

Landslides as ecosystem disturbance - their implications and importance in South Ecuador

Derumbes como perturbacion en un ecosistema - implicaciones y importancia en el Sur de Ecuador

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July 2005

Download at: <http://www.lyonia.org/downloadPDF.php?pdfID=2.386.1>

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Abstract

Landslides along the Andean mountain chain produce serious damage with widespread environmental and economical effects for the Andean countries. Landslides have a particularly high significance in Southern Ecuador. Only few studies address the causes and effects of landslides, and much more data is needed to understand this phenomenon. In this paper the causes as well of landslides, their shapes in different environments and the environmental effects of landsliding are discussed from the biological and economical point of view. Special attention is given to South Ecuador, where constant landslides are characterized by a distinct vegetation and specialized pioneer flora. The lack of knowledge about gap size, seed bank and other internal or environmental factors does not allow advance mitigation of landslide effects. Key words: Ecuador, Landslide, Disturbance, Species loss

Resumen

Los derrumbos en las montañas Andinas, han ocasionado serios daños con amplias repercusiones ambientales y efectos económicos para los países andinos. Los derrumbos tienen una particular alta significancia en el sur del Ecuador. Solamente pocos estudios han direccionado las causas y efectos que estos producen, siendo necesario poner más atención en este tipo de estudios. En este trabajo se enfoca las diferentes causas así como las formas que se presentan y las repercusiones en el ambiente, tanto desde el punto de vista biológico así como un análisis económico. Se realiza un enfoque dirigido al sur del Ecuador, sitio de constantes derrumbos, con una flora especializada en colonizar estos ecosistemas perturbados. La falta de atención a factores como tamaños del gap, banco de semillas entre otros intrínsecos y ambientales no nos permite actuar con precaución en la mitigación de sus efectos. Palabras clave: Ecuador, Derrumbo, Perturbación, Pérdida de especies,

Introduction

For many years, vegetation recovery was studied as an important topic in plant ecology (Peet & Christensen 1980). The study of environmental disturbances has a long research tradition, focusing on different impacts, restoration and succession (White & Jentsch 2001). Some studies suggest that natural disturbance plays an important role in maintaining biodiversity (Christensen *et al.* 1989). These processes of regeneration and succession are highly important in view of increasing forest changes caused by natural or human activities. Habitat fragmentation may increase the disturbance rates (Bergeron & Brisson 1990).

Natural and anthropogenic landslides are common all over the Andes including Ecuador, and are producing serious and continuous damage (Benitez 1989). Unfortunately very few studies have been carried out in Ecuador (Ohl & Bussmann 2004; Stern 1992; Benitez 1989). Landslides are influenced by a series of internal (cryoclastic or thermoplastic phenomena) and external environmental factors, especially climate, slope, soil type, earthquake frequency and road construction. These factors, sometimes combined, are the main driving forces to produce debris and slides. The Andean mountains have always been influenced by drastic climate processes, which directly influence land movements and plant composition, as a part of a natural dynamics. The disturbance regimens, have critical implications in ecosystem maintenance, and influence species loss. Native or alien species invasions play an important role in the recovery process after landslides.

Discussion

Fall and Movement

In many mountain ranges, continuing movements of material occur on steep slopes. "Rock fall" is often used as the general term without further reference to the material involved (Dikau *et al.* 1996). A fall occurs when the natural slope exceeds the limit for the balance of the material composing it. The fall may have various direct and indirect natural or anthropogenic causes.

It is noteworthy to consider that the Andes are characterized by active plate convergence and uplift due to the South American Plate colliding with the Nazca Plate (Van der Hammen 1988). Intense seismic activity occurs constantly. The uplift average is as much as a meter per thousand years, and rapid erosion has resulted in widespread unstable slopes (Eriksen *et al.* 1989). The way landslides move and their velocity have inter-relations with the nature of the fall, size and provenance of the material. Different fall classifications based on either genetic or descriptive approaches are used (Whalley 1974). The most common international classification is based on the origin and nature of the material, although many other descriptions and suggestions exist. Terzaghi (1962) for example describes falls according to the rock type, focusing on the rupture mechanism and the action of water in the rock.

Slide and Landslide

The term landslide is used for a movement of material along a recognizable shear surface (Buma & Van Asch 1996). At least two different kinds of slides are recognized: Rotational, which basically describes how, after failure is initiated, the slump mass starts to rotate; and translational, which is not a circular failure, but a movement largely controlled by surface of weakness within the structure of the slope-forming material. Translational slides may occur in three types of material: rock, debris and soil. Depending on the slope angle and the velocity, slides will either stay as a discrete block on the failure surface or break into debris. According to Varnes (1978), cited in Dikau *et al.* (1997), show the following classification (Table 1):

Table 1. Classification of Landslides suggested by Varnes (1978)

Type of movement			Type of material		
Bedrock			Engineering soils		
			Predominantly coarse	Predominantly fine	
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	Rotational	Few units	Rock slump	Debris slump	Earth slump
	Translational	Many units	Rock block slide	Debris block slide	Earth block slide
Lateral spreads			Rock slide	Debris slide	Earth slide
			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow	Earth flow (soil creep)
Complex			Combination of two or more principal types of movements		

Table 1. Classification of Landslides suggested by Varnes (1978).

Disturbances and Species Loss

Different kinds of disturbances, such as fire, landslides, flooding, grazing among others change the biological organization of ecosystems. "Disturbances play a crucial role in maintaining biotic diversity" (Darwin 1859). Species evolve a diverse spectrum of abilities relative to disturbance (Vogl 1974). After a particular disturbance, some species increase in number or invade, while others decrease or retreat (Walker *et al.* 1999). Dominant and minor species can occur in the same functional group and can be similar with respect to their contribution to ecosystem function. Dominant and less dominant species switch in abundance under changing environmental conditions allowing "functional stability".

Latin America has the largest extend of all tropical forest (Whitmore 1997), but also the highest deforestation rate, with approximately 32 million ha or 0.96%/yr. Plant diversity in the Ecuadorian Andes is considered extreme with a high degree of endemism (Lozano *et al.* 2003; Lozano & Bussmann in prep), probably due to the composition of different lineages, and also influenced by

environmental as well as geographic factors (Richter 2003). Many mountain plant species are restricted to narrow and specific elevation ranges (Young 1994), allowing explosive radiation as reported by Gentry (1982) and Jost (2004). The best examples are the narrow altitudinal belts of the "San Francisco Reserve" in the elfin forest, where Bussmann (2002) reports an extremely diverse community complex. Disturbance in areas with such speciation conditions affects a whole "micro-ecosystem" and requires "complex" processes to recover again.

During the last decades, tropical American forests are rapidly altered and disappearing, with logging statistics showing a loss of 2.6 millions ha/year. Their extreme biodiversity richness is changing and high species loss occurs, with long term effects difficult to predict.

No data exist on the exact deforestation rate in Ecuador. Data suggest a forest loss to deforestation of 136.000 to 340.000 ha/year (FAO 2001). South Ecuador does not show a very high rate of deforestation because most of the logging is concentrated in the North and West of the country. A high amount of logging occurs however in the South as well.

Succession

Succession of vegetation usually follows natural and anthropogenic processes. The term succession is used to describe many types of vegetation changes on widely different scales in both space and time (Finegan 1984). Earliest studies describe the sequence of species that successively invade a site (Cooper 1913), show changes in Biomass, productivity, diversity and niche (Odum 1969), while others have focused on physical stresses to plants and competition for resources between plants as the main mechanisms determining the course of succession (Colinvaux 1973). Therefore competitive interactions with herbivores, predators, and pathogens are of critical importance to the course of succession (Connell & Slatyer 1977). The high primary net productivity of successional ecosystem can support large animal populations (Linares 1976), hence such standing patch interaction serve as important nuclei of species establishment during succession process.

Factors of the physical environment (light, temperature, soil, relative humidity) trigger ecophysiological responses, for example seeds of pioneer species in soil seed banks take advantage of disturbance enhancing the optimal conditions of early successional plants. Few data and comparative studies of fragmented ranges exist (Young 1994). Distribution and size of patches probably reflect seed dispersal more than site differences (Ewel 1983). Other considerations on succession are described by Richter (2003), specifically for Southern Ecuador. There, climatic conditions, mainly humidity and physiography of mountain chains, depict micro-site and environments varieties. These, combined with regimens of frequent and different sized disturbance, especially "landslides", can be considered optimum spots for a high rate of genetic exchange as consequence of micro-geographic niche partitioning.

Succession is important for two reasons: the value of the concept in the development of ecology as a science and its enormous potential in the development of programs for the conservation and exploitation of biological resources (Richards, 1976 cited in Finegan, 1984).

The pioneer vegetation on landslides in South Ecuador shows often a high number of species. Fifty six families, 127 genera and 264 species were found on natural landslides, while man-made landslides had 69 plant families, 127 genera and 313 species (Lozano & Bussmann 2005).

Anthropogenic Disturbance and Economical Significance

From an engineer point of view, mountains offer very difficult conditions for road construction and maintenance (Young 1994). Because road maintenance is politically unattractive compared to the establishment of new roads, minimal efforts are made to maintain existing infrastructure. The socio-economical expenses after "landslides" triggered by road construction have been studied in St. Vincent, St. Lucia and Dominica, where the average annual cost for landslide damage to roads range from \$115,000 to \$121,000 in normal years (De Graff *et al.* 1989). The average annual cost of landslide investigation, repair and maintenance in the larger islands of Trinidad and Tobago are \$1,26 millions and \$0,96 millions, respectively. In an average year the cost of repairing landslide damage to roads throughout the Caribbean amounts to \$15 million. Ericksen *et al.* (1989), indicate that in the central and southern Andes the average annual property damage is on the order of few millions to several tens of millions of dollars. Major landslides, which occur at 5- to 10-year intervals, may however cause property damage of hundreds of millions of dollars, in addition to personal insurance claims involved.

Stern (1992) describes how earthquakes caused a nationwide socio-economic tragedy and environmental disaster on Mach 5, 1987 in Northeastern Ecuador. Thousands of human lives and countless homes were lost in the aftermath of landslide and floods, Chávez and Lara (1989) estimate 400000000 m³ of debris material and Figueroa *et al.* (1987) reported up to 6000000000 m³ of

landslide-related silt and debris was deposited in and transported downstream by the Aguarico and Coca rivers. Thirty-three km of the trans-Ecuadorian oil pipeline and 45 km of the natural gas pipeline were destroyed, and it took eight month repair the damage. Benitez (1989) reports that a landslide near Chunchi 1983 blocked the Pan American Highway, seriously damaged homes, and a loss of 150 lives was the final result of this tragedy. The social economic impact related to cattle-raising and agriculture activities, without considering life insurance claims, exceed \$4 millions on the past decade. In southern Ecuador "landslides" continuously damage roads, especially on the way to Zamora and Valladolid. This has led to serious disasters and large economical expenses.

Conclusions

Landslides at the Ecuadorian Andes are wide-spread, because of unstable slopes combined with environmental conditions as well as inappropriate road construction and other anthropogenic factors. Millions of dollars have been expended during the lasts decades in the mitigation of landslides hazards in Ecuador alone. The disturbance of watersheds still continues, without any mitigation plan or conservation measures, and no strategies for forest preservation and restoration are included in the national policy.

In cloud forests succession of gaps starts with a slow cover of mosses and other cryptogams, followed by herbs, shrubs and trees arriving in the final stages. Many mountain plant species are restricted to narrow and specific elevation ranges. The species richness in southern Ecuador indicates high amount of pioneer plants in regeneration. It is however still not sufficiently understood if perturbations act as a motor for the maintenance of biodiversity.

Fragmentation by natural and anthropogenic disturbance regimens, especially landslides in the Ecuadorian Andes, seems usually to be linked to legal and economical factors. Policy evaluations need to include criteria such as social requirements, and tools of environmental management must be applied to a constant landslide mitigation plan effort maintain biodiversity.

Acknowledgements

We thank the **German Science Foundation (DFG) for support of this project** (DFG FOR 402-1/1 TP7 and FOR 402-2/1 A2, as well as the National University of Loja, Department of Botany and Ecology, Herbarium LOJA.

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