Natural Hazards and Earth System Science
Authors’ response to the Referee #2’s comments

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Interactive comment on “Forest harvesting is associated with increased landslide activity during an extreme rainstorm on Vancouver Island, Canada” by J.N. Goetz et al.

J.N. Goetz et al.

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*Note: reply to referee’s comments are in blue text and indented.

Referee #2

GENERAL COMMENTS

Dear authors, I found your manuscript “Forest harvesting is associated with increased landslide activity during an extreme rainstorm on Vancouver Island, Canada” interesting, well written and organized. However some flaws are present in the methods and in the assumption. One of the big issue is the equation forest structure=time since harvesting that needs to be clarified. I think, and I am quite sure, that some openings or some low density forest are related to other causes than forest utilizations. Natural disturbances (windthrow, insects, disease, wildfires…) or site limitation (rocky site, superficial water table…) can create forest structure similar to post-harvesting one. I agree with you that forest canopy cover is very important in preventing landslide, is a sort of lamination factor, at least up to a certain threshold (when it is saturated, same water in, same out). The key point is the forest structure and cover, after in the discussion you can talk about the processes that lead to that structure (i.e. disturbances, both natural and anthropogenic – harvesting). Among forest operation, the machinery used in the logging activity could have an influence on landslide initiation (this information is available on the cutblock dataset?). In the confusion matrix you considered also the masked points, it is better not to use these data since you are testing your classification. Furthermore you should use more than 100 points (at least 50 points per class), and eventually other indices (i.e. Kappa Index, in your case 0.65 masked included…). Since all your analyses are based on derived data (real ground truth validation is missing) you have to provide some overall accuracy information (errors propagation).

> Vancouver Island has experienced heavy logging activities for the past 150 years. It has been estimated that approximately 75% of Vancouver Island’s forests have been logged (Pew and Larsen, 2001 in Forest Ecol Manage). Therefore, we assumed that logging is the primary disturbance of forest stands on the island. A previous study, also for coastal temperate forest in British Columbia, found that only a small spatial extent of forest disturbances relative to logging are related to natural disturbances (Pearson, 2010). Since reading this comment, we have conducted a new analysis (now included in the revised manuscript and described in detail below) to estimate the proportion of forest cover classes associated with logged conditions.

Overall, we found for assumed logging related classes, i.e. sparse, open and semi-open forest, were for the majority (60%) associated with logged forests. Additionally, our previous comparison with the BC forest inventory (VRI) also found that compared to closed forest cover, sparse, open and semi-open forest had a stronger association to logged areas.

Our assumption of time related to forest structure is based on the work of Cohen and Spies (1992 in Remote Sen Environ) and Cohen et al. (1995). They illustrated how forest attributes such as canopy closure can be used to accurately estimate forest stand age in terms of the position in forest succession (e.g. young, mature, and old-growth). After our classification, we characterize the age of the forest cover classes with the VRI data set (page 5533, lines 6-14) and found that sparse and open forest had the lowest associated with the lowest recover periods (page 5539 line 15).

Different logging activities can indeed have an impact on landslide initiation, however, this has long been identified and practices are largely standardized now. In either case, we might expect to see a change in spatial distribution of landslides from one cutblock to the next, but the susceptibility remains similar to our modeled results.

Given our previous results characterizing the forest cover classes (page 5533 line 6 to page 5534 line 5) and a new analysis of logging disturbances, we believe that we have provided enough evidence to support the association of the forest cover classes to logging.

We have also updated our validation of the forest classification with the following new analysis. A new confusion matrix has been created and includes producer's and user's accuracy, as well as the kappa coefficient.

Methods

To improve our assessment of the forest cover classification, reference data was collected by visual interpretation of high resolution DigitalGlobe™ and Spot images from 2003 to 2012 available in Google Earth™ (earth.google.com). The Landsat imagery used for the classification of forest cover was utilized as ancillary data to ensure the reference conditions were relevant to the time of the classification (i.e. the summer of 2006). The locations for the reference data collection was based on the random spatial sample used for the non-landslide point locations. At each reference location a suitable forest cover class was assigned, e.g. sparse, open, semi-open or closed forest. Additionally, an attribute indicating if the reference sample was in a location that has been previously logged was included. This attribute is used to determine the proportion of each forest cover class associated with logging. The modified manuscript now reports the kappa coefficient and user's and producer's accuracy.

Results

The forest cover classification had an overall accuracy of 93.5% (±2.2% with a 95% confidence interval) and 0.896 kappa coefficient.

As calculated from the reference data, 60% of the sparse, open, and semi-open forest cover samples were in logged areas. In contrast, only 4% of the closed forest samples were in a location that was logged. The sparse forest samples were least related to logging with a 46% proportion of samples in logged areas.

Discussion

For the majority of reference data sampled, logging was the most important contributor to the classified forest cover conditions. It was generally observed during the collection of reference data that other site conditions that lead to sparse or open forest were exposed bedrock; thin patches of forest located in high mountain regions; and landslide run-out or snow avalanche paths. Thus, although some of the landslides initiated in sparse forest may also be related to timber harvesting activities, other forest disturbances may also play a role in these areas (Guthrie and Evans, 2004b). However, relative to logging disturbances of forest stands in the BC coastal temperate forests, natural disturbances observed at a regional scale are only of a small extent (Pearson, 2010).

Reference

Pearson, A. F.: Natural and logging disturbances in the temperate rain forest of Central Coast, British Columbia, Canadian Journal of Forest Research, 40, 1970-1984, 2010.

All of the above analysis has been inserted into the appropriate sections within the revised manuscript.

Double -check the references, some are missing in the text, some in the list.

We've gone through the citations and reference list to make sure everything matches. The changes are commented on in the reply to Referee #1.

Check carefully data in the tables (e.g. table 4. Landslide density in "All" is wrong).

The table has been corrected.

Further remarks are on the attached pdf.

All the best.

Thanks. We've made a list below to comment on the remarks found in the attached pdf.

COMMENTS FROM SUPPLEMENT MATERIAL

Page 5525, Title: I would change the title, focusing on the structure or canopy cover.

As commented in the response to the general comment of this referee, we believe we have provided enough evidence to support that the forest cover classes for the majority represent logged areas. Additionally, forest service roads also significantly increased the odds of the landslide initiation. We use "forest harvesting" in the title to allow the association to both the effects of logging and the effects of forest service roads.

Page 5529, line 19: Add the author abbreviation for all the species. In this case *Tsuga heterophylla* (Raf.) Sang.

These have been added to the revised manuscript.

Page 5529, line 23: Change amabilis fir to Pacific silver fir.

This has been updated in the revised manuscript.

Page 5530, line 1: "Uprooting is common", this is incomplete. There are several factors promoting uprooting vs. snapping trees on windthrow.

We agree, but a full analysis of windthrow factors is beyond the scope of this paper. We simply state that this is a common issue.

Page 5534, line 4-10: Why 100m? You considered only downslope, upslope or both? Why?

With our distance from variable, we considered the potential of landslides occurring both downslope and upslope from the road. Landslides related to service roads in steep terrain can occur in either the fill material (downslope) or the cut slopes (upslope; Jakob, 2000; VanBuskirk et al., 2005). Additionally, we considered only distances up to 100 m by assuming that road-related landslides would be initiated in the fill or cut slopes, which from the centre of the road would not exceed this distance.

The paragraph on Page 5534, line 4-10 was modified to the following,

"Since landslides related to service roads in steep terrain can occur in either the fill material or the cut slopes (Jakob, 2000; VanBuskirk et al., 2005), distances upslope and downslope from roads were considered. Also, assuming road-related landslides were initiated in road fill and road cuts, only distances from roads up to 100 m were considered to have a potential influence on landslides"

Page 5534, line 12: "Through visual inspection", on the field? On screen?

We have clarified this by making the following modifications,

"Through visual inspection of Landsat scenes overlaid by the BCDRA, it was determined that the service roads…"

Page 5540, line 9-11: This sentence is too speculative. It is an overgeneralization.

We have omitted this sentence from the manuscript.

Page 5540, line 17: "Odds ratios", I like these statistics, and I think odds ratios is very informative. But you have to provide a significance value too.

We decided not present P-values of individual predictor variables because the observations could possibly be spatially dependent (Brenning, 2005; Atkinson and Massari, 2011). Therefore, to avoid the potential to overfit to the training data and to account for the violation of the independence assumption, we applied a non-overlapping spatial block bootstrap to produce alternative estimates of the odds ratios and their confidence limits.

We modified the following the sentence to clarify why we calculated alternative estimates of the model effects,

"Since there is inherently a dependent data structure in spatial data (Brenning 2005; Atkinson and Massari, 2011), alternative estimates of the predictors' effects size and confidence limits were obtained by applying a non-overlapping spatial block bootstrap to account for possible spatial autocorrelation within the models (Brenning, 2012)."

The following reference was also added:

Atkinson, P. M., and Massari, R.: Autologistic modelling of susceptibility to landsliding in the Central Apennines, Italy, Geomorphology, 130, 55-64, 2011.