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Suicidal forests? – Modelling biomass surcharge as a potential landslide driver in temperate rainforests of Chilean Patagonia

Sina Spors[1], Erkan Istanbulluoglu[2], Violeta Tolorza[3], and **Christian Mohr**[4]
[1]Institute of Geosciences, University of Potsdam, Potsdam, Germany (sspors@uni-potsdam.de)
[2]Civil and Environmental Engineering Department, University of Washington, Seattle, United States (erkani@uw.edu)
[3]Department of Civil Engineering, University of La Frontera, Temuco, Chile (violeta.tolorza@ufrontera.cl)
[4]Institute of Environmental Science and Geography, University of Potsdam, Potsdam, Germany (cmohr@uni-potsdam.de)

Temperate rainforests are the biomass richest biomes on Earth. They play a crucial role within the global carbon cycle and help to mitigate climate change by storing carbon. In this particular biome, shallow landslides are the most prominent geomorphic agents, re-mobilising stored carbon. In the Valdivian temperate rainforest of Northern Chilean Patagonia, field observations indicate a surprisingly low landslide rate under undisturbed conditions, whereas young tree stands suggest high geomorphologic activity. To solve this dilemma, we assign biomass-rich forests, as the ones blanketing the hillslopes within Pumalin National Park studied here, the role as active geomorphic agents.

We hypothesize that Patagonian rainforests comprise an intrinsic system in which efficient biomass accumulation (i.e., increase of biomass surcharge) promotes landsliding which in turn controls cyclic and fast landscape turnovers. To test this hypothesis, we develop a physics-based numerical ecohydrological and slope stability model using the Python-toolkit Landlab to quantify the control of forest biomass dynamics on hillslope stability. To this end, we simulate process cascade-cycles of natural disturbances, vegetation (re-)growth and landsliding.

Our models reveal that biomass surcharge may cause landslides in up to 9 % of the entire study area under loadings of 700 t ha^{-1} biomass with the upper segments of steep hillslopes being most susceptible to failure. Under undisturbed forests, surcharge had the greatest impact on slope stability after a 100-years-long period of initially rapid biomass accumulation yielding up to ~1000 t ha^{-1}. While root cohesion clearly dominated slope stability, biomass surcharge transiently exceeded the influence of root cohesion and caused slope failure during a time window of some 5-10 years after landscape disturbance. After high magnitude but low frequency disturbances, such as explosive volcanic eruptions, failure probability exerted a linear decline over multiple disturbance cycles independent of the amount of biomass load. In contrast, for disturbances of low magnitude but high frequency, such as wind storms, both biomass and failure probability decreased scaled to disturbance timing and magnitude.

Our unprecedent results suggest that biomass loads may be an important, yet unexplored, tipping-point mechanism in biomass-rich forests, particularly on slopes already close to failure. For forests

that remain undisturbed for several centuries, we estimate some 100 years as a minimum period required, after which biomass-rich forest stands may become intrinsically instable, thus suicidal, and ultimately trigger landscape rejuvenation. However, cumulative effects of disturbances may stabilise hillslopes on the long-term, providing one plausible explanation for the generally low landslide rates observed in the study area. Yet, our ^{10}Be-based erosion estimates from nearby catchments, exceed all reported erosion rates on centennial-scale, i.e. covering several disturbance cycles, along the Chilean Andes Orogen despite dense vegetation cover. Hence, we conclude that the bulk of erosional work in such environments is performed during only few years immediately in the aftermath of landscape disturbances. Then, erosion may be extremely high even under the dense vegetation cover of coastal temperate rainforests.

Our findings highlight the great potential of integrating vegetation dynamics and particularly time-varying biomass surcharge to predict slope stability in biomass-rich temperate rainforests.