Influence of landslides on invasibility of forest ecosystems

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Abstract

In the past, the ecological role of landslides in altering floristic composition and biological diversity has been largely ignored, however a major earthquake of shallow depth measuring 7.6 on the Richter scale struck central Nepal on 25 April 2015 and after shock of 12 May 2015 measuring 6.8 causing widespread destruction and appeared as a substantial natural disturbance agent. Here I provide perspective on the influences of landslides on species invasion, which is related in several ways to biophysical and biological diversity. Methodology includes an analysis of pre-disaster remote sensing image data to compare with post-disaster landslide conditions in 14 worst earthquake hit districts of Nepal, development of biophysical models of species occurrence by reviewing of the ecology, distribution pattern and habitat preferences of 12 worst invasive plant species and field verification of species presence and absence. Satellite image classification shows occurrence of significant number of landslides and alteration in topography and microclimate in the forested areas. Biophysical model revealed that such sudden alteration creates source habitats and hotspots for sink population of invasive species present in the ecosystems. Results shows that landslides amplified landscape heterogeneity by changing forest canopy structure, light intensity reaching to the forest floor, soil structure, chemistry, topography and microclimate and produce distinct spatio-temporal patterns of vegetation distribution. Increased tree mortality, dispersal limitation, quick growth of thicket-forming invasive species vegetation could drastically reduce native forest recovery on landslide disturbed sites. On the larger scale of the landscape, remote sensing and GIS are useful tools for investigating the influence of landslides on species invasibility and long-term forest dynamics.

Introduction

In the past, the ecological role of landslides in altering floristic composition and biological diversity has been largely ignored, however a major earthquake of shallow depth measuring 7.6 on the Richter scale struck central Nepal on 25 April 2015 and after shock of 12 May 2015 measuring 6.8 causing widespread destruction and appeared as a substantial natural disturbance agent. The earthquake triggered a large number of landslides of various types over a broad area in a steep mountainous terrain, which also produced extensive damage to housing settlements and many other infrastructures. Ground surface movements can be detected and quantified from satellites using optical (Delacourt et al 2004) images.

Optical images have the advantages of a higher spatial resolution, ideal for detecting small landslides, and a near-vertical acquisition that avoids masks due to the steep slopes that often surround landslides. Ground motion can be quantified by the correlation of two successive orthorectified images (Leprince et al, 2007). This process has been successfully applied to estimate landslide surface deformation (Delacourt et al., 2004 and Stumpf et al., 2014). These studies have used a large variety of satellite optical platforms, including Quickbird, SPOT5 and ASTER images.

Studies on landslides amplified landscape heterogeneity by changing forest canopy structure, light intensity reaching to the forest floor, soil structure, chemistry, topography and microclimate and produce distinct spatio-temporal patterns of vegetation distribution. The impressive ability of species to invade areas outside their native distributions is founded in the evolutionary characteristics of ecological niches—the set of environmental factors that determine where a species can and cannot maintain populations—and in their relation to current geographic distributions. Recent theoretical modeling efforts have demonstrated that species' ecological niches are likely to evolve only slowly and under circumscribed conditions (Vitousek, 1990, Holt and Gaines 1992).

The problem of bio-invasion is worldwide and predicting invasive species distributions is one of the important but challenging task to delimitate invaded habitats and impact of an invader on any native ecosystem. Invasions do occur naturally (Botkin 2001, Schullery 2001), there is so far little evidence to support the hypothesis that landslides induced by earthquake triggered the invasion of exotic species. Very few attempts have been made to relate invasion and large scale natural disasters that alters the existing environmental conditions which creates opportunities for invasive species to establish. A wide variety of modelling techniques have been developed to predict bioinvasion (Guisan and Thuiller, 2005). Most important strategy for estimating the actual or potential distribution of a species is to characterize the environmental conditions that are suitable for the species and to then identify where suitable environments are distributed in space (Pearson et al 2007). The model can be used to predict species occurrence in areas where that distribution is unknown. Altitudinal patterns in mountains provide a suitable model for investigating invasion processes, as across a relatively short geographical range there are large environmental changes, such as climate, geometric constraints (e.g. boundary constraints) (Rahbek, 2005). An increase in altitude is usually accompanied by decreasing temperatures and the length of the growing season, while the period of frost and the intensity of ultraviolet light increases with increasing altitude (Körner, 2003).

Nepal is a crossroads of migration and forms a transition zone between the plants of the western Asiatic and Mediterranean elements, the Sino-Japanese elements, Central Asiatic plants from the north and tropical species of the lowland plains from the Gangetic plains of India (Press et al 2000). These young mountain chains contribute to the diversity of plants, and have provided biogeographically ample opportunity for alien species to grow and establish (Tiwari et al 2005).

With the statistical techniques, remotely sensed images and GIS tools, the development of predictive habitat distribution models of species or communities to their present environmental condition is being popular day by day in ecology (Guisan and Zimmermann, 2000, Joshi et al 2009). Light intensity determined high vegetative growth and high percentage of the variation in seed production per plant. Prediction of potential occurrence of invasive species and landslide areas could enhance the accuracy of such predicting models. The concept of ecological niches of species is used to predict the source population of selected 10 invasive species. The niche can be defined as a set of tolerances and limits in multidimensional space that define where a species is potentially able to maintain populations (Grinnell 1917).

In this paper, I investigate susceptibility of the recipient environment can be enhanced by landslides. As a case study I selected ten world's worst invasive species also grows in different ecological zones of Nepal. The hypothesis that landslides as a result of big earthquake accelerated invasion was tested.

Materials and methods

In this study, field investigation, along with GIS and remote sensing technology, was used to map invasive species and landslides. The main purposes of the field work were validate the location of landslides and to understand the general distribution pattern of invasive species. Information was collected on the source and sink population and pre-successional stage of invasion. Field verification and species data collection was done between April-Sept 2015. Pre- and post-earthquake imagery provided by google was used to ascertain the presence of post-earthquake landslides; i.e. either there was no landslide present on the landscape before earthquake or the pre-existing landslide had moved visibly on the imagery since the earthquake.

The coverage, detail and quality of the landslide inventory are primarily determined by the available imagery. Detection of all landslides within the 14 districts was not possible since some of the images were not cloud free. The imagery has been investigated at 1:5,000 to 1:10,000 scales (with smallest features that can be distinguished ranging from about 5 to 15 m). Most of the landslide data and information was extracted from Durham University (www.dur.ac.uk/geography; British Geological Survey www.bgs.ac.uk; Earthquake without frontiers, www.ewf.nerc.ac.uk and data collected by ICIMOD, www.icimod.org.

Figure 1. Google image of Pre (left) and post (right) earthquake

The image resolution ranged from 2 m to more than 22 m – some images were panchromatic while others were multispectral. The detail of landslide areas under clouds or course resolution was not available to ascertain if they are solely associated with the earthquake or are part of the natural landscape processes in the area. The imagery was loaded into a Geographic Information System (GIS) and points / lines /polygons digitised on screen, directly onto the imagery. In some cases it was not possible to obtain the satellite imagery but they could be viewed on the supplier's web portal, in which case the landslide information was traced out on the portal and transferred by eye to the GIS.

Forest cover, and other base maps (altitude, aspect, district boundary) were obtained from FRA project (FRA 2015). A hybrid approach in the image analysis and field data collection was adopted using interpretation of satellite images (with field verification) at first stage and the presence of invasive species in the field at second stage.

All selected 10 invasive species are highly successful in the region and ranked among the world's worst invasive species (ISSG 2004). Native to Central America almost all of them are currently found along the different elevation of study area. They dominates in open and degraded forest, but remains virtually absent from closed canopy forest. They are heliophytes (GISD 2015) and capable of producing millions of seeds under optimal light conditions (Erasmus 1985, Witkowski and Wilson 2001). Intensity of light reaching to the ground suddenly increased immediately after the landslides. This information was used to determine the probability of invasion success of a heliophytic species. Dispersal over short distances occurs through wind, while short hooks clinging seeds to animal fur, clothes, edible fruits etc facilitate zoochoric dispersal over longer distances. Most of them are short-lived perennial with above ground parts dying off in the dry season and re-sprouting at the start of the rains from reserves of starch stored in its roots, still some of them like lantana is perineal in nature and produce large number of edible fruits and also expands through vegetative growth.

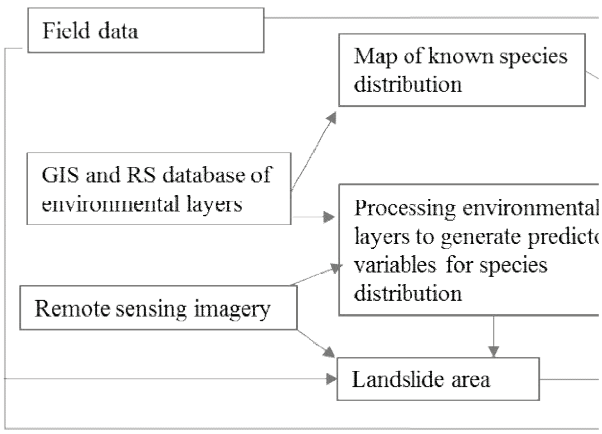

Figure 2. Flow diagram detailing the main steps in predicting distribution of invasive species

Presence and absence of species were recorded using mobile cellphone (GPS installed) and predicted the probability of presence along environmental dimensions. Predictive accuracy tested by comparing sets of points resampled from known occurrence points. The final step in the framework is to project the ecological model onto landscapes that could be invaded. That is, using the same set of ecological dimensions, the ecological niche model is projected onto the landslide area in the study. The stored mobile GIS map file is presented in the figure

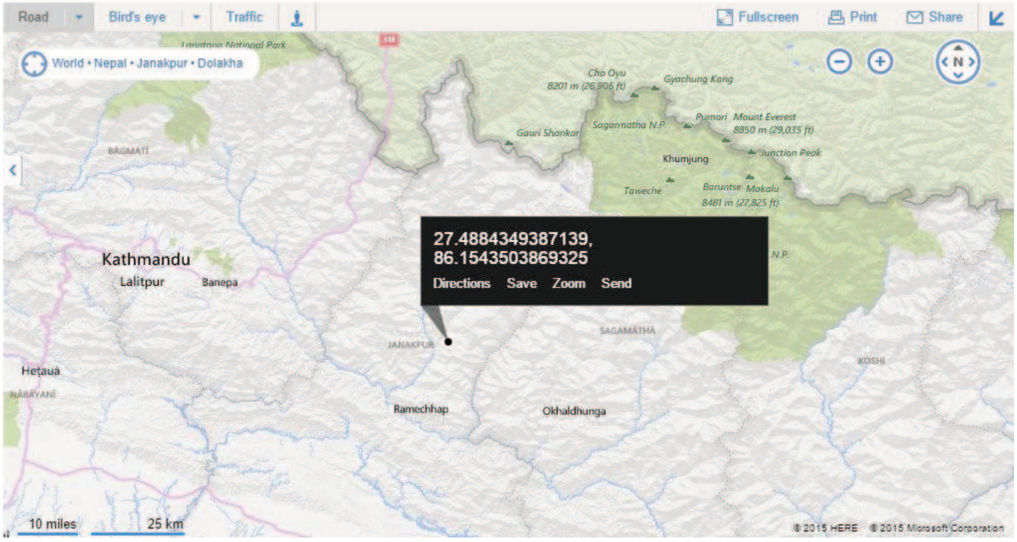

Figure 3: Field observation and cellphone based mobile GIS location map

Landslide areas were observed and seedlings density of invasive species were recorded. This step may or may not be testable, depending on whether the invasion has taken place or is yet to happen.

Study area

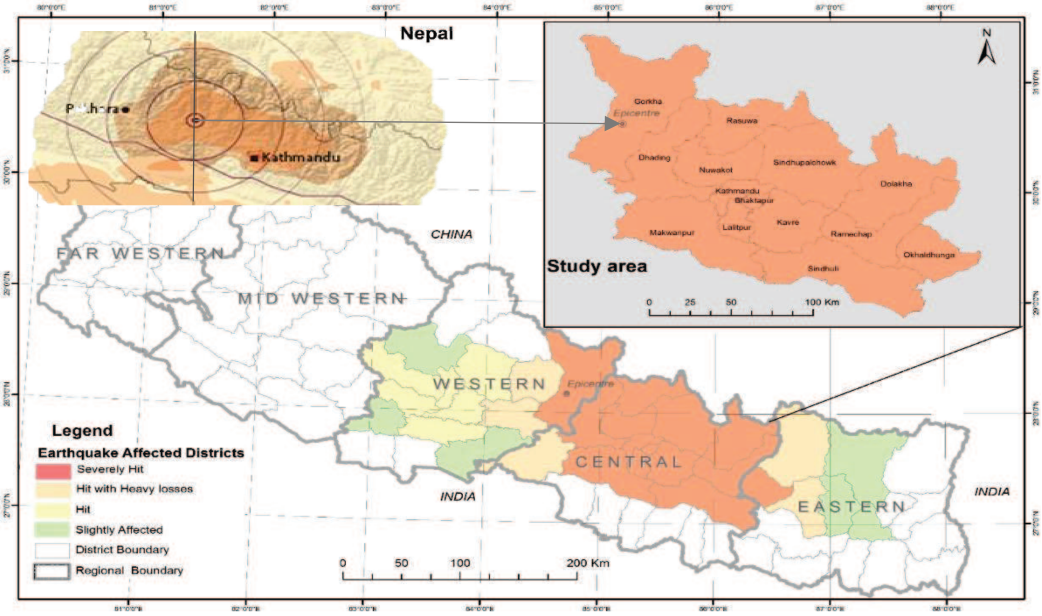

Figure 4: The study covered severely earthquake hit 14 districts in central Nepal.

Results

Figure 5 shows altitudinal limits of the distribution of invasive species. The lowest limit for Hyptis was below 1000m and highest altitudinal limit for Xenthium was below 2500m.

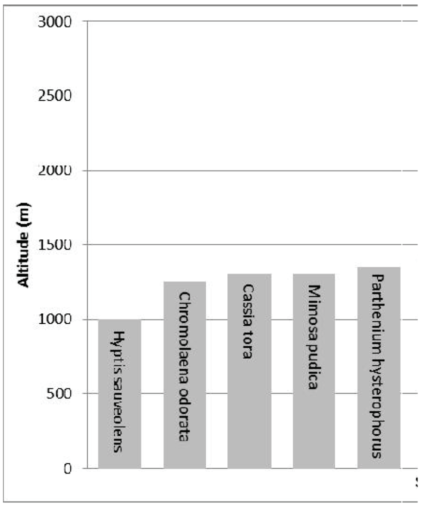

Figure 5: Distribution of invasive species along the altitudinal gradient

Total 4490 number of landslides were detected sized between 10 sq m to 5000 sq m.; 12.9% were mapped as point, 76.4 as line and 10.4 as polygon (Figure 6). The figure 7 shows the forest cover and the landslide area triggered by the recent earthquake. Almost 79% of the total landslide area falls within the forested area.

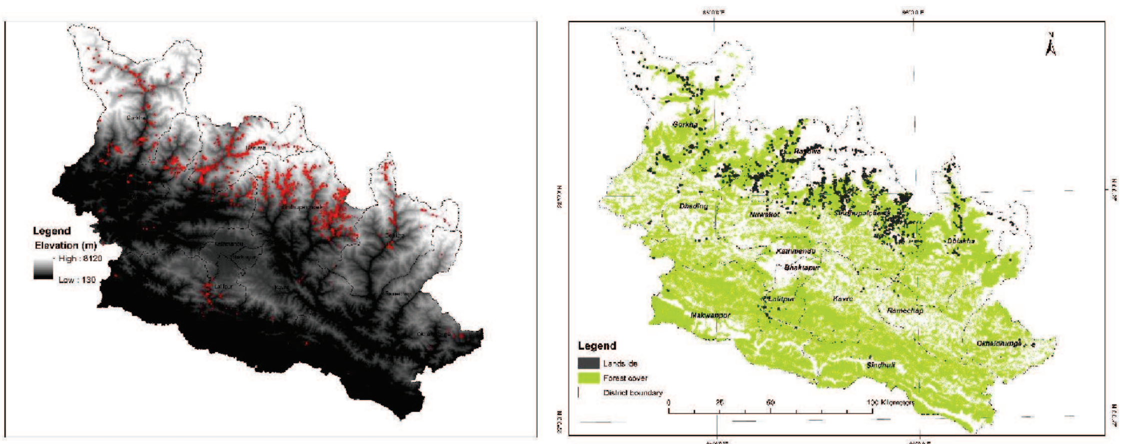

Figure 6: DEM and Landslides (Left) and forest cover map and landslides of the study area (right)

Figure 7 indicates predicted probability map of 4 species presence (grey) and landslide data (black) within the earthquake hit 14 districts. The map of other 6 species was not presented due to page limitation)

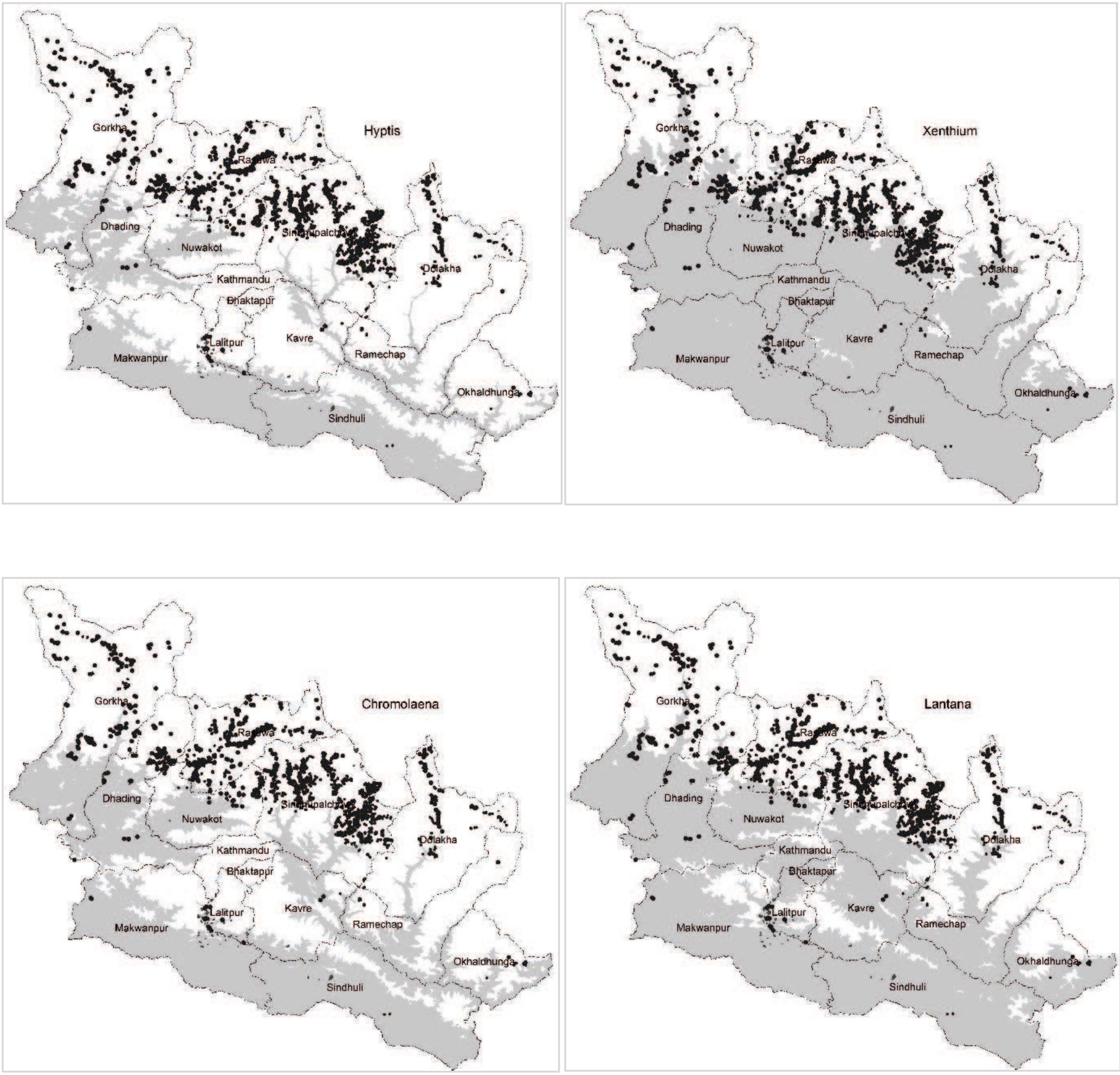

Figure 7: Predicted probability map of species presence (grey) and landslide data (black) and district boundary

Analysis showed a highest probability of 5 species (Lantana, Amaranthus, Ageratum, Bidens and Xenthium) which could invade about 50 % of the total landslide area. The probability of Hyptis invasion is the lowest (Figure 8 left). Field observation revealed that in most of the recent landslide areas Chromolaena seedlings were well established (Figure 8 right). The presence of Chromolaena seedlings was highly significant ($p < 0.1$) in the post-earthquake landslides areas within its predicted species distribution range.

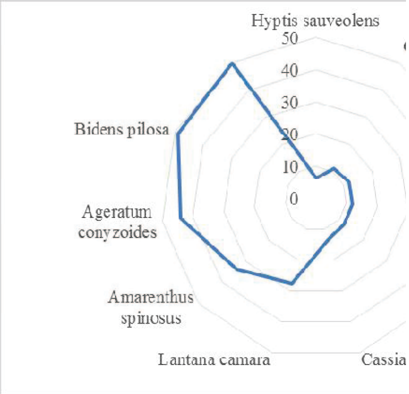


Figure 8: Probability of species invasion (left) and an early establishment of Chromolaena and Ageratum in a new landslide area (right).

Discussion and conclusion

Landslides are a major threat in all mountainous regions in Nepal not only from human casualty and physical damage perspective but also from biodiversity viewpoints. In this paper I therefore argue that invasion accelerated naturally in native forested area as a result of earthquake induced landslides. Presence of seedlings of invasive species in newly occurred landslides clearly showed a changing status of sink population of some invasive species into their source population across the landscapes.

This findings suggest that the direct climatic factors altered by the landslides enhancing invasion in the area. The local plant communities, influenced by local environments not only as a result of human management but also natural disturbances, were strongly associated with the habitat invasion risks posed by propagule pressure of invasive species. Increased tree mortality, dispersal limitation, quick growth of thicket-forming invasive species vegetation could drastically reduce native forest recovery on landslide disturbed sites. Field observation revealed that under dense forest canopy and low light intensity conditions, although vegetative population of those species were present in the system as a sink population, a high biomass of other shrub and herb species, did not allow invaders to grow and to produce seeds. The canopy dominance of native species control invasiveness of these ten species through competitive exclusion. Landslides easily breaks the dominance of other native species thus creating the conditions for fast growing invaders to attain canopy dominance.

Modeling spatial patterns of range expansion after initial invasion need an in-depth understanding of species trait. This is one of the powerful tools to regulate the species to see special distributions and possible extension in case of small change in microclimate change. This study showed that the potential occurrences of species on the geographical spaces under the prevailing environmental conditions can be predicted using remote sensing and GIS techniques and the possible extension with respects to change even in microclimate can be predicted.

The Nepal earthquake generated many extremely large and deep-seated landslides having volumes of millions of cubic meters. Many landslides that initiated at the top of slopes have related cracks behind the main scarp. These cracks indicate a potential for further land sliding during and after the rainy season. Subsequent rainfall could also induce debris flows because co-seismic landslides greatly increase the occurrence of rainfall-induced debris flows (Tang et al., 2010, 11) which in later years certainly will serve as source material for rainfall-induced debris flows. Such debris flow will provide more space for established invasive species. Such a widespread landslides altered biotic and abiotic climate which may provide ample space for cryptic invaders. However, the magnitude of future expansion of number of invasive species can only be quantified if more data becomes available about the microclimate, spatial distribution of invasive species and area of landslides and rainfall-induced debris flows in the different catchments.

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