Resilience of Bornean logged-over lowland tropical rainforests in terms of above-ground biomass recovery

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Abstract

Tropical rainforests have been drastically modified due to the expansion of human activities, leading to the occurrence of a large area of degraded forests. Whether such degraded tropical rainforests can provide comparable ecological services (such as carbon sequestration and the conservation of biodiversity) as old-growth forests has been investigated by earlier ecologists across Central and South America, Africa, and SE Asia. These earlier studies have commonly reported a more-or-less steady above-ground biomass (AGB) recovery of degraded tropical rainforests during secondary succession. However, I questioned if this steady biomass recovery model was applicable to highly degraded logged-over tropical rainforests in north Borneo and investigated the net AGB accumulation rate, the distribution, and the causes of logged-over remnant forests covered with dense ferns and vines. This doctoral dissertation consists of five chapters.

Chapter 1. General introduction

I conducted a literature review on the resilience of human-modified tropical rainforests with an emphasis on net AGB accumulation rate during secondary succession as an index of resilience. I found a wide variation of net AGB accumulation rates depending on various factors including climate, soil characteristics, topographic features, surrounding landscape

conditions, and disturbance history. However, few studies analyzed the relationships between net AGB accumulation rates and biological factors such as proliferation of ferns or vines as the initial condition of a succession. Also, the earlier studies were biased toward moderately disturbed forests only and few studies analyzed the AGB accumulation rates of highly degraded forests. Therefore, I pointed out the necessity to conduct a study about the secondary succession in highly degraded human-disturbed forests by focusing on the effect of the biotic factors in the initial condition, both from the field-based and remote-sensing approaches. “Initial condition” was here defined as the successional phase after the latest disturbance because disturbances were usually repeated at various time spans in the same stand.

Chapter 2. Influences of fern and vine coverage on the above-ground biomass recovery in a Bornean logged-over lowland degraded secondary forest

I conducted a field survey and analyzed the relationship between fern/vine coverage and above-ground biomass (AGB) accumulation of logged-over forests. The numbers of newly recruited trees as well as existing small-diameter trees were both lower, and the mortality of remnant trees was higher with increasing fern/vine coverage. The growth rate of pioneer trees was suppressed when fern/vine covered their crowns. Consequently, both absolute and relative net AGB accumulation rates between 2014 and 2019 were lower in the forests with higher fern/vine coverage. Relative net AGB accumulation rate became zero or negative when the initial AGB of a remnant forest was small and the coverage of fern/vine exceeded a threshold value. The results suggested that the recoverability of these degraded forests was lower than the previously predicted. Moreover, secondary succession was totally arrested

when the coverage of fern/vine became denser than the threshold value.

Chapter 3. Mapping the spatial distribution of fern thickets and vine-laden forests in the landscape of Bornean logged-over lowland tropical secondary rainforests

In Chapter 3, I classified the logged-over forests into fern thickets, vine-laden forests, and logged-over forests without ferns and vines from Landsat satellite imageries using machine learning techniques. I firstly developed a model to explain the pre-demarcated three vegetation types on aerial photos taken from UAVs using Landsat reflectance values, vegetation indices, GLCM texture variables, and Sentinel-1 radar signals on a 30 x 30-m pixel basis. The best model successfully distinguished the three vegetation types from each other with a 86.6% overall accuracy. Subsequently, I extrapolated the model to the whole landscape and obtained a vegetation map. The spatial distribution of the fern thickets and the vine-laden forests accounted for 30.7% of the whole area, suggesting that forest AGB recovery might be retarded in approximately one-third of the logged-over forests.

Chapter 4. Divergence of three classes of secondary vegetation as a response to different logging intensities: reconstructing logging histories with a Landsat time series analysis

I investigated what factors caused the formation of fern thickets in terms of logging histories. I hypothesized that the fern thickets received more intense selective logging than the forests without ferns and vines did in the past. I tested the hypothesis using a Landsat time series analysis (1988–2019) with the vegetation map of Chapter 3. Temporal changes of a

vegetation index (a surrogate of AGB) were derived from LandTrendr algorithm for each pixel. A sudden reduction of the vegetation index indicated the timing of logging with its decrement indicating the magnitude of logging in terms of harvest volume. Most pixels classified to the fern thickets demonstrated a large drop of the vegetation index than the logged-over forest without ferns and vines did. Moreover, the estimated AGB before the last logging in the fern thickets was much lower than in the latter. These patterns indicated that the fern thickets were formed when highly degraded forests with a reduced AGB were further harvested with high-impact logging.

Chapter 5. General discussion

I discussed the resilience of Bornean logged-over lowland tropical rainforests covered with dense ferns and vines based on the results of the Chapters 2 to 4. The suppression of secondary succession by ferns and vines and the wide spread of this vegetation type across the landscape suggest that it would take much longer than the previously expected for those forests to recover in their AGB. I conclude that the forest resilience of the fern thickets and some of the vine-laden forests has been lost. Therefore, the provisioning of ecological services in Bornean logged-over lowland tropical rainforests, specifically carbon sequestration potential, may be lower than the previously assumed.