Monitoring Biomass of Mangrove Species Using Remote Sensing Data for Implementation of REDD+ Policies in Vietnam

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Abstract

Climate change is one of the main concerns and the biggest challenges for all scientists to deal with. The "reducing emissions from deforestation and forest degradation" (REDD+) activities and "blue carbon" programs under the United Nations Framework Convention on Climate Change (UNFCCC) are expected to offer the reliable methods for monitoring, reporting, and verification (MRV) for providing reference levels (or baselines), and protect biodiversity and ecosystem services. Mangroves play an important role in the global carbon cycle by reducing greenhouse gas (GHG) emissions, and mitigating climate change impacts. However, these forests have been lost worldwide, resulting in the systematic loss in carbon stocks. Additionally, the roles of mangrove forests remain poorly quantitatively characterized as compared to other forest ecosystems, due to the practical difficulties and the cost-effectiveness in measuring and monitoring mangrove forests biomass and their carbon stocks. Without a quantitative method for effectively monitoring the carbon stocks in the mangrove ecosystems, sensible policies and actions for conserving mangroves in the context of climate change can be hard to be made.

This thesis presents a novel technology to retrieve biomass of mangrove species and monitor their changes using optical and SAR remote sensing data combined with different machine learning techniques and to promote the implementation of the REDD+ mechanism and blue carbon projects by introducing the willingness to pay (WTP) concept to mangrove ecosystem services. The present thesis selected Hai Phong City located on the northern coast of Vietnam, where the mangroves are distributed within zones I and II of the four mangrove zones in Vietnam as a case study.

This thesis first determines the relationship between biophysical parameters of specific mangrove species and remote sensing data and then attempt to estimate above-ground biomass (AGB) of these species using multiple linear regression models delivered from dual-polarization HH and HV backscatters of ALOS-2 PALSAR-2 imagery. In the second part, the present thesis investigates the applicability of machine learning techniques and remotely sensed data for estimating AGB and carbon stocks of mangrove species. For the improvement of model performance, this thesis test the usability of selected machine learning techniques with an integration of optical and SAR data for the AGB estimation of mangrove forests. In the last part, the thesis shows a case study at Cat Ba Biosphere Reserve for monitoring mangrove forests change between 2010 and 2015, and attempt to evaluate the economic values of mangrove ecosystem services and the social benefits of mangrove restoration in the context of climate change by estimating WTP using contingent valuation method (CVM).

The results of this research show that a high correlation was observed between the means backscattering coefficients (σ^0) of dominant mangrove species at dual polarizations HH and HV and various biophysical parameters, apart from tree density. The sensitivity of (σ^0) at HV polarization is higher than that of (σ^0) at HH polarization. I investigated the use of machine learning techniques for the estimation of AGB of *Sonneratia caseolaris* in a coastal area of Hai Phong city. The performance of the model was assessed using root-mean-square error (RMSE), mean absolute error (MAE), coefficient of determination (R^2), and leave-one-out cross-validation. The multi-layer perceptron neural networks (MLPNN) model performed well (R^2= 0.776) and outperformed the machine learning techniques. The MLPNN model-estimated AGB ranged between 2.78 and 298.95 Mg ha^{-1} (average 55.8 Mg ha^{-1}), below-ground biomass ranged between 4.06 and 436.47 Mg ha^{-1} (average 81.47 Mg ha^{-1}), and total carbon stock ranged between 3.22 and 345.65 Mg C ha^{-1} (average 64.52 Mg C ha^{-1}). I also investigated the usability of machine learning techniques with an integration of ALOS-2 PALSAR-2 (L-band HH, HV) and Sentinel-2 multispectral data for the estimation of AGB of mangrove plantation at a coastal area of Hai Phong. The Support Vector Regression (SVR) model showed a satisfactory result (R^2 = 0.596) and estimated AGB ranged between 36.22 and 230.14 Mg ha^{-1} (average = 87.67 Mg ha^{-1}). I conclude that ALOS-2 PALSAR-2 data can be accurately used with MLPNN model for estimating mangrove forest biomass and an integration of ALOS-2 PALSAR-2 and Sentinel-2 data can be accurately used with SVR model for estimating the AGB of mangrove plantations in tropical areas. The findings provide useful information and understanding of the spatial distribution of AGB and carbon stocks for different mangrove species.

CVM was employed to estimate household WTP for mangrove restoration, drawing upon data from a survey of 205 respondents in a coastal commune of the biosphere reserve. The results showed that gender, education level, occupation, the participation of respondents in mangrove restoration activities, and the attitude of respondents toward future climate scenarios were significant factors influencing their WTP for a mangrove restoration project. The estimation yielded a mean WTP at 192,780 VND (US$8.64) and 712.3 million VND (US$31,943) as the total annual benefit for the villagers in the study area. The current work can provide significant comment regarding Payment for Ecosystem Services (PES) for developing regional and national blue carbon trading markets. This will support provincial decision making on mangrove conservation and management. The results of this study may promote the implementation of mangrove conservation and restoration strategies in climate change mitigation approaches such as REDD+ and blue carbon programs.

Keywords: *Blue carbon, climate change, contingent valuation method, mangrove species, mangrove restoration, machine learning, ALOS PALSAR, Sentinel-2, REDD+, willingness to pay.*