論文の内容の要旨

論文題目　**Quantitative Models for Supporting Multipurpose Management Planning of Teak Plantations in Java, Indonesia**

（インドネシア・ジャワ島におけるチーク人工林の多目的管理計画策定に関する定量的研究）

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Teak (*Tectona grandis* L.f.), the main plantation species (about 1.1 million ha) in Java, Indonesia, has been managed for over 100 years to produce high-quality timber. The plantations have provided many benefits not only for generating national income, but also for supporting the livelihoods of rural communities living in surrounding forests in Java. The plantations are managed by Perum Perhutani (PP), a state-owned forestry enterprise. Current forest management planning of teak plantations, however, has limitations in supporting sustainable forest management (SFM). It ignores the potential risk of destruction in determining annual allowable cuts, whereas forest destruction seems to be an inevitable problem in teak plantations. In addition, the existing harvest scheduling method only concerns with achieving sustained timber yields, while SFM demands for achieving sustainability of multiple forest benefits. Up to now, however, there is still lack of management planning tools for supporting SFM of teak plantations. This study therefore aimed to develop quantitative models for supporting multipurpose management planning of teak plantations at risk of destruction. The specific objectives of this study were as follows: 1) to propose an alternative method for estimating survival probability and destruction rate of teak plantations, 2) to develop models for estimating stand biomass that can be used to quantify carbon stocks of teak plantations, and 3) to develop alternative harvest scheduling models for optimizing multiple benefits (i.e., timber and carbon sequestration) of teak plantations at risk of destruction.

Chapter 2 introduces the study area, i.e., Kebonharjo forest management unit (FMU), Central Java, which is one of the 57 FMUs managed by PP. Teak is the main plantation species in this FMU, accounting for 71.2% (12,678.8 ha) of the total area (17,801.3 ha). The FMU has a dry season of 5 months (May–September) with annual rainfall of 720–1155 mm, which is a favorable climatic condition for producing high-quality teak timber. The plantations are managed under a clear-cutting with artificial regeneration system. The current age-class structure of teak plantations in this FMU is imbalance in which 80.7% of the plantations are dominated by young stands (≤ 30 years old). Declining productive teak stands due to forest disturbances has becoming an emerging issue in this FMU as well as other teak plantations areas in Java.

Chapter 3 argues that the first attempt towards improving the existing harvest scheduling method is developing parametric models for estimating survival probability and destruction rate of teak plantations. There is, however, lack of reliable methods that can be used to estimate survival probability and destruction rate of forest stands. This study therefore proposed an alternative method, based on the theory of survival analysis coupled with forest register data, for estimating survival probability and destruction rate of teak plantations. The forest register data were obtained from the FMU for the period 1977–2007. Survival and destruction of the plantations were modeled using probability distribution models. Model parameters were estimated using the maximum likelihood estimation method designed for left-truncated and right-censored data. Results showed that survival probability and destruction rate of teak plantations for the period 1977–1987 were well modeled using Weibull model, while those for the periods 1987–1997 and 1997–2007 were well modeled using log logistic models. All models confirmed that destruction rates varied over stand ages and planning periods. The rates of stand destruction were relatively low (< 2% per year) in the period 1977–1987, but increased up to 3% and 14% per year in the periods 1987–1997 and 1997–2007, respectively. The highest rate of destruction mostly occurred in young stands, implying an alarming condition for the sustainability of teak plantations. Therefore, appropriate management activities to eliminate the risk of stand destruction are absolutely required to ensure the sustainability of teak plantations. The survival and destruction models developed in this study are useful for forest managers to evaluate the risk of destruction over a specific planning period and to support the development of alternative harvest scheduling methods that incorporate the risk of destruction for teak plantations in Java. The proposed method can also be applied to other regions, especially when only forest register data are available.

Chapter 4 discusses that teak plantations are not only provide financial benefits from timber production, but they also provide environmental benefits from carbon sequestration. Compared to timber benefits, quantification of carbon sequestration benefits of teak plantations is still lacking. This study therefore developed empirical biomass models that can be used to quantify carbon stocks of teak plantations. Stand biomass and other stand variables were derived from forest inventory data of the FMU. Linear and nonlinear regression models were used to develop four types of biomass models: volume-to-biomass, basal area-to-biomass, age-to-biomass, and age and basal area-to-biomass. These models were validated using an independent data set to assess their performances. Results indicated that teak stand biomass was accurately estimated using the volume-to-biomass model. This model provides a direct conversion of stand volume to stand biomass without the use of biomass expansion factors. While the accuracy of the age and basal area-to-biomass model was comparable to that of the volume-to-biomass model, the basal area-to-biomass and age-to-biomass models were less accurate. Differences in the number of trees and mean diameter, even within a certain stand age, were possible causes of the high variation in stand biomass that resulted in the weaker performances of the basal area-to-biomass and age-to-biomass models. In addition, this study confirmed that site index may not be a consistently reliable indicator for site productivity in term of forest biomass, because teak stand biomass was more strongly affected by differences in stand density (either number of trees or basal area) than by variability in the site index. Depending on the availability of input data, at least one of these models will be appropriate for estimating teak stand biomass, especially when tree-wise data are not available. These models should prove quite valuable in supporting the multipurpose management of teak plantations.

Chapter 5 further discusses the limitation of harvest scheduling method that currently used by PP in the management planning of teak plantations. The existing harvest scheduling method is not only unable to incorporate the potential risk of destruction when PP determine annual allowable cuts, but it also less support for multipurpose management planning of teak plantations. This study proposes an alternative harvest scheduling model for optimizing multiple benefits (i.e., timber and carbon sequestration) of teak plantations at risk of destruction. The proposed model, which incorporated the destruction and biomass models (developed in Chapter 3 and 4, respectively), simulated the dynamic of age-class structures from one (a 5-year) period to another and then optimized harvest levels throughout a planning horizon using linear programming models. The optimal harvest levels were sought for three management scenarios: optimizing harvest volumes, optimizing net present values (NPV), and optimizing NPV while increasing carbon stocks. Each scenario was evaluated using four destruction rates (i.e., zero, low: 4.4−6.3% per period, medium: 9.4−15.9% per period, and high: 18.5−49.6% per period) and three cutting-age limits (i.e., 51, 61, and 71 years). The results showed that increasing destruction rates resulted in the reduction of harvest levels, financial benefits, carbon stocks, and led to imbalance forest structures. Meanwhile, reducing cutting-age limits increased harvest levels and financial benefits, but resulted in greater removal of carbon stocks and mature stands (especially when destruction rates were high). These findings suggest that instead of reducing cutting-age limits (implying shortening rotation lengths), eliminating or minimizing forest destruction seems to be an appropriate management strategy for ensuring the sustainability of teak plantations. In addition, incorporating carbon sequestration benefits (i.e., increasing carbon stocks by 10% from period to period) into the management objectives resulted in the reduction of financial benefits, but such multipurpose management scenario produced better forest structures than timber management. This study suggested that the proposed harvest scheduling model provides greater flexibility for forest managers to develop appropriate management scenarios at risk of destruction; hence, it can be used as an alternative harvest scheduling model for supporting multipurpose management planning of teak plantations.

Chapter 6 concludes that this study provided scientific contributions for improving the existing management planning of teak or other plantation forests in Java. Specifically, this study proposed an alternative method for estimating destruction rate, developed empirical models for estimating stand biomass, and proposed an alternative harvest scheduling model for integrating multiple benefits (i.e., timber and carbon sequestration) of teak plantations at risk of destruction. Although the results of this study might be specific for the study area, the proposed methods are general and applicable for other areas because plantation forests management in Java has some similarities.