LANDSLIDE-DERIVED FOREST BIOMASS LOSS FROM TROPICAL CYCLONE MORAKOT IN THE SUBTROPICAL FOREST

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ABSTRACT: Landslide is a wide range of ground movements of a mass rock, debris, soil down a slope, which can cause a catastrophic disaster. Tropical cyclone with extreme precipitation is one of the major factor to trigger large amount of landslide. Most of landslide studies focused on landslide extraction, risk assessment, warning and geomorphometric characteristics, and few of them focused on loss of biomass. The loss of biomass from landslide is critical to alter vegetation succession and forest carbon and nitrogen cycles, as well as export large amounts of woody debris to stream and ocean ecosystems. Therefore, estimating landslide-derived biomass loss plays an important role in feedbacks between tropical cyclones and carbon cycling. This study was carried out in southern Taiwan and targeted at tropical cyclone Morakot from 7 to 9 August 2009, which caused maximum accumulated precipitation of 2777 mm in southern Taiwan. Two Landsat images in 24 June 2009 and 18 January 2010 were acquired from U.S. Geological Survey. Support vector machine (SVM) classification was adopted for landslide susceptibility assessment. Spectral mixture analysis was used to derive photosynthetically active vegetation cover (PV), non-photosynthetically active vegetation cover (NPV) and soil. The estimation of biomass was derived from the empirical equation between PV and biomass. The results showed that the total areas of landslide were 120.35 and 242.19 km^2 before and after tropical cyclone, and tropical cyclone increased approximately two times of landslide in southern Taiwan. The mean and median area of per landslide were 6469.64 and 1799.53 m^2 before tropical cyclone event, while the mean and median were 5751.97 and 1799.43 m^2 after disturbance event. The mean estimated AGB was 308.26 Mg ha^{-1} in this subtropical forest ecosystem and the landslide-derived biomass loss was 4.157 Tg of AGB and 2.079 Tg C after tropical cyclone disturbance. Overall, the results showed that the extreme tropical cyclone caused catastrophic landslide would contributed massive AGB loss to alter the forest carbon cycling and ecosystem processing.

1. INTRODUCTION

Landslide is a wide range of ground movements of a mass rock, debris, soil down a slope, which can cause a catastrophic disaster. Climate change may exacerbate the intensity or frequency of extreme precipitation, which might cause and alter the characteristics and intensity of landslide (Crozier, 2010; Chiang and Chang, 2011). Tropical cyclone with extreme precipitation is one of the major factor to trigger large amount of landslide (Tsou *et al.*, 2011; Chen *et al.*, 2016). For instance, tropical cyclone Morakot caused 1677 mm precipitation in three days and resulted in a catastrophic landslide with a volumn of 25×10^6 m^3 and hundreds of death in 2009 at Shiaolin village in southern Taiwan (Tsou *et al.*, 2011).

Most of landslide studies focused on landslide extraction, risk assessment, warning and geomorphometric characteristics (Martha *et al.*, 2010; Chiang and Chang, 2011; Tsou *et al.*, 2011; Tsai *et al.*, 2013; Chen *et al.*, 2017), and few of them focused on loss of biomass (Schomakers *et al.*, 2017). The loss of biomass from landslide is critical to alter vegetation succession and forest carbon and nitrogen cycles, as well as export large amounts of woody debris to stream and ocean ecosystems (Hilton *et al.*, 2011; West *et al.*, 2011; Schomakers *et al.*, 2017). Studies have showed that the intensity of tropical cyclone under warmer sea surface temperature might increase but the frequency is still controversial (Bender *et al.*, 2010; Knutson *et al.*, 2010; Emanuel, 2013). Therefore, estimating landslide-derived biomass loss plays an important role in feedbacks between tropical cyclones and carbon cycling.

The objective of this study is (1) using Landsat images to extract spatial-temporal patterns of landslide; (2) estimating landslide-derived forest biomass loss. Overall, this study will facilitate the understanding of effects of landslide on forest carbon budget under tropical cyclone in a subtropical forest ecosystem.

2. MATERIALS AND METHODS

This study was carried out in southern Taiwan (23°10’ N, 121°13’ E) with warm and humid climate. The vegetation of study site is a moist subtropical mixed evergreen forest and conifer forest in high altitude. The period of tropical cyclone Morakot is from 7 to 9 August 2009 and it produced an maximum accumulated precipitation of 2777 mm in southern Taiwan (Ge *et al.*, 2010).

Two Landsat images in 24 June 2009 and 18 January 2010 were acquired from U.S. Geological Survey (https://earthexplorer.usgs.gov/). Two Landsat images were level 2 surface reflectance product with radiometric and atmospheric correction. Support vector machine (SVM) classification with a small number of samples, nonlinearity and high dimension was widely adopted for landslide susceptibility assessment (Huang and Zhao, 2018). A pairwise multiclass SVM classification was used to extract tropical cyclone derived landslide in this study (Hsu and Lin, 2002). Training dataset was classified as landslide, forest, building, agriculture-soil and water.

Training samples was split into training and evaluation sets and iterative trainer was used to train a SVM supervised classifier. Due to the similar spectra of sediments in the river and the landslide, we include digital elevation model (DEM) to extract slope as the threshold to estimate landslide if the slope is larger than 20 degree.

Spectral mixture analysis was used to derive subpixel components and each endmember component is a linear combination of endmember spectra (Asner and Lobell, 2000):

$$R_i = \sum_{\mathrm{k}=1}^{\mathrm{n}} f_k R_{i\mathrm{k}} + \varepsilon_i \qquad \text{and} \qquad \sum_{\mathrm{k}=1}^{\mathrm{n}} f_k = 1$$

where k is endmember, i is spectral bands, R is surface reflectance, f is the fraction of endmember. The photosynthetically active vegetation cover (PV), non-photosynthetically active vegetation cover (NPV) and soil were three major endmembers in natural environment. The estimation of biomass was derived from the empirical equation between PV and biomass in Taiwan (Chung, 2011):

$$\mathrm{AGB} = -140.11 + 691.02\ \mathrm{PV}^2$$

Where AGB is above ground biomass (Mg ha^{-1}), PV is photosynthetically active vegetation cover. The PV before tropical cyclone was used to estimate pre-event AGB, and biomass loss was estimated by pre-event AGB located at increased landslide after disturbance.

3. RESULTS AND DISCUSSION

The results showed that the total areas of landslide were 120.35 and 242.19 km^2 before and after tropical cyclone, and tropical cyclone increased approximately two times of landslide in southern Taiwan (Figure 1). The mean and median area of per landslide were 6469.64 and 1799.53 m^2 before tropical cyclone event, while the mean and median were 5751.97 and 1799.43 m^2 after disturbance event. The new increased landslide was 121.84 km^2 and majorly located at mountain areas with the 37.66° mean slope of landslides, and it was similar with the mean slope of the landslide (38.22°) before tropical cyclone (Figure 2). The similar mean area and slope of landslide between two period implied that rainfall-trigged landslide might cause similar geometry characteristics. A study showed that earthquake-induced landslide was located at steeper gradient and caused larger landslides, while rainstorm-induced landslide was located at the gradient between 25 – 40° (Huang *et al.*, 2017).

The mean estimated AGB was 308.26 Mg ha^{-1} in this subtropical forest ecosystem and the landslide-derived biomass loss was 4.157 Tg of AGB and 2.079 Tg C after tropical cyclone disturbance in southern Taiwan (Figure 3). A study also showed that tropical cyclone-triggered landslides caused 2.6 Tg of AGB loss in Kaoping reservoir in southern Taiwan, and a total of 3.8 – 8.4 Tg coarse woody debris was transported to the oceans, carrying 1.8 – 4.0 Tg of organic carbon (West *et al.*, 2011). Such a highly concentrated flux of carbon and nutrients could play an important role in transferring terrestrial nutrients to marine environment. Overall, the extreme tropical cyclone caused catastrophic landslide would contributed massive AGB loss to alter the forest carbon cycling and ecosystem processing in the long-term time.

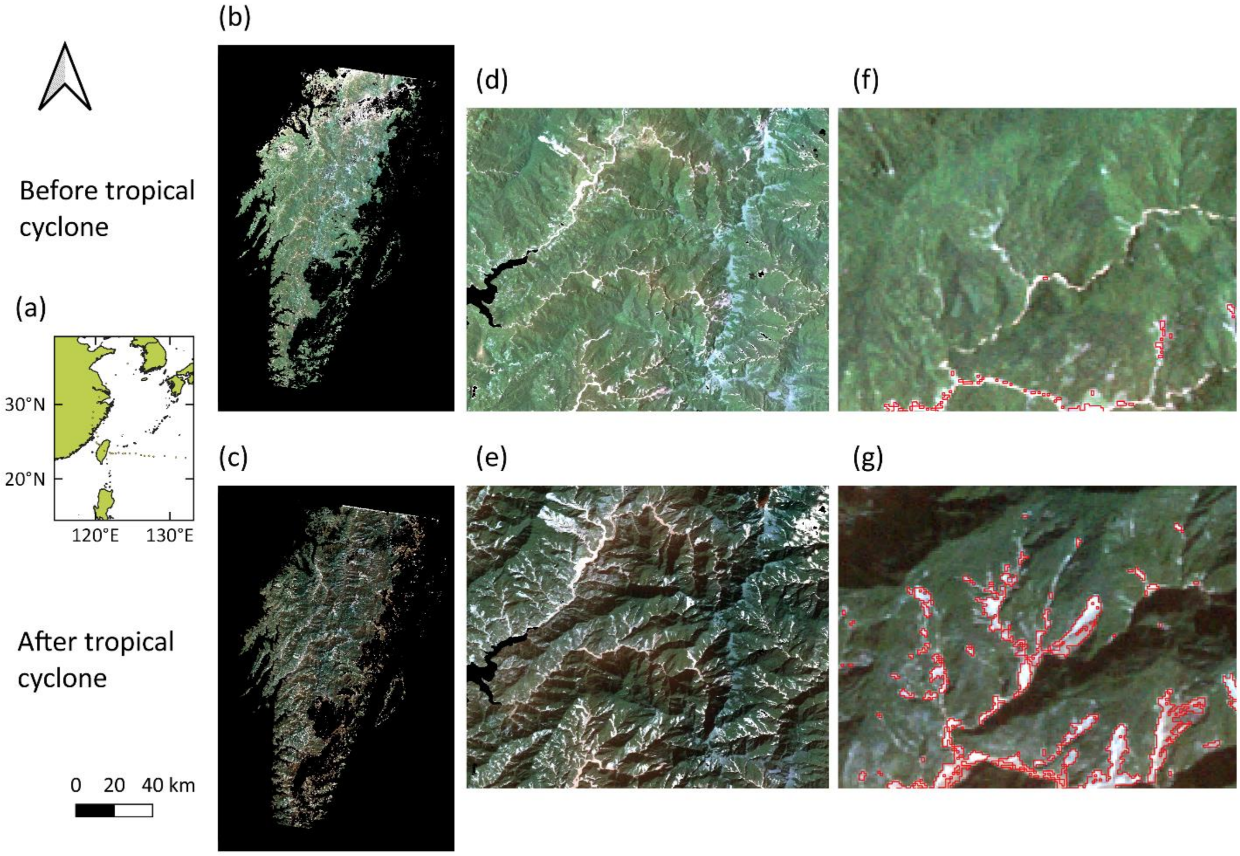

Figure 1. (a) Map of Taiwan with Morakot tropical cyclone track in August 2009. (b) and (c) were the study area of Landsat imagery in June 2009 and January 2010. (d) and (e) were the Landsat imagery before and after tropical cyclone. (f) and (g) were derived-landslide with support vector machine classification before and after tropical cyclone disturbance.

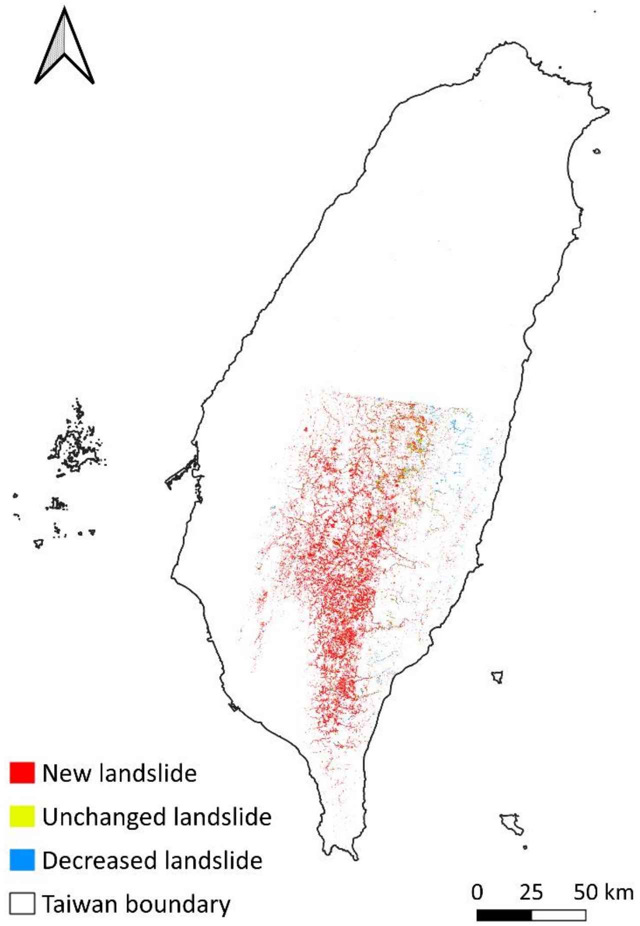

Figure 2. The spatial dynamics of landslide after Morakot tropical cyclone. The red color implied the new increased landslides after Morakot, while bule color implied decreased landslides.

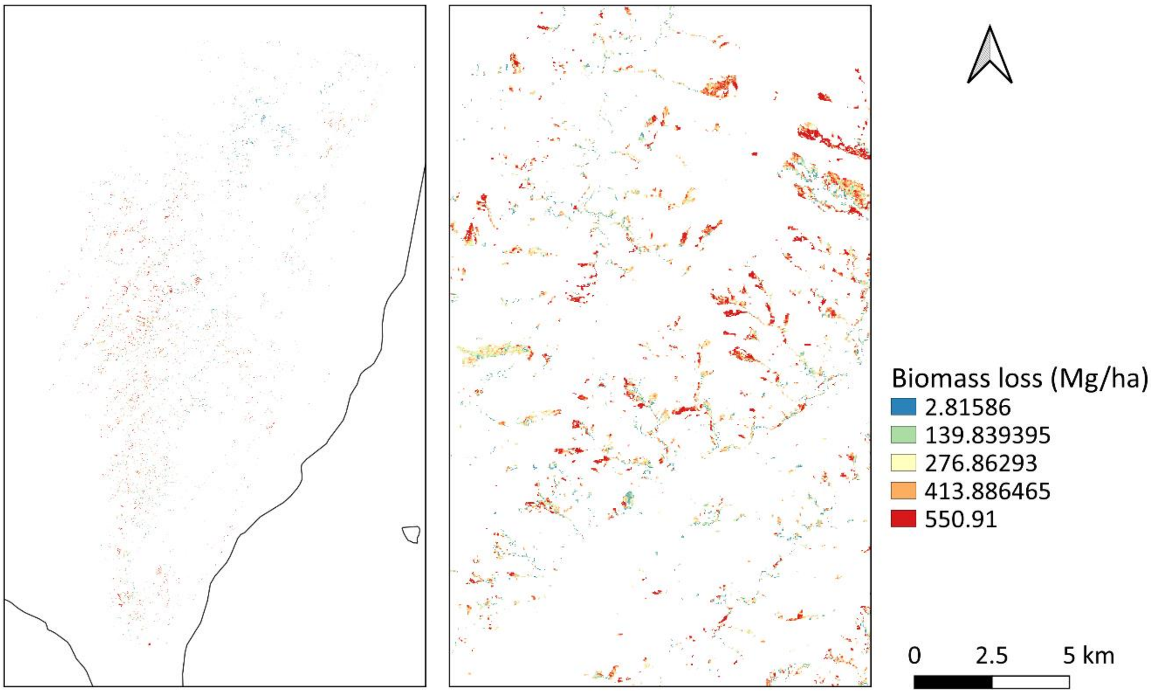

Figure 3. The landslide-derived above ground biomass (AGB, Mg ha^{-1}) loss after Morakot tropical cyclone.

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