学 位 論 文 審 査 の 要 旨

博士（環境科学）　　氏　名　ANAK SUAB Stanley

審査委員　主査　准教授　Ram Avtar
副査　教授　渡邉　悌二
副査　教授　露崎　史朗
副査　講師　Alexius Korom (Universiti Teknologi MARA)

学 位 論 文 題 名

Multi-sensor remote sensing techniques for sustainable management of tropical forest and plantations in Northern Borneo
（ボルネオ島北部の熱帯林とプランテーションの持続可能な管理のためのマルチセンサーリモートセンシング技術）

The tropical forests of Borneo play a crucial role in maintaining biodiversity, mitigating climate change, and supporting local livelihoods. However, deforestation, largely due to past industrial-scale and illegal logging, as well as forest fires, has led to the degradation of these forests. Subsequently, the remaining forests have been converted to oil palm, industrial forest, rubber plantations, and other agricultural uses. Despite these challenges, recent studies indicate a slowing down of deforestation since 2012, attributed to various factors such as low crude oil palm prices, improved fire prevention measures, wetter conditions, and government policies. Oil palm, with its low land footprint and potential for sustainable management over its 25-year productive life cycle, remains a significant contributor to the region's economy.

Industrial Tree Plantations (ITP) have also seen significant progress over three decades in Borneo, providing a consistent supply of timber compared to logging natural forests. However, achieving sustainable management practices for both tropical forests and plantations is imperative for ensuring progressive socio-economic growth in the region. Such management practices align with United Nations Sustainable Development Goals (SDGs) and initiatives like Reduction of Emission from Deforestation and Forest Degradation (REDD+).

To address the challenges facing sustainable forest and plantation management, advanced geospatial and remote sensing technologies offer immense potential. These technologies enable mapping, monitoring, assessment, estimation, planning, and decision support at local scales. Multi-sensor remote sensing techniques, combined with machine learning, have been employed to analyze dynamic changes in land use and land cover (LULC), including forest and plantation conversions.

The year 2010, 2017, 2019 and 2023 LULC maps produced using multi-sensor technique

and machine learning achieved overall accuracies of 81% (2010), 88% (2017), 77% (2019) and 87% (2023) respectively. This research involved detailed LULC change analyses to reveal trends such as forest conversion to oil palm and secondary forest, as well as the conversion of soil clearcut areas and mangroves to other land uses. Field surveys further provide insights into forest status outside plantations, highlighting the potential for carbon sequestration and storage in these forests.

Canopy height estimations using advanced techniques like TDX InSAR acquisitions offer valuable information for sustainable management practices. The study explored the potential of TDX InSAR acquisitions for estimation and mapping of tropical forest and plantation canopy heights in Northern Sabah, Malaysian Borneo. InSAR based coherence data was used and method of (SINC) model and two machine learning (ML) models of Random Forest (RF), and Symbolic Regression (SR) and corresponding LULC also multi-sensor references dataset for the estimations. 70% of the ICESat-2 ATL08 data to train the ML models and the remaining 30% for the validation. The out of bag (OOB) RMSE of the RF and SR models are 5.4 m and 5.96 m respectively. These estimations contribute to understanding forest and plantation growth dynamics, aiding in decision-making processes.

Environmental sustainability assessments, utilizing multi-sensor remote sensing and Multi-Criteria Decision Analysis (MCDA) models, provide insights into the ecological health of different land use categories. Such assessments aid in identifying areas for improvement and mitigation strategies to ensure environmental protection.

Overall, the integration of multi-sensor remote sensing techniques into research methodologies offers valuable insights into the sustainable management of tropical forests and plantations in Borneo and beyond. These findings contribute to ongoing efforts to balance socio-economic development with environmental conservation in the region. This study develops various methods that can be useful to extract biophysical parameters of forest and plantation areas in Northern Borneo using a multi-sensor approach, which can help the plantation industry and policy makers to work towards sustainable plantation and forest management.

The examination committee recognized that this thesis presents important findings to develop various methodologies to process multi-sensor remote sensing data that can be useful for sustainable plantation and forest management in Northern Borneo. This study can be further extended to other study sites. In addition to his excellent academic knowledge and publications, his academic records throughout the Ph. D. course were outstanding. Based on this evidence, the committee concluded that Stanley Anak Suab is eligible for the degree of Doctor of Philosophy in Environmental Science.