INTERNATIONAL COOPERATION AND PARTNERSHIP IN UTILISING REMOTE SENSING TECHNIQUES FOR ENHANCED ASSESSMENT OF FOREST RESOURCES AND ECOSYSTEM HEALTH

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Abstract. Forests play a definite role as substantial carbon sinks. Tropical deforestation, particularly in regions like Sabah, poses a significant global threat with substantial environmental and socio-economic impacts. While approximately 63% of Sabah's land mass is still forested, assessing and monitoring such a vast area is deemed to be spatially challenging. This research introduces an innovative approach to enhance forest resources and ecosystem health assessments through advanced remote sensing techniques. Leveraging technologies such as UAVs, LiDAR, multi-spectral imaging, and geospatial analyses, we aim to improve current evaluation methods for forest resources and key ecosystem health indicators. Furthermore, this research explores the crucial role of international cooperation in strengthening forest management by facilitating expertise and data sharing among stakeholders. Specifically, collaborations with WWF and ANRICA within the Tabin Landscape demonstrated the potential of integrating local knowledge and on-the-ground efforts with advanced remote sensing technologies for improved forest resource assessment. This paper demonstrates the importance of leveraging remote sensing technologies with international collaboration and partnership as a way forward in better assessment of forest resources and ecosystem health while promoting sustainable forest management.

Keywords: *Remote sensing, ecosystem health, forest resource assessment*

1.0 INTRODUCTION

Forests are not only a significant carbon sink, but they also provide crucial habitats for a wide range of flora and fauna species, regulate local and regional climate, and support the livelihoods of humankind worldwide. The forests of Sabah have undergone significant changes in land use and management over the past few decades (Reynolds et al., 2011). From 1990 to 2015, the forests, particularly the concession logging areas, experienced continuous industrial harvesting, including premature re-logging of previously logged areas and large-scale conversion of natural forests to other land uses such as agricultural plantations. This phenomenon has led to widespread deforestation and concerns over the sustainability of forest management practices. However, assessing forest resources and ecosystem health has become increasingly important, particularly in global environmental challenges such as climate change and biodiversity loss.

Moreover, sustainable management of forest resources is essential for maintaining the long-term economic and social well-being of communities that rely on them. The increasing demand for timber and agricultural land has also put immense pressure on Sabah's forests, leading to unsustainable practices threatening the ecosystem's delicate balance. Urgent action is needed to address these challenges and ensure the long-term sustainability of Sabah's forest resources, vital for the region's ecological, economic, and social well-being. To complement such an approach, international cooperation is essential to effectively utilise an innovative approach for Sabah's forest resources management and ecosystem health monitoring.

Collaborations between countries, research institutions, and conservation organisations can facilitate data sharing, expertise, and best practices, ensuring that the latest advancements in remote sensing technology are leveraged to their full potential. Through data sharing, joint research initiatives, and capacity-building programs, global stakeholders can leverage their collective expertise to advance the field of remote sensing applications in forest management (Mo et al., 2023) (Xu et al., 2021) (Khan et al., 2020) (Jackson & Adam, 2020). Such collaborative efforts can also lead to standardised protocols, harmonised data collection, and the development of open-access platforms for knowledge exchange. By fostering international cooperation, the assessment of

forest timber and ecosystem health through remote sensing can be enhanced, ultimately contributing to the sustainable stewardship of these invaluable natural resources.

Recognising the potential of remote sensing applications in forest resources assessment, the Forest Research Centre, through the Sabah Forestry Department, has actively integrated remote sensing into the forest assessment and monitoring programme. Leveraging open-sourced satellite imagery and spaceborne LiDAR, remote assessment has become more accessible and provides broader applications for researchers. Furthermore, LiDAR (Light Detection and Ranging) technology using UAV lidar has been incrementally integrated into the assessments as well. This programme includes biomass and carbon estimation, land use land cover mapping, forest cover change, and forest health monitoring.

Other than that, the airborne LiDAR system uses laser pulses to measure distances to the Earth's surface, capturing detailed information about vegetation canopies and topography within the area of interest. The Nomad aircraft, on which the ADAM system is mounted, allows for efficient and comprehensive data collection over large forested areas, leaving every part of the landscape to be explored. Simultaneously, ground-based measurements are taken from permanent sample plots within the landscape areas to validate LiDAR data. These measurements typically include tree height, diameter at breast height (DBH), and species identification, which are essential for relating LiDAR metrics to actual biomass and carbon estimates.

For the biomass estimation models, LiDAR-derived metrics, such as canopy height and volume were used to develop statistical models that estimate forest biomass and carbon stocks. This process involves collecting significant LiDAR data and ground-based biomass measurements. The data is then used to train the statistical models, such as regression models, which can correlate LiDAR data with ground-based biomass measurements to enable extrapolation across broader areas (Zhao et al., 2015). In addition to LiDAR, the project integrates data from other remote sensing sources (like Sentinel and Landsat 8/9) for wall-to-wall mapping to enhance the spatial context and temporal analysis of forest carbon assessments.

2.0 SFD COMMITMENT TOWARDS ENHANCED REMOTE SENSING TECHNOLOGIES IN FOREST MANAGEMENT, PROTECTION AND CONSERVATION

This section will further discuss the key policies and principles for adopting remote sensing technologies, the innovative approach to enhancing forest resources and ecosystem health assessments through advanced remote sensing techniques, improvements made to current evaluation methods for forest resources and key ecosystem health indicators, and the importance of leveraging remote sensing technologies with international collaboration and partnership to assess forest resources and ecosystem health better while promoting sustainable forest management.

2.1 Promotion of Sustainable Forest Management

The Sabah Forestry Department promotes the sustainable use and management of forest resources. By adopting remote sensing technologies, the department can monitor forest health, assess biodiversity, and evaluate the impacts of human activities more effectively. The data collected from remote sensing enables informed decision-making that balances environmental conservation with economic development. The policy framework aligns with international initiatives such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation), promoting carbon accounting and sustainable forest management. Remote sensing is vital in measuring forest carbon stocks, monitoring deforestation, and ensuring compliance with REDD+ commitments.

2.2 Capacity Building and Research Collaboration

The Sabah Forestry Department is committed to effectively building local capacity to use remote sensing technologies. This includes specialised training programs for staff and collaboration with academic institutions and research organisations to foster knowledge exchange and technical skills. The department's commitment to capacity building and research collaboration is valuable in promoting the use of remote sensing technologies in forest assessments. These partnerships not only enhance the development of methodologies tailored to local ecosystems but also allow for the application of modern

technology in forest assessments, thereby improving the accuracy and efficiency of forest management and conservation efforts.

2.3 Data Integration and Management

The department seeks to establish centralised databases integrating remote sensing data with other relevant datasets (e.g., ground-truth measurements and ecological surveys). This integration enhances the department's ability to analyse forest dynamics, track changes over time, and make data-driven management decisions. Policies will likely be established to promote data sharing among government agencies, NGOs, and research institutions. Ensuring stakeholders have access to accurate and timely remote sensing data fosters collaborative efforts for forest conservation and management, providing a sense of security about the comprehensive analysis of forest dynamics. The department's commitment to data sharing reflects its dedication to transparency and collaboration in its forest management and conservation efforts.

2.4 Monitoring and Evaluation

The Sabah Forestry Department emphasises the need for continuous monitoring of forest resources, a task facilitated by technology such as SAR's all-weather, day-and-night imaging capabilities. Implementing methodologies for periodic evaluations enables the department to assess the effectiveness of management strategies and adapt them as needed based on real-time data. Furthermore, SAR facilitates the development of key performance indicators (KPIs) that reflect the health of ecosystems over time. By establishing metrics derived from SAR data, the department can track forest cover changes, biodiversity health, and the impacts of human activities, providing a reliable basis for decision-making.

2.5 Environmental Conservation and Biodiversity Protection

Policies encourage using remote sensing to support ecosystem-based management approaches. The department can take better-informed conservation actions and protect critical habitats by mapping and assessing ecosystem services with remote sensing data. Remote sensing technologies allow timely identification of threats such as illegal logging, land encroachment, and natural disasters. The department can respond more effectively by employing automated change detection algorithms on remote sensing imagery, ensuring comprehensive ecosystem coverage.

3.0 EXPERIENCES WITH INTERNATIONAL ENGAGEMENT IN REMOTE SENSING TECHNOLOGIES

The collaboration between the Sabah Forestry Department, WWF Malaysia and ANRICA (Asia Network for Remote Sensing, Information, and Communication Technologies for Agriculture) has made significant strides in enhancing forest carbon assessments for selected forest landscapes in Sabah. This region is renowned for its rich biodiversity and extensive forest resources, which are critical in global carbon dynamics. Integrating LiDAR technologies into forest carbon assessments provides a precise method for estimating biomass and carbon stocks, contributing to an enhanced approach towards better sustainable forest management and climate change mitigation efforts. The primary objectives of the collaboration assessment included:

3.1 Accurate Carbon Stock Estimation

Quantifying the amount of carbon stored in Sabah's forests is essential for reporting to international frameworks such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation).

3.2 Supporting Conservation Strategies

To provide scientific evidence to inform conservation policies and practices, protecting valuable forest ecosystems.

3.3 Capacity Building

Enhancing local capacity to utilise advanced remote sensing technologies will foster sustainable forest management practices and enable stakeholders to make data-driven decisions.

4.0 OUTCOMES AND IMPACTS

The outcomes and impacts of the international cooperation and partnership in utilising remote sensing techniques for enhanced assessment of forest resources and ecosystem health are as listed below:

4.1 Improved Carbon Inventory Data

The project has generated carbon LiDAR-inventory data that reflects the unique forest types in the Tabin Landscape. This data potentially supports policy decisions and international reporting on carbon emissions and sequestration (Gonzalez et al., 2016). It can also be used as a model for similar biomass and carbon stock assessments in other landscape areas in Sabah.

4.2 Practical Implications of Enhanced Forest Management Practices

The project lays the groundwork for improved forest management practices, including selective logging, reforestation efforts, and protecting high-carbon stock areas by accurately assessing carbon stocks. For instance, accurate carbon stock estimates can guide the department in identifying areas for reforestation or protection, thereby promoting biodiversity conservation and enhancing ecosystem resilience within the landscape.

4.3 Capacity Building Initiatives

The project has included training sessions and field assessments for the Forest Research Centre and Sabah Forestry Department personnel. This capacity-building component exposes the skills necessary to use LiDAR technology owned by ANRICA and the mapping activity procedures deployed during the assessment.

4.4 Contribution to Climate Change Goals

The data generated through this project aids Sabah in contributing to national and global future climate targets. By accurately measuring and reporting forest carbon stocks, Sabah can demonstrate its commitment to addressing climate change impacts under international agreements such as the Paris Agreement. This helps Sabah meet its climate change goals and contributes to the global efforts to mitigate climate change.

5.0 CHALLENGES AND LIMITATIONS

While the Sabah Forestry Department and WWF Project with ANRICA have been considered successful, several challenges remain. Integrating LiDAR data requires technical expertise in processing and analysing large datasets. Continuous training and capacity-building efforts are necessary to keep local teams adept at using these sophisticated technologies. Sustaining long-term monitoring initiatives can be costly. This project must secure ongoing funding to maintain LiDAR acquisition and analysis in the future, and ensuring ongoing engagement and support from local communities is vital. The project must address the concerns and ensure local populations feel empowered by the data generated.

Such engagement with the international agency and support from local stakeholders exemplify the practical application of LiDAR technologies to be exported locally for forest carbon assessment. The project enhances carbon inventory data by integrating cutting-edge remote sensing technology with ground-based validation and community engagement. It contributes to sustainable forest management and climate change mitigation strategies. This initial and kick-start assessment and partnership serves as a model for other regions seeking to leverage advanced technologies in addressing global environmental challenges, ultimately promoting the health and resilience of forest ecosystems and their functions remain in place.

6.0 GENERAL CONSIDERATION OF BEST PRACTICES AND RECOMMENDATIONS

International cooperation in utilising remote sensing for forest assessment is essential for effective monitoring, sustainable management, and conservation of forest ecosystems. However, achieving successful collaboration across diverse stakeholders internationally and locally requires implementing best practices and recommendations that address the challenges. Below are detailed recommendations to enhance international cooperation in remote sensing for forest assessments.

6.1 Development of Standard Protocols

Establishing transparent and standardised protocols for data acquisition, processing, and analysis is crucial. Stakeholders can improve data consistency and comparability across regions by developing guidelines specifying sensor calibration, data preprocessing methods (e.g., atmospheric correction), and calculating relevant vegetation indices (such as NDVI). A working group involving experts from various fields, including remote sensing, forestry, ecology, and environmental science, should be formed to establish best practice guidelines that reflect the diverse ecological contexts of different regions.

6.2 Implementation of Quality Control Measures

To ensure the reliability of remote sensing data, rigorous quality control procedures should be incorporated. This includes validating satellite-derived measurements with ground-truthing campaigns, where field data is systematically collected and used to calibrate and validate satellite observations. Robust validation techniques, such as cross-validation, where measurements from one area are used to validate predictions in another area, will help improve the accuracy of remote sensing assessments. The remote sensing community should strive to establish and publicly share these validation datasets.

6.3 Creation of Centralized Data Repositories

Develop international centralised data repositories that facilitate access to remote sensing datasets. These repositories should include standardised metadata to ensure users can understand the context, limitations, and potential applications of the data. Initiatives like the Global Open Data for Agriculture and Nutrition (GODAN) can serve as models for establishing similar frameworks for forest and environmental data, ensuring long-term sustainability and access (Roberts, 2021).

6.4 Development of Data Sharing Agreements

Establish formal data-sharing agreements that outline the terms of collaboration among participating organisations, governments, and local communities. Such agreements should specify data ownership, usage rights, and protocols for sharing and citing data. Guidelines should emphasise the fair use of data while fostering an environment of transparency and collaboration. Intellectual property concerns must be addressed to build trust among stakeholders.

6.5 Use of Interoperability Standards

Implement interoperability standards that ensure remote sensing datasets can be utilised across different platforms and tools. Employing formats such as GeoJSON or adopting standards set by the Open Geospatial Consortium (OGC) will facilitate the integration of diverse datasets and streamline efforts across organisations.

7.0 CONCLUSION

To conclude, the following technical input and robust protection and conservation measures should be considered;

1. Establish a regional remote sensing data hub and platform for sharing satellite imagery, LiDAR data, and other geospatial information to support forest monitoring and assessment across international borders.

2. Develop standardised methodologies and protocols for using remote sensing techniques to quantify forest biomass, carbon stocks, and ecosystem services, ensuring comparability and reliability of data across different countries and regions.

3. Implement robust policy frameworks and enforcement mechanisms to protect forests from unsustainable practices, such as illegal logging and land-use conversion, based on the insights of remote sensing-based monitoring.

4. Invest in capacity-building and training programs to equip local stakeholders, including forest managers and communities, with the skills and knowledge to effectively use remote sensing technologies for sustainable forest management.

5. Identify international funding mechanisms and partnerships to support the implementation of these remote sensing-based forest monitoring and conservation initiatives in Sabah and other tropical regions.

6. Collaborate with regional and global organisations, such as the UN Food and Agriculture Organization and the Committee on Earth Observation Satellites, to align forest monitoring efforts and contribute to international reporting frameworks.

7. Multidisciplinary research teams should be able to integrate remote sensing data with field-based forest inventories and ecological assessments to understand forest dynamics and ecosystem health comprehensively.

Implementing these technical and policy-driven measures will allow the international community to leverage the power of remote sensing to enhance the assessment and conservation of Sabah's forests, ensuring their long-term sustainability and the well-being of the communities that depend on them. Holistic approaches that foster international cooperation and partnership will be crucial in addressing the pressing environmental challenges facing the region's forest resources. Strong political support for biodiversity and ecosystem protection is also necessary for the success of such initiatives.

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