of different sensors and remove geometric distortions caused by cameras. Next, mission planning is designed based on the topography, weather, and lighting conditions in the study areas. Flight parameters, such as flight path, flying altitude, image waypoints, flight speed, camera length, and exposure time, are carefully designed to ensure data overlaps, full coverage, and data quality. Subsequently, remote-sensing data are collected autonomously based on flight planning, or by the flexible control of the ground pilot. Data are checked and supplementary photographs are taken if necessary. After data acquisition, a series of methods are employed for data processing and analysis.

The general workflow for data processing is presented in the following steps [14, 16]:

(1) Data pre-processing

Images captured by UAV platforms typically require pre-processing to ensure their usefulness for further processing. This involves tasks such as camera distortion correction, image color adjustment, noise elimination, vignetting, and blur removal.

(2) Aerial Triangulation (or Structure from Motion)

This process aims to recover the camera pose (position and orientation) for each image and 3D structures (i.e., sparse point clouds) from image sequences. GPS and inertial measurement unit data are often used to initialize the position and orientation of each image, and camera poses can be estimated using image matching. Tie-points are generated, and connection relationships among images are built. Bundle adjustment is then used to optimize the camera positions and orientations and derive 3D structures.

(3) DSM Generation and 3D Reconstruction

Oriented images are used to derive dense point clouds (or DSM) using dense image matching. DSM provides a detailed representation of the terrain surface, which, combined with surface reconstruction and texture mapping, can lead to a well-reconstructed 3D model of the scene.

(4) DEM (Digital Elevation Model) and Orthophoto Generation

A DEM can describe the surface topography without the effects of raised objects, such as trees and buildings. It can be generated from either sparse or dense point clouds. Each image is then orthorectified to eliminate geometric distortion and mosaicked into a seamless orthorectified mosaic at the desired resolution.

(5) Image Interpretation and Application

Based on orthophotos and 3D models, image interpretation is performed to achieve scene understanding, including image/scene classification, object extraction, and change detection. The interpretation results can then be applied to various applications, such as thematic mapping, precision agriculture, and disaster monitoring.

Optical remote sensing devices capture images of the Earth's surface in visible and near-infrared wavelengths. There are various types of optical sensors, including multispectral sensors and hyperspectral sensors. Multispectral sensors capture images in several specific bands, typically ranging from visible to near-infrared. Hyperspectral sensors capture images in many narrow spectral bands, allowing for more detailed information about the Earth's surface. Thermal remote sensing devices, on the other hand, detect the temperature of the Earth's surface. Thermal sensors can be used to detect heat sources, such as forest fires, and can also be used to monitor soil moisture levels and other environmental factors [14].

Remote sensing technology can be used in UAVs with a broad range of sensors and tools: high-resolution digital cameras, infrared/thermal cameras, multi-spectral cameras (passive sensors), LiDAR Laser Imaging Detection and Ranging (active sensors). The possibility of equipping UAVs with a wide choice of sensors in association with georeferencing systems has supported forestry scientific research by monitoring anomalies and trends which, if observed by traditional means from the ground, could have been manifested in a less obvious way. Thermal sensors are used effectively to detect water stress and in forest fire monitoring and wildlife detection while multispectral sensors can be applied for determining burned areas in a post-fire scenario. LiDAR sensors can provide accurate measurements targeting land objects for an effective forest inventory. LiDAR is a powerful tool for the direct 3D measurement of various tree attributes, even at a fine-grained scale. It can be used for individual tree detection and crown delineation, for retrieving inventory parameters such as diameter, height, and biomass, and for predicting carbon dynamics [14, 17].

In this research, there are various types of sensors that can be mounted on VTOL UAVs, including visible light cameras, multispectral cameras, and thermal cameras. In addition to these sensors, LiDAR technology can also be used to collect detailed 3D information about the Earth's surface. LiDAR works by emitting laser pulses and measuring the time it takes for the pulses to bounce back, allowing for precise measurements of the distance between the sensor and the Earth's surface. Once the remote sensing data have been collected, it must be processed and analyzed. This can involve several steps, including preprocessing to correct atmospheric and sensor noise, image enhancement to improve the quality of the images, and image classification to identify different types of land cover.

4. A Case Study of the Areas at Risk of Deforestation and Forest Encroachment in Khao Yai National Park

Forests play a significant role in mitigating climate change by acting as carbon sinks. They absorb carbon dioxide from the atmosphere through photosynthesis, storing carbon in their biomass and soils. Deforestation and forest encroachment release large amounts of carbon into the atmosphere, exacerbating climate change. Analyzing areas at risk helps prioritize forest protection and sustainable land use practices, which contribute to carbon sequestration and climate change mitigation. Analyzing the risk of deforestation and forest encroachment supports effective land-use planning. It aids in identifying areas suitable for agriculture, infrastructure development, and urban expansion while minimizing the impact on forests. By integrating the analysis into land-use decision-making processes, governments and land managers can promote sustainable development practices and avoid irreversible loss of forest cover.

Our RCD-UAVs of UAVs have chosen to conduct a case study on the area at risk of deforestation and forest encroachment in Khao Yai National Park in Thailand utilizing VTOL UAVs with remote sensing capabilities for several reasons. Firstly, Khao Yai National Park is a crucial area for biodiversity conservation, and it is one of the most significant protected areas in Southeast Asia. It is home to several endangered species and is part of a UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage site, making it an important site for conservation efforts [18]. Secondly, the rate of deforestation in Thailand has been alarming in recent years, with significant areas of forest land being cleared for agricultural purposes and urbanization. The Thai government has recognized the importance of forest conservation and has implemented several policies and initiatives to address this issue [19]. The case study on the areas at risk of deforestation and forest encroachment in Khao Yai National Park provides valuable insights into the effectiveness of these policies and highlights the areas that require attention and action. Lastly, our research center has expertise in developing and utilizing UAV technology for environmental monitoring, making this study a natural fit for our research objectives. Through this case study, we aim to contribute to the advancement of remote sensing techniques for forest management and support evidence-based decision-making to facilitate sustainable resource management practices.

After analyzing physical factors and aerial photography from our UAVs remote sensing technology that affect the risk of deforestation in Khao Yai National Park and its surrounding areas, six key factors were identified: (1) slope, (2) distance from rivers, (3) distance from transportation routes, (4) distance from communities, (5) distance from agricultural areas, and (6) elevation above sea level. Scores were assigned to each factor by dividing them into classes, as shown in Fig. 3. The color-coding system uses dark green, light green, yellow, and red to indicate the levels of low, moderate, high, and very high in each factor.

The areas at risk of deforestation and forest encroachment were then mapped, as illustrated in Fig. 4. The figure depicts the areas at risk of deforestation and forest encroachment in the Khao Yai National Park and adjacent areas. The color-coding system uses dark green, light green, yellow, and red to indicate the levels of low, moderate, high, and very high in each factor. The analysis revealed that the majority of the high to medium-risk areas, which constitute 27.82% and 57.52% of the total area, respectively, are concentrated within the Khao Yai National Park and the surrounding area within 1 km. Nearly 80% of the areas at risk of deforestation are in the medium to high-risk category, as shown in Table 1.

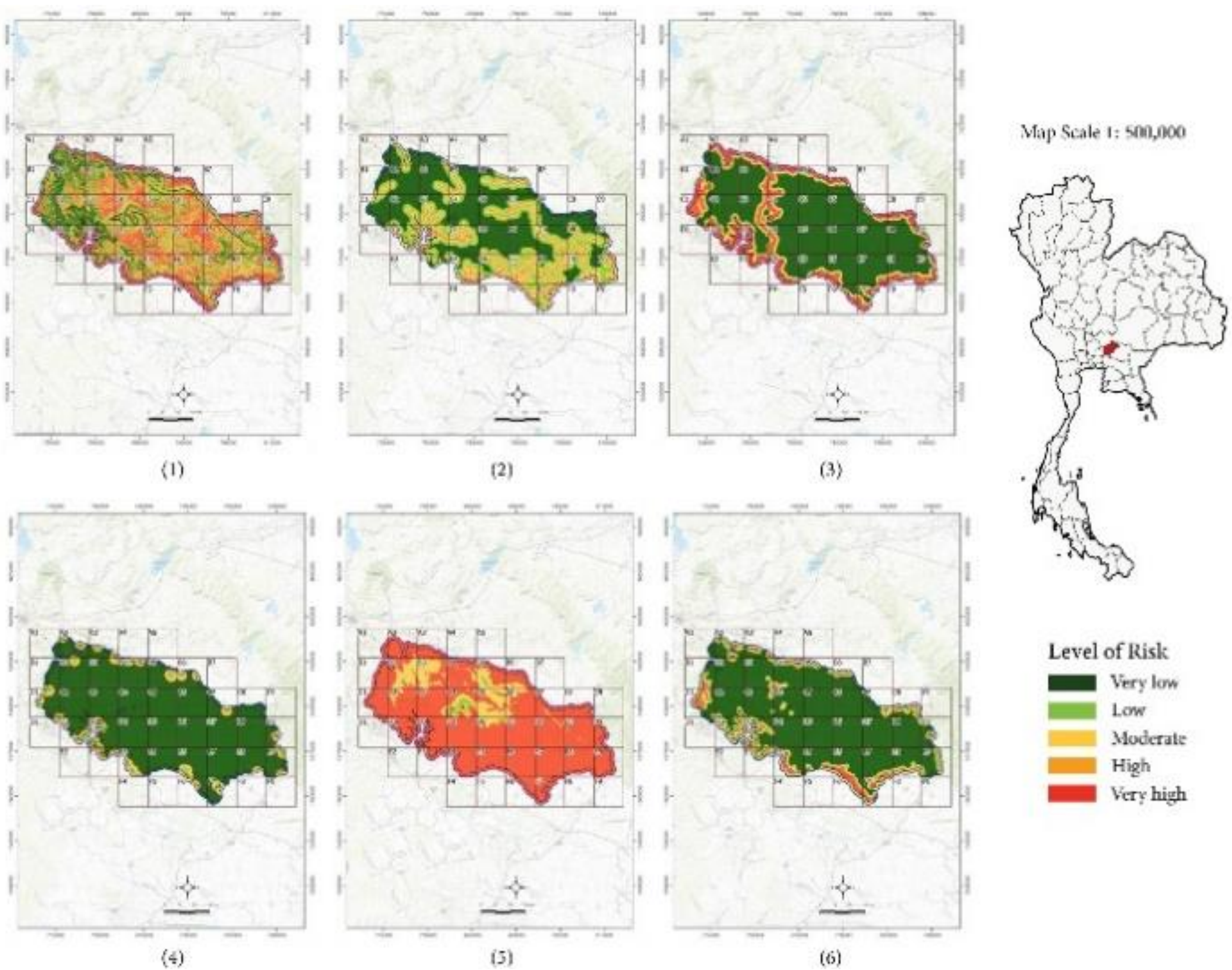

Fig. 3 Factors affecting the risk of forest encroachment in Khao Yai National Park and adjacent areas: (1) slope, (2) distance from rivers, (3) distance from transportation routes, (4) distance from communities, (5) distance from agricultural areas, and (6) elevation above sea level.

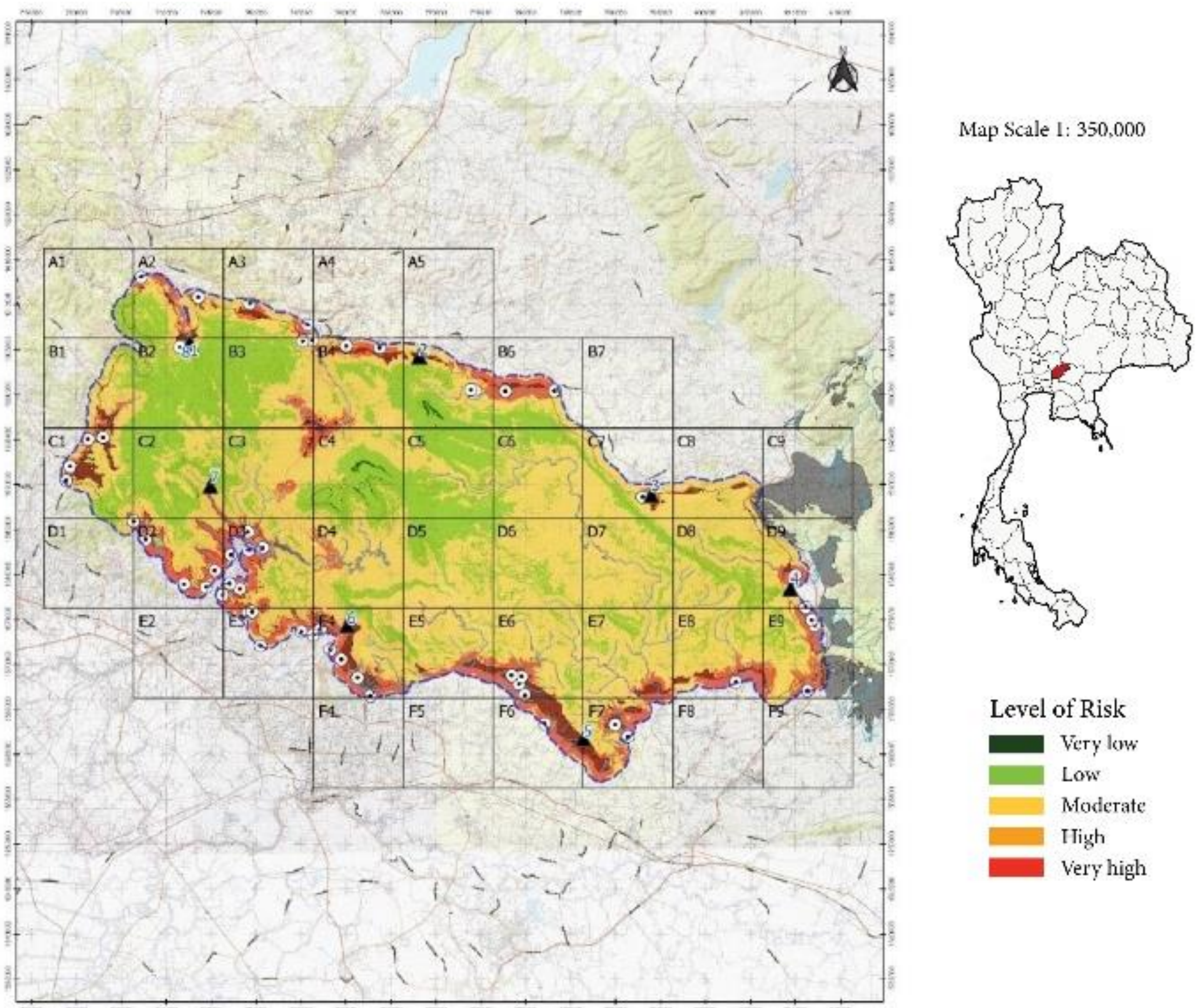

Fig. 4 Illustration of the areas at risk of deforestation and forest encroachment in the Khao Yai National Park and adjacent areas.

Table 1 The areas at risk of forest encroachment in the Khao Yai National Park and adjacent areas.

Risk	Square meter	Percentage (%)
Low	4,336,200.00	0.17
Moderate	707,621,400.00	27.82
High	1,462,915,800.00	57.52
Very high	368,369,100.00	14.48
Total	2,543,242,500.00	100.00

5. Recommendations

The significance of Khao Yai National Park as a biodiversity hotspot and protected area, coupled with the alarming rate of deforestation in Thailand, makes this study particularly important. The research center's expertise in UAV technology for environmental monitoring further strengthens the suitability of this study for their research objectives. The analysis reveals that a significant portion of the high to medium-risk areas (27.82% and 57.52% of the total area, respectively) are concentrated within Khao Yai National Park and its immediate surroundings within 1 km. Additionally, it highlights that approximately 80% of the areas at risk of deforestation fall within the medium to high-risk categories.

Recommendations for VTOL UAVs remote sensing development and mitigating the risk of deforestation and forest encroachment in Khao Yai National Park are:

(1) Continued use of VTOL UAVs for forest monitoring

The successful utilization of VTOL UAVs for resource and environmental missions, including forest monitoring, should be continued and expanded. These UAVs offer advantages such as quick and efficient surveys of large areas, inventory of tree species, and monitoring of forest health. The VTOL capability allows them to take off and land vertically, enabling operation in challenging terrain.

(2) Enhancing remote sensing capabilities

The remote sensing technology employed in the VTOL UAVs should be improved to gather high-quality and detailed data. This could include using advanced sensors such as LiDAR (Light Detection and Ranging) to obtain three-dimensional information about the forest structure and vegetation density. Combining different remote sensing techniques, such as multispectral and thermal imaging, can provide a comprehensive view of the forest's health and changes.

(3) Data collection and processing

Efficient workflows should be developed for data collection and processing to ensure timely analysis and delivery of information. This could involve automating image processing algorithms to detect changes in vegetation cover, deforestation hotspots, and encroachment patterns. Machine learning techniques can be utilized for accurate classification and interpretation of remote sensing data.

(4) Integrated monitoring system

The VTOL UAVs should be integrated into a broader monitoring system that includes ground-based observations and satellite imagery. Combining data from multiple sources can provide a more comprehensive understanding of the deforestation and encroachment dynamics, allowing for more informed decision-making.

(5) Collaboration and stakeholder engagement

Collaboration should be fostered between the research center, government agencies, local communities, and conservation organizations. Stakeholders should be engaged in the monitoring process, knowledge-sharing be encouraged, and local communities be involved in forest conservation efforts. This collaborative approach can lead to more effective strategies for mitigating deforestation and encroachment.

(6) Policy support and enforcement

Strong policies and regulations should be advocated to protect Khao Yai National Park and its surroundings. It should be ensured that laws against illegal logging, encroachment, and habitat destruction are enforced effectively. Initiatives should be supported for sustainable land-use practices, reforestation, and alternative livelihoods for local communities to reduce pressure on the forest resources.

(7) Public awareness and education

Public awareness should be raised about the importance of Khao Yai National Park's biodiversity and the consequences of deforestation. educational Campaigns should be conducted to promote responsible forest management and public participation be encouraged in conservation efforts. A sense of stewardship should be fostered among the local communities and visitors.

By employing these technical approaches and implementing comprehensive mitigation strategies, there is a greater likelihood of successfully addressing the risk of deforestation and forest encroachment in Khao Yai National Park, thereby protecting its unique biodiversity and contributing to sustainable forest management practices.

6. Conclusion

This research conducted on the areas at risk of deforestation and forest encroachment in Khao Yai National Park has provided valuable insights into the drivers and extent of deforestation in this crucial biodiversity hotspot. The utilization of VTOL UAVs with remote sensing capabilities, combined with the expertise of the research center, has enabled a comprehensive analysis of the risk factors and mapping of at-risk areas. The findings highlight the urgent need for action to address the high to medium-risk areas concentrated within the national park and its immediate surroundings. Strengthening monitoring and surveillance efforts using UAV technology is essential for tracking changes in risk levels and implementing timely intervention measures. A review of existing policies and their enforcement is necessary to identify strengths and weaknesses and refine them accordingly. Enforcing regulations and penalties against illegal deforestation and encroachment will play a crucial role in deterring such activities. Promoting sustainable land use planning, particularly in agricultural areas near the at-risk zones, is of paramount importance. Encouraging responsible agricultural practices, such as agroforestry and precision farming techniques, can alleviate pressure on forests while supporting local livelihoods. Furthermore, investing in capacity-building programs and knowledge-sharing initiatives will empower local communities with the necessary skills and understanding of sustainable resource management practices. By implementing these technical and policy recommendations, there is a greater likelihood of effectively addressing the risk of deforestation and forest encroachment in Khao Yai National Park and its surrounding areas. The sustainable management of this vital ecosystem will contribute not only to the preservation of biodiversity but also to the long-term well-being of local communities and the broader goal of global environmental sustainability.

Acknowledgements

The authors gratefully acknowledge the support and funding provided by the Thai government and the International Aviation Academy and Industry, KMITL (King Mongkut's Institute of Technology Ladkrabang), Thailand. Their financial assistance has been instrumental in the successful execution of this research project. Additionally, we express our sincere gratitude to the aforementioned institutions for providing valuable resources, facilities, and access to relevant information, which greatly contributed to the overall quality and comprehensiveness of this study. Without their support, this research would not have been possible.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Johnston, D. W. 2019. "Unoccupied Aircraft Systems in Marine Science and Conservation." *Annual Review of Marine Science* 11 (1): 439-63. doi: 10.1146/annurev-marine-010318-095323.

[2] Panagiotidis, D., Abdollahnejad, A., Surový, P., and Chiteculo, V. 2017. "Determining Tree Height and Crown Diameter from High-Resolution UAV Imagery." *International Journal of Remote Sensing* 38: 2392-410.

[3] Cho, A., Yoo, C., Kang, Y., and Park, B. 2014. "Heave Motion Estimation of a Ship Deck for Shipboard Landing

of a VTOL UAV." *Journal of the SOCIETY FOR Aerospace System Engineering* 8: 14-9.

[4] Kim, J., Lee, K., Wang, H., An, J., Park, S., Lee, S., Kim, M., and Han, Y. 2013. *Pre-Concept Design Study of VTOL UAV*. Sejon: Sejon University.

[5] Guimarães, N., Pádua, L., Marques, P., Silva, N., Peres, E., and Sousa, J. J. 2020. "Forestry Remote Sensing from Unmanned Aerial Vehicles: A Review Focusing on the Data, Processing and Potentialities." *Remote Sensing* 12 (6): 1046. doi: 10.3390/rs12061046.

[6] Jo, D., and Kwon, Y. 2019. "Development of Autonomous VTOL UAV for Wide Area Surveillance." *World Journal of Engineering and Technology* 7: 227-39. https://doi.org/10.4236/wjet.2019.71015.

[7] Yu, S., Heo, J., Jeong, S., and Kwon, Y. 2016. "Technical Analysis of VTOL UAV." *Journal of Computer and Communications* 4: 92-7. http://dx.doi.org/10.4236/jcc.2016.415008.

[8] Zhu, Y., Jeon, S., Sung, H., Kim, Y., Park, C., Cha, S., Jo, H.-W., and Lee, W.-K. 2020. "Developing UAV-Based Forest Spatial Information and Evaluation Technology for Efficient Forest Management." *Sustainability* 12 (23): 10150. https://doi.org/10.3390/su122310150.

[9] Banu, T. P., Borlea, G. F., and Banu, C. 2016. "The Use of Drones in Forestry." *Journal of Environmental Science and Engineering B* 5: 557-62. doi: 10.17265/2162-5263/2016.11.007.

[10] Gómez, C., Alejandro, P., Hermosilla, T., Montes, F., Pascual, C., Ruiz, L. Á., Álvarez-Taboada, F., Tanase, M. A., and Valbuena, R. 2019. "Remote Sensing for the Spanish Forests in the 21st Century: A Review of Advances, Needs, and Opportunities." *For. Syst.* 28: 1-33.

[11] Raparelli, E., and Bajocco, S. 2019. "A Bibliometric Analysis on the Use of Unmanned Aerial Vehicles in Agricultural and Forestry Studies." *Int. J. Remote Sens.* 40: 9070-83.

[12] R. Dunford, K. Michel, M. Gagnage, and H. Piégay. 2009 "Potential and Constraints of Unmanned Aerial Vehicle Technology for the Characterization of Mediterranean Riparian Forest." *Int. J. Remote Sens.*, vol. 30, 2009. https://www.tandfonline.com/doi/full/10.1080/01431160903023025.

[13] Xiang, T. Z., Xia, G. S., and Zhang, L. 2019. "Mini-Unmanned Aerial Vehicle-Based Remote Sensing: Techniques, Applications, and Prospects." *IEEE Geosci. Remote Sens. Mag.* 7: 29-63.

[14] Dainelli, R., Toscano, P., Di Gennaro, S. F., and Matese, A. 2021. "Recent Advances in Unmanned Aerial Vehicle Forest Remote Sensing—A Systematic Review. Part I: A General Framework." *Forests* 12 (3): 327. doi: 10.3390/f12030327.

[15] Chianucci, F., Disperati, L., Guzzi, D., Bianchini, D., Nardino, V., Lastri, C., Rindinella, A., and Corona, P. 2016. "Estimation of Canopy Attributes in Beech Forests Using True Colour Digital Images from a Small Fixed-Wing UAV." *Int. J. Appl. Earth Obs. Geoinf.* 47: 60-8. doi: 10.1016/j.jag.2015.11.007.

[16] Guan, S., Zhu, Z., Wang, G. 2022. "A Review on UAV-Based Remote Sensing Technologies for Construction and Civil Applications." *Drones*, vol. 6, no. 5, p. 117, 2022. https://doi.org/10.3390/drones6050117.

[17] Goodbody, T. R. H., Coops, N. C., and White, J. C. 2019. "Digital Aerial Photogrammetry for Updating Area-Based Forest Inventories: A Review of Opportunities, Challenges, and Future Directions." *Curr. For. Rep.* 5: 55-75. https://link.springer.com/article/10.1007/s40725-019-00087-2.

[18] Kosola, O., and Amornsiriphong, S. 2019. "Public Policy Formation for Tourism in a Natural World Heritage Site with Community Network Participation: A Case Study of Khao Yai National Park, Thailand." *International Journal of Innovation, Creativity and Change* 7 (1): 263.

[19] Trisurat, Y., Shirakawa, H., and Johnston, J. M. 2019. "Land-Use/Land-Cover Change from Socio-Economic Drivers and Their Impact on Biodiversity in Nan Province, Thailand." *Sustainability* 11 (3): 649. doi: 10.3390/su11030649.