Master of Science Thesis

Human disturbance on *Polylepis* mountain forests in Peruvian Andes

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ABSTRACT

Mountains occupy about 20–25 % of the global land surface and are estimated to contain approximately 28 % of the world's forest. Mountain forests are valuable in many ways: they offer variety of ecosystem services and products, possess different habitats and great species richness. To optimize conservation activities and efforts scientists have defined hotspot areas that contain high proportion of endemic and endangered species. Human disturbance affects the natural state of ecosystems and is a significant threat to species living in these areas. In addition, fragmentation of ecosystems, patch size and edge effects can influence species richness and extinction rates. The eastern slopes of the Andes form one of the world's biodiversity hotspot areas. *Polylepis* forests that grow on the slopes of Andes form one of the highest tree lines in the world. They are an important habitat for many endemic species. These forests also have a major role in the water cycle of the Andes and they protect the ground from erosion. *Polylepis* forests have likely been under human pressure for thousands of years. Only 3 % of the potential forest cover remains in Peruvian Andes. Also the quality of forests has decreased. From about 30 *Polylepis* species approximately half is classified as vulnerable. It has been estimated that grazing, burning of pastures and logging are the biggest threats for the *Polylepis* forests. In this study the aim was to find out which form of human disturbance is the principal threat to these forests in the area of the mountain chain of Vilcanota, located in Cuzco area, Southeastern Peru. It was also studied if the amount of human disturbance differed between small and large forest patches or between forest edge and interior. In addition it was studied if the amount of human disturbance differs in forest patches depending of forest characteristics. Last was studied if regeneration or structure of forest differed in forest patches according to the amount of human disturbance. Five study areas were chosen that each had one small and one large forest patch. In each forest patch one study plot was placed on the edge and one in the interior of the forest. Variety of different marks of grazing, fire and logging were observed. Basic information was also collected from forest structure and characteristics. I found out that grazing pressure on the ground and logging were the two most visible forms of human disturbance in the area. Grazing pressure on the ground was mainly low but percentage of totally logged trees was 20 % or more from the original tree cover on half of the study plots. Based on my results logging formed the biggest threat. In general these forests could benefit if the harvesting of wood material would be restricted.

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TIIVISTELMÄ

Vuoristot kattavat 20–25 % maapallon pinta-alasta ja niiden alueella kasvaa noin 28 % maapallon metsistä. Vuoristometsät ovat monella tapaa arvokkaita: ne tarjoavat useita ekosysteemipalveluita ja raaka-aineita sekä sisältävät suuren määrän elinympäristöjä ja eliölajeja. Ne ovat kuitenkin myös erittäin haavoittuvaisia. Resurssien optimoimiseksi tutkijat ovat nimenneet maapallolta hotspot-alueita, joilla esiintyy suuri määrä endeemisiä ja uhanalaisia lajeja. Ihmistoiminta vaikuttaa ekosysteemien luonnolliseen tilaan ollen merkittävä uhka hotspot-alueiden lajeille. Lisäksi ekosysteemin pirstaleisuus, laikun koko ja reunavaikutukset voivat vaikuttaa alueen lajirunsauteen ja sukupuuttovauhtiin. Andien itärinteet muodostavat yhden maailman biodiversiteetin hotspot-alueista. Niiden rinteillä kasvavat *Polylepis*-metsät muodostavat yhden maailman korkeimmista puurajoista. Ne ovat tärkeitä elinympäristöjä monille endeemisille lajeille. Metsillä on myös merkittävä rooli Andien vedenkierrossa ja ne suojaavat maaperää eroosiolta. *Polylepis*-metsät ovat todennäköisesti olleet tuhansia vuosia ihmisvaikutuksen alaisena. Nykyään *Polylepis*-kasvillisuus kattaa enää vain 3 % potentiaalisesta alueesta Perun Andeilla. Myös metsien laatu on heikentynyt. Noin 30 *Polylepis*-lajista puolet on luokiteltu vaarantuneiksi. *Polylepis*- metsien suurimpia uhkia on arvioitu olevan karjanlaidunnus ja laidunten poltto sekä metsien hakkuu. Tämän tutkimuksen tarkoitus oli selvittää mikä näistä tekijöistä vaikuttaa merkittävimmin Perun Cuscon alueella sijaitsevan Vilcanota-vuoriston *Polylepis*-metsiin. Tutkimuksessa selvitettiin myös eroaako ihmishäiriön määrä pienten ja isojen metsälaikkujen tai metsän reunan ja sisäosan välillä. Lisäksi selvitettiin eroaako ihmisvaikutuksen määrä metsän ominaisuuksien mukaan. Lopuksi tutkittiin eroaako metsälaikkujen uusiutuminen ja rakenne ihmishäiriön mukaan. Tutkimukseen valittiin viisi eri aluetta, jolta kultakin valittiin pieni ja iso metsälaikku. Jokaiseen metsälaikkuun tehtiin yksi koeala reunalle ja yksi metsän sisäosaan. Koealoilta havainnoitiin useita laidunnuksen, polton ja metsänhakkuun merkkejä. Myös perustietoa metsän rakenteesta ja ominaisuuksista kerättiin. Ihmisvaikutuksen muodoista merkittävimmin alueella näkyi karjan laidunnuksen vaikutus maanpintaan sekä puuaineksen keruu. Karjanlaidunnuksen vaikutus maanpintaan oli pääasiassa vähäinen, mutta hakattujen puiden määrä alkuperäisestä puustosta oli 20 % tai enemmän puolella koealoista. Tuloksieni perusteella hakkuu muodosti suurimman uhan *Polylepis* metsille. Kaiken kaikkiaan metsät voisivat hyötyä puumateriaalin käytön rajoittamisesta.

Contents

1. INTRODUCTION

Mountains occupy about 20-25 % of the global land surface and are estimated to contain approximately 28 % of the world's forest (Meybeck et al. 2001, Price 2007, Kapos et al. 2000 qtd. Price & Butt 2000). Mountain forests are in many ways unique and important environments. Mountain regions sustain remarkable variety of habitats and mountain forests are often hotspots of biodiversity, especially in tropics (Agenda 21 1992, Fjeldså & Kessler 1996, Jeník 1998, Atta-Krah & Ya 2000, Stepp et al. 2005, Price 2007, Gradstein et al. 2008). This is due to special physical and environmental characteristics of mountains. Already over a short distance great differences may occur in ecological conditions like altitude, climate, soil and vegetation (Agenda 21 1992, IUCN 2004). In many cases mountain ecosystem are seen as isolated patches surrounded by different matrix which can impede the dispersal of species (Ricketts 2001, Gustafson & Gardner 1996, Brown 1971). Because of isolation and habitat variety mountains harbor many endemic species found nowhere else on earth (Chaverri-Polini 1998). Mountain forests offer a great variety of ecosystem services and products and they are important due to their biological, ecological, economical, recreational, spiritual ethical and cultural values and because of the value they have for tourism (Miller 1998, Atta-Krah & Ya 2000, Price & Butt 2000, Gradstein et al. 2008). They slow down water runoff from the glaciers and capture and maintain rainfall and melt water by absorbing and storing water in soil and in forest biomass (Fjeldså & Kessler 1996, Gradstein et al. 2008). Mountain forests also protect the soil from erosion and reduce the amount of sediment leaching into water systems (Fjeldså & Kessler 1996, Price & Butt 2000). Forests improve soil fertility by replenishment and provide fodder for livestock as well as energy in a form of fuelwood which are highly important ecosystem services to mountain-inhabiting people (Miller 1998, Price & Butt 2000). Mountain forests can also operate as sanctuaries for species driven to extinction by human activity or climate change from the low-elevation areas as well as facilitate distribution of species in a form of ecological corridors (Miller 1998, Price 2007). Slope and altitudinal gradients make mountain habitats especially vulnerable to climate change and erosion and usually they need very long time to recover from heavy losses of vegetation and soil (Meybeck et al. 2001, Miller 1998). However mountain forests near the equator are being fragmented and the area of these forests has reduced (Gradstein et al. 2008). The United Nation Conference on Environment and Development (UNCED), held in Rio de Janeiro 1992 raised mountain ecosystems in the consciousness of people through Agenda 21. Agenda 21 is entitled "Generating and strengthening knowledge about the ecology and sustainable development of mountain ecosystems". According to UNCED Agenda 21 "mountain environments are essential to the survival of the global ecosystem". However they are under great pressure and rapidly changing. Loss of habitats and genetic diversity, landslides, accelerated rate of soil erosion as well as poverty of mountain inhabiting people is threatening mountain ecosystems and most mountain ecosystems are degraded in consequence.

To be able to optimize conservation activities and efforts scientists have defined areas that contain high proportion of endemic species as well as species whose existence is in great danger mostly because of human activities (Cincotta et al. 2000, Myers et al. 2000). These 25 areas are called biodiversity hotspots and most of them are situated near the equator (Mittermeier et al. 1998, Myers et al. 2000). Predominant habitats in these hotspots are tropical forests (Myers et al. 2000). For example 44 percent of world's vascular plants and 35 percent of terrestrial vertebrates can be found at these 25 hotspots. The aim of defining these areas is to be able to direct available resources for conservation in a way that most of the world's species could be conserved with as small efforts and resources as possible. Many of these hotspot areas are under severe threat (Mittermeier et al. 1998). Human population density is usually high in these hotspot areas which can multiply the rate of human pressure on these areas (Burgess 2007, Fjeldså & Burgess 2008). To be able to tackle mountain forest conservation issues efficiently, complex combination of economic, political, and demographic factors should be taken under consideration (Cincotta et al. 2000, Price & Butt 2000).

1.1. Patch size, habitat fragmentation and edge effects

Island biogeography model by MacArthur and Wilson (1967) describes the factors that affect the species richness of an island. Island is a separate unit from its surroundings. There is a wide diversity between islands as they vary in size, shape, degree of isolation and ecology. Larger area of an island has thought to be able to sustain grater amount of species because it usually also seals in a greater variety of different habitats than small islands. Another major factor influencing to islands species richness has thought to be islands distance to main land, the islands rate of isolation. The closer the island is the main land, the easier it is for an organism to colonize it and correspondingly the greater is the species richness. The colonization rate of an island that is large and / or close to the main land is greater than of an island that is small and / or far from the main land. Correspondingly the extinction rate is grater when the island is small and / or far from the main land than it is when island is large and / or close to the main land. According to MacArthur and Wilson (1967) small islands that contain smaller populations and smaller amount of available habitats are more prone to local extinctions than large ones. Later island biogeography model has not been applied only to the islands but also in different kind of habitat patches.

Wilcove et al. (1986) define habitat fragmentation as a process during which: “a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original”. Species react in a different way to the habitat fragmentation (Laurance 2008). Some species decline fast while others remain quite stable and yet others even become more abundant. Habitat loss and fragmentation can both be factors behind extinctions and often it is hard to separate impact of these factors because of covariance. According to Rybicki & Hanski (2013) habitat fragmentation is very harmful for the long term persistence of species in cases where only small proportion of total habitat remains. Fragmented forests are also prone to fires (Cochrane & Laurance 2002).

Laurance (2008) points out that in addition to the factors presented in island biogeography model there are several other factors that affect the species richness and extinction rate of a fragment, like edge effects. According to the definition made by Laurance (2008) “Edge effects are diverse physical and biological phenomena associated with the abrupt, artificial boundaries of habitat fragments”. On the edges there may be different factors that change the living conditions or cause disturbance that does not exist at all or in the same scale in the interior of the patch (Burkey 1993, Laurance 2008). For example edge effects may refer to the effects as proliferation of light tolerant plants, changes in microclimate and lighting conditions that have an influence on seedling germination and survival on the edge of patch (Laurance 2008). In history edges or transition zones between different ecosystems were seen beneficial to biodiversity (Lay 1938, Leopold 1933). However, later on many scientists have concluded that edges have many unfavorable characteristics as a habitat (Harris 1988). According to Laurance (2008) edge effects can be a major factor causing local extinctions and ecosystem change. In a study carried out by Burkey (1993) was found out that seed predation rate was higher in the edges than in the interior part of a forest. Instead Laurance et al. (1997) discovered that in Amazonian rain forest fragments tree mortality increased near the forest edges because of the changes in microclimate and elevated wind conditions. According to Cochrane & Laurance (2002) fire can also operate as edge effect. Fire usually originates in the surrounding pastures from where it proceeds to forest edges and further into fragment interiors. Quality of the forest patch matrix can also have an influence on the regeneration of a forest patch. If characteristics of a forest patch matrix differ greatly from the characteristics of forest patch it can reduce the regeneration of a forest on the forest edge (Gascon et al. 2000). In this case edge effects can penetrate further into the forest interior and it may lead to expanded alterations in vegetation on the forest edge when forest species are replaced by simpler vegetation. This in turn may lead to diminution of the area of forest patch or even to disappearance of the forest fragment.

1.2. Human disturbance and its consequences on tropical mountain forests

White and Pickett (1985) define disturbance as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability, or the physical environment". Disturbance can be divided into two categories: natural disturbance and human disturbance. Natural disturbance as for example landslides, storms and lightning strikes cause death of organisms in their ecosystems (Connell 1978). Death of an organism creates free space in ecosystem which gives an opportunity to new organisms to gain living space. Scales of frequency and intensity of disturbance differ. The intermediate disturbance hypothesis suggests that an ecosystem maintains the highest biodiversity at intermediate scales of disturbance. Respectively the biodiversity is thought to be lower in both extremes; when the disturbance is nonexistent or if its intensity and frequency is low or on the other hand when the frequency and / or intensity of the disturbance is high. Land use processes, however, are a form of human disturbance that creates a different kind of pressure to the ecosystem than natural disturbance processes (CEES 1990). According to FAO (2002) agriculture and forestry cause the biggest human pressure on terrestrial ecosystems. Human disturbance decreases the area of pristine environment and cause fragmentation of natural habitats (FAO 2002). It alters ecosystem processes such as trophic structures, energy flow, chemical cycling, and natural disturbance processes. In addition, human population has altered Earth’s surface by replacing original biomes with urban and agricultural ones (Foley et al. 2005). According to Laurance (2008) habitat conversion by humans is highly nonrandom process. Accessibility as closeness of the road or human settlement of an area is a matter of high importance (Laurance 2008, Toivonen et al. 2011). “Because of the nonrandom clearing, habitat remnants are often a highly biased subset of the original landscape. Remnants frequently persist in steep and dissected areas, on poorer soils, at higher elevations, and on partially inundated lands” (Laurance 2008). Human disturbance alters fragment sizes and decreases biodiversity especially when some species become extinct (FAO 2002, Mladenoff et al. 1993). Environmental change has occurred mainly after two major events in human history: the agricultural revolution approximately 10, 000 years ago and the industrial revolution in mid-1700s (Miller 1998). Currently more than half of the worlds remaining mountain forests are under direct threat because of conversion to agricultural land, logging and meeting energy needs (Atta-Krah & Ya 2000).

12 percent of global human population inhabits mountain areas, majority in developing and transition countries (Price & Messerli 2002, Huddleston et al. 2003, Mowo et al. 2007). In some mountains human population density is high and increasing fast (Atta-Krah & Ya 2000, Mowo et al. 2007). In general South American mountains are usually sparsely populated and falsely thought to represent pristine environments (Ellenberg 1979). In Peru 47 % of population lives in mountains (Huddleston et al. 2003). Mountain-inhabiting people consist of people from different social classes and they form different

kind of communities (Price 2007). Some of the people live in rural communities and others in urban cities or tourist communities. However, the majority of the human population in the mountains is composed of people living in rural communities who rely on the natural resources of land, forests and water for their livelihood (Huddleston et al. 2003, Mowo et al. 2007). Also in Latin America little more than half of the mountain population lives in rural areas (Huddleston et al. 2003). Poverty is generally moderate in the lower areas but becomes extensive and severe at higher elevations. According to Huddleston et al. (2003) majority of rural mountain people are linked to agricultural activity for their livelihood and it seems that agricultural resource base continues to be highly important source of livelihood also in future. Grazing and forestry are predominant uses of mountain land in all regions of the world. In Central and South America mixed land use practices (growing crops, livestock grazing and exploitation on forest resources) are typical to mountain people living between 2,500–3,500 m.

1.2.1. Herding

Especially at higher elevations in developing and transition countries livestock herding is the main form of livelihood (Huddleston et al. 2003). This pastoral farming system depends on extensive grazing methods that can support 25 persons per km^2 at the most. In many areas where people rely mainly on grazing for their livelihood this critical number has already been reached or surpassed which explains why environmental degradation occurs in many pastoral areas in mountains. Effects of livestock grazing can be hard to detect in nature because grazing has had at least some kind of effect on majority of areas and natural state of an area can no longer be seen (Fleischner 1994). Fleischner (1994) listed three ways how grazing of livestock can influence ecology of certain area: 1) Alteration of species composition of communities, 2) disruption of ecosystem function and 3) alteration of ecosystem structure. Proulx and Mazumder (1998) observed that in nutrient-poor ecosystems species richness declined under high grazing. They suggested that it is due to limitation of available resources that prevents re-growth of species after grazing. They also observed that forage production and ecological condition decreased under heavy stocking and increased under light stocking. Number of animals and grazing intensity are important factors when studying the ecological effects of grazing (Holechek et al. 1999). For example, Marquardt et al. (2009) discovered that the amount of completely browsed tree seedlings by cattle increased under high stocking density when compared to low stocking density. However, it seemed that browsing was seldom the reason for fatal damage. Marquardt et al. (2009) speculated that trampling or up-rooting might cause fatal damage to trees. Kozlowski's (1999) field experiments showed that severely compacted forest soil affected stand regeneration by inhibiting seed germination and seedling growth and by increasing seedling mortality. Blackhall et al. (2008) observed that seedlings and saplings of some tree species were reduced in size and deformed under grazing pressure.

Sometimes pastoral activity may also lead to overgrazing of pastures (Tivy 1990). Overgrazing occurs when certain area is grazed too intensively. These areas are especially prone to erosion and overgrazing may convert pastures to less productive semi deserts or deserts (Tivy 1990, Miller 1998). At the Andean region Spaniards introduced cattle and sheep and they are now favored in animal husbandry (Fjeldså & Kessler 1996). In the region cattle and sheep are an indicator of wealth and that is why many highlands are overstocked and cause a strong erosion of the landscape. Renison et al. 2010 studied how livestock and topography influence patterns of forest cover, soil compaction, soil loss and soil chemical properties on forested mountain areas in South America. Their results supported the hypothesis that degradation of forests and their soils was in part triggered by domestic livestock rearing.

1.2.2. Use of fire

Controlled burning of range lands is particularly characteristic of pastures of Australia and South America (Harris 1980 qtd. Tivy 1990). The use of fire gives an advantage to fire tolerant plant species. This favors herbaceous species (especially grasses) at the expense of woody forms (Tivy 1990). Fire can also favor other tree species at the expense of others and change the species composition of an area (Veblen 1985). Fire and / or grazing can inhibit tree growth and regeneration in woodland and forest ecosystems (Veblen 1985, Fjeldså & Kessler 1996, Nepstad et al. 1999). Especially burns during the period of early rains affect scrub and tree growth (Fjeldså & Kessler 1996). Continuing burning and overgrazing may lead to formation of unproductive vegetation. Blackhall et al. (2008) found evidence that cattle browsing might affect tree species structure of regenerating forest after natural or human induced fire. Overburning may occur when the intensity of burning is too high (Tivy 1990). Recovery from overburning can be slow and unsure because of grazing pressure and / or the escalation of erosion. Burning of forest also releases carbon stocks to the atmosphere (Nepstad et al. 1999).

1.2.3. Logging

Forest can be classified as renewable resources if used sustainably (Miller 1998). It means that forests are not harvested or degraded more frequently than they can regenerate and recover. Since agricultural activity began human activities have reduced, fragmented and degraded the earth's forest cover. FAO's forest resources assessment in 1990 showed that tropical upland forests were disappearing at a greater rate than in any other forest biome, by 1.1 % per year (FAO 1993). Many tropical forests are being cleared for timber, grazing land, and conversion to farmland (Atta-Krah & Ya 2000, Miller 1998). In addition, charcoal making and fuelwood usage is typical to developing countries (Mowo et al. 2007). In mountain households fuelwood remains the main source of energy for cooking and heating (Atta-Krah & Ya 2000, Rijal & Bhadra 2001). The heavy dependence on fuelwood is further worsened by the low level of efficiency on utilization of these fuels (Rijal & Bhadra 2001).

Logging can affect the species composition and favor other tree species and their regeneration at the expense of others (Veblen 1985). Logging and fuelwood collection can degrade forest quality even when the area of the forest maintains the same (World Bank 2008). It can also degrade forest productivity, structure, biomass and species composition (Nepstad et al. 1999, Foley et al. 2005, World Bank 2008, Toivonen et al. 2011).

1.2.4. Soil erosion

Erosion is a process where soil components are eroding away from certain land area (Miller 1998). It affects the most on surface litter and topsoil layer. Soil erosion can be separated in two main types, water and wind erosion (Tivy 1990, Miller 1998) Most of soil erosion is caused by water and there are three distinguishable types of water erosion: Sheet erosion, rill erosion and gully erosion (Miller 1998). Soil erosion is a natural process but it can be speeded up by human activity when natural or semi natural vegetation cover is removed (Tivy 1990, Miller 1998). According to Miller (1998) and Tivy (1990) farming, logging, construction, overgrazing by livestock, deliberate burning of vegetation and other activities that destroy plant cover leave soil vulnerable to erosion because plant roots have an important role in anchoring the soil and preventing soil particles from moving. Such human activities can destroy the topsoil layer of certain land area in few decades and turn it into unusable wasteland even tough nature took hundreds to thousands of years to produce it (Miller 1998). According to Miller (1998) in tropical and temperate areas it takes up to hundreds of years for a couple of centimeters of new topsoil to form. When topsoil erodes away faster than it forms, it can no longer be considered as renewable resource. Erosion of topsoil makes a soil less fertile and decreases its ability to hold water. Respectively water system is encumbered by eroding soil particles which may lead to flooding and fish mortality. Espigares et al. (2009) found out that soil seed density was lower in highly eroded slopes. They also suggest that higher soil erosion rates imply a reduction in seedling emergence.

1.3. Andean *Polylepis* forests

The Andean mountains are located in the western part of South America where they pass through the continent in north-south direction. Peru is situated in the southern hemisphere, western part of South America, in one of the most significant global biodiversity hotspot areas (Myers et al. 2000). The Andes form almost the half of the land surface of Peru (Huddleston et al 2003). *Polylepis* species are evergreen tree species that exist in the Andean region (Schmidt-Lebuhn et al. 2006). The area of Cuzco, Peru is regarded as one of the most species rich areas for *Polylepis* species, with six species of *Polylepis* recorded in the area (Fjeldså & Kessler 1996). The genus has evolved and diversified during the uplift of the Andes in Plio-Pleistocene from lower mountain forest form towards high-Andean specialists (Simpson 1986; Kerr 2003; Schmidt-Lebuhn et al. 2006). *Polylepis* trees can reproduce vegetatively or by seeds (Hagaman 2006). Currently *Polylepis* species grow in fragmented patches forming tree lines at almost 5,000 m in Central Andes (Fjeldså & Kessler 1996, Toivonen 2014). In this zone *Polylepis* trees are the only tree species that form forest-like vegetation (Fjeldså & Kessler 1996). Forest patches are usually surrounded by low grass, scrub or rock (Fjeldså & Kessler 1996, Gareca et al. 2009). Each of the forest patches is usually dominated by one or two *Polylepis* species (Fjeldså & Kessler 1996). *Polylepis* forests have probably been under human pressure for thousands of years (Ellenberg 1979). For example Renison et al. (2006) found evidence of fire from 70 % of the study plots and signs of livestock from almost all the plots they studied in *Polylepis* forests in mountains of Central Argentina, in spite of the low number of human settlements. It is estimated that from potential forest cover of *Polylepis* only 10 % remains in Bolivia and respectively 3 % in Peru (Fjeldså & Kessler 1996). Moreover, the quality of remaining forests has observed to reduce in last decades (Jameson & Ramsay 2007). From about 30 *Polylepis* species approximately half is classified as vulnerable (Schmidt-Lebuhn et al. 2006, IUCN 2013). Nowadays, *Polylepis* forest patches cover typically couple of km^2 while one of the largest patches known covers the area of 60 km^2 (Fjeldså & Kessler 1996). *Polylepis* forests can be considered as key ecosystems in the Andes because they are vital habitats for variety of plant and animal species, some of them which are rare and endemic (Fjeldså 1993, Fjeldså & Kessler 1996). In general there is usually high biodiversity in these forests (Fjeldså & Kessler 1996).

Peruvian highlands of the Andes have been densely populated for thousands of years (Fjeldså & Kessler 1996). The altitudinal region between 3,500 – 4,000 meters above the sea level is intensively cultivated and used for grazing. *Polylepis* forests are highly important to the Andean people. These forests store water, slow down surface water runoff and protect soil from erosion (Fjeldså & Kessler 1996, Fjeldså 2002, Hagaman 2006). Forests are the only source of timber, fuel wood and charcoal at high altitudes and they also act as a source of medicinal components and non-timber products (Fjeldså & Kessler 1996). They are also used for livestock grazing and they protect humans and animals from high solar radiation (Fjeldså & Kessler 1996, Hagaman 2006). In addition, *Polylepis* forests are connected to the culture and traditions of local people (Fjeldså & Kessler 1996). However, it is estimated by Fjeldså & Kessler (1996) that combined effect of grazing and burning of pastures is the biggest threat for the *Polylepis* forests and their regeneration. Fjeldså & Kessler (1996) and Fjelsdså (2002) have also pointed out that logging and charcoal burning are the most visible forms of human disturbance in *Polylepis* forests.

1.4. Objectives of the study, research questions and hypothesis

Objective of this study was to untangle the anthropogenic factors that have the most severe impact on the persistence of *Polylepis* forests in the area of the mountain chain of Vilcanota, in Cuzco area, Southeastern Peru, so that in the future the exploitation of these forest resources could be directed and carried out in a way that minimize the threat to the existence of these species.

Specifically, my aim was to find out:

- which form of human disturbance (livestock grazing, burning of pastures, logging) is the principal threat to the existence and regeneration of *Polylepis* forests.
- does the amount of human disturbance differ between small and large forest patches or between forest edge and interior part of the forest.
- does the amount of human disturbance differ in forest patches depending on forest characteristics (tree density, elevation, slope).
- does the regeneration or structure of forest differ in forest patches according to the amount of human disturbance

My hypotheses were: 1) Human disturbance is more severe in small forest patches than in large forest patches. 2) Human disturbance is more severe on the edge of forest patch than in the interior part of forest patch. 3) The effect of human disturbance decreases with increasing density, elevation or slope of the forest patch due to decreased accessibility. 4) There is a smaller amount of saplings in forest patches where grazing pressure is high than in forest patches were grazing pressure is lower. 5) Forest density, number of saplings, mean tree height and mean diameter are lower in the patches of high logging pressure in comparison to the patches of lower pressure.

2. MATERIAL AND METHODS

2.1. Study species

I studied two different species of *Polylepis*: *Polylepis subsericans* and *Polylepis racemosa*. *P. subsericans* is endemic to central Peru, specifically for the area of Cuzco (Fjeldså & Kessler 1996). It is found at the elevation range between ca. 4,200–4,900 metres above sea level (masl), where it forms one of the highest tree lines globally (Toivonen 2014). Trees can grow up to 13 m tall only few hundreds meters below the tree line (Kessler et al. 2014). *P. racemosa* is widely distributed from northwestern Bolivia to the northern Peru, and can grow up to 20 m tall (unpublished data of J. Toivonen). There might be large inter-specific variation in appearance among *P. racemosa* individuals, especially between different regions (Fjeldså & Kessler 1996). In Peru *P. racemosa* grows on slopes in the range between 2,900–4,100 masl. In my study area, *P. racemosa* stands are found below the *P. subsericans* stands, without much overlap in elevation ranges with *P. subsricans*. The nomenclature and species division follows the identification of Kessler and Schmidt-Lebuhn (2006). Number of leaflets is one of the key characteristics in identification (Fjeldså & Kessler 1996) (Figure 1 & 2).

IUCN (2013) has evaluated both species as vulnerable. That means that species are "facing a high risk of extinction in the wild in the medium-term future". *P. subsericans* is listed as vulnerable in categories A1acd and B1+2c. It means that there is “an observed, estimated, inferred or suspected population reduction of at least 20 percent over the last 10 years or three generations, whichever is the longer, based on direct observation, a decline in area of occupancy, extent of occurrence and/or quality of habitat and actual or potential levels of exploitation. Also extent of occurrence is estimated to be less than 20,000 km^2 or area of occupancy is estimated to be less than 2,000 km^2. The estimates are indicating severely fragmented population or the species is known to exist at no more than 10 locations and continuing decline, inferred, observed or projected, in area, extent and / or quality of habitat”. *P. racemosa* is listed as vulnerable in category A1c. It means that there is “an observed, estimated, inferred or suspected population reduction of at least 20 percent over the last 10 years or three generations, whichever is the longer, based on a decline in area of occupancy, extent of occurrence and / or quality of habitat”.

Figure 1. The blade of *P. subsericans* leafs is divided into three leaflets. Photo © A. Raudaskoski.

Figure 2. In the study area the blade of P. racemosa leaf is divided at least into five leaflets. Photo © A. Raudaskoski.

2.2. Study area

This study was carried out in the Cordillera Urubamba, which belongs to the mountain chain of Vilcanota in Cuzco region, Peru. Cordillera Urubamba is located in the northern side of the Urubamba River. Five study areas were chosen: Qosqoqahuarina, Willoq, Choquechaca, Mantanay and Cancha Cancha (Figure 3). Most of the study sites were selected according to Toivonen et al. (2011) so that time was not wasted in locating the sites. Additional sites were chosen based on the expert opinion given by the local non-governmental conservation organization Ecosistemas Andinos which operates in the region.

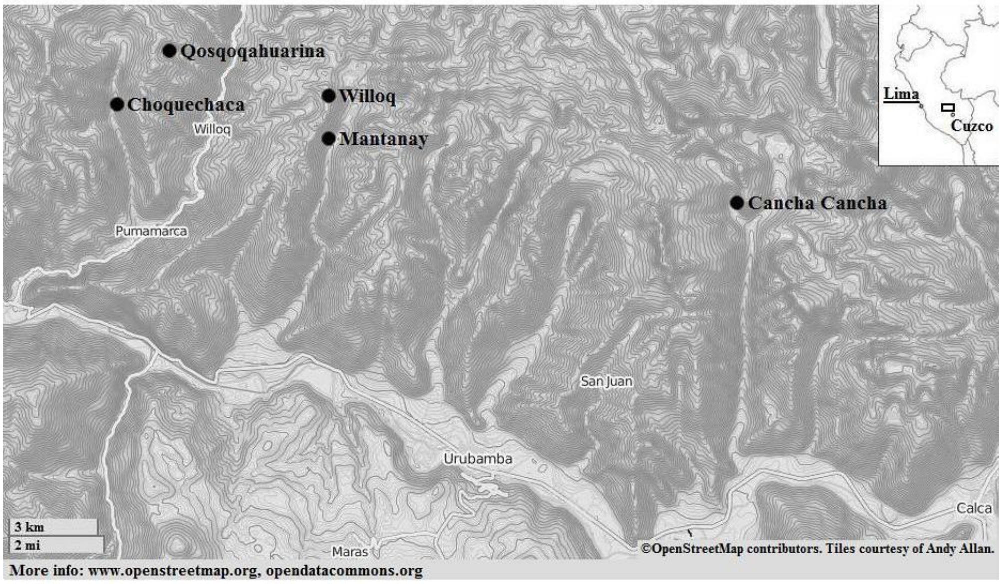

Figure 3. Location of five study areas in the mountain chain of Vilcanota in Cuzco Region, Peru.

2.3. Study design and data collection

The field work was carried out during June-August in 2012. Two forest patches were chosen from each of the five study areas. Forests were selected in a way that they represented small and large forest patches (Figure 4 & 5). Two study plots were established in each forest patch. One of the two study plots was placed in the edge of the forest patch and the other in the interior part of the patch. In this way it was possible to study if the amount of human disturbance differed according to forest patch size or study plot location (edge / interior). In total, there were 20 study plots in the five study areas. Study plots were situated between 3,924–4,495 masl (Table 1).

Figure 4. Small forest patch in Cancha Cancha. Photo © A. Raudaskoski.

Figure 5. Part of the large forest patch in Choquechaca. Photo © A. Raudaskoski.

Table 1. Study plot information.

Number of study plot	Name of the study area	*Polylepis* species	Forest patch size	Place of plot	Elevation (m)
1	Qosqoqahuarina	*P. subsericans*	small	edge	4,418
2	Qosqoqahuarina	*P. subsericans*	small	interior	4,412
3	Qosqoqahuarina	*P. subsericans*	large	edge	4,432
4	Qosqoqahuarina	*P. subsericans*	large	interior	4,448
5	Willoq	*P. subsericans*	small	edge	4,466
6	Willoq	*P. subsericans*	small	interior	4,495
7	Willoq	*P. subsericans*	large	edge	4,410
8	Willoq	*P. subsericans*	large	interior	4,439
9	Mantanay	*P. subsericans*	small	edge	4,210
10	Mantanay	*P. subsericans*	small	interior	4,236
11	Mantanay	*P. racemosa*	large	edge	4,086
12	Mantanay	*P. racemosa*	large	interior	4,142
13	Choquechaca	*P. racemosa*	small	edge	4,071
14	Choquechaca	*P. racemosa*	small	interior	4,095
15	Choquechaca	*P. racemosa*	large	edge	3,924
16	Choquechaca	*P. racemosa*	large	interior	3,948
17	Cancha Cancha	*P. racemosa*	small	edge	4,328
18	Cancha Cancha	*P. racemosa*	small	interior	4,357
19	Cancha Cancha	*P. racemosa*	large	edge	4,089
20	Cancha Cancha	*P. racemosa*	large	interior	4,128

Study plots were 10 x 10 m in size. The plot that was placed at the edge of the forest patch was placed on the side of the forest patch that was the most accessible for humans and domestic animals. That was usually at the side of the walking path. From that side of the forest patch a representative area was chosen so that it visually corresponded to the predominant structure of the forest observed on the forest edge. The plot was placed inside the forest at 5 meters distance from the forest edge (Figure 6). The plot that was placed in the interior part of the forest patch was placed roughly in the center of the widest continuously forested area of the patch, so that it corresponded to the predominant structure of the interior part of the forest patch.

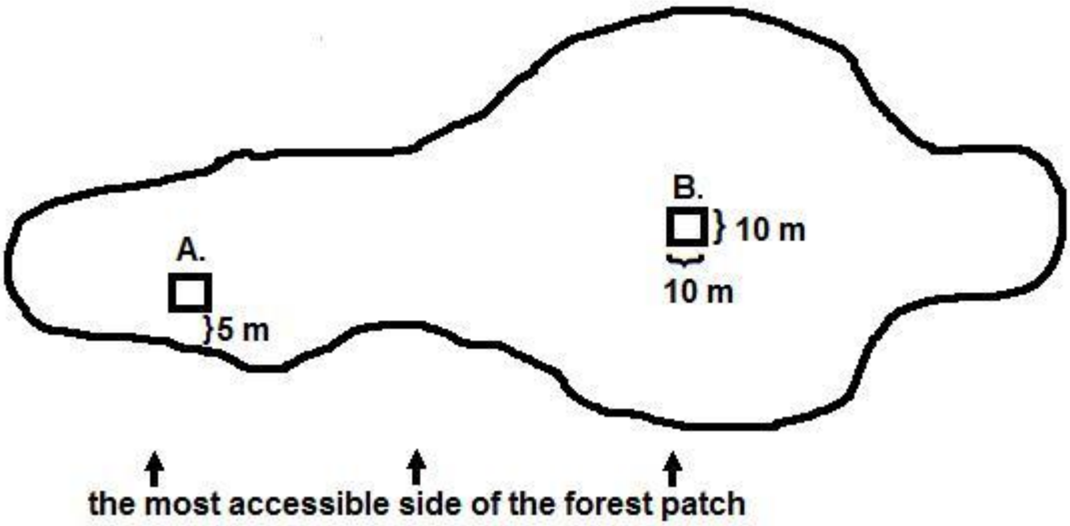

Figure 6. Location of the study plots in the forest patch. The size of the both plots was 10 m x 10 m. A. = plot at the edge of the forest patch. The plot is situated at the side of the forest patch that is the most accessible for humans and domesticated animals and at 5 meters distance from the edge. B. = plot in the interior part of the forest patch. The plot is situated roughly in the center of the widest area of the forest patch.

To estimate the degree of human disturbance, grazing marks on the vegetation, grazing marks on the ground and marks of fire were observed in each study plot by using a four level scale. To estimate grazing marks I used a similar scale than the one used in Mustola´s (2012) study. The scale used to observe grazing marks on the vegetation was: 1 = no marks, 2 = some marks, 3 = marks all around a plot, 4 = severe marks. Observed marks were trampling and browsing of *Polylepis* vegetation. Scale used to observe grazing marks on the ground was: 1 = no marks, 2 = some marks, 3 = about ⅓ from the plot area had marks, 4 = more than ⅓ of the plot area had marks. Observed marks of grazing on the ground were feces and pugmarks of domesticated animals and paths. The scale used to observe fire marks was: 1 = no marks, 2 = some marks, 3 = marks all around a plot, 4 = severe marks. Observed marks of fire were marks caused by burning of pastures in vegetation or stones or preparation of charcoal. In each plot the total number of stumps was counted. Also the total number of cut branches was counted from 18 study plots. These two variables indicated the degree of logging. In addition, the total number of trees (≥ 1 m) and saplings (< 1 m) was counted in each plot to quantify forest density and regeneration. Also, trees height and circumference at the breast height were measured from 12 trees in each plot so that the nearest three trees from each corner of the study plot were selected. If there were less than 12 trees (circumference at breast height ≥ 10 cm) in the plot, all the trees were measured. If the main tree trunk branched before the breast height the measure was taken just before the branching. Tree height was measured with a tape measure. For tall trees, visual estimation was used to complement the tape measurement. In addition, slope percentage was measured from the middle of each study plot with a tape measure and a level. Slope percent was calculated with formula:

$$slope\ (\%) = \frac{rise}{run} * 100$$

where run was constant of horizontal distance (100 cm) and rise was change in elevation (cm) at the distance of constant.

2.4. Statistical analyzes

All statistical analyzes were conducted with IBM SPSS Statistics 20 software.

2.4.1. Derived variables

In addition to original four scale variable from the grazing marks on the ground, new variable was created where four scales were reduced to two. Categories 1 (no marks) and 2 (some marks) were pooled to new category 1 as well as categories 3 (⅓ from the plot area has marks) and 4 (more than ⅓ from the plot area has marks) to new category 2. This way new category 1 reflected low grazing pressure on the ground and new category 2 reflected high grazing pressure on the ground. Number of stumps and number of trees (≥ 1 m) on each study plot were summed up to estimate the original tree cover before logging. The percentage of stump number from the original tree cover was also calculated for each study plot. Mean circumference of trees was calculated for each study plot from the measured circumference values. Also the mean height of trees was calculated correspondingly.

2.4.2. Forest structure

Individual linear regression analyzes were used to study if elevation can explain the variation in different aspects of forest structure, such as forest density, number of saplings, mean tree height or mean tree circumference.

2.4.3. Difference in the amount of human disturbance depending on the species, patch size and plot location

Fisher's exact test (crosstabs) was used to study if the amount of grazing pressure on the ground differed between species, forest patch size or edge effect. In this test four scale variable of the grazing marks was used. Independent samples t-test was used to study if the amount of stumps differed between species, forest patch size or study plot location. Independent samples t-test was used also to study in more detail if amount of stumps differed between plots that were situated in the edge and interior parts of forest in small forests. Independent samples t-test was used to study if the amount of branch cutting differed between species, forest patch size or study plot location.

2.4.4. Difference in the amount of human disturbance depending on different characteristics of forest patch

Independent samples t-test was used to study if the amount of grazing pressure on the ground differed depending on forest patch density, elevation or steepness of the slope. Again, to be able to delete the ecological influence of elevation, standardized residuals of forest density were used with grazing pressure. Linear regression analysis was used to study if forest density can explain the variation in the degree of logging (stumps and branch cutting). Yet, again, standardized residuals of forest density, instead of raw values, were used in the linear regression analysis with logging variables. Two-tailed Pearson correlation test was used to study if forest patch elevation or steepness of the slope were related to the degree of logging.

2.4.5. Difference in regeneration and structure of forest depending on the amount of human disturbance

Independent samples t-test was used to study if the number of saplings was different between forest patches that had high or low grazing pressure on the ground. Linear regression analyze was used to study if logging (number of stumps or cut branches) was able to explain the variation in different variables that reflected the forest regeneration and structure (forest density, number of saplings, mean height of trees and mean circumference of trees). Yet again, to be able to delete the ecological influence of elevation standardized residuals of forest density and residuals of natural logarithm transformation of mean height of trees and mean circumference of trees were used with stumps and cut branches. Raw values of saplings were used, because elevation did not explain the variation of values in the variable in previous testing (Table 3).

3. RESULTS

3.1. Forest structure measurements

In *P. subsericans* forest patches mean forest density was 36 trees per 100 m^2 (sd 17, min 4, max 58) (Table 2). Mean density of saplings was 45 saplings per 100 m^2 (sd 28, min 7, max 90). Mean height of trees was 3.3 m and mean circumference of trees was 37 cm.

In *P. racemosa* forest patches mean forest density was 21 trees per 100 m^2 (sd 12, min 6 , max 42). Mean density of saplings was 22 saplings per 100 m^2 (sd 22, min 0, max 56). Two of the study plots had only tiny saplings (1–2 cm) that were not counted. Mean height of trees was 8.5 meters and mean circumference of trees was 65 cm.

Table 2. Information of forest structure and slope by study plots.

Number of study plot	*Polylepis* species	Forest density (trees / 100 m^2)	Number of saplings	Mean height of trees (m)	Mean circumference of trees (cm)	Slope (%)
1	*P. subsericans*	25	15	3.6	33	60
2	*P. subsericans*	26	21	3.4	52	57
3	*P. subsericans*	37	80	2.7	43	20
4	*P. subsericans*	49	7	2.8	45	50
5	*P. subsericans*	58	28	2.3	25	55
6	*P. subsericans*	55	43	2.2	18	57
7	*P. subsericans*	47	90	2.7	22	37
8	*P. subsericans*	29	60	2.6	23	32
9	*P. subsericans*	4	37	9.4	106	60
10	*P. subsericans*	26	67	5.2	52	72
11	*P. racemosa*	24	56	5.6	66	57
12	*P. racemosa*	15	17	8.2	60	73
13	*P. racemosa*	35	17	3.7	33	38
14	*P. racemosa*	28	55	4.4	59	35
15	*P. racemosa*	11	tiny saplings	9.0	79	47
16	*P. racemosa*	27	tiny saplings	5.5	41	48
17	*P. racemosa*	13	8	11.2	66	35
18	*P. racemosa*	42	18	6.0	40	44
19	*P. racemosa*	6	0	24.8	137	37
20	*P. racemosa*	7	2	19.1	138	39

Elevation explained statistically significantly the variation in forest density but it did not explain the variation in the number of saplings (Table 3). However, it was again able to explain statistically significantly the variation in natural logarithm transformation of mean height of trees and natural logarithm transformation of mean breast high circumference of trees.

Table 3. Ecological influence of elevation to forest structure was resolved with linear regressions between study plot elevation and different response variables that reflect the forest structure. Standardized residuals of response variables from this test was used in later analysis.

	Model figures - Study plot elevation			
Dependent variable	R^2	F	p-value	direction of correlation
Forest density	0.388	$11.432_{df = 1}$	0.003	+
Number of saplings	0.043	$0.711_{df = 1}$	0.411	+
Mean height of trees (ln-transformation)	0.390	$11.531_{df = 1}$	0.003	-
Mean circumference of trees (ln-transformation)	0.360	$10.119_{df = 1}$	0.005	-

3.2. Prevalence and severity of impact of different forms of human disturbance

Only one of the study plots had marks of grazing on the *Polylepis* vegetation (Table 4). In that particular plot only some marks of browsing were detected. On the other hand, 85 % of the study plots had marks (feces, pug marks and paths) of domestic animals on the ground. Grazing pressure on the ground was mainly low. However grazing pressure on the ground was high in 25 % of study plots. Use of fire was detected only in one study plot. One partially burned tree trunk was observed on the plot. Great majority, 95 %, of the study plots had marks of logging. Stumps and cut branches were found from the study plots. Mean number of stumps on study plots was 6 (sd 4, min 0, max 17) and mean number of cut branches was 7 (sd 6, min 0, max 19). There were no stumps on two of the study plots but there were cut branches on one of these two. Percentage of stumps from the original tree cover was more than 15 % on the 14 study plots and 20 % or more on 10 study plots (Figure 7).

Table 4. Frequency of different forms of human disturbances on study plots.

Form of human disturbance	Number of study plots where marks were detected	Number of study plots where no marks were detected
Grazing (vegetation)	1	19
Grazing (ground)	17	3
Use of fire	1	19
Logging (stumps / cut branches)	19	1

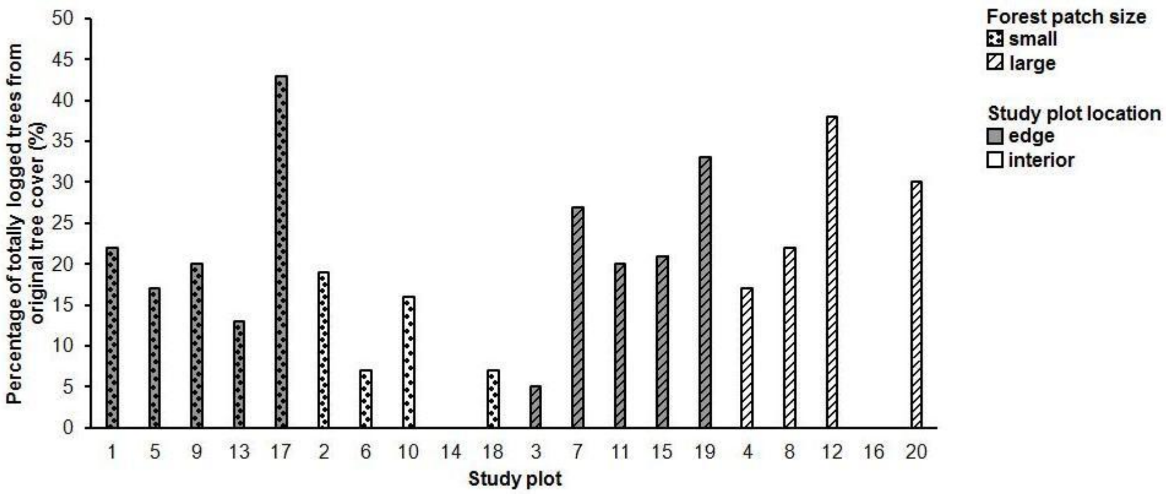

Figure 7. The percentage of totally logged trees (number of stumps) from original tree cover (trees ≥ 1 m + stumps) separately for each study plot. See study plot information from Table 1 & 2.

3.3. Difference in the amount of human disturbance depending on the species, patch size and plot location

The amount of grazing marks on the ground did not statistically significantly differ between *P.racemosa* and *P.subsericans* forests (Fisher's exact test: P = 0.074). Thus, further comparisons concerning forest patch size and edge effects were conducted with pooled data. The most of the plots in small and in large forest patches had some marks of grazing on the ground (Table 5). The plots that had no marks of grazing were from both groups (small and large). Also the plots that had high grazing pressure (scale 3 + 4) were from both groups. The amount of grazing marks on the ground did not statistically significantly differ between large and small forest patches (Fisher's exact test: P = 0.820). The most of the plots that were situated on the edge and in the interior of the forest patch had some marks of grazing on the ground. The plots that had no marks of grazing were from both groups (edge and interior). Also the plots that had high grazing pressure (scale 3 + 4) were from both groups. The amount of grazing pressure on the ground did not statistically significantly differ between study plots that were situated on the edge and in the interior of forest patches (Fisher's exact test: P = 0.820).

Table 5. Distribution of plots in different categories of grazing disturbance on the ground (scale 1–4, see page 16) differently for forest patch size and study plot location. The numbers under forest patch size and study plot location reflect the number of study plots in each category.

Grazing marks on the ground		Forest patch size	
		Small (n = 10)	Large (n = 10)
Category of disturbance	1	1	2
	2	7	5
	3	1	2
	4	1	1
		Study plot location	
		Edge (n = 10)	Interior (n = 10)
Category of disturbance	1	1	2
	2	7	5
	3	1	2
	4	1	1

Number of stumps did not statistically significantly differ between *P. racemosa* and *P. subsericans* forests (Independent sample t-test: t = 1.613, df = 18, P = 0.124). Thus, further comparisons concerning forest patch size and edge effects were conducted with pooled data. The plots that were situated in small forest patches had an average of 5 (sd 4, min 0, max 12) stumps and the plots in large forest patches had an average of 6 (sd 5, min 0, max 17) stumps. The number of stumps did not statistically significantly differ between large and small forest patches (Independent sample t-test: t = -0.404, df = 18, P = 0.691) (Figure 8). The plots that were situated on the edge of forest had an average of 7 (sd 5, min 1, max 17) stumps and the plots in the interior of forest patches had an average of 4 (sd 3, min 0, max 10) stumps. The both plots that had no signs of totally logged trees were situated in the interior of the forest patch. The number of stumps did not statistically significantly differ between study plots that were situated on the edge and in the interior of forest patches (Independent sample t-test: t = 0.926, df = 18, P = 0.367). The number of stumps did not statistically significantly differ between study plots that were situated on the edge and in the interior of forest patches in small forests (Independent sample t-test: t = 1.558, df = 8, P = 0.158).

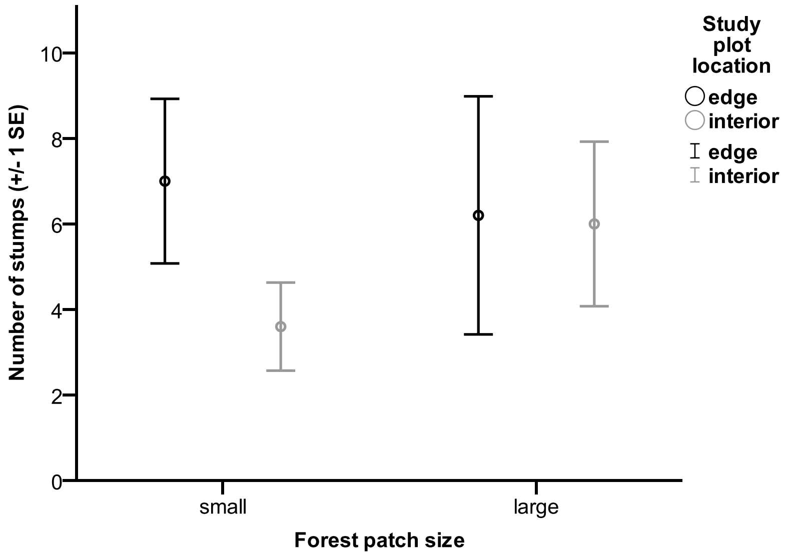

Figure 8. Number of stumps (+/- 1 SE) in small and large forest patches separately for study plots on the edge and in the interior of the forest patch.

Number of cut branches did not statistically significantly differ between *P. racemosa* and *P. subsericans* forests (Independent sample t-test: t = 0.194, df = 16, P = 0.848). Thus, further comparisons concerning forest patch size and edge effects were conducted with pooled data. The plots that were situated in small forest patches had an average of 5 (sd 4, min 0, max 13) cut branches and the plots in large forest patches had an average of 9 (sd 6, min 0, max 19) cut branches. The number of cut branches did not statistically significantly differ between large and small forest patches (Independent sample t-test: t = -1.685, df = 16, P = 0.111) (Figure 9). The plots that were situated on the edge of forest had an average of 9 (sd 7, min 0, max 19) cut branches and the plots in the interior of forest patches had an average of 6 (sd 4, min 0, max 13) cut branches. The number of cut branches did not statistically significantly differ between study plots that were situated on the edge and in the interior of forest patches (Independent sample t-test: t = 1.024, df = 16, P = 0.321). The number of cut branches did not statistically significantly differ between large and small forest patches in interior part of forests (Independent sample t-test: t = -1.555, df = 7, P = 0.164).

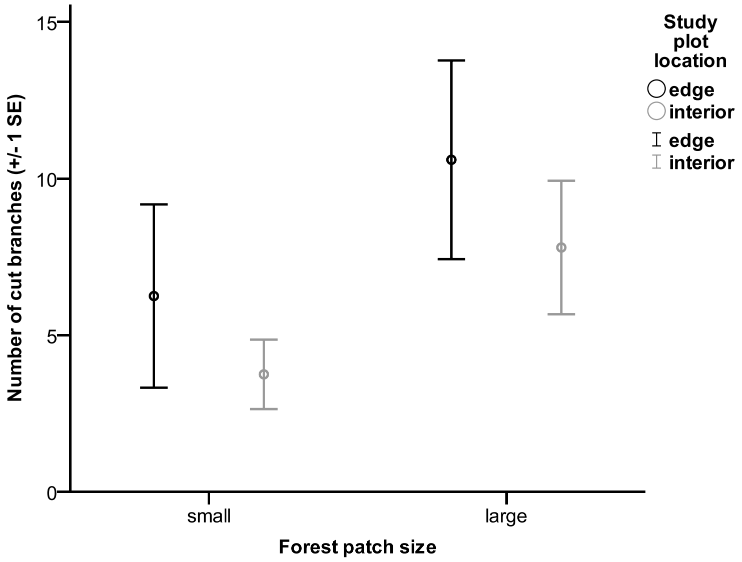

Figure 9. Number of cut branches (+/- 1 SE) in small and large forest patches separately for study plots on the edge and in the interior of the forest patch.

3.4. Difference in the amount of human disturbance depending on different characteristics of forest patch

The residual of forest density was not statistically significantly different between study plots that had low or high grazing pressure based on grazing marks on the ground (Independent sample t-test: $t = 0.168$, $df = 18$, $P = 0.868$). The elevation of study plots was not statistically significantly different between study plots that had low or high grazing pressure based on grazing marks on the ground (Independent sample t-test: $t = -0.931$, $df = 18$, $P = 0.364$) (Figure 10). Patch slope was not statistically significantly different between study plots that had low or high grazing pressure based on grazing marks on the ground (Independent sample t-test: $t = 0.672$, $df = 18$, $P = 0.510$).

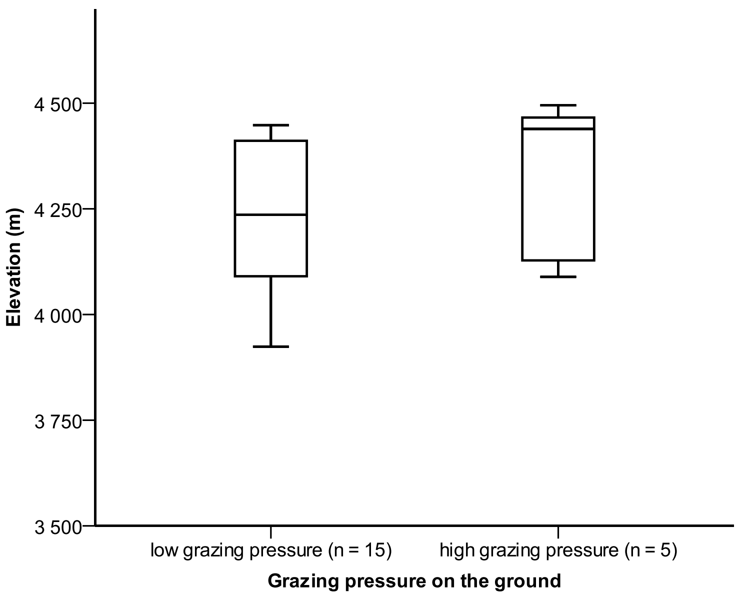

Figure 10. The difference in the amount of grazing pressure on the ground depending on elevation.

Residuals of forest density did not statistically significantly explain the number of stumps (Linear regression: R2 = 0.012, F = 0.219, df = 1, P = 0.645). The greater the study plot elevation was, the greater was the number of stumps (Two-tailed Pearson correlation test: r = 0.517, n = 20, P = 0.020) (Figure 11). There was no statistically significant correlation between forest patch slope and number of stumps (Two-tailed Pearson correlation test: r = 0,091, n = 20, P = 0,701).

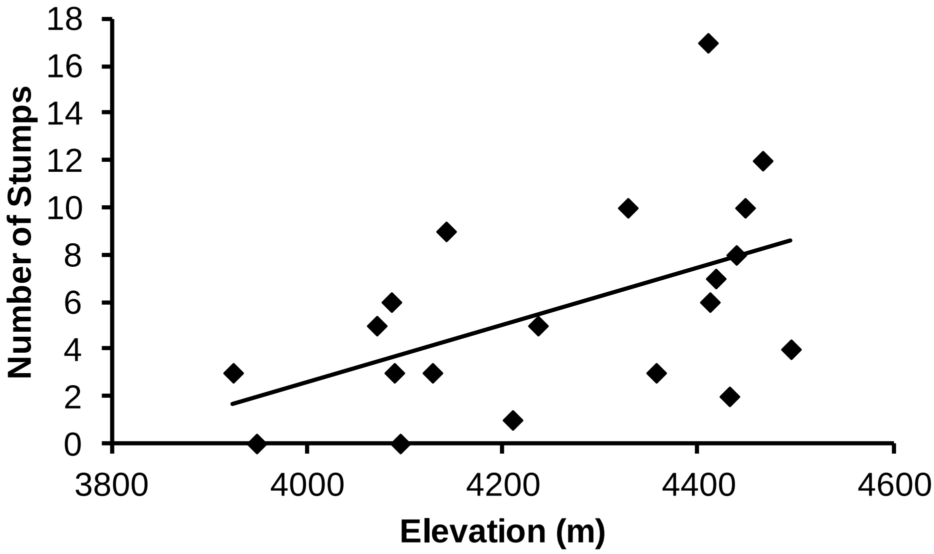

Figure 11. The linear relationship between number of stumps and elevation.

Residuals of forest density did not statistically significantly explain the degree of cut branches (Linear regression: R^2 = 0.057, F = 0.964, df = 1, P = 0.341). There was no statistically significant correlation between study plot elevation and number of cut branches (Two-tailed Pearson correlation test: r = 0.233, n = 18, P = 0.352) nor between patch slope and number of cut branches (Two-tailed Pearson correlation test: r = -0.174, n = 18, P = 0.490).

3.5. Difference in regeneration and structure of forest depending on the amount of human disturbance

Number of saplings did not statistically significantly differ between forests patches that had low or high grazing pressure on the ground (Independent samples t-test: t = 0.741, df = 16, P = 0.469).

Number of stumps did not statistically significantly explain the variation in residuals of forest density, number of saplings, residuals of natural logarithm transformation of mean breast high circumference of trees or residuals of natural logarithm transformation of mean height of trees (Table 6). Branch cutting did not statistically significantly explain the variation in residuals of forest density, number of saplings, residuals of natural logarithm transformation of mean breast high circumference of trees or residuals of natural logarithm transformation of mean height of trees (Table 7).

Table 6. Linear regressions between number of stumps and different dependent variables (n = 20). * = standardized residuals of variable from the linear regression with elevation has been used.

	Model figures - Number of stumps			
Dependent variable	R^2	F	p-value	direction of correlation
Forest density*	0.012	$0.219_{df = 1}$	0.645	+
Number of saplings	0.014	$0.221_{df = 1}$	0.644	+
Mean circumference of trees* (residuals of ln-transformation)	0.035	$0.653_{df = 1}$	0.430	-
Mean height of trees* (residuals of ln-transformation)	0.001	$0.022_{df = 1}$	0.883	-

Table 7. Linear regressions between number of cut branches and different dependent variables (n = 18). * = standardized residuals of variable from the linear regression with elevation has been used.

	Model figures - Number of cut branches			
Dependent variable	R^2	F	p-value	direction of correlation
Forest density*	0.057	$0.964_{df = 1}$	0.341	-
Number of saplings	0.002	$0.025_{df = 1}$	0.876	-
Mean circumference of trees* (residuals of ln-transformation)	0.067	$1.153_{df = 1}$	0.299	+
Mean height of trees* (residuals of ln-transformation)	0.178	$3.473_{df = 1}$	0.081	+

4. DISCUSSION

4.1. Prevalence and severity of impact of different forms of human disturbance

According to Fjeldså and Kessler (1996) livestock grazing together with burning of pastures is the main threat for *Polylepis* vegetation in Peru. They also state that logging and charcoal burning are the most visible forms of human disturbance in these forests. Based on the results of this study no significant evidence was found that livestock grazing would cause a major direct threat to *Polylepis* vegetation in the area of Vilcanota by browsing or trampling the vegetation. In fact, only one of the study plots showed evidence of this type of disturbance. Instead the pressure of livestock grazing on the ground was more visible in the area but the pressure was still mainly low. Livestock grazing may cause compaction of soil and make the topsoil prone to erosion (Kozlowski 1999, Tivy 1990). Paths and pugmarks were detected from the study plots. So it is clear that grazing livestock creates at least some sort of pressure to topsoil. Also livestock feces were detected from the study plots. They may increase the nutrient load of the *Polylepis* forests. However, it is unknown how significant is the effect and whether it is beneficial or harmful for the *Polylepis* vegetation.

Controlled burning of range lands is particularly characteristic of pastures of Australia and South America (Harris 1980 qtd. Tivy 1990). However I did not find evidence of burning of pastures from my study plots. Based on the results of this study it seems that at the moment burning of pastures is not threatening the existence of *Polylepis* species in the mountain range of Vilcanota. It is possible that the lack of expertise in discovering the old marks of burning had an influence on results. Nevertheless I found evidence of charcoal preparation but scarcity of evidence (one burned tree trunk) suggests that it alone is definitely not a major threat to *Polylepis* forests in the area either. Findings of this study differ a lot from the findings made in a study by Hagaman (2006). He studied *Polylepis* forests in Bolivia and found evidence of fire from almost all of his study plots.

Polylepis forests are the only source of timber, fuelwood and charcoal at high altitudes and they are under great logging pressure (Fjeldså & Kessler 1996). I found stumps and / or cut branches from all but one of the study plots. Also percentages of totally logged trees from original tree cover were relatively high. However, it is worth noting that the method of calculating variable “percentage of number of stumps from original tree cover” could have slightly overestimated the amount of original tree cover because it is possible that the smallest trees at the measuring day and trees that were logged long time ago (old stumps) would not grow simultaneously in the forest even though the forest would be in natural state. This can have a magnifying effect on the percentages of logged trees. All things considered according to my results logging (stumps and branch cutting) seems to be the main form of human disturbance operating in the area of Vilcanota, Peru. Hereby it seems that it poses the biggest threat to *Polylepis* vegetation in the area. Existence and regeneration of these forests may be endangered if extensive logging exceeds the rate of regeneration. However Fjeldså and Kessler (1996) state that the *Polyepis* vegetation regenerates well after cutting.

In general there may be some seasonal effects influencing the forms of human activity present at the time of investigation. This is especially likely considering the grazing marks which may be short lived. However, the previous logging and burning are most likely visible for years and it is not likely to see any seasonal effects on them. Moreover, Hagaman (2006) showed that in Bolivia in the area near the border of Peru most of the fuelwood collection and pasture burning is carried out during dry season from May to September and this study was conducted in the period.

4.2. Difference in the amount of human disturbance depending on the species, patch size and plot location

Because the results under this topic pointed in the same direction the discussion is made jointly for different human disturbance factors (grazing, logging). As expected the amount of human disturbance did not differ between *P. subsericans* and *P. racemosa* forests based on my results. The result was not surprising considering the state of communities and living conditions in high Andes. People probably exploit the scarce wood resources regardless of the tree species. For example accessibility can be the main factor influencing the rate of human exploitation and not species (Hagaman 2006, Toivonen et al. 2011). Each community exploits the forest fragment that is the closest and / or in other ways the most accessible to their community.

Human disturbance has altered forest patch sizes (Mladenoff et al. 1993). According to MacArthur and Wilson (1967) small patches that contain smaller populations and smaller amount of available habitats are more vulnerable than large ones. According to my results the amount of human disturbance did not significantly differ between small and large forest patches and disturbance was visible in forest patches of both size groups. Also the patches that had no signs of human disturbance were from both groups. My hypothesis was that human pressure is more severe in small than large forest patches. However, based on my results the hypothesis is rejected. It is possible that even the large patches of *Polylepis* forests were too small to resist human disturbance. It is also possible that via education people of the area have gained a better understanding of the state of the forests and directed the use of forests more evenly between all forest patches nearby.

Edges may have many unfavorable characteristics as a habitat (Harris 1988). For example according to previous studies the amount of disturbance may increase on the habitat edge (Burkey 1993, Laurance 2008). In this study, however, human disturbance was visible in study plots that were located on the edge and in the interior of the forest patch and in most cases (grazing, branch cutting) the patches that had no signs of human disturbance were also from both groups (edge, interior). However, both study plots that had no signs of stumps were located in the interior of the forest patch. In total the difference in the amount of human disturbance did not depend significantly on study plot location. Results of this study differ with the study conducted by Hagaman (2006). He observed that there were more marks of grazing, woodcutting and fire in the edges of *Polylepis* forests than in the interiors. My hypothesis was that human pressure is more sever on the forest patch edge that in the interior part of the forest patch. However, these results do not support the hypothesis and based on my results the hypothesis is rejected. Findings may be a consequence of the fact that even the patches in the larger group were so small that edge effects were able to penetrate into the interior part of the forest. It has been stated in other studies that edge effects may extend up to 300–500 m or even up to several kilometers into fragment interiors (Curran et al. 1999, Laurance & Birregaard 1997, Laurance 2000). For example FAO (1993) define edge as a zone as wide as 10 km.

Even though the difference in the number of stumps did not depend significantly on study plot location, it was studied in more detail if the number of stumps differed between edge and interior plots in small forests because it seemed that in small forest patches there was smaller number of stumps in interior parts of forests than on edges. This seems somewhat reasonable and at least partly supports the hypothesis discussed above, although the trend could be expected to appear stronger in large forest patches. Despite the trend the amount of logging did not significantly differ between edge and interior plots in small forests. Similarly it was studied in more detail if the number of cut branches differed between large and small forest patches in interior parts of forests because based on the data it seemed that in interior part of forests there were more cut branches in large forest patches than in small forest patches. The result is contrasting to my hypothesis that the human pressure would be more severe in small forest patches than larges. Yet again, despite the trend the number of cut branches did not differ significantly between large and small forests in interior parts of forests. Relatively small sample size may both explain some of the observed trends and the fact that they are not statistically significant even when seem to be evident based on the figures.

4.3. Difference in the amount of human disturbance depending on different characteristics of forest patch

The denser the forest is, the more difficult it is for humans and grazing animals to roam. Also the greater the elevation or the slope of the forest patch is, the harder it is to reach (Hagaman 2006). However, according to the result of this study there was no difference in the amount of grazing pressure on the ground depending on forest patch density, elevation or slope. Nonetheless, it seemed that forest patches that were under high grazing pressure were on average higher from the sea level than forests that had low grazing pressure. This may be a consequence of the fact that especially at higher elevations in developing and transition countries livestock herding is the main form of livelihood (Huddleston et al. 2003). Lack of other options may force poor population of high areas to depend more on agricultural activities than people in lower areas who live closer to the population centers.

There was no difference in the number of stumps depending on forest patch density or slope either. However, the results indicated that the number of stumps increased towards higher altitudes. One possible explanation for the higher number of stumps detected in higher elevations could be the fact that forest become denser in higher elevations. This way there are more tree trunks to fell. According to Hagaman (2006) after reaching 4,000 m fuelwood resources decrease. In lower elevations there are also other species that people can exploit but in high elevations *Polylepis* forests are under more extensive pressure because they become the only source of wood. According to Hagaman's (2006) interviews people living at higher elevations preferred to use *Polylepis* trees as fuelwood and people living at lower altitudes preferred other species instead. There was no difference in the amount of cut branches depending on forest patch density, elevation or slope.

Even though forest density, elevation and slope affect the accessibility of forest, it seems that the forest that are dense, located in high elevations or situated in steep slopes in the area of Vilcanota are still under the human pressure. Living conditions become harder in high elevations as does poverty (Huddleston et al. 2003). This is why human dependence on sparse natural recourses can become more extensive in higher areas than in lower areas where people have more options. It is also possible that other factors as forest patch closeness to the community, road or market place are more determining ones influencing on the forest use (Hagaman 2006, Toivonen et al. 2011). My hypothesis was that the higher the density or the greater the elevation or the slope of the forest patch is, the smaller is the rate of human pressure. Because of the contrary results of my study the hypothesis is rejected.

4.4. Difference in regeneration and structure of forest depending on the amount of human disturbance

Livestock grazing can alter forest regeneration, species composition and ecosystem structure of an area (Blackhall et al. 2008, Fleischner 1994, Kozlowski 1999, Marquardt et al. 2009). For example Espigares et al. (2009) found out that soil seed density was lower in highly eroded slopes. Also the number of animals and grazing intensity are important factors when studied the ecological effects of grazing (Holechek et al. 1999). In this study the number of saplings was compared between study plots that had low or high grazing pressure on the ground but there was no significant difference between the groups. My results do not support the suggestion made by Espigares et al. (2009) that higher soil erosion rates imply a reduction in seedling emergence or findings of Kozlowski (1999) that severely compacted forest soil affects stand regeneration by inhibiting seed germination and increasing seedling mortality. Findings of this study may be implication of the fact that the ground of only two of the study plots had more than ⅓ of the plot area covered by grazing marks. So it is possible that the soil of all or the most of the study plots in category "high grazing pressure" was not severely compacted and therefore there were no difference in the number of saplings between study plots that had low or high grazing pressure on the ground either. Also trampling or up-rooting might cause fatal damage to saplings (Marquardt et al. 2009). However, there was hardly any evidence of this kind of direct threat to *Polylepis* vegetation. The hypothesis was that there is a smaller amount of saplings in forest patches where grazing pressure is high than in forest patches were the grazing pressure is low. Again, based on my results the hypothesis is rejected.

Logging and fuelwood collection can degrade forest quality even when the area of the forest maintains the same (World Bank 2008). Wood collection can also alter productivity, biomass and stand structure of a forest (Jameson & Ramsay 2007, Nepstad et al. 1999, Toivonen et al. 2011). However, in this study number of stumps did not explain the variation in residuals of forest density, number of saplings, residuals of mean breast high circumference or residuals of mean height of trees. Respectively branch cutting did not explain the variation in residuals of forest density, number of saplings, residuals of natural logarithm transformation of mean breast high circumference or residuals of natural logarithm transformation of mean height of trees. My hypothesis was that forest density, number of saplings, mean tree height and diameter are lower in the patches of high logging pressure in comparison to the patches of lower pressure. However, results indicate that the difference in forest density, number of saplings, mean tree height and diameter does not depend significantly on logging pressure. Based on my results the hypothesis is rejected.

4.5. Sources of error

In this study there are at least some sources of error that I want to point out. Trough out the study coincidence can have a major effect on results because of the small sample size. Some true relationships between studied variables may not be discovered because of small sample size. On the other hand some of the significant results between variables may simply be a result of coincidence. Also the uncertainties with forest patch sizes can have an effect on results. Moreover, the surveys were conducted together with a group of assisting researchers and this way some researcher effects can add uncertainty to the results.

CONCLUSIONS

According to my results logging (totally felled trees and branch cutting) seems to be the main form of human disturbance operating in the area. Logging pressure was clearly visible in the study area also outside my study plots, and the data clearly shows that logging affects majority of *Polylepis* stands in the area. Hereby it seems that it poses the biggest threat to *Polylepis* vegetation in the area of Vilcanota. My overall conclusions are that the *P. racemosa* and *P. subsericans* stands in the area of the mountain chain of Vilcanota could benefit if the rate of logging would be restricted on the area. This should not be done simply by preventing the forest use from local people but with the help of the government and the third sector organizations so that in future there would be sustainable options available for local people and the existence of *Polylepis* forest would no longer be endangered. If possible this should be done in cooperation between all parties. Without a doubt *Polylepis* forest preservation will eventually benefit the local communities as well. According to the interview executed by Hagaman (2006) local people believe that *Polylepis* trees grow faster than they do. Because of this the people underestimate the time needed for forest recovery and regeneration. Therefore it would be important that there would be education programs to increase local people´s knowledge about sustainable forest management. It would help the people to determine the amount of harvested trees and to select the trees so that it would not degrade the quality of *Polylepis* forests.

It is also important to note that both species had quite big difference in number of saplings between different study plots. None of the factors in this study explained the difference well. Further studies could try to gain understanding on this matter. The determination of the factors that affect on regeneration of these forests would increase the knowledge needed to protect the forests.

On the other hand it is possible that the state of *Polylepis* forests on the mountain chain of Vilcanota has already started to improve. The lack of evidence of burning of pastures seemed odd when Fjeldså and Kessler (1996) estimated it to be the greatest threat together with grazing of livestock. Among other parties a local non-government organization Asociación Ecosistemas Andinos has already increased the knowledge of local people and spread the information of harmful effects of burning to *Polylepis* vegetation. It is possible that the effects of awareness raising has already started to paid off especially when the consequences of climate change and enhanced greenhouse effect have become more tangible in the highlands of Andes and the people are forced to take these issues seriously.

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