Polylepis Forests of the Andes: A socio-environmental case study from the Huascarán Biosphere Reserve, Ancash, Peru

by

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Abstract

Analysis of *Polylepis* forest landscapes are presented with reference to spatial, ecological, and human ecological data collected from a 1999 field investigation of three valleys in the Huascarán Biosphere Reserve, Peru. Forest discourses are reduced to three perspectives, Declension, Adaptation, and Interaction. The dominant perspective of natural resource managers and conservationists is declensionist. Results of the field investigation are presented as a case study to evaluate *Polylepis* forests with regard to each discourse. Biogeographic dynamics and characteristics of forests are assessed using historical aerial photography, remote sensing technology, GIS, forest stand structure analysis, and ethnographic methods. A spatial change analysis over a thirty-four year time period suggests that the shape and distribution of *Polylepis* forests are resilient. Stand structure analysis and ethnographic data reveal that the ecology and human ecology of *Polylepis* forests run counter to the perceptions of biosphere managers. While anthropogenic impacts, notably timber harvest, livestock grazing, and grassland fires are present, analysis indicates forest resiliency and healthy regeneration. The argument advanced here claims that if conservation and management of *Polylepis* forests is to be successful the declensionist perspective must be reevaluated in favor of an interactionist perspective, which accounts for the political ecology of forests and people.

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CHAPTER ONE
INTRODUCTION

Introduction

Landscapes represent many things to many people. When we consider the word 'Andean' in reference to a landscape, for example, what do we mean to impart to our audience? We could be referring to any number of qualities indicative of the Andes: landscapes dominated by serrated glacial peaks and windswept open grasslands, highland communities that blend traditional and modern culture, or perhaps we refer to ecological and biogeographical characteristics, which distinguish the area from any other on earth. This plurality of possible meanings is revealing of the richness imbued in the term, 'Andean.' In reference to the mountains of Peru then, we must bear in mind that the word, 'Andean', implies much more than simple biogeography. The term robustly captures the peoples and the history of the Peruvian highlands as well. If so then we ought to maintain at the forefront of our consideration that the word 'Andean' implies an intimate relationship between humanity and mountain biogeography: a relationship that has influenced the formation of Andean cultures as much as Andean ecologies.

In keeping with the richness of the idea of an 'Andean landscape', let us consider that: embodying both the ecology and the culture of an area, landscapes are the material, aesthetic, and cultural expression of historical and contemporary human-environmental interactions. Mutually inclusive of environmental and cultural systems, landscapes are sculpted from the recursive interaction of humanity and nature. However, if we concede that landscapes are a blend of material ecology, culture, and history, then how do we conserve them as such? How do we effectively tease apart 'natural' and 'anthropogenic' factors that drive and condition landscape patterns, in order to propose conservation policies, strategies, and natural resource management techniques? In the case of the Andes distinctions such as 'natural' or 'anthropogenic' are not easily made because these landscapes are as deeply cultural as they are ecological. This thesis is intended to explore these issues through one element of the Andean landscape considered to be of critical import to conservationists, *Polylepis* spp. forests. The centerpiece of the thesis is a case study, completed during the summer of 1999, on *Polylepis* forests of the Huascarán Biosphere Reserve (HBR), Ancash, Peru. Building upon this case study the thesis presents a socio-environmental analysis of *Polylepis* forest cover change through an exploration the social and natural dimensions of forest ecology and an assessment of the validity of dominant discourses on the conservation and biogeography of *Polylepis* forests.

Situated within a growing tradition of integrated society-environment science, the theoretical framework that will inform the overall analysis on *Polylepis* forest conservation in the HBR will be a broad political ecology. Discourse analysis, an approach within political ecology, will serve to guide the thesis in two ways. First, the thesis as a discourse itself will be couched within the dominant interpretations of *Polylepis* forest cover change in the Andes. Second, the analysis of various discourse on *Polylepis* will investigate environmental knowledge and perceptions constituted through methodological assumptions, rhetoric, and power networks (Forsyth 1998) that allow particular definitions of *Polylepis* landscapes to emerge. It will be shown that environmental knowledge and perceptions of *Polylepis* forests necessarily influence the type of conservation activities engaged within the HBR. It will be argued that understanding how socio-environmental interactions at the local scale affect landscape pattern is critical to efforts by land-use managers and conservationists in developing sophisticated site-specific recommendations and policy for natural resource use and management.

This introductory chapter will frame the major focus and themes of the thesis, situate the study within a broader literature of academic and policy studies, and detail the research setting for the HBR case study.

Political Ecology

An intention of the socio-environmental analysis presented here is to reveal the complexity of *Polylepis* forest cover dynamics in the Huascarán Biosphere Reserve. The synthesis of social and environmental science promises to offer nuanced explanations, more holistic and complex than traditional analyses of environmental change that emphasize either social or environmental dynamics. As a hybrid study, drawing upon applied and theoretical works from a variety of disciplines, the integration of society and environment in this thesis is made tractable under the rubric of political ecology.

This type of integrated analysis is increasingly sought after as a more sophisticated way in which to understand the driving factors of environmental change. We see this clearly with regard to mountain regions in general, where the broader issue of socio-environmental interactions is becoming increasingly important. Under Agenda 21, Chapter 13, the "Report of the United Nations Conference on Environment and Development" states:

> Mountains are highly vulnerable to human and natural ecological imbalance. Mountains are the areas most sensitive to all climatic changes in the atmosphere. *Specific information on ecology, natural resource potential and socio-economic*

> *activities is essential* [to conservation and development in mountain regions]… There is, however, a lack of knowledge of mountain ecosystems. The creation of a global mountain database is therefore vital for launching programs that contribute to the sustainable development of mountain ecosystems (Mountain Forum 1998 *emphasis added*).

Agenda 21 and its concomitant prescribed actions suggest a type of study that brings together mountain ecology and political economy to fully appreciate the complex factors that condition mountain areas. Such studies can be categorized as instances of political ecology.

Political ecology, which broadly defines the relationship between political economy and ecology as its purview of interest, began as the effort to address the political and social construction of environmental degradation (Blaike and Brookfield 1987). More recently political ecology has broadened into a suite of approaches within a framework through which society-environment issues are analyzed. One general approach is characterized as strictly political analyses of environmental conflict between actors (Bryant and Bailey1997). Another approach, known as 'Liberation Ecology', challenges the hegemony of the state and international institutions in defining environmental issues (Escobar 1996; Peet and Watts 1996). Through a combination of post-structural environmental analyses and critical theory to understand how local movements contest the legitimacy of their knowledge and rights to natural resources within political settings, Liberation Ecology seeks to analyze the role of power, authority, and policy in environmental issues.

For the purposes of this thesis I draw upon that branch of political-ecology that is firmly rooted in biogeography and ecology. Karl Zimmerer's and Kenneth Young's recent publication, *Nature's Geography: New Lessons for Conservation in Developing*

Countries (1998), provides a series of examples of how political ecology can be applied to biogeographical landscapes and regions in addressing issues of conservation and natural resource use in a third-world tropical context. They state:

> We believe that a better understanding of the multifaceted functioning of biogeographical landscapes and regions would be of paramount importance for supporting and designing programs appropriate for protected areas, such as nature reserves and national parks, and for the inhabited lands surrounding those protected areas (Zimmerer and Young 1998: 328).

Furthermore, the authors stress that in the attempt to address natural disturbances and human-induced changes on biogeographic landscapes and regions, "the premise that not all change is the same must serve as the cornerstone for the conservation debates and the political contention which surrounds them" (Zimmerer and Young 1998: 7). Geography then, in terms of conservation, matters. Claims of landscape change or degradation ubiquitously applied across biogeographical regions, though effective perhaps in rhetorical debate need to be unpacked with regard to the geography of change or degradation. The critical point being that landscape change occurs in differentiated and articulated patterns, unequally distributed across both spatial and temporal scales. The nature and character of such patterns are paramount to land-use managers, conservationist, or developers prescribing effective conservation and development strategies.

This orientation to studies on the interaction between society and ecosystems (mountain or otherwise) entreat researchers to design their work across multiples scales of time and space (Allan 1995). In short the goal is to link historical-cultural, political-economic, and ecological dynamics specific to a given place to understand not only how and why environmental changes occur through time, but how to conserve such environments as well (Forsyth 1998). However, moving from local site-specific to national and global scales while drawing on the critical import of history is highly complex. Nevertheless, several examples exist that offer ambitious attempts to marry the various components of a political ecology on mountain areas (Brower and Dennis 1998; Echavarria 1998; Horn 1998; Metz 1998; Young 1998; Zimmerer 1996b; Young and León 1995). Each of these studies focuses on biogeographical changes to the landscape as specific to a given context. The political ecology of biogeographical landscapes then, as general framework allows for an analytic treatment of the various actors and institutions, which influence the distribution and conservation of *Polylepis* forest patches within HBR.

Discourse Analysis

Discourse analysis as a sub-field of political ecology addresses how "discursive constructions and their power geometrics" (Braun and Castree 1998: 13) have material consequence on resource management and policy development (Neumann 1998; Zimmerer and Young 1998; Bryant and Bailey 1997; Peet and Watts 1996; Zimmerer 1996c). However, consideration of where discourse analysis intersects with social and environmental science, helps to focus attention on a difficult but poignant question elucidated by Timothy Forsyth. Forsyth (1998: 108) asks: "Is it possible to integrate these approaches [social and environmental], and hence provide an awareness of social constructions of environment at the same time as a falsification of inaccurate statements unhelpful to environmental management or development?"

Peet and Watts (1996: 13) affirm the need to beware of the seductive ease by which totalizing interpretations explain natural phenomena, alerting us to the fact that, "truths are statements within socially produced discourses rather than objective 'facts' about reality." Truth and humanities role in conditioning the environment is mediated by a myriad of social, political, and economic systems, a theme that has become the focus of in-depth analysis (Braun and Castree 1998; Haraway 1991; Latour 1987, 1992). The focus within the present analysis is how interpretations, fluid with respect to their contestation and negotiation among actors, achieve concrete hegemonic affect. Peet and Watts (1996: 38) express this position succinctly as an appeal to the use of dialectical analysis:

> In our view, dialectical analysis instead imagines a system of relations which does not consume the autonomy of the particular; it is one in which a number of dynamic tendencies in shifting hierarchical arrangements are constantly disturbed and dislocated by new sequences of different events, a dynamic which has pattern, order, and determination without being teleological.

For the purposes of this thesis the key point is that while socio-environmental studies seek to tease out the complexities that drive landscape change, there needs to also be awareness that newly posited explanations are themselves incomplete.

Environmental explanations are both attempts to fully comprehend processes of environmental change, but also are subject to the uncertainty of human knowledge and ecological dynamics. Interpretations of environmental change (i.e., what constitutes degradation) and complexity of ecosystem function (i.e., how is change propagated or mitigated through the ecosystem) render explanations buttressed upon qualifications. For example, a multitude of interpretations of degradation can simultaneously exist, each one dependent upon the position or intention of the observer. As such the silviculturalist and forest ecologist have fundamentally different ways to define forest degradation. In addition, analysis of ecosystem function is subject to the scale at which an ecosystem is studied. Nevertheless the accepted wisdom of environmental degradation and ecosystem function, once rooted as a dominant environmental orthodoxy, serve as an explanatory heuristic without regard to scale. Forsyth (1998) cautions that when scientists, academics, politicians or others critically assess dominant environmental orthodoxy, that subsequent new explanations do not simply supplant the dominant orthodoxy.

Such caution is warranted as we have seen above, however, environmental orthodoxy may fail in two other respects as well. First, as ubiquitous claims to change or degradation, environmental orthodoxy may fail to correlate with empirical observations at different points on a landscape. Second, the policy recommendations of environmental orthodoxy may fail to have positive material consequence upon the actual environmental problem that such explanatory discourse intends to alleviate (e.g., to claim that high population pressure causes degradation, does not mean that the removal of people from a landscape will necessarily solve the problem of degradation).

How multiple interpretations on *Polylepis* distribution collapse into a single orthodoxy is a central interest of this thesis. By considering the various discourses that make up the suite of explanations on *Polylepis* distribution will reveal that the discourse of science and of the state provides the dominant interpretations of contemporary landscape pattern inside HBR. Interestingly, however, the question of landscape pattern remains open to fierce debate and uncertainty at the level of scientific discourse. Despite this uncertainty reserve staff maintain a policy of forest conservation and management that assumes a singular interpretation. This interpretation as we shall find in the following chapters may in fact not be suited to landscape pattern and process inside the HBR.

In order to assess contemporary discourses on the distribution, condition, and conservation of *Polylepis* forests it is necessary to consider both how Andean landscapes and *Polylepis* have been historically interpreted. If we assume that ecological processes are based in material reality, but that all understandings of such processes are socially mediated, then we may be able to understand knowledge claims concerning *Polylepis* forests. Claims about the condition of *Polylepis* forests, and the landscapes upon which they exist, are predicated upon ecological 'reality', but such claims, limited by human and ecological understanding, are ultimately incomplete (Braun and Castree 1998; Forsyth 1998; Zimmerer and Young 1998; Bryant and Bailey 1997; Peet and Watts 1996). Chapter Two of the thesis examines the claims made by local people living in the buffer zone of the reserve, reserve policy, and conservation NGO perspectives on the condition of *Polylepis* forests. These claims are assessed relative to the suite of scientific discourses on *Polylepis* (i.e., on what scientific grounds are local, state, and NGO claims legitimated). Finally an assessment is made of scientific claims on *Polylepis* landscapes in order to identify the limitations and insights of such claims with regard to the HBR.

The Setting

The core of the Huascarán Biosphere Reserve is Huascarán National Park (3,400 km^2). Within the central Peruvian Andes of the Department of Ancash, the HBR is located within the Cordillera Blanca (Appendix 1: Figure 1), the highest tropical mountain range in the world. The reserve contains forty-four deep valleys and 60 peaks with elevations greater than 5700 m, including Nevado Huascarán the tallest peak in Peru (6,768 m). The national park was established in 1975, declared an UNESCO Biosphere Reserve in 1977, and a World Heritage Site in 1985. Established above 4,000 meters the core area of the HBR is characterized by open high elevation grasslands (*puna*) and patches of *Polylepis* (*quenual*) forest in the upper valleys, glacial lakes and glacial geomorphology[1]. The park and its buffer zone (a total of 5,710 km²) have a tremendous degree of biodiversity with 779 plant, 112 bird, and 10 mammal species that have been identified (Kolff and Kolff 1997; The Mountain Institute 1996; Bracko and Zarucchi 1993; Smith 1988).

Although no settlements are located within the national park, along the western side of the range a number of small and medium sized villages are established along the Río Santa - located in the agricultural valley, Callejón de Huaylas. The largest city in the Callejón de Huaylas and capital of the Department of Ancash is Huaraz. Huaraz (approximately 90,000 people), a relatively modern city, has been a regional center of commerce and governance for centuries. The Callejón de Conchucos flanking the eastern side of the park is far more remote and less populated. Beyond the park but within the Reserve's buffer zone live approximately 226,000 inhabitants (The Mountain Institute 1996), 10% of whom directly access the park for natural resources (e.g. forests, pastures, medicinal plants, water, flowers) (Byers 1999).

The livelihood of local people within the region is based primarily on agriculture and livestock. In recent years upwards of 100,000 tourists visit the reserve annually

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[1] According to the *Parque Naciónal Huascarán, Plan Maestro – Generalidades y Diagnostico* (1990a) 47% is grassland and 0.9% is forest in the park.

drawing more local people of the Callejón de Huaylas into the growing tourism industry (The Mountain Institute 1996). In addition, a number of major international mining operations have been launched outside the buffer zone, which have the potential to draw laborers from rural villages (Recharte 1999).

The Problem and Findings:

Polylepis forests, distributed in a patchwork pattern, are considered among the most threatened Neotropical vegetation types of the highland Andes. Spanning from northern Venezuelan to the northern reaches of the Chilean and Argentinean Andes, *Polylepis* forests prevent upland soil erosion, dampen peak flood events, and provide critical habitat to many species (Fjeldså and Kessler 1996; Lægaard 1992; Smith 1977). As the highest growing angiosperm on the planet, reaching an upper altitudinal limit of 5,200 meters, the twenty species that comprise the *Polylepis* taxa are themselves endangered and currently protected by Peruvian national law (Decreto Supremo 1973).

The main factors thought to be influencing forest distribution are changing production practices, market penetration, and climate change (see Chapter Two: *Discourse and Science, declension, adaptation, and interaction*). Exactly how *Polylepis* have derived their particular spatial patterning on the Andean landscape remains open to debate. Despite the lack of a conclusive explanation to account for contemporary *Polylepis* distribution, a great deal of local and international interest exists in developing conservation and land-use planning for the species. How conservationists engage with discourses and interpretations over the condition of *Polylepis* forests will inform strategies for conservation and protection.

Environmental discourses have the potential to read the landscapes of the central high Andes as being relatively 'natural' or 'anthropogenic' – 'degraded' or 'intact'. Moreover, such interpretations may further reinforce hegemonic discourse on the causal mechanisms of environmental degradation, which have far reaching consequences for highland Andean peasants (*campesinos*) where *Polylepis* remains extant. In addition, these discourses constitute the basis for the allocation of monetary and human resources for forest protection.

Patches of *Polylepis* forests within the HBR are located predominantly in the northern and more humid regions of the reserve. According to the HBR staff patches of *Polylepis* forest exist in a range of conditions from rare intact old-growth, to those that are severely degraded. It has been suggested that the fragmentation and degradation of *Polylepis* forests have depleted the Andean highlands of endemic species of *Polylepis*-adapted birds (Fjeldså 1992a, 1992b). Nevertheless, the headwater regions of the Marañón River remain among the few 'hotspots' for such birds where Pleistocene refugia of *Polylepis* forest patches remain extant (e.g. *Polylepis* patches at intermediate elevations below Pleistocene glaciers) (Fjeldså 1992a, 1992b). The HBR is one of the principal headwaters of the Marañón River, and contains numerous patches of *Polylepis* forest, wherein individual forest patches of only 2 - 5 hectares house 35 - 40 bird species, many of which are endangered and/or threatened (Fjeldså 1992b). In the conservation of Andean avifauna the parameters of forest patch size, connectivity, and heterogeneity are of potentially critical important to endemic and migratory highland bird species (Fahrig 1997; Andren 1994; Kotlair and Wiens 1990; Fahrig and Paloheimo 1988; Freemark and Merriam 1986).

Given the fragmentation of *Polylepis* patches, and potentially unsuitable habitat of the surrounding landscape matrix between them, a good understanding of both the spatial pattern of *Polylepis* patches and its relationship to the landscape matrix within which they are imbedded is necessary to derive appropriate conservation strategies. Presently, however, the reserve has poor information with regard to the geography of *Polylepis* forests. Until managers are able to determine the geographic articulation of patches throughout the reserve, and the concomitant anthropogenic and natural dynamics that condition such dynamics, little may be accomplished to increase forest cover and conserve those species that rely on it.

The dynamics that drive *Polylepis* forest cover change are complex. Recent repeat photographic landscape assessment by Byers (1999) within HBR suggests that several *Polylepis* patches remain resilient or have increased in extent since the mid-1930s. Byers replicated in 1997 and 1998 photographs from 10 photopoints established during the 1936 and 1939 German/Austrian climbing expedition in the Cordillera Blanca (Appendix 1: Figure 1). Photopoints are locations where landscape photographs were taken from in the 1936 and 1939 expeditions. Byers' visual comparisons of historic and contemporary photographs indicate that changes in glacial recession, grazing impacts, and urban expansion are prevalent. Importantly, however, Byers' visual comparisons found that *Polylepis* forest patches to be resilient and slightly increasing in cover, while *Eucalyptus* and *Pinus* forest cover had expanded dramatically.

Analysis of data from the present study, collected from three valleys within the reserve, suggest that *Polylepis* forests patches have remained remarkably resilient in size and distribution from 1962 to 1999, and that some show slight increases in cover. This finding demonstrates that dominant discourses on forest cover change do not correlate with landscape pattern in the reserve. The lack of forest cover change and the slight increases of forest cover are significant since these findings casts serious doubt upon both HBR policy and its prevailing scientific explanation, which claims that human land-use (e.g. grazing and woodcutting) is degrading forest patches within the reserve. The significance of ‘no-change’ in forest cover is non-trivial, because it alters the central question that managers and conservationists must ask, from: “how and why are *Polylepis* forest patches continuing to degrade and fragment on the landscape”, to “what processes are taking place on the landscape which prevent *Polylepis* forest patches from expanding?” As shown in Chapter Three and Chapter Four this shift in emphasis from fragmentation and degradation to retardation of expansion is significant in terms of prescribing conservation actions for *Polylepis* forests in the reserve.

Presently a paucity of scientific understanding exists about the socio-environmental geography of mountain regions of the world. It is problematic throughout the 6000 km of Andean Cordillera that a lack of critical attention is given to deforestation, which frustrates the understanding of landscape change. Fernando Echavarria points out that: “specific knowledge about the extent of forest clearing, analysis of forest patch structure and fragmentation, and information on the nature and degree of human change has been restricted by the absence of baseline data and information on rates of change” (Echavarria 1998: 101). The present study is intended to contribute to efforts in the Ancash/HBR region to promote conservation and environmentally sound land-use planning for *Polylepis* forest. This study provides information concerning *Polylepis* forests in the reserve that hopefully will be helpful to

HBR staff and conservation groups. The need for basic data on the spatial distribution and heterogeneity of *Polylepis* patches, forest structure, and spatio-temporal changes of forest cover is vital to proposing land-use planning appropriate to *Polylepis* forest conservation. Moreover, conservation planning designed to induce regeneration of *Polylepis* forest may in the future help forest scientists understand the theoretical questions and debates surrounding the species (Metz 1998). Finally, this study will contribute to the literature on *Polylepis* distribution, providing a valuable case study of a micro-regional assessment of the socio-environmental factors that drive forest cover change.

Conclusion and Implications

If an Andean landscape implies an intimate relationship between humanity and mountain biogeography, as stated in the introduction, then human agency on the landscape may be interpreted as natural as that of *Polylepis*. The critical idea here is that the Andean landscape is Andean precisely because it is the marriage of anthropogenic and natural dynamics. "Andean-ness" marries the material, aesthetic, and cultural expression of historical and contemporary human-environmental interactions.

To conclude this much suggests that whether it be a landscape, animal or plant communities, level of biodiversity, indigenous cultures or otherwise, the work of conservation and sustainable development implies that we either have an extant characteristic of a place that we choose to protect, or that we envision a possible future state of being. In other words, when we suggest that Andean landscapes deserve to be protected and conserved, what exactly do we mean; what are we conserving and for whom? Does our vision of an Andean landscape lack the presence of people? How do we negotiate between the materiality of the landscape and the ideology implied within our discourse over conservation and development?

Returning then to the issues outlined above, let us consider that the suite of land-use practices of highland *campesinos* have not affected the Andean landscape equally in all places. Traditionally the peoples of the highland Andes have relied on *Polylepis* as a source of fuel wood, construction and artisanal materials. Moreover, contemporary pressure from fuelwood gathering, timber extraction, and livestock grazing may further degrade remaining *Polylepis* stands. But changes in production practices in the remote highlands, driven by certain types of global market integration (resulting in changes in land-use and labor force in the region), and the advent of forest plantations of alternative species (e.g. *Eucalyptus globulus)* at lower elevations, may reduce pressure on *Polylepis* forests. This synopsis of land-use practices suggests that local socio-environmental interactions influence landscape patterns in the reserve. How highland peoples interact and effect landscape pattern and process at local scales will be important to informing conservation action and policy for *Polylepis*. Given the wide-ranging academic speculation on *Polylepis* distribution, understanding local human-environmental interactions are all the more important.

Despite the lack of a conclusive theory, research suggests that in order to understand the dynamics which condition forest landscape pattern and process, analyses must focus upon socio-environmental interactions at local scales (Byers 1999; Forsyth 1998; Young 1998; Braun 1997; Stern 1995; Young and León 1995; Allen 1995; Lauer 1993; Hewitt 1988). However, few studies focus upon micro-regional change in

Polylepis pattern over time (e.g. Braun 1997; Kessler 1995; Stern 1995). These studies center primarily upon forest cover change, neglecting to account for the role of local land-use regimes. Lack of data on micro-regional distributional patterning of *Polylepis*, accounting for spatio-temporal forest cover change and local forest-use regimes, frustrates conservation planning for the species.

This thesis argues that a micro-regional analysis of *Polylepis* forest cover change coupled with an assessment of discourse on *Polylepis* landscapes, serves to offer an alternative explanation to landscape change in the HBR. Chapter Two will explore the array of discourses that describe the condition and geography of *Polylepis* forests. An analysis of spatial data and ecological data derived from my 1999 fieldwork season will be completed in Chapter Three and Chapter Four respectively. Finally, Chapter Five will offer an alternative account to landscape change in the reserve followed by recommendations for conservation of *Polylepis* forest patches.

CHAPTER TWO
DISCOURSE ON POLYLEPIS FOREST COVER CHANGE

> I am only suggesting considerations that may induce us to regard all models in the right way, respecting each and idolizing none. We are all, very properly, familiar with the idea that in every age the human mind is deeply influenced by the accepted model of the universe. But there is a two-way traffic; the model is also influenced by the prevailing temper of the mind. We must recognize that what we call a 'taste in universes' is not only pardonable but inevitable. We can no longer dismiss the change of models as a simple progress from error to truth. No model is a catalogue of ultimate realities, and none is a mere fantasy. Each is a serious attempt to get in all the phenomena known at a given period, and each succeeds in getting in a great many. But also, no less surely, each reflects the prevalent psychology of an age almost as much as it reflects the state of that age's knowledge.
>
> C. S. Lewis – *The Discarded Image* (1964: 222)

Introduction

Along the 6000 km spine of the Andean Cordillera, the region comprised of Peru, Ecuador, and Bolivia encapsulate the "Andean essence" (Gade 1999: 36). The idea of an 'Andean essence' is built upon an understanding of the intimate relationship between Andean culture and ecology. Where the development and persistence of highland cultures occurred in the Andes define the essence of the region, more so than simply a physiographic definition. The collective region of Peru, Ecuador, and Bolivia, where a profound history of human-environmental interaction has shaped both culture and landscape, is called the *Corazón* (heart) of the Andes.

In a recent publication, Daniel Gade (1999), explores this idea of the Andean essence. He suggests that twenty material symbols constitute the essence of *lo Andino. Lo Andino* translates as 'the Andean', or 'that which is Andean'. It is the "cultural complex that has survived the harsh acculturation imposed during the colonial period and the technological changes of the modern world" (Gade 1999: 36). Among the elements Gade sites as indicative of *lo andino* are *Polylepis* forests. *Polylepis* spp. forests referred to as *queñual, queñuali,* or *queñuar* in local parlance of the central highlands, simultaneously embody and fortify our understanding of the Andean landscape. However, as we shall see, the Andean landscape and *Polylepis* forest not only remain open to interpretation, but their meaning has evolved over time.

This chapter will explore the variety of interpretations that define how *Polylepis* forests are understood. Following a brief overview of *Polylepis* forest, a Latourian approach to the sociology of science is employed in order to assess the three dominant modes of interpretation of *Polylepis* forests, which I term *Declension*, *Adaptation*, and *Interaction*. These three interpretations allow for a more critical exploration of the historic and contemporary discourse of *Polylepis* forests, and how such discourse has been established in the Huascarán Biosphere Reserve.

***Polylepis* spp. Forests**

Polylepis spp. were first described scientifically by Ruíz and Pavon during their 1794 botanical expedition to Peru and Chile (Steele 1964). However, almost two centuries transpired before Beryl Simpson would complete the definitive modern taxonomy of the *Polylepis* genus in 1979. Belonging to the Rosaceae family the twenty species that comprise *Polylepis* exist between 1,800 - 5,200 meters above sea level in the Andes. As the highest occurring angiosperm in the world, *Polylepis* exhibits considerable variability and adaptability despite the austere of the conditions within which the genus is typically found. Species of *Polylepis* range as far as northern Venezuela to the northern reaches of the Chilean and Argentinean Andes (Fjeldså and Kessler 1996). Remarkably these species are able to grow between 1 - 27 meters in height in various tree and shrub-like forms, which occupy steep slopes, rocky areas, precipitous valleys/ravine walls, and flat open areas.

In general the trees of the genus *Polylepis* can be described as having a bark composed of deep red layers of thin exfoliating sheets. Indeed, the genus' namesake, *Polylepis*, literally means 'many - layered.' This soft quilt-like bark, which can be up to 2.4 cm thick, is thought to be an adaptation to the extreme variability of daily temperature change (Simpson 1979). The crooked and twisted morphology suggests that the genus has been sculpted over the centuries by the windy, cold, and arid environments of the high Andes. Its lateral branches show a "flush" type formation, with long naked branch segments with leaves bunched at branch tip: leaves which are woolly and downy, and short and thick, always in a compound (imparipinnate) structure (Simpson 1979). Fruit of the *Polylepis* is dispersed principally by wind. The presence of spines on fruiting bodies, however, suggest that avian dispersal is possible, though no birds have been recorded foraging on *Polylepis* fruit (Simpson 1979). Highland birds do however rely on *Polylepis* forests for habitat. As mentioned in Chapter One the density and diversity of birds – many of which are endemic to the region – in forest patches is remarkable high.

On the western slopes of the central Andes, where the highest elevations of *Polylepis* occur, average rainfall can be 200 – 500 mm per year[1] (Simpson 1979). Within the Cordillera Blanca a distinct dry and wet season exist. Measures of rainfall distribution in the

[1] Rainfall varies tremendously due to micro-climatic conditions, however, the general rainfall pattern is of increasing annual precipitation moving west to east and from south to north along the Andes (Young 1989; Valencia 1992; and Fjeldså and Kessler 1996). Given this extreme seasonality with respect water stress, dendrochronological studies may reveal growth patterns for (Byers 1998 personal communication), however, none have been undertaken to date.

region reveal an extreme pattern, where rainfall is as low as 5 mm per month during the dry season (March – September) and as much as 150 mm per month during the wet season (October – February) (Cerrate 1979). Variation in temperatures follows the typical pattern in the tropics, whereby daily variation is greater than monthly variation. However, this daily temperature variation can be extreme. Night-time temperatures typically fall below freezing, while intense solar radiation can create temperature changes of 40 - 50 °C in the arid highlands (Fjeldså and Kessler 1996). According to Simpson (1979, 15): "theoretically, the daily freezing temperatures, the inability of roots to absorb nutrients below the uppermost soil levels that are heated during the day, and the presence of a constant, drying wind should preclude tree growth. The occurrence of woodlands at elevations up to 5,200 m therefore presents a physiological problem".

The 'physiological problem' of how and where the genus can occur, touches upon one of the central issues in the *Polylepis* controversy. *Polylepis* forests occur in uneven, patchy distribution patterns across the highland Andes. An uneven distribution pattern, encompassing both the genus in general and its respective taxa, has been interpreted as an adaptive function of the to the 'physiological problem.' Such an interpretation falls within that realm of discourse I refer to as the *adaptation perspective*. Directly counter to this discourse is the *declension perspective*. The discourses that delineate the declension perspective explain *Polylepis* distribution patterns as an expression of anthropogenic forces that have affected the Andean landscape. Between the perspectives of adaptation and declension is a third, the *interaction perspective*. Quite simply this perspective seeks to understand *Polylepis* biogeography as a combination of anthropogenic and physical/environmental forces.

Discourse and Science: declension, adaptation, and interaction

As a sociologist of science, Bruno Latour (1987, 1992, 1999), is interested in the production of knowledge, certainty, and fact within the praxis of science. In the 1987 publication, *Science in Action*, Latour clearly expresses his overarching intellectual agenda. Scienctists, according to Latour (1987, 30), "do not speak of the world but, rather, construct representations that seem to push [the world] away, but also bring it closer." The map in other words becomes the territory: scientific observation, mediated by epistemology and technology, progressively abstract and transform nature into language, symbols, and/or signs. This act of transformation draws nature into the discursive purview of human exchange rendering the phenomena of study entirely devoid of its original materiality while simultaneously making it all the more tractable, manageable, and transportable.

Latour maintains that nature – or the environment – is defined through this process of progressive abstraction. He states that, "nature is the final cause of the settlement of all controversies, *once the controversies are settled.* As long as they last *Nature will appear simply as the final consequence of the controversies*" (Latour 1987: 98 emphasis in original). In other words as various perspectives, interpretations, models, theories, or discourse about the world are proposed they exist simultaneously in tension with alternatives. The relative success of a given abstraction (e.g. gravity is a fundamental physical force that governs the behavior of objects) over others that attempt to account for some phenomena is a complicated matter that Latour is at pains to describe in his various works. Nevertheless, the general point is that abstractions compete essentially on the basis of adequate behavior. If an abstraction posits, for example, that gravity works in a certain manner, then the observed world must behave adequately relative to the abstraction – or to put differently does the world behave according to the abstraction. It is not until controversy over various competing abstractions are settled that nature becomes the cause of its success. "As long as controversies are rife, Nature is never used as the final arbiter since no one knows what she is and says. But *once the controversy is settled*, Nature is the ultimate referee" (1987:97 emphasis in original).

As reviewed above in Chapter One in the sections *Political Ecology* and *Discourse Analysis*, truth in discourse is derived from contestation and negotiation. But to claim that the truthfulness of a discourse is defined via a social process and not based in "reality" does not deny the ontological basis of a physical existence beyond our discursive realms. Rather, discourse – or more generally, language – is the medium by which we apprehend our world. It is beyond the scope of this thesis to launch into a detailed discussion of a philosophical review of this position (see Braun and Castree 1998; Forsyth 1998; Proctor 1998; Zimmerer and Young 1998; Rabinow and Sullivan 1979; Clifford and Marcus 1986 for discussion on this issue). The question here is not over the existence of an objective world, but rather how various views of the world take precedence over others. With regard to this thesis my interest is how various groups perceive the Andean landscape, and more specifically landscapes wherein *Polylepis* forest stands remain extant.

The story of the Andean landscape is one of human impact and a process of humanization. Generally speaking, areas of high biodiversity have historically been centers of human population growth in the Andes (Chepstow-Lusty *et al.* 1998). Evidence of human occupation and land-use of the Peruvian highlands goes back to 10 - 11,000 BP (Ellenberg 1979; Lynch 1980), while human presence has been documented as far back as 25,000 BP (Hoffstetter 1986). It is estimated that prior to the arrival of the Spanish Conquistadors, 12 -

14 million (Gade 1992) people lived on the coast and in highlands of Peru, Ecuador, and Bolivia. While exact historical population numbers are difficult to define regionally (Denevan 1992) the pattern of human settlement concentrated along the coast and in the highlands was well established during the Incan period (Hemming 1970).

Today this population pattern remains at least somewhat similar, as revealed by the current distribution of villages (percentage-wise, however, population is much more concentrated on the coast today). On the western slopes of the Peruvian Andes, villages and cities tend to be located along the coast and on upper slopes between 2,000 - 3,500 meters where humid forests occur, while the barren inhospitable lands beyond the coast are virtually devoid of human presence (Valencia 1992). By all accounts Andean peoples have long been a part of the highland landscape. The construction of earthworks (e.g. canals, terracing), intensive agriculture, and animal husbandry has precipitated alterations on the landscape that are centuries old (Seibert 1983; Denevan 1987; Gade 1992; Zimmerer 1996a).

With regard to *Polylepis* it has been suggested that during the pre-conquest Andes the genus played an important role by supplying timber for construction and tools, firewood, and artisanal materials (Simpson 1979; Seibert 1983; Kessler and Driesch 1993; Kessler 1995). Although Spanish conquest triggered widespread changes in Andean culture and landscapes systems, we may assume that *campesinos* maintained their reliance on *Polylepis* forests both during and immediately following colonialism (Gade 1992). However, it is important to note that *campesino* access to timber resources was dramatically changed under Spanish control of forests. Equally important is that the Spanish imported with them a new understanding of forest resources.

In 1559 King Phillip II declared in the *Recompilation of the Law of the Indies* that:

> *The Indians may freely cut wood in the forests for their use, and that no impediments be placed on them except that they do not cut [the trees] in such a manner that [they] cannot grow and increase* (Thurner 1997: 42).

This right of access to common resources decreed by Spanish royalty would condition the nature of land tenure practices in Peru for centuries until modern National Park policy. In 1712 an official declaration of *ejidos* (commons) in the Cordillera Blanca region was made under the Land Recomposition Law. The passage of this law reinforced the established pattern of Spanish colonial land-use in the region. For example, during a visit by Archbishop Morgrovejo to the Cordillera Blanca area in 1593, he described vast herds of sheep, owned by Spanish colonists, numbering in the tens of thousands were driven to pasture in the high *quebradas* of the Cordillera Blanca (Thurner 1997). In essence the right to access common property in the form of timber, grasslands, and water in the Cordillera Blanca was considered an inalienable right afforded to both the indigenous and Spanish population of the region.

Access to common natural resources would, however, eventually be used as a means of controlling *campesinos* to secure labor and benefit for the Peruvian state. This is exemplified by the treasurer of the Department of Ancash commenting, in 1842, on the resources-for-contribution compact between *campesinos* and the Peruvian State:

> The contribution that the indigenes satisfy is not excessive... it is necessary. It is not excessive because they are granted certain prerogatives in the payment of parish fees, tithes etc., and because they have free access to the *quebradas* (valleys) of forests for the extraction of sticks of wood for the market. It is necessary because in the instances when they have stopped contributing by virtue of a pardon, we experience a scarcity of work-hands, since the indigenes need only one piece of rough clothing per year; and their fields, although small, proportion them with their simple foods, being the only thing that they like to eat, and they desire nothing else. They do not strive to abandon their idleness which is characteristic of them except at the time when the contribution is collected (Thurner 1997: 40).

Campesinos of the Cordillera Blanca and Callejón de Huaylas were the sole suppliers of fuelwood to the kitchens and kilns of Spanish colonists, in addition to consuming wood for personal use. Unfortunately the extent of *Polylepis* timber use from the pre-Incan to the contemporary period is not available. Moreover, secondary effects on stands of *Polylepis*, resulting from agricultural and/or rangeland practices over the centuries are exceedingly difficult to understand. In general the important point is that *Polylepis* forests in the region of the Cordillera Blanca were transformed in the colonial era to a common resource held by the Spanish crown, and were used to leverage control over *campesinos*.

During the early 1960s when agrarian reform was gaining political support as a means to dismantle the *Hacienda* system in Peru in favor of land redistribution, interest in conservation of the Cordillera Blanca also was gaining urgency. By 1966 a local law was passed in the region making illegal the cutting of trees and hunting of wildlife inside the Cordillera Blanca, intended to serve as a sanctuary for endangered wildlife and remnant patches of *Polylepis* forest (Baker 1980). Government policy discourse on *Polylepis* had by the late sixties taken on an environmental and conservation orientation, wherein the long history of intensive land-use was considered the culpable force that derived the patchy appearance of *Polylepis* on the landscape. In 1973 Peruvian national law declared *Polylepis* an endangered and protected genus.

It would not be until 1977, however, that a clear scientific position on the issue was established. Heinz Ellenberg delivering to the British Ecological Society the Second Tansley Lecture, entitled "Man's Influence on the Tropical Ecosystems in South America", concluded that:

> Today [Andean valleys] are almost completely devoid of forest-like vegetation. But some persist, and the available meteorological data tells us that these valleys could be clothed in woodlands if man had not interfered for hundreds of years… [woodlands] were destroyed partly by cutting firewood and timber and by burning adjacent grassland areas during the dry season, but mainly by the browsing of indigenous as well as introduced livestock. The ecosystems of the tropical Andes are far from being untouched nature. In my opinion, we should wonder why some forests or tree stands are left there, instead of wondering why they are so small and rare that they could be looked upon as exceptions (Ellenberg 1979: 407 and 415).

Echoes of Ellenberg's position are found today in contemporary writing. In a report produced by an Oxford University Team studying the avifauna of highland *Polylepis* forests, claims that:

> Human disturbance in the form of burning, grazing, and cutting in the surrounding páramo and puna grasslands is assumed to have taken place over a period of thousands of years. Indeed, there is good evidence to suggest that the high altitude *Polylepis* woodlands were once widespread, covering substantial areas of the highlands. These practices continue today and represent a serious threat to high altitude woodlands (Smith 1998: 64).

Implicating human – *campesino* – agency in the fragmentation of *Polylepis* forest and degradation of the highland Andes has become one of the dominant modes of interpretation to explain contemporary landscape patterns.

Contemporary extent and spatial distribution of *Polylepis* forest patches since the Ellenberg lecture has become the subject of contentious debate within scientific circles. This debate can be generalized as having three dominant perspectives:

1) *Declension*: anthropogenic factors leading to widespread deforestation and expansion of grasslands (Smith 1998; Fjeldså and Kessler 1996; Kessler 1995; Kessler and Driesch 1993; Verweij and Beukema 1992; Lægaard 1992; Lozada 1991; White 1985; Williamson et al. 1986; Siebert 1983; Milliones 1982; Hanson et al. 1984; Cerrate 1979; Ellenberg 1979);

2) *Adaptation*: natural fragmentation and speciation of *Polylepis* forests as a response to global climate change and physiological adaptation to particular mico-climates (Laurer 1993; Simpson 1986, 1979; van der Hammen 1986; Hansen 1984; Smith 1977); and

3) *Interaction*: species adaptation to microclimates coupled with anthropogenic disturbances that have spatially articulated *Polylepis* forest in a patchwork pattern (Young 1998; Chepstow-Lusty 1998; Stern 1995; Young and León 1995; Valencia 1992).

Declension Perspective

The overall history of *Polylepis* forests and interpretations of their geography as reviewed above suggests a declensionist reading of the landscape. The most poignant evidence marshaled to support the history of declension in the high Andes centers upon the issue of current versus potential distribution of *Polylepis*. Kessler (1995) revealed through an exhaustive study of 194 *Polylepis* patches in the Bolivian highlands that, statistically speaking, the genus shows no proclivity to particular micro-climates. Occurring on all soil types[2] (except seasonal flood plains and salinated soils), the genus is not limited by edaphic factors or by known biotic factors (e.g., mycorrhizal associations or grazing pressures[3]). Moreover, Kessler's exclosure experiments, which inhibited the influence of grazing and fire on grasslands, exhibited rapid invasion of *Polylepis*[4]. The conclusion drawn from the

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[2] No evidence exists which correlate *Polylepis* to particular geological parent materials, however, the genus does not avoid geological forms (Kessler 1995).

[3] Kessler (1995) found that although grazing can prevent *Polylepis* from invading grasslands, no data exists that show browsers preferring *Polylepis*.

[4] It is significant to note that naturally occurring fire due to lightening strikes have yet to be proven in the highland Andes (Chepstow-Lusty *et. al.* 1998).

Kessler study suggests the potential distribution of *Polylepis* being dramatically higher if anthropogenic disturbances were eliminated from the landscape. *Polylepis*, then, would be the climax cover of the Andean highlands under natural conditions, and extensive grasslands produced by human agency an aberration from the normal successional pathway in the Andes (Ellenberg 1979; Lægaard 1992; Kessler 1995; Fjeldså and Kessler 1996). Fjeldså and Kessler (1996) argue that like the central Andes evidence of large scale and pervasive anthropogenic grasslands exist in the case of the grasslands of the Patagonian Steppe. The treeless steppe of the Patagonia was quickly invaded by forest cover following the removal of fire from the ecosystem when the Spanish eliminated the indigenous people of the area, who employed fire in the hunting of guanacos.

The the declensionist argument is based on finding fault with the land-use practices of highland Andean *campesino*s. Furthermore, the incipient creation of high grasslands and relictual *Polylepis* cover is relatively recent in the history of the Andes, dating back to the opening of the Holocene epoch. The declensionist perspective suggest the Andes to be an un-natural environment – where human agency on the landscape has produced degraded conditions. The implication for conservation policy is that to reproduce or promote a natural environmental state of being that human agency on the landscape ought to be removed.

Adaptation Perspective

Addressing how contemporary Andean landscape patterns arose, however, must attempt to account for time scales in describing the ecology of the species. When we choose to begin telling the story of a given landscape – either 100, 100,000, or 1 million years ago – will influence the types of patterns we observe, and our interpretations of that landscape.

Longer time scales, giving at times an appearance of relative stability may dampen what at shorter time scales may seem like chaotic or wild variation. This is clearly the case when considering contemporary *Polylepis* patterns, which have been interpreted as a natural distribution based upon the adaptation of the species over extremely long time frames, rather than a product of human agency on the landscape. The adaptation perspective views the 'patchiness' of *Polylepis* forests as relatively stable, resulting from adaptation of the taxa to climatic variation over extremely long time frames. The most vocal advocate of the adaptive species perspective, as a counter interpretation to that of landscape declension, has been Beryl Simpson (1979; 1986).

Polylepis forests were present in South America during the Miocene, some twenty million years ago, as taxa that occurred at lower elevations (Simpson 1979). It is generally thought, however, that *Polylepis* advanced to higher elevation habitats, which became available at the end of the Tertiary period during the late Pliocene, created by continental uplift of the tropical Andes (Simpson 1979, 1986; van der Hammen and Cleef 1986; Fjeldså and Kessler 1996; Chepstow-Lusty *et. al.* 1998). Paleohistorical pollen evidence (van der Hammen 1974; van der Hammen and Cleef 1986; Hansen 1984) reveals that following *Polylepis* forest establishment, the taxa underwent periods of expansion and contraction as a function of climate fluctuation. Generally speaking during dryer and cooler epochs *Polylepis* were receding and grasslands were expanding, while during wetter and warmer epochs the opposite pattern occurred. 30,000 BP, according to van der Hammen (1974), the Andes underwent a wet and warm climate regime, which created conditions favorable for *Polylepis* forests to expand and dominate the landscape (near Bogotá, Colombia). However, by 21,000 BP a pattern of cooler and dryer climate established, which led to a virtual disappearance of

Polylepis from the pollen record (van der Hammen 1974). Simpson (1979, 17) suggests that based on pollen evidence, "complete coverage of this high Andean area by woodlands was an uncommon event and has not occurred since 30,000 BP - long before the active influence of man." She goes on to conclude that the natural contraction of *Polylepis* forest 21,000 BP, which isolated genetic populations of the genus, serves to explain the variety of taxa that currently exist (Simpson 1986). Moreover, the uneven distribution of the taxa across the northern, southern, eastern, and western expanse of the Andean cordilleras supports the thesis of long term fragmentation of *Polylepis* (see: Simpson 1979 for spatial distribution of the various taxa).

The adaptation perspective concludes, that while agricultural practices extend only as far back as 10,000 BP (Lynch 1980; Smith 1980), and hunting and gathering to 20,000 BP (Fjeldså and Kessler 1996), *Polylepis* had already disappeared from the pollen record prior to the arrival of humans (van der Hammen 1974) or coincided closely with their arrival at 30,000 BP (Hansen et. al 1984). The 'physiological problem' of how *Polylepis* is able to occur in conditions that do not normally support forest cover is a function of the adaptation of the species to particular micro-climates. For example, on the western Peruvian cordilleras, precipitation increases with altitude, which represents an aberration from the general pattern found in tropical mountains. Humid easterly winds rising over the eastern cordilleras from the Amazon lose moisture rapidly as they gain in elevation. This loss in moisture is revealed by the rapid decline in vegetative cover on the western slopes of the Andes (Valencia 1992). Historic precipitation patterns have subjected the taxa of *Polylepis* to on-going water stress, forcing speciation and specialization to particular micro-climates (Simpson 1986).

Various interpretations have addressed issues of location, aspect, form, and habitat of the species as adaptive strategies for survive where edaphic, biotic, and climatic conditions that govern *Polylepis* distribution (Troll 1968; Walter and Medina 1969; Smith 1977; Simpson 1979; Kessler 1995). Advancing Carl Troll's (1959) classical analysis of Andean geography, Simpson (1979, 15) claims: "the ability of *Polylepis* to grow above the montane cloud forest could... be explained by the presence of micro-climate phenomena that produce 'lower elevation' conditions." Thus ravines and narrow valleys, with warmer and moist conditions, are micro-climatically favorable to *Polylepis*. This adaptive behavior is couched within a larger pattern of vegetation-elevation associations (Holdridge 1947; Troll 1968; Brush 1977) in the Andes. Associations of this sort both restrict *Polylepis* expansion into areas inhospitable to the genus, such as open valley floors that are too cool, and promote its establishment at elevations where cloud condensation negates arid conditions normally too severe for the species (Simpson 1979; Fjeldså and Kessler 1996).

The adaptive species perspective does not, however, entirely negate the role of human agency on the landscape. Simpson (1986, 304) herself claims that: "Superimposed on these natural geologic and climatologic events," which led to uneven distribution of *Polylepis* forest, "have been human actions... [and]... because of these human influences, it is unfortunately impossible precisely to reconstruct the evolutionary history of the genus." Much of the confusion surrounding the issue of *Polylepis* is due to the fact that it is "impossible" (Simpson 1979, 14) to distinguish between the pollen of *Polylepis* taxa (Kessler 1995). Individual species of *Polylepis* are effectively invisible in pollen sample analysis. This invisibility does not allow us to ask a crucial question: did *Polylepis* arise as a suite of about twenty species unevenly but pervasively distributed across the highland Andes, and subsequently fragmented due to human agency; or did the adaptation of an early stock (e.g., *P. multijuga, P. pauta, P. lanuginosa*) to climatic change and habitat reduction lead to the twenty extant species, observable today in an uneven distribution pattern?

Thus, while the Ellenberg declensionist hypothesis can not be disproved, the confounding influence of human agency on the landscape coupled with the invisibility of *Polylepis* in pollen analysis, disallow the unequivocal acceptance of the adaptation perspective. If, for example, we wish to assess the effects of the little ice age ca. 1490 - 1900 AD on the Andean landscape, teasing apart the role of climatic variation and human influence becomes extremely difficult. Chepstow-Lusty *et. al.* (1998) assert that one phenomena exacerbates the other: climate change trigger changes in human land-use that in turn influences landscapes. Climate change and land-use practices, then, are not mutually exclusive in their relation to landscape change, but rather are recursively linked.

The argument for adaptation of *Polylepis* species as an explanatory tool to account for distribution patterns is focused upon climate change. Creation of high grasslands and patches of *Polylepis* forests is an ancient condition on the Andean landscape that existed prior to the arrival human settlement and agency. The adaptation perspective suggests the Andes to be a semi-natural environment. Human agency on the landscape has not produced the patchy forest conditions and grasslands of the Andes, but it has confounded scientific efforts to comprehend the natural history and development of a landscape under climatic and geologic change. The implication of this perspective is to down play the role of human agency on the landscape.

Interaction Perspective

Notable attempts to marry the declension and adaptation perspective exist (Young 1999; Young and León 1995; Valencia 1992; Young and Valencia 1992). Young and León (1995, 659) invite us to consider that: "habitat fragmentation is a natural consequence of the distribution of ecosystems in a complex topography... thus it is critical to understand the degree and impact of this natural fragmentation when evaluating the additional fragmentation caused by human activity." Suffice to say here that this perspective, aligned closely to that of political ecology, does not assume a natural state for the environment. Rather the interactionist perspective considers the complex interaction among climate change, land-use, and ideology about the environment that leads to understanding landscapes as natural, un-natural, or some combination thereof. I will return to this topic in Chapter Four.

Institutional and *Campesino* Discourse

Given the ideas explored above we can at this point make two conclusions: first, there is ample evidence for an interpretation of Andean landscapes as anthropogenic, and second, forest resources have largely been out of *campesino* control at least since the sixteenth century and probably earlier as well since the Incan state controlled forest resources. But who – if anyone – is responsible for forest degradation, and what the landscapes of the Cordillera Blanca should look like if in fact they were not 'degraded' by a long history of human land-use, is unclear. Moreover, it is not obvious what choice of conservation action should be engaged given the variety of interpretations and history that have been mentioned thus far.

Nevertheless, institutional and local *campesino* discourse, within the Huascarán Biosphere Reserve have adopted perspectives that align themselves within the framework developed in the preceding section. The HBR official mission statement in the *Parque Nacional Huascarán: Plan Maestro – Generalidades y Diagnostico* (1990a: 20) states the primary objective of conservation efforts in the reserve to: "proteger y conservar la flora y fauna silvestre, formaciones geológicas, restos arqueológicos y bellezas escénicas – protect and conserve wild flora and fauna, geological formations, archeological remains, and scenic beauty." Yet, as a biosphere reserve there is a secondary commitment to support those people who live within and adjacent to the buffer zone. While there is recognition of the cultural heritage of the region that has played a definitive role with regard to the landscapes within the reserve, the overriding management scheme is to mitigate and to remove human agency from the landscape in order to maintain and promote natural conditions – a declensionist perspective.

This is apparent in the language used by the HBR. The use of words such as *relictus* (relicts) to refer to forests and categories such as *paralizadas* (paralyzed) and *en explotación* (under exploitation) for valleys considered to suffer from over-extraction of natural resources is revealing. To consider forests as 'relicts' implies that forests are remnants of once larger or more vigorous stands. While terms such as *paralizadas* and *en explotación* are descriptively vague, in that no clear definition is provided to distinguish these conditions, they point to a broader pattern in HBR planning and policy material. *Campesino* activities are persistently described as threats to the condition and biodiversity of the park. These threats to the natural condition of the area are defined as fire, agriculture, grazing, collection of medicinal plants, and removal of timber from the core area/national park.

In addition the HBR staff have developed a system of user groups in the villages that abut the core area of the reserve. These user groups are defined by land-owing/voting members of each village who work with the HBR staff to determine how they are permitted to access resources within the core area. According to reserve policy *campesino* access to resources within the reserve is limited to use of grasslands for grazing of cattle. In exchange for this access the user groups must maintain trails within the core area and support HBR staff in efforts to restore natural conditions. It is intriguing to note the similarity of this relationship, between the HBR and local *campesinos* and that of the Spanish colonialists and *campesinos* with regard access to natural resources. Finally HBR policy assumes that the *Polylepis* forests within the park are relicts of larger forests that have been destroyed by *campesino* land use practices.

Conservation efforts outside of state run efforts by the HBR is promoted by an international group, The Mountain Institute (TMI). TMI *Plan Estratégico: El programa Andino de El Instituto de Montaña 1997 –2000* (1997: 1) state's in reference to the HBR that, "pocos paisajes expresan de forma tan dramática la relación de adaptación entre población humana y ecosistema como las regiones de alta montaña – few landscapes express as dramatic an adaptive relationship between human population and ecosystems as those of high mountain regions." In many ways TMI agree with the HBR staff concerning environmental threats. However, TMI's position is most closely aligned with that of the interactionist perspective.

The commitment of TMI is to promote the balance among biodiversity conservation, cultural survival of local heritage, and the sustainable development of local communities. In doing so TMI assumes an orientation similar to that of political ecology in order to understand the role of the economic and political forces on landscapes and their conservation. As such TMI understands *Polylepis* forest patches as relicts of once larger forests, but see these forests as conditioned by the political and economic forces as much as environmental ones.

The *campesino* perspective of landscapes within the HBR, albeit different than the policy and scientific definition of declension, is one of decline and degradation. Time and time again in my interviews with local people the general perspective was that the land is not as productive as in the past. With regard to *Polylepis* forests the local perspective is that these forests are not for accessible for consumption. Indeed, one interviewee claimed: "recuerdo cuando los bosques quenuales crecieron rectos – I remember when quenual [*Polylepis*] forests once grew straight." This is a curious suggestion that suggests a perspective of *Polylepis* forests as not as useful now as in the past – that trees do not grow straight they are not appropriate for construction and other purposes.

Given the institutional and *campesino* perspectives on *Polylepis* forest it is interesting to note that the adaptation perspective is not supported. Moreover, it is interesting that the perspective of declension – a loss of a natural state of the landscape due to human land-use is the prevailing view of the HBR and *campesino.* How these perspectives fair with regard to the ecological and spatial analysis of *Polylepis* forests within the HBR is the subject of the following chapter.

CHAPTER THREE
ANALYSIS OF SPATIAL CHANGE

Introduction

In the previous chapter various interpretations and discourses that describe *Polylepis* forests within the Andes were explored. In this chapter I begin to lay out the foundation for an alternative interpretation on the basis of findings from the Huascarán Biosphere Reserve case study. As a site specific, micro-scale interpretation of *Polylepis* forest change, the intention is not to refute the interpretation of either the Huascarán management staff or conservation groups working in the area. Rather the overall goal is to shed light on the dynamic of forest cover change in order to move the overall discourse on the biogeography of *Polylepis* forests to a new vantage-point. It is from this new vantage-point we may begin to ask more sophisticated and site-specific questions about the nature of forests within the Huascarán Biosphere Reserve.

The centerpiece of the interpretation offered here is an analysis of spatial change and ecological data on *Polylepis* forests within the HBR. Both analyses are inter-related and ultimately must be considered together in order to propose an alternative interpretation of contemporary *Polylepis* forest cover change in the HBR. However, for ease of presentation the spatial and ecological analysis is divided into Chapter Three and Four respectively. The current chapter presents an overview of the sites that were selected for study within the HBR and methodology for analysis. Following this overview is a spatial analysis of forest cover change for each of the HBR study sites. In the Chapter Four I will shift my attention to an analysis of ecological data collected during field research. The analysis of ecological data will be subdivided into three sections; respectively dedicated to a thorough examination of each study site. The choice of the order of presentation is chronological, following the research/analysis activities engaged in the production of this thesis. In a detailed fashion each of the sections of Chapter Three and Chapter Four explores the variety of technical and analytic tools and methods applied to the spatial and ecological data set.

In addition it is critical to note that both the spatial and ecological analyses were riddled with technical difficulties. Analysis of imagery and data reveal that quantitatively my findings are inconclusive; that is to say the quantitative results discussed below are to be interpreted primarily as estimations. Nevertheless, it is important to state that the most conclusive demonstration of *Polylepis* forest dynamics derives from a qualitative comparison of forest cover based upon quantitative estimates. In other words quantitative analysis provided an understanding (i.e. estimation) of spatial change and ecological condition of forests in the HBR that is limited both by choice of methodology and errors in analysis. It is through careful qualitative consideration of these estimates that I arrive at a demonstration not of forest cover change but rather of forest cover resiliency. This demonstration is explored in Chapter Five in the *Synthesis of Findings* section. Only by first following the discussion of Chapter Three and Chapter Four can a relevant discussion of the overarching topic of *Polylepis* forest cover resiliency be accomplished.

Overview

Study sites within the HBR were selected in order to complete an analysis of spatial change and ecological dynamics of *Polylepis* forests. The site selection process had two primary goals. The first was, to locate three areas in the reserve with *Polylepis* forests and the second was to identify three areas that represents a range of forest conditions. In particular I sought a range of conditions from relatively undisturbed to degraded forest conditions within the HBR. By adhering to each of these goals, forests could be studied in a manner that captured both variation across the reserve and variation across HBR staff designation of forest condition.

Following conversation with the superintendent and the lead forester of the biosphere reserve, three sites were selected; Quebrada Llanganuco (Demanda), Quebrada Ishinca, and Quebrada Aquilpo (see Table 1, Appendix 1: Figure 2, and Appendix 2: Maps 1, 2, & 3).

Table 1: General Overview of Study Valleys

Valley Name	Number Plots	Number Patches	Forest Cover	Topographic Range	Nearest Village/ User-Group	Number Voters	Village Pop.
Demanda	18	6	285 ha²	4100 – 6600 m	Humacchuco	100	800
Ishinca	24	8	274 ha²	4000 – 5700 m	Collón	105	1000
Aquilpo	22	6	65 ha²	3900 – 5600 m	Jomcopampa	96	300

Each *quebrada* (valley) allows for certain advantages as a unit of study. The primary advantage is that each valley is a discrete site with its own user-group (see Chapter Two: *Institutional and Campesino Discourse*), and hence a particular land-use and land-management regime. In addition, each site is similar in term of physical geography, meaning that similar topography, aspect, and slope exist in each valley. As we will find further on when discussing ecological data from each valley, land-use and land-management practices of unique user-groups in each valley is vital in understanding the dynamic of forest cover change.

The overall analysis of this study is based upon a research design that incorporates both qualitative and quantitative methods. Qualitative methods employed an ethnographic approach, intended to identify historic and contemporary land-use practices that affect

Polylepis woodlands. Quantitative methods (detailed below) were used to empirically evaluate the condition and spatial pattern of the forests within the three study valleys (e.g. Brower and Dennis 1998; Echaavarria 1998; Lyon *et al.* 1998; Deppe 1998; Braun 1997; Byers 1996; Stern 1995; Turner and Gardner 1991; Dunn *et al.* 1991). Several studies offer potential models, in a general sense, for this research approach; such as Braun's (1997) and Stern's (1995) use of remote sensing and aerial photography to evaluate changing spatial patterns of *Polylepis* forests; and Brower and Dennis' (1998) examination of the socio-environmental factors that drive forest patches dynamics in the Everest region of the Himalayas (a review of the efficacy of these techniques is discussed in *Discussion of Spatial Change Analysis* in the present chapter).

Qualitative methods relied upon unstructured interview completed with three groups who have an interest in *Polylepis*: local people from the three villages of Jomcopampa, Humacchuco, and Collón to assess their historic and contemporary use of *Polylepis* (nine interviews), HBR staff (two interviews), and a conservation organization working in the region, The Mountain Institute (two interviews). In addition, data was collected on land-use activities (see Appendix 3: *Field Research Activities and Design*), such as contemporary grazing, that occur in the vicinity of *Polylepis* patches that may influence forest pattern, as well as what forest alternatives to *Polylepis* exist that may reduce timber extraction pressure on *Polylepis* forests.

Coupled with the qualitative analysis is a geographic information system (GIS) database. Aerial photographs of the region from 1962, and Landsat TM imagery from 1986 and 1996 were utilized to complete a spatial analysis intended to detect changes in forest patch pattern. The GIS database was verified with a ground truth sampling of 1999 forest patches to increase confidence in the findings of the spatial analysis. In addition, forest patches were assessed with regard to their structural characteristics. Ecological data on forest structure has been shown to reveal information on the correlation between land-use practices and forest stand degradation (e.g., Brower and Dennis 1998; Byers 1999, 1996). For a more detailed account of overall research methods and design see Appendix 3: *Field Research Activities and Design.*

Analysis and Results of Spatial Change

Analysis of the spatial change of *Polylepis* forests of the Peruvian Andes yielded interesting, but limited findings. A detailed review of the results of the spatial analysis on forest cover change, focusing upon *Data layer Preparation* and *Change Analysis*, will expose the challenges inherent to such analyses. Following this review a discussion of the results is used to provide an initial interpretation of forest cover change within the HBR (see Appendix 4: *Methodology for Spatial Change Analysis* for a detailed account of the conceptual design and implementation techniques employed in this study).

Data Layer Preparation

1962 Aerial Photos

Elevation contour maps were successfully created and the digital elevation models built in Arc/Info for each study area. However, problems were encountered in ortho-rectification of aerial photographs. Difficulty in identifying control points in the natural landscape made it impossible to lower the root mean square error (RMSE) of rectification below 1.0 – 1.2 pixels[1] for all three valleys. RMSE in general exceeded 11.0. Because of this level of error it was impossible to determine whether the observed change is real, disallowing the use of aerial photos in formal spatial analysis except for qualitative visual interpretation.

1986 and 1996 TM Images

The 1986 and 1996 images were geo-rectified with RMSE of 0.37 and 0.42 respectively. However, when subsetted images of the three valleys were overlaid approximately a 1.0 to a 1.5 – pixel error in mis-registration was observed. Because of this mis-registration spectral normalization of the 1986 to the 1996 failed for two reasons (see Appendix 4 for explanation of spectral normalization). First, due to a lack of satisfactory control points geo-rectification was unable to be completed within an acceptable degree of confidence: 0.5 pixel. The fundamental challenge in geo-rectification of Landsat TM imagery is that the Affine (1st order linear polynomial) transformation algorithm is not able to deal with topographically dynamic landscapes (i.e., varied, steep, and complex topography). The Affine transformation assumes a linear relationship between ground control points and photogrammatic distortions across the image to be rectified. Due to the tremendous non-linearity of elevation change across mountainous environments the Affine transformation is insufficient to successfully rectify imagery. Higher order transformations (e.g. 2nd and 3rd order non-linear polynomials) are also highly susceptible to errors in rectification (Jenson 1996; Lillesand and Keifer 1994). The only immediate solution to deal with this issue would be to rectify the entire Landsat TM image with ortho-rectified photographs to account for

[1] Unless otherwise stated pixel resolution is 30 meters (90 square meters).

non-linear change across the landscape, which was not feasible since a set of ortho-rectified photographs that covers the entire area of interest was not available (I will return to this issue in the discussion of results).

Ultimately, however, this error in rectification resulted in a second more serious problem with the selection of points for the purpose of standardized radiometric normalization (see Appendix 4 for explanation of standardized radiometric normalization). Despite the high degree of confidence (a 0.95 R-squared value for radiometric normalization) mis-registration in the geo-rectification process skewed the normalization process and produced unacceptable classifications of the 1986 imagery.

Although standardized radiometric normalization failed, band ratio normalized images were created from the 1986 and 1996 images (see Appendix 4 for explanation of band ratio normalization of images). These images were used to produce two sets of classifications; a forest/non-forest classification for all three study sites from the 1986 and 1996 imagery (see Appendix 2: Maps 4, 5, & 6), and a base-map of 6 classes for all three study sites in 1996 (see Appendix 2: Maps 7 & 8). Difficulties were encountered in this process as well. They include potential mis-classification of pixels that reside at boundaries between spectral classes and shadow effects that could not be adequately mitigated for through the use of band ratio normalization. Finally, because it was not possible to collect a sufficient number of independent ground-truth data points, beyond those collected for the purpose of defining training areas, a confusion matrix to analyze classification error was not possible.

Given these difficulties, the original 1986 and 1996 imagery (i.e., geo-rectified imagery not subjected to any normalization process) for all three study sites were visually interpreted and classified (using a 1 ha minimum-mapping unit) into vector coverages. Imagery was geo-rectified and digitized on-screen in Erdas-Imagine, imported into Arc/Info to be cleaned, and finally prepared into forest/non-forest maps (see Appendix 2: Maps 9, 10, & 11) in Arc/View. This same process was used to produce base-maps for 1996 imagery (see Appendix 2: Maps 1, 2, & 3).

Change Analysis

Patch Level Analysis

Calculations in ArcView Patch Analyst at the patch level revealed little evidence of change (see Table 2). First, change in patch size was analyzed. More than half the study patches increased in size, however, the amount of change in patch size varied considerably. Some patches appeared to remain relatively stable (change of .7%) while others showed evidence of change (range from a decrease of 35% to an increase of 43%) (see Table 3).

Second, change in patch shape was analyzed. Fifty percent of patches showed an increase in the perimeter/area ratio. Change in the corrected perimeter/area ratio ranged from negative 17.2% to positive 15.1%, while other patches changed as little as .5% (see 1 Table 3). The area weighted mean fractal dimension did not change significantly for any patch between 1986 and 1996 (see Table 3).

Valley Level Analysis

Overall, at the valley level the analysis did not show significant evidence of change. Quantitative analysis of change in patch size and shape was successfully completed for the 1986 and 1996 Landsat TM images using ArcView Patch Analyst. Statistics calculated at the

Table 2: Patch Level Statistics

Valley	Year	Patch ID	Patch Size	Change in Patch Size between 1987 and 1996	Change in Corrected Perimeter/Area Ratio	Mean Patch Fractal Dimension
Quebrada Aquilpo	86	1	8.44			1.06
	96		6.30	-25.4%	2.1%	1.06
	86	2	0.96			1.01
	96		0.74	-22.6%	-5.5%	1.00
	86	3	3.73			1.07
	96		3.94	5.5%	10.8%	1.09
	86	4	7.23			1.08
	96		7.87	9.0%	-2.6%	1.07
	86	5	6.26			1.06
	96		6.11	-2.4%	1.2%	1.06
	86	6	250.77			1.18
	96		232.17	-7.4%	0.5%	1.18
Quebrada Ishinca	86	1	4.25			1.04
	96		2.78	-34.5%	1.2%	1.05
	86	2	4.94			1.09
	96		6.27	27.1%	-6.8%	1.07
	86	3	3.12			1.03
	96		2.60	-16.5%	4.0%	1.04
	86	4	9.90			1.10
	96		8.47	-14.4%	-3.9%	1.10
	86	5	1.78			1.04
	96		1.77	-0.7%	-8.2%	1.03
	86	6	19.21			1.10
	96		20.95	9.1%	-10.6%	1.08
	86	7	38.74			1.17
	96		39.55	2.1%	15.1%	1.17
	86	8	163.08			1.18
	96		165.68	1.6%	-17.2%	1.17
Quebrada Llanganuco	86	1	1.68			1.01
	96		1.93	15.1%	1.7%	1.02
	86	2	0.50			1.04
	96		0.55	11.0%	-8.4%	1.02
	86	3	3.63			1.07
	96		3.09	-14.9%	-2.8%	1.06
	86	4	2.36			1.03
	96		3.15	33.3%	1.3%	1.03
	86	5	0.89			1.09
	96		1.26	42.7%	-4.1%	1.08
	86	6	2.99			1.06
	96		3.52	17.4%	11.3%	1.07

Table 3: Summery Statistics

Patch Size	
55% of patches increased in size	
Absolute Range of Percent Change	.7% - 43%
Real Range of Percent Change	-35% - 43%

Perimeter/Area Ratio	
The P/A ratio decreased in 50% of patches	
Absolute Range of Percent Change	.5% - 17.2%
Real Range of Percent Change	- 17.2% - 15.1%

valley level include all forest patches in the valley, not simply the 20 study patches. These statistics reveal very little change in both total forested area and in the area weighted mean fractal dimension between 1986 and 1996 (see Table 4). These results indicate that the amount of forest cover did not change significantly between the two time periods, nor did the shape complexity of patches change. The mean perimeter/area ratio does indicate evidence of change (see Table 4). It should be noted that the uncorrected perimeter/area ratio introduced error because the formula does not normalize the relationship between patch size and patch perimeter.

Table 4: Valley Level Statistics

Valley	Year	Number of Patches	Total Forested Area in the Valley (ha2)	Change in Forest Area	Change in Mean Perimeter/ Area Ratio	Area Weighted Mean Fractal Dimension
Quebrada	1986	19	313			1.16
Aquilpo	1996	19	285	-8.9%	21.3%	1.17
Quebrada	1986	19	267			1.15
Ishinca	1996	18	274	2.7%	-9.7%	1.14
Quebrada	1986	9	59			1.16
Llanganuco	1996	9	65	9.7%	-13.3%	1.16

Potential Sources of Error in the Change Analysis

Although minimal change was detected between 1986 and 1996, it is difficult to tell whether this measurement or estimate of change is real. There are two major sources of error. First, when digitizing from the Landsat TM imagery, human error in visual interpretation is introduced. Small landscape features are particularly difficult to digitize accurately due to the resolution of TM imagery. These errors mostly likely account for major changes observed in the patch level analysis. Several of the patches with significant percent-wise change in area are very small patches (see Table 3). It is difficult to interpret whether this change is real, or based on digitization errors. Second, due to error in mis-registration it is impossible to tell whether change between the 1986 and 1996 images is real.

Nevertheless, we may glean some insight into the dynamics of forest cover change when 1986 and 1996 Landsat TM classified scenes (see Appendix 2: Maps 4, 5, & 6) are overlaid with vector coverages (see Appendix 2: Maps 1, 2, & 3) of forested areas for all three sites. These overlays suggest that visual interpretation of forested areas closely follow the pattern of forest cover for all three sites in 1986 and 1996. From a perspective of visual impression we can interpret this to mean that change in forest cover is minor, or if non-existent between 1986 and 1996. Due to poor results in the classification of forest patches in Quebrada Llanganuco Landsat TM imagery, only Quebrada Aquilpo and Ishinca were used for this demonstration. Discrepancies between the automated classification of forest cover and vector coverages (see Appendix 1: Figure 3) can be attributable to small errors in digitization and/or miss-classification (see above: *1986 and 1996 TM Images*).

Discussion of Spatial Change Analysis

The analysis of the 1986 and 1996 Landsat TM imagery did not show conclusive evidence of change in the spatial distribution, size and shape of *Polylepis* spp. forest patches for study sites in the Huascarán Biosphere Reserve. Based on findings presented thus far two general points can be made.

First, little change in forest cover can be detected from the present study. This suggests that a ten-year time period may not be sufficient to assess forest cover change given the resolution of Landsat TM imagery. 30-meter resolution of Landsat TM appears to be too coarse to detect small differences in forest cover over a 10-year period. Even if difficulties in mis-registration were eradicated a 30-meter pixel size could result in essentially the same findings. Thus a production of a more quantitatively rigorous evaluation of spatial change would require resolving the difficulties associated with mis-registration of images/coverages, running an analysis of change over a longer time frame, and locating higher resolution imagery than Landsat TM. Since 1962 is the earliest date for imagery, this would have to be the first time-step for such a change detection study and other sources of satellite imagery such as SPOT or IKONOS would need to be accessed for the biosphere reserve.

Second, and perhaps more importantly is the question of whether such a fine-grained analysis is necessary. Even if higher resolution imagery were found and a more rigorous analysis was completed the question remains how such a study could support the management of forest resources in the biosphere reserve or add to our understanding of *Polylepis* forest distribution. Given that the state of understanding of *Polylepis* forests at this time is basic, the questions asked center on; where are forests located, what is their distribution, and is there a trend in cover change over time? The type of study outlined above may move toward answering these questions, but the costs could be high both in terms of time expenditures for the collection of more detailed ground-truth data and funding to obtain higher resolution imagery.

Considering the future possibility of more rigorous work in the area raises another issue. How can the technical difficulties and findings detailed in this thesis be reconciled with other researchers who have completed similar work (e.g., Echaavarria 1998; Lyon *et al.* 1998; Deppe 1998; Braun 1997; Stern 1995)? In reviewing more closely the efforts of these researchers it is interesting to note that errors and technical difficulties of the kind described in this thesis are a part of their work as well. However, engagement with such technical issues are all but absent from discussions of their findings. For example, Stern's (1995: 342) use of a Zoom Transfer Scope (ZTS) as a registration technique is problematic because ZTS technology cannot mitigate against the inherent distortions in aerial photography of mountainous areas. As a result error in registration can be great, however, Stern does not address this potential difficulty nor reconcile it with respect to her overall findings. This calls into question Stern's (1995: 339) claims of an "overall decrease of (-11%) of pasture and agricultural fields; an increase (+5%) of páramo, attributed to fire and grazing pressure at higher elevations; and an increase (+7%) of forest, in part the result of legal protection and active management". Indeed, she suggests that "time sequence analysis of air photographs, of a scale readily available to the public, proved to be an effective technique to assess general changes in vegetation and land-use patterns in the highly-modified landscape of the inter-Andean region" (1995: 347). Braun's (1997) use of a 1:50,000 cartographic map to geo-rectify Landsat MSS imagery is less than desirable given the pixel size of MSS being 80 meters and the virtual absence of reliable control points for the purposes of image co-registration (i.e., geo-rectification of the Landsat MSS image to the cartographic 1:50,000 map). Braun also fails to provide us an assessment of how error in geo-rectification may influence his findings of *Polylepis* forest distribution on the Sajama Volcano in the western Andes of Bolivia. In Lyon *et. al.* (1998: 145) work in Chiapas, Mexico, we find that despite challenges to image rectification no assessment of accuracy or difficulty is detailed. Deppe (1998) does provide us a detailed process of geometric and radiometric correction of imagery, but again offers no assessment of accuracy. However, because Deppe's (1998: 287) work was completed on lowland coastal Brazil topographic distortions are minimal, suggesting greater confidence in the use of a 1st order linear transformation in the registration process. Finally, Echaavarria (1999) provides the most straightforward assessment of the challenges (e.g., ground control points, atmospheric effects due to shadows and cloud cover, and spectral normalization) he encountered in the completion of spatial change analysis in the Podocarpus National Park of highland Andean Ecuador. Although, these difficulties are problematic it is clear that Echaavarria's analysis is a first attempt to assess forest cover change in a data poor and difficult environment.

It is critical note that because all the researchers mentioned above work under the challenges that come along with study areas in data poor and/or mountainous environments does not suggest that their work is inconsequential. Rather, the point is that nascent work in such areas is ultimately the best possible approximation of biogeographical dynamics. This type of pioneering work is intended to be first attempts to guide more refined work in the future. The analysis completed in this thesis is yet another attempt to break new ground under difficult research conditions.

As such the present analysis at face value can demonstrate, albeit through visual comparison of quantitative estimates, that forest patches within the study sites are remarkably resilient (see Appendix 1: Figure 3 and description in *Synthesis of Findings* section, Chapter Five). In addition to visual comparison of Landsat TM classifications of forest cover with vector coverages (see Appendix 1: Figure 3), comparisons of raw 1996 Landsat TM imagery to the 1962 aerial photography reveals that pattern of forest cover appears resilient (see Chapter Four: *Synthesis of Findings* for discussion and Images 1 & 2 and 3 & 4 for demonstration of patch resiliency). Given this suggestion of the resiliency of forest cover over time, a replication of this research with greater investments in time and money at the same study sites within the reserve could yield little new information. The research presented here goes a long way in shedding light on basic questions that can serve as a baseline for future work completed in the area with respect to monitoring and change analysis of forest cover. By providing us a first glance at the dynamic of forest cover resiliency, from a management and academic perspective, is important.

The case for the resiliency of *Polylepis* forest patches based on the use of remote sensing and GIS technology is qualitative and remains tentative. We turn our attention at this point to the analysis of ecological data to help refine our understanding of *Polylepis* forest dynamics in the Huascarán Biosphere Reserve.

CHAPTER FOUR
ANALYSIS OF ECOLOGICAL AND HUMAN ECOLOGICAL DATA

Ecological and Human Ecological Data

To shift our attention from a dynamic of *Polylepis* forest cover change to resiliency of forest patches, forces a fundamental re-conception on how to interpret the landscape in the Huascarán Biosphere Reserve. To consider a thesis of resiliency – of essentially no change on the *Polylepis* landscape – suggests that a closer look within the forests of the HBR is in order. Moving away from a birds-eye perspective on forests, what follows is a detailed exploration of the structure of forest patches within each study site. Looking at forest structure in my 1999 field season cannot in and of itself tell us anything directly about forest cover change. However, stand structure can reveal the current condition of forests, whether a forest is declining and degraded or relatively healthy and vigorous. By considering the forest structure of the three valleys, the interpretation offered seeks to aid our understanding of forest dynamics within the biosphere reserve.

Patches selected from each study site represent a range of variability within the valley, and within each patch study plots were established to collect structural data (see Appendix 5: *Forest Stand Structure: Field Methodology*). This data was combined with qualitative field notes on each plot and patch for all three valleys. These notes allowed for a general description of each plot and overall patch, estimation of ground cover and ground cover type, and description of anthropogenic impact intensity and type (see Appendix 6: *Forest Stand Field Notes*). In addition these field notes allowed for the creation of interval and descriptive variables for each plot and patch (see Appendix 7: *Interval and Descriptive Variables*). These variables allow for a richer analysis of forest patches and study sites.

Following a description of each study site is an aggregate multi-level stand analysis garnered from ecological data and key ecological characteristics of forest structure. Finally the chapter closes with a detailed discussion valley level stand analysis with respect to stand analysis and a consideration of the land-use and the natural resource management regime particular to each area. Once an examination of the details of forest stand structure in all three valleys and their particular land-use/management contexts is completed, an integrated perspective for resiliency of *Polylepis* forest patches in the Huascarán Biosphere Reserve can be presented in Chapter Five.

Study Sites

Quebrada Demanda (the Pisco Area)

Quebrada Demanda, popularly known as Pisco, lies about 20 kilometers by road from the village of Humacchuco. Nestled within the heart of biosphere reserve the valley is surrounded by some of the tallest and most impressive peaks within the Cordillera Blanca (e.g. Nevado Huascarán). Quebrada Demanda is part of the greater Llanganuco watershed (see Appendix 2: Map 1). Access to the area is made easy by a major road running directly by the mouth of the valley. From the road itself the Pisco area is about 4 kilometers by foot. Pisco is sparsely forested and dominated by native highland grasses. Impacts in the area due to cattle are abundant as noted by the presence of cattle terrace-sets, and grasses cut short by livestock. *Polylepis* forests within the area are generally found on very steep rocky slopes, however, one example of a riparian forest patch on the valley floor does exist. Generally the wide valley floor in this area is comprised of a mixture of grasses and wetland.

According to the *Parque Nacional Huascarán: Plan Maestro* (1990a) – the management policy document for the biosphere reserve, Pisco is officially located in Sector Llanagunco (see Appendix 1: Figure 2) and classified as part of the park's Recuperation Zone. Recuperation zones are areas considered by the HBR staff to be degraded and the focus of restoration efforts. Within the reserve the valley lies along the most popular trekking circuit, which is called Llanganuco – Santa Cruz. The Pisco area is the most popular destination for adventure tourists who climb Nevado Pisco both for vistas and acclimatization for higher elevation mountaineering. At the head of the valley is a privately run mountaineering lodge that houses and feeds climbing parties. Moreover, Pisco is located directly above Laguna (Lake) Chinancocha, the most intensely visited conventional tourist destination within the reserve. During the height of the tourist season there are hundreds of tourists that travel by bus to this area to walk and boat.

In addition to the intense pressure of tourism the area is also under intense pressure from grazing. Some 200 cattle graze in the Pisco area (according to local informants), which is the head of Quebrada Llanganuco. These cattle are driven to the area to avoid contact with conventional tourists who use the area around Laguna Chinancocha. As such within the Pisco area one will find trekkers and mountaineers co-existing with hundreds of cattle. Due to the impacts from these pressures the Pisco area is considered severely degraded by the biosphere staff. Because of its economic importance, as a source of tourism revenue, the area is highly regulated and the focus of conservation practices – ranging from *Polylepis* reforestation efforts, grassland management, and waste management. Finally, according to biosphere officials the forests in the Pisco area are degraded and show few signs of recovery.

For these reasons Pisco was selected as an example of a heavily impacted study site for this thesis.

Quebrada Ishinca

Quebrada Ishinca is located nearby Huaraz, the largest city in the Callejón de Huaylas. No more than one hour by car to the village of Collón from Huaraz, one could be at the head of Quebrada Ishinca in 8 to 9 hours. Collón is the closest village to Quebrada Ishinca and forms the basis for the user-group, which has rights to use resources within the valley. The valley itself is long, approximately 10 km, and has a considerable number of *Polylepis* forest patches (see Appendix 2: Map 2). Dominated by shrubland and forest patches, it is only toward the head of the valley and in the hanging valleys that make up the Ishinca watershed that grasslands pervade. The valley is bisected east to west by a river that carries glacial waters down from the uplands. Valley walls are steep quickly approaching a slope of 40 degrees and more once off the narrow valley floor. The floor of the valley is extremely narrow, almost V-shaped until for about two thirds of its length. Only in the upper third does the valley widen to about one-half kilometer. It is in this portion of the valley floor that grasses and wetlands dominate over shrubs and forest. Similar to the Pisco area, forests within Quebrada Ishinca tend to occur on steep and rocky slopes leading up to cliffs and de-glaciated scree-fields. The bottom third of the valley, which drains into the Callejón de Huaylas, is a continuous *Polylepis* forest stand – 4 to 6 km long and 2 km wide. Such stands are rare in the Cordillera Blanca.

According to the *Parque Nacional Huascarán: Plan Maestro* (1990a) – the management policy document for the biosphere reserve, Quebrada Ishinca is located in

Sector Llanganuco (see Appendix 1: Figure 2) and classified as part of the Primitive Zone. A Primitive Zone is an area considered having minimal human influence and important for its beautiful scenery, as well as importance to adventure tourism. Within the reserve, Ishinca, is a major destination for mountaineers seeking to climb the three peaks easily accessible from the valley head. Second only to Pisco in terms of popularity among mountaineers, Ishinca, is also as an site for acclimatization. That one can be at the head of the valley in one day and summit a three 5000+ meter peaks, which are technically straight forward, in less than a week make it a favorite site for tour groups and private climbing parties. Testimony to this fact is that a second private climbing lodge has recently been built at the head of the valley provide food and lodging to mountaineering parties. Due to the growing popularity of the area by climbers and hikers the reserve in 1999 established a control post in Collón to sell camping and climbing permits. In addition, to the impacts of tourism in the valley *campesinos* graze approximately 120 head of cattle (according to local informants) in the upper reaches of the valley. Similar to Pisco in this respect, in Ishinca one will find large numbers of cattle grazing between the camp sites of mountaineering and hiking groups. Impacts of cattle are prevalent given the ubiquity of terrace-sets along valley slopes, and grasses cut short from grazing pressure. According to reserve officials this valley is moderately degraded, but does show sign of forest recovery. For these reasons Ishinca was selected as study site for this thesis.

Quebrada Aquilpo

Quebrada Aquilpo is located directly north of Quebrada Ishinca (see Appendix 2: Maps 3 & 8). The two valleys are nearly identical with respect to their physiography and ecology. They also share the same qualities in terms of their forests; Aquilpo has a large contiguous tract of *Polylepis* forest at the mouth of the valley that grows in a deep incised narrow V-shaped area. This larger forest and V-shaped part of the valley gives way to the upper two-thirds of the valley that has forest patches isolated mainly on boulder fields located beneath cliff walls. In addition Aquilpo, like Ishinca displays tremendous dynamism with regard to its geomorphology. That is like Ishinca the valley is riddled with massive debris slides that result from mass wasting events in the uplands. These slides carry rock and soil from the uplands wreaking damage on the vegetation in the lowlands. As such many of the forests in Aquilpo are defined by these events, which cut patches in two or create barriers to their advancement.

Unlike Ishinca, however, Aquilpo is not dominated by shrublands. Once beyond the large tract of forest at the mouth of the valley, Aquilpo widens and is almost totally dominated by grasslands. At the head of the valley lies a massive wetland formed by either the catastrophic drainage of an alpine lake or a filling of the lake with biomass, leading to the establishment of grasses and wetland species. The valley does not boast the same high peaks as other valleys, though glaciated mountains do define the upper reaches of the watershed. A river running east to west bisects the valley in two with its waterfalls and drop pools.

Quebrada Aquilpo, according to the *Parque Nacional Huascarán: Plan Maestro* (1990a) – the management policy document for the biosphere reserve is located in sector Llanganuco (see Appendix 1: Figure 2) and is classified as part of the Restricted Zone. The Restricted Zone of the reserve is defined as areas that are to have minimal to no human impacts, and represent ecosystems with fragile and unique floral and faunal species. Restricted zones, like Aquilpo, are totally protected for the purpose of scientific study –

however limited access to grasslands by campesinos is permitted. Tourism in the valley is non-existent. The village of Jomcopampa forms the basis of the user-group who has rights to access resources in the valley. Interviews with local people from this village indicate that 89 head of cattle are kept within the valley. The entire herd, unlike Ishinca and Pisco, is community owned. No privately owned cattle are permitted into the valley. Nevertheless impacts from cattle do exist in the valley as evidenced by grasses are cut short by livestock grazing and terrace-sets riddling the valley slopes. According to reserve officials the valley is essentially intact, nearly in pristine condition, and shows signs of forest recovery. For these reasons Aquilpo was selected as a study site for this thesis.

Aggregate Multi-Level Stand Analysis

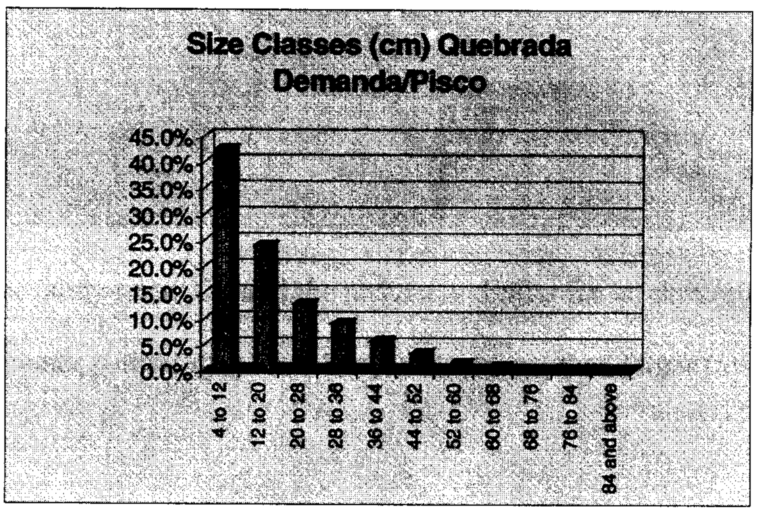
Polylepis Forest Size Class Distribution

Polylepis forest patches for all three study sites are comprised of *P. sericea* and *P. weberbaueri*. In Quebrada Demanda forest patches are small in size (2-10 ha) and occur in isolated positions below cliff faces on steep slopes (20 – 50 degrees). Quebrada Ishinca and Aquilpo have a similar pattern of patches located on steep slopes below cliffs. However, patches in both Ishinca and Aquilpo are fairly large (15 – 30 ha) toward the head of each valley, while the bottom third of both valleys is dominated by a large contiguous forest stands.

Within Quebrada Demanda all six patches were selected for study at this site (out of an estimated 9 patches for the entire Llanganuco watershed) (see Appendix 2: Map 9), which resulted in 18 study plots, and a total of 209 *Polylepis* trees measured. Trees sampled in Demanda include mature individuals that reach a maximum height of 19 meters and a DBH size of 63 centimeters. Within Quebrada Ishinca eight patches (out of an estimated 16 patches for the entire Ishinca watershed) (see Appendix 2: Map 10) were selected for study, which resulted in 24 study plots, and total of 273 *Polylepis* trees measured – trees in this area are mature and reach heights of 22 meter and DBH measurements up to 90.5 centimeters. And within Quebrada Aquilpo a total of six patches (out of an estimated 15 patches for the entire Aquilpo watershed) (see Appendix 2: Map 11) were selected for study, which resulted in 22 study plots, and total of 244 *Polylepis* trees measured. Trees sampled include mature individuals that reach the height of 17 meters and a DBH of 147 centimeters.

Although no data currently exists to derive age classes for *Polylepis* trees, size classes were determined for each valley. Graph 1, 2 and 3 depicts a curve for *Polylepis* size classes

Graph 1



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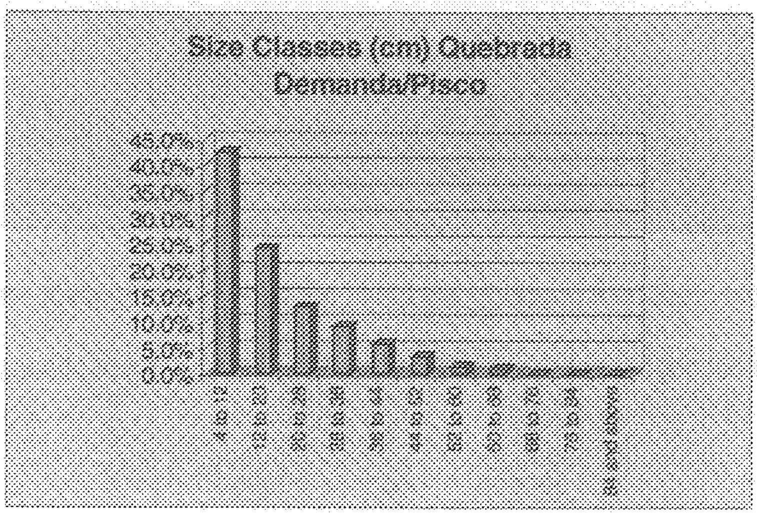
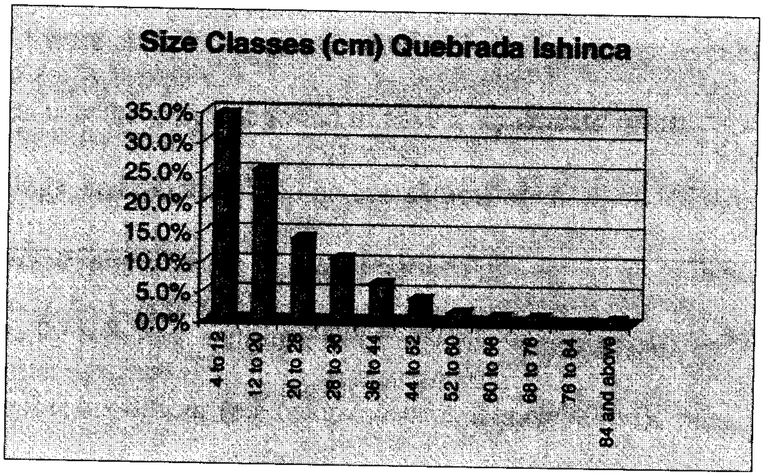
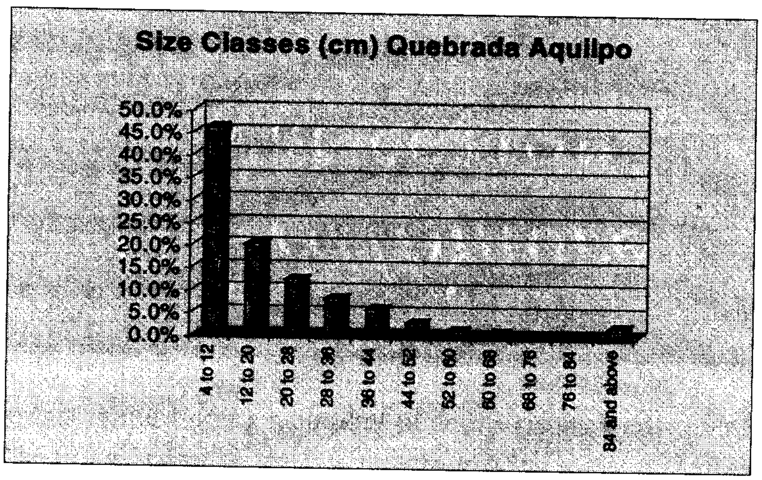


Graph 2



Graph 3

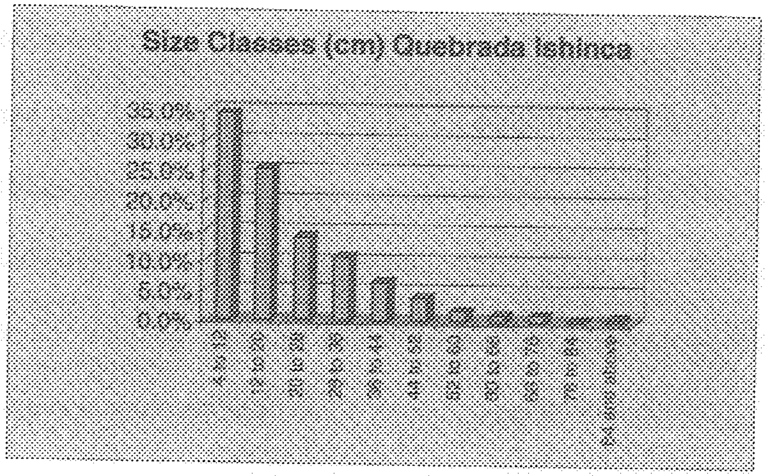


for each of the three study sites. Overall the pattern is similar for all three study sites, tending toward a greater percentage of smaller diameter trees than larger trees at the valley scale.

Ecological Variables

A series of linear and multiple regressions were performed for all study sites on several variables to see if trends in the data exist. Graph 4 shows a relatively strong positive

Graph 2



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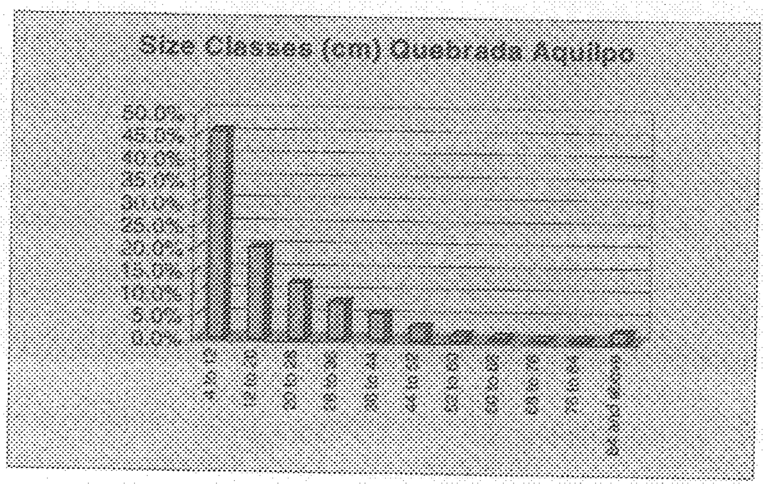

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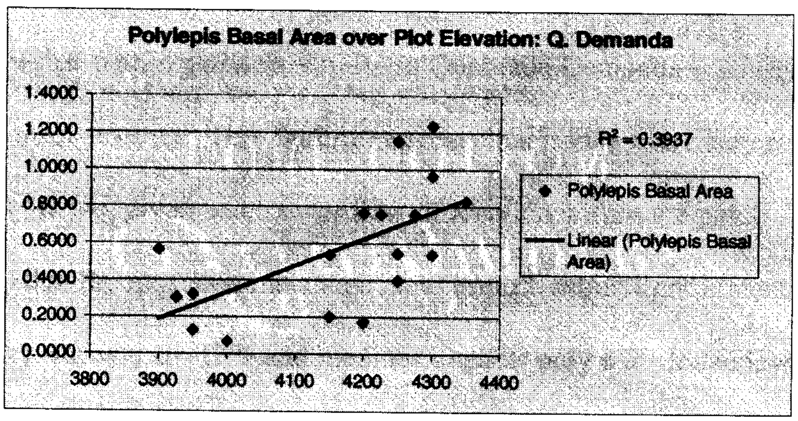
A series of linear and multiple regressions were performed for all study sites on several variables to see if trends in the data exist. Graph 4 shows a relatively strong positive correlation between basal area (measured in meters squared) and elevation. Of all the regression tests that were completed, the one that analyzed basal area over elevation in Quebrada Demanda was the only one found to have a significant result. Number of *Polylepis* seedlings and saplings was found to hold no correlation when regressed over elevation, slope, and aspect. The lack of significance of these relationships across all valleys suggest that growing conditions for seedling, saplings, and *Polylepis* trees are not affected across a wide range of physiographic conditions (e.g., slope, aspect, and elevation).

Graph 4



Based upon this initial finding a number of comparisons were completed between impact variables, specifically impact severity and impact type, and plot location. The following set of graphs show the comparisons completed.

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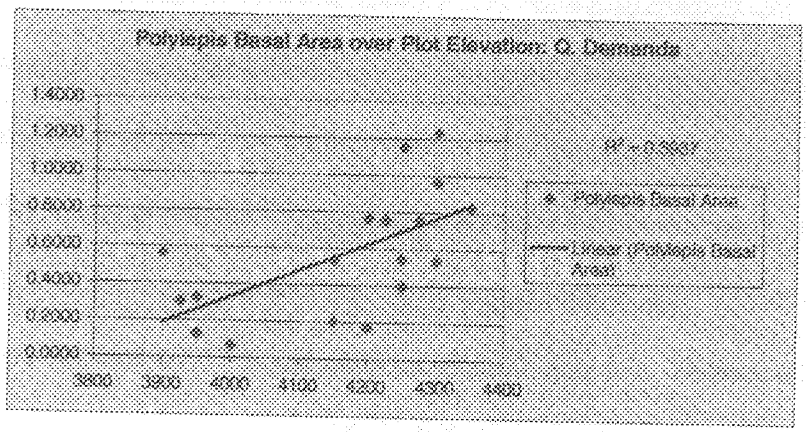

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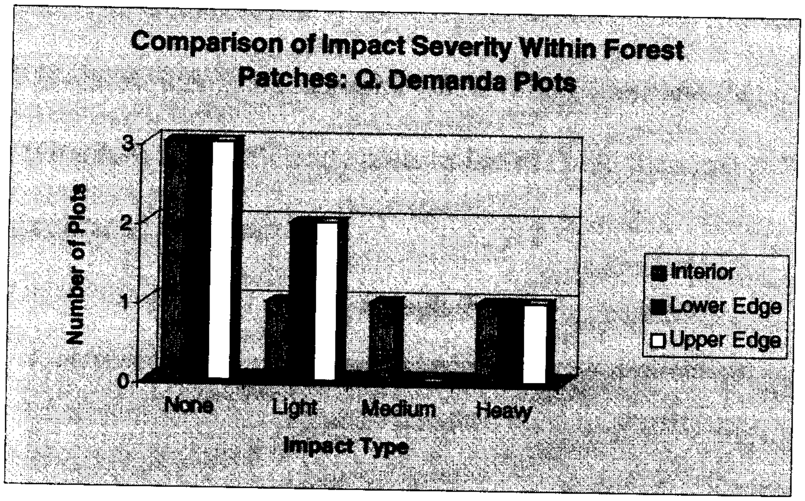
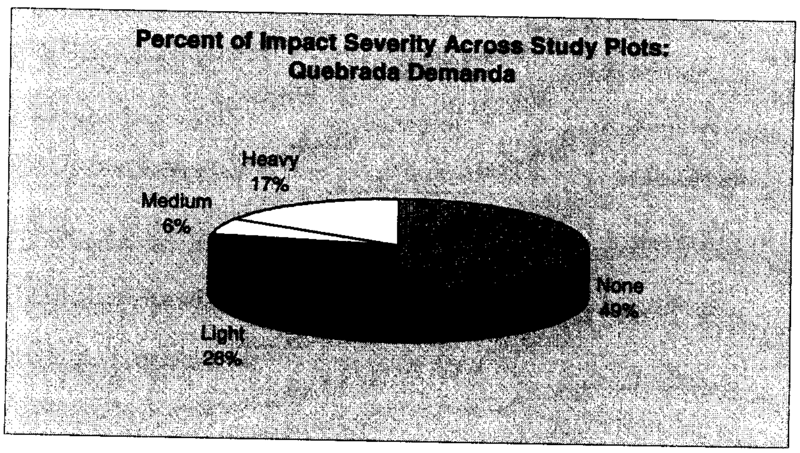
Graph 5



Graph 5 indicates that within patch variability in Quebrada Demanda is nearly non-existent with regard to impact severity. This finding suggests that it is just as likely to find one type of impact severity in any given patch regardless of location within the patch. Graph 6, however, reveals that the most common state is no impact, while light impact severity is nearly 25%, heavy impacts are 17% and medium impacts only 6%. Indeed, within-patch

Graph 6



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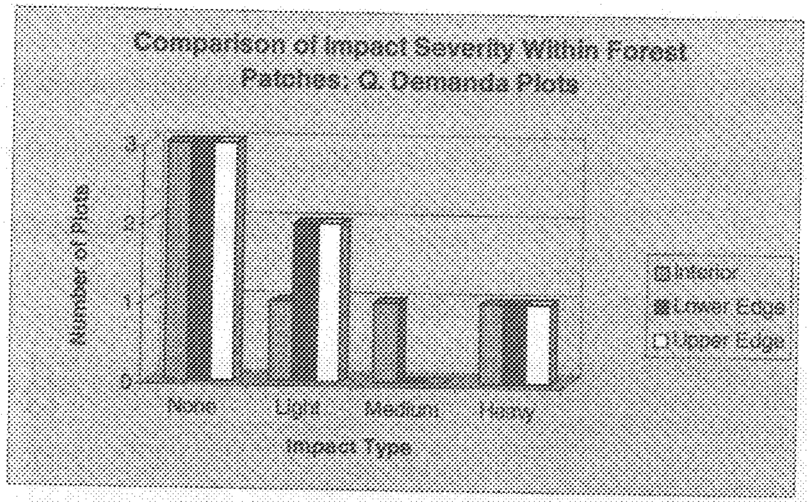

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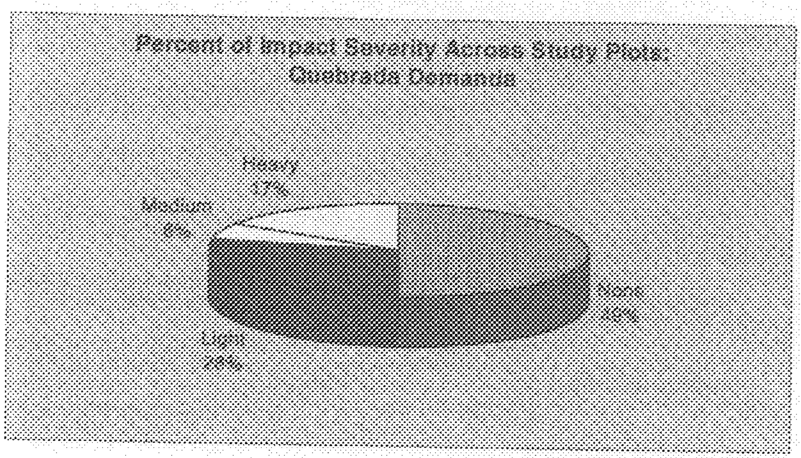
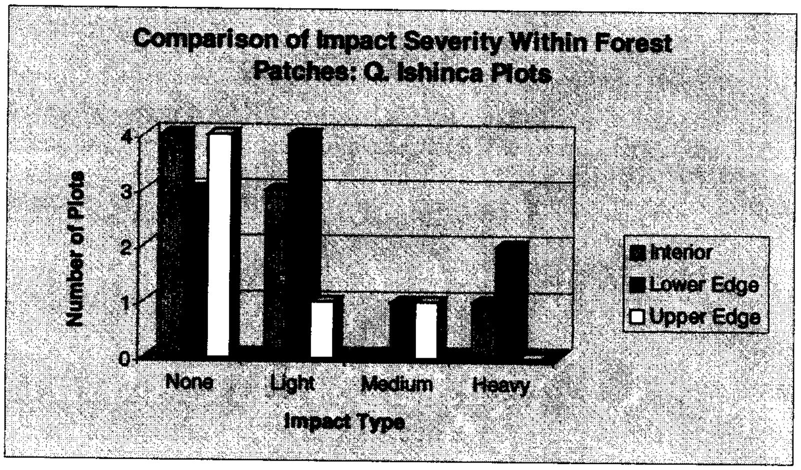


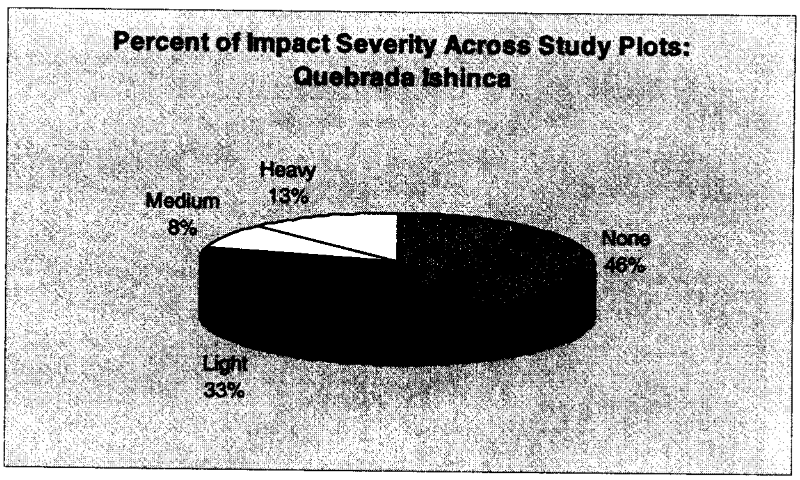
comparisons suggest that impact severity was not influenced by proximity to trails (generally on lower edge of patch) or to high grasslands (generally on upper edge of patch).

Quebrada Ishinca reveals similar findings. Graph 7 indicates that within patch variability for Quebrada Ishinca is nearly non-existent with regard to impact severity. Indeed, Graph 7 is almost identical to Graph 5. In addition, it is clear that the percentage of impact severity (Graph 8) across all study plots in Ishinca hold the same pattern as that found in Graph 6 for Quebrada Demanda.

Graph 7



Graph 8



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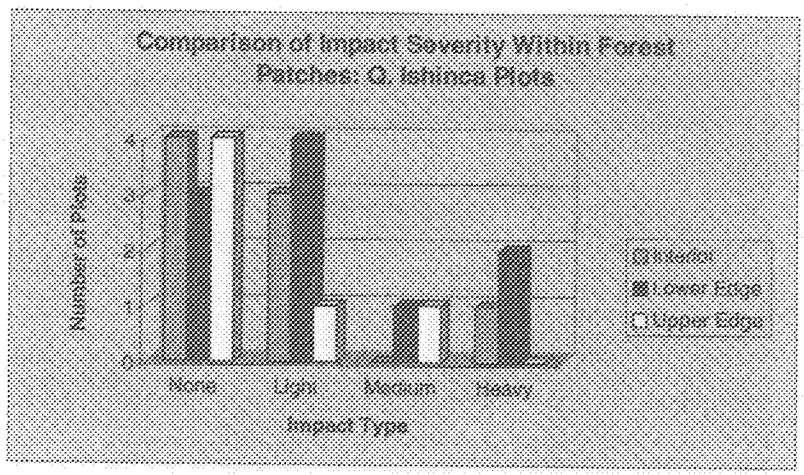

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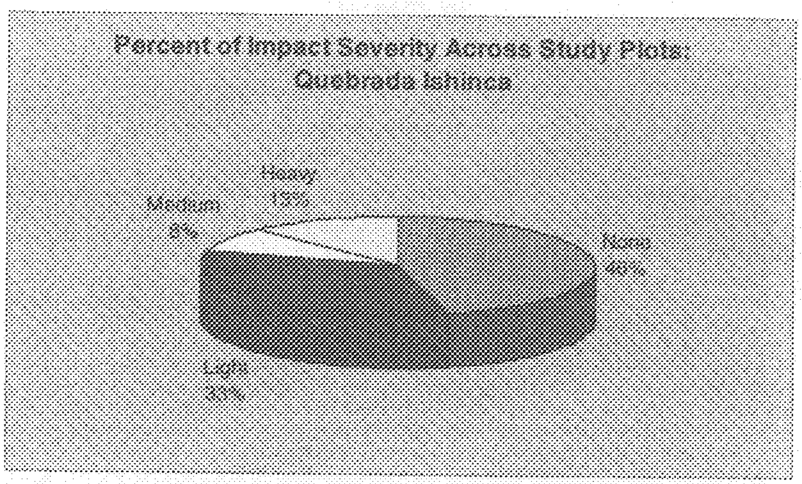

Within Quebrada Aquilpo noticeable differences are detected compared to Demanda and Ishinca. Graph 9 indicates that within patch variability in Quebrada Aquilpo is slightly skewed with regard to impact severity to upper and lower edges. The percentage of impact severity across all study plots (Graph 10) in Aquilpo is different from that of Demanda (Graph 6) and Ishinca (Graph 8). Heavy and medium impact severity is much higher than in either of the other two study sites, while light impacts and no impacts appear to be lower (see Chapter Five: Graph 29).

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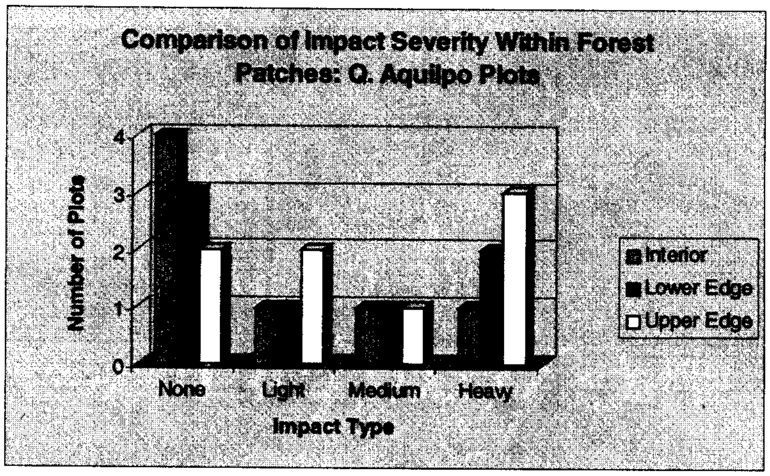
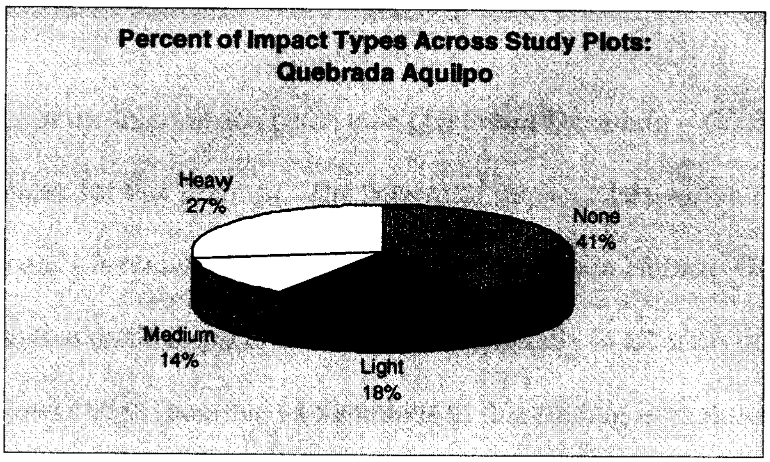


Graph 10



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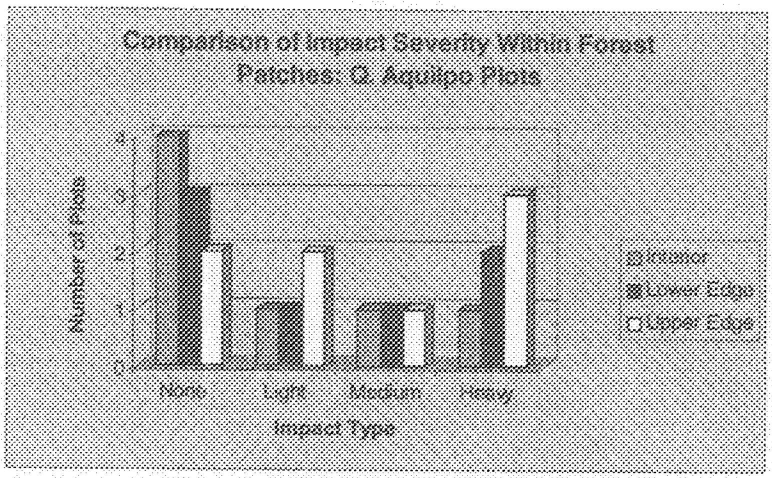

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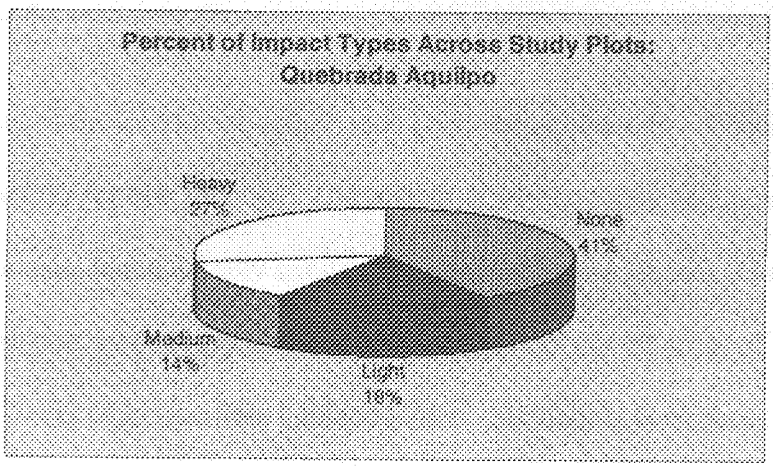

Although no discernable trend in impact severity can be found within patches (except for slight differences observed in Q. Aquilpo) there does appear to be spatial patterning with regard to impact types. Graph 11 displays the types of impacts observed in the Quebrada Demanda with respect to location within patches. Notably cattle impacts were found more often along the upland or upper edge of forest patches and that the only evidence of forest

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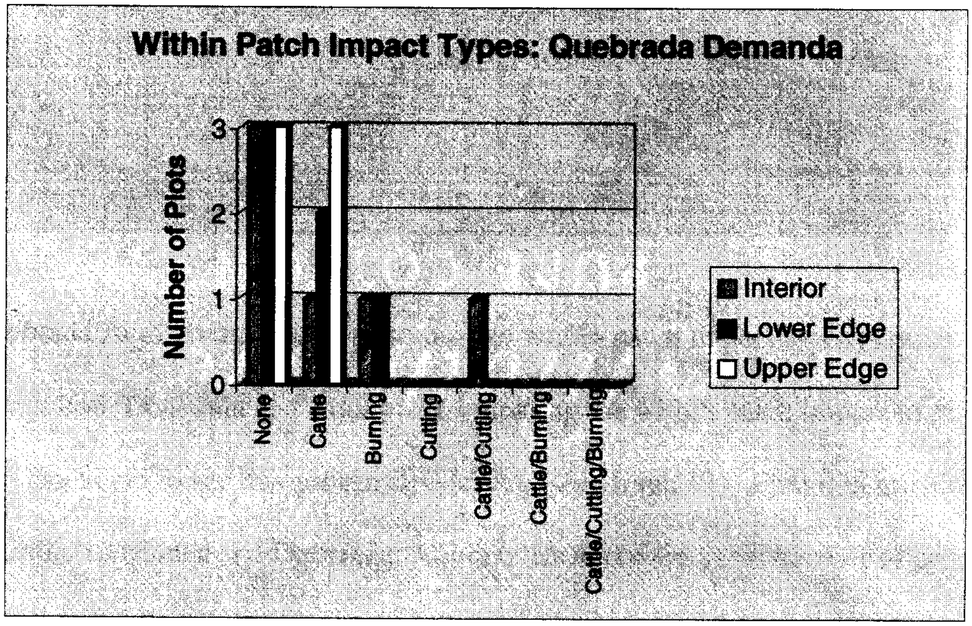

cutting was found in the interior of a patch (see *Quebrada Demanda – Discussion* for possible explanations for this finding). The pattern of impact types within patches observed in Quebrada Demanda is remarkably similar to that of Quebrada Ishinca (Graph 12). It is interesting to note that cattle impacts are found nearly equally in all areas of a patch, interior, upper edge, and lower edge (possible explanations of this finding is explored below, *Quebrada Ishinca – Discussion*).

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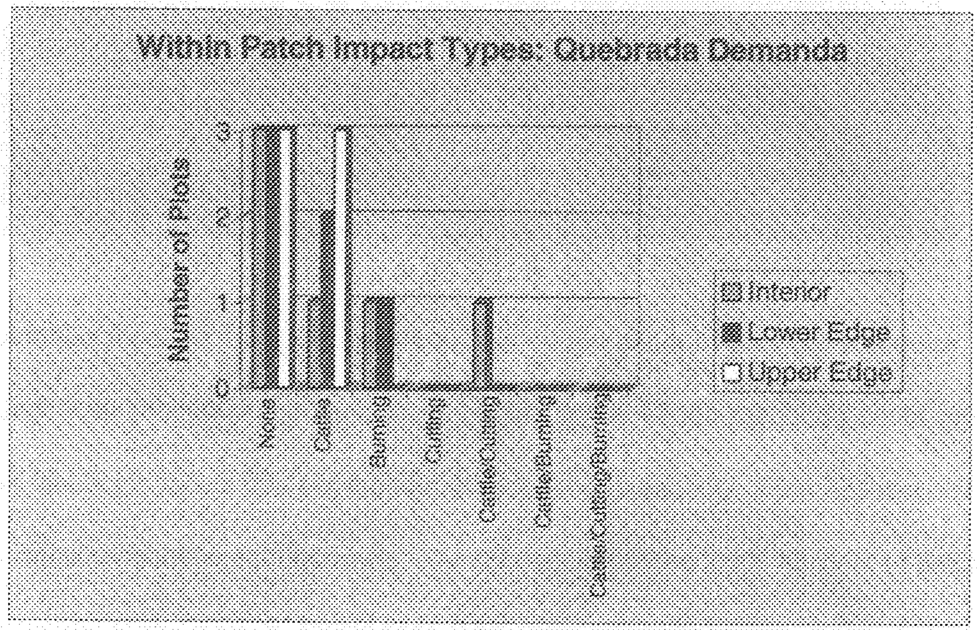

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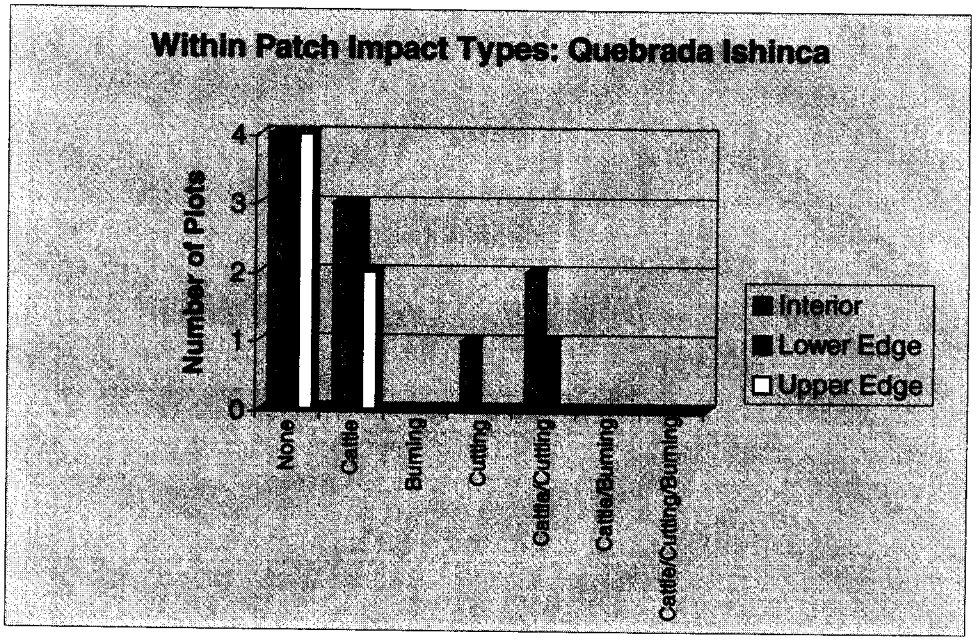

Within Quebrada Aquilpo the spatial patterning of within patch impact types is quite different from both Demanda and Aquilpo. Comparing the within patch impact to plot location we can begin to see this pattern developing (see Graph 13). First it is interesting to note that similar to Ishinca and Demanda, Aquilpo has about the same number of cattle impacts occurring at the interior, lower edge, and upper edge of patches. Second, a markedly higher number of plots reveal signs of burning and cattle impacts along upper edges of patches (possible explanations of this finding is explored below, *Quebrada Aquilpo–Discussion*).

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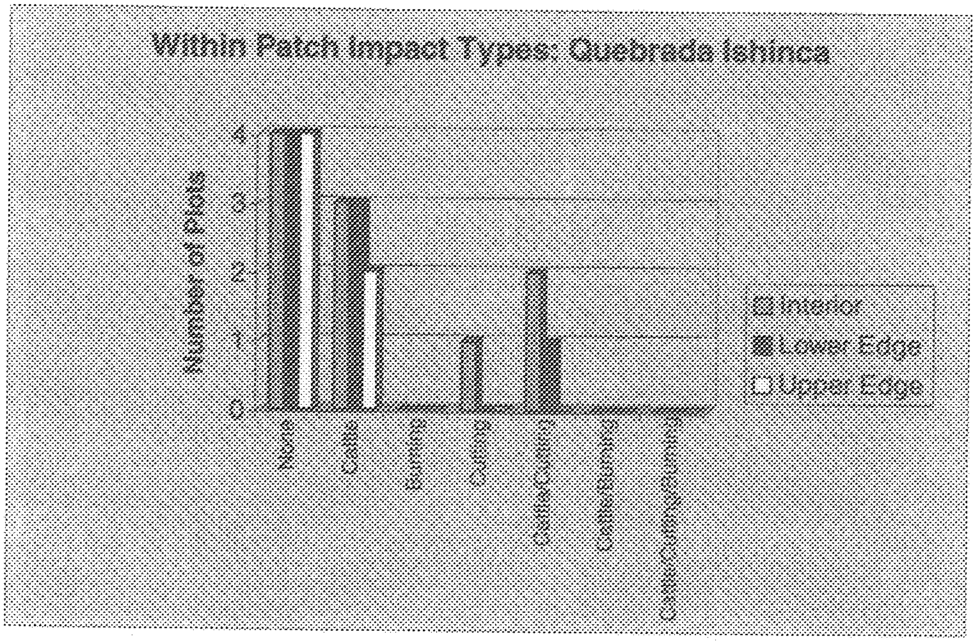

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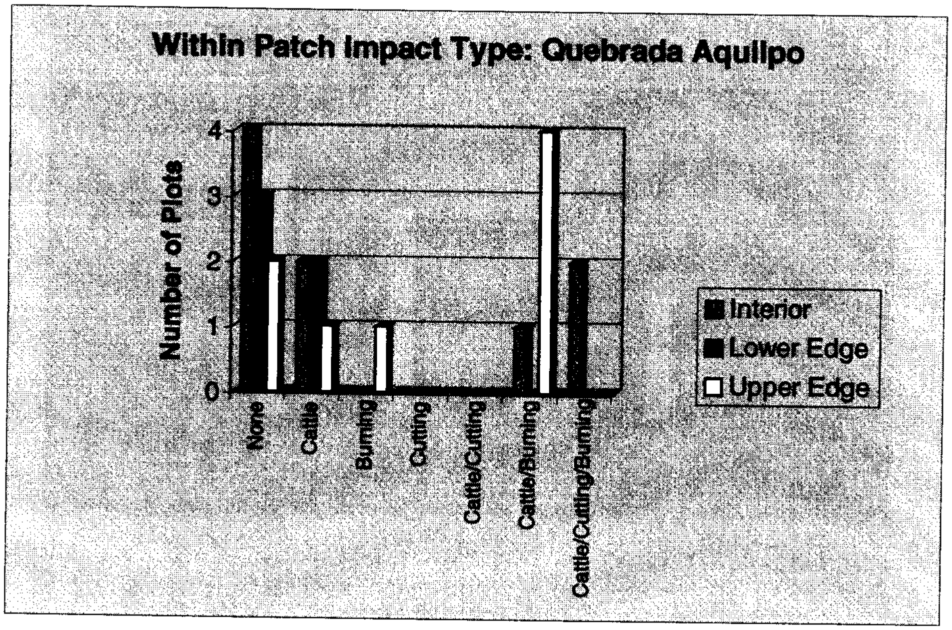

Distribution of Tree Types

Graph 14 depicts the absolute number of trees alive and dead observed in all three valleys. Note that *Gynoxis* spp. is represented in this graph. *Gynoxis* is the only tree type that was observed growing within *Polylepis* forest patches (the ecological relationship between these tree species is unknown). Nearly identical numbers of trees are recorded for Quebrada Demanda and Quebrada Ishinca. However, a conspicuous spike in the number of dead trees for Quebrada Aquilpo is apparent. This surprisingly different number of dead trees is due largely to extensive burns found along the upper edges of patches where entire trees were killed. Dead trees in Quebrada Aquilpo are found in only three of the study patches within that valley (see Appendix 2: Map 11 patches 2, 4, and 5). The use of fire in Quebrada Aquilpo is explored in greater detail below under *Quebrada Aquilpo– Discussion*.

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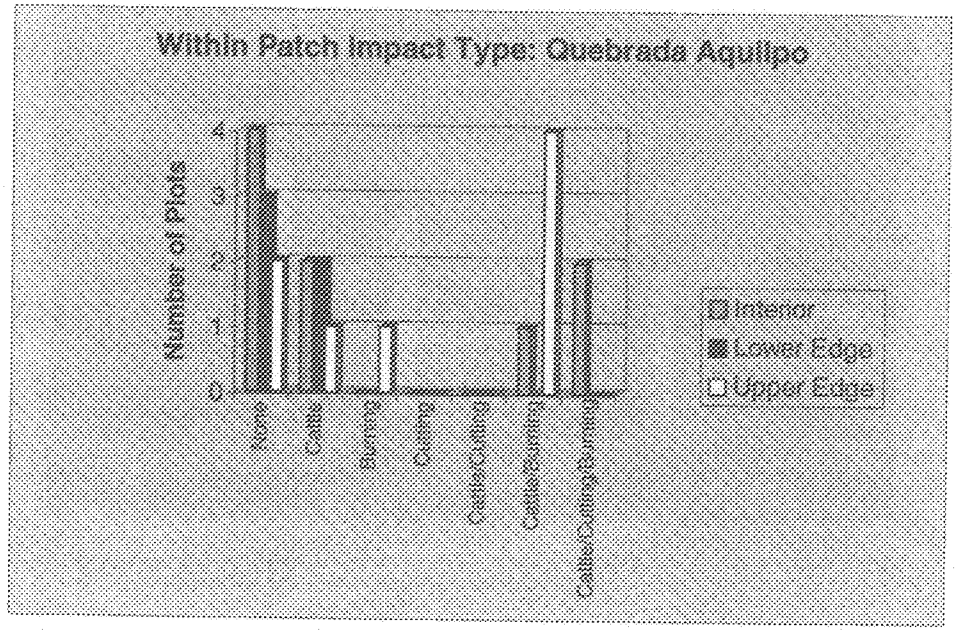

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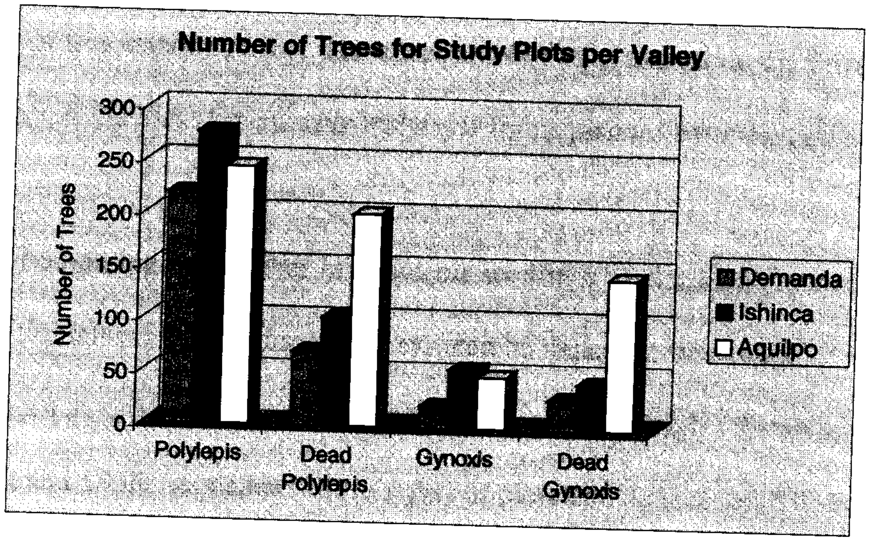

Seedling and Sapling Regeneration

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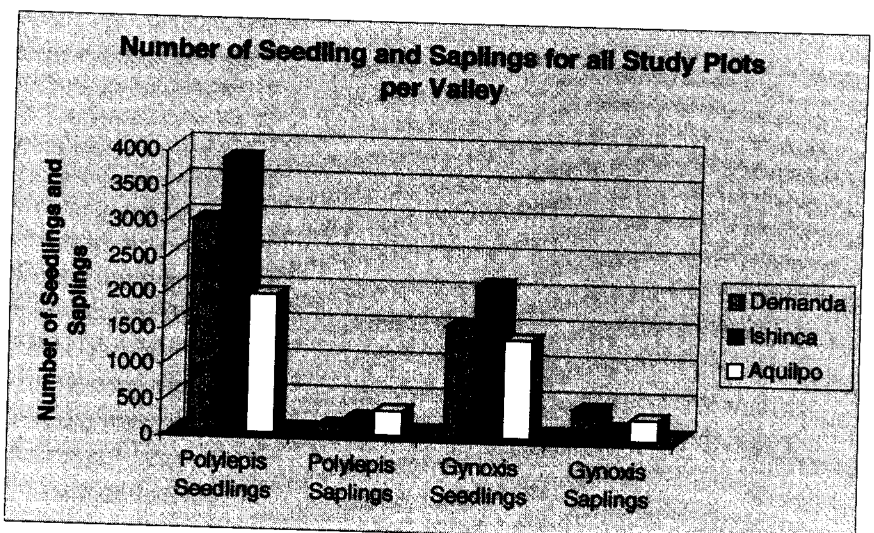

seedlings survive to a sapling stage of development. Given that the highest percentage of trees measured in all three valleys were between 4 and 12 centimeters in diameter may

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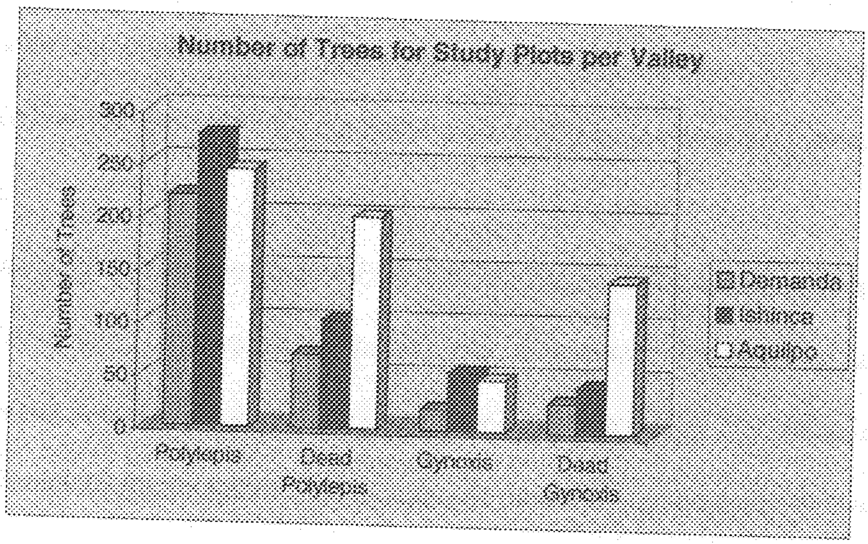

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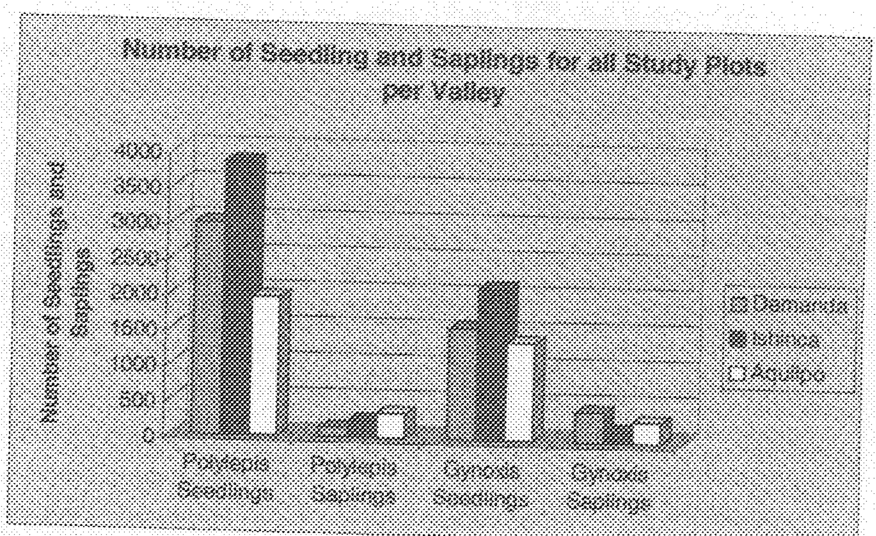
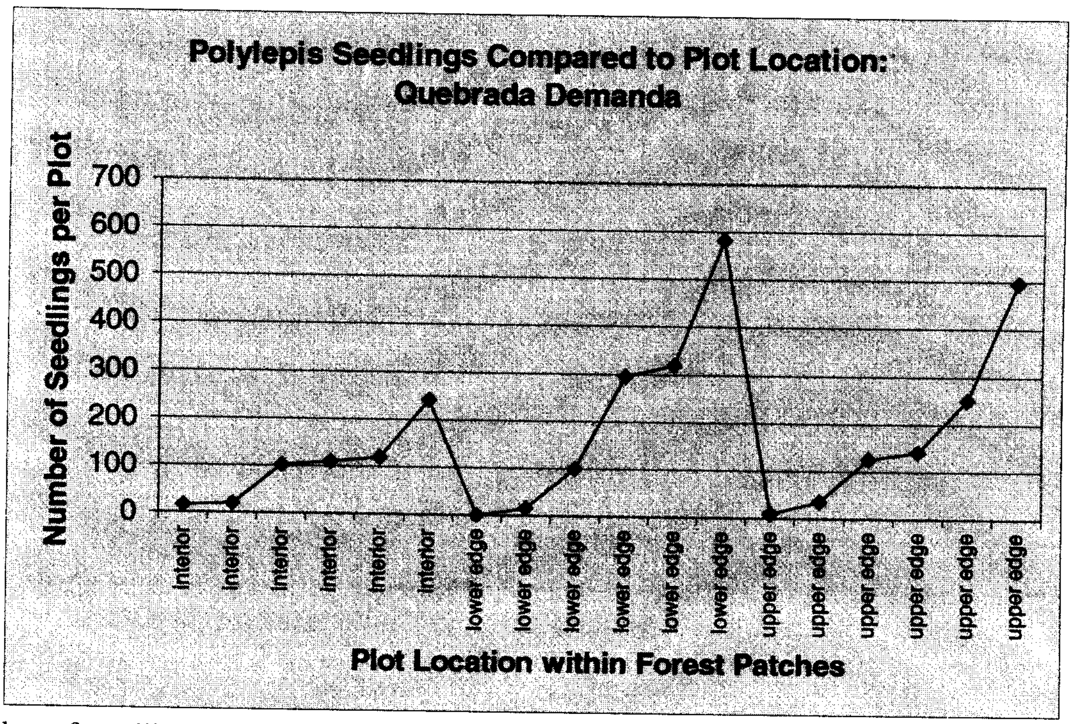


seedlings survive to a sapling stage of development. Given that the highest percentage of trees measured in all three valleys were between 4 and 12 centimeters in diameter may indicate rapid saplings re-establishment when light gaps occur in forest canopy or when conditions favor tree establishment. The shear number of seedlings on the forest floor appears to support the idea that existing *Polylepis* forest patches have the potential of regeneration.

When comparing the number of *Polylepis* seedlings to plot location within patches a general result, which is identical for all valleys, can be detected. The range of number of seedlings in a patch varies greatly in all types of location (see Graph 16). (Note that in graphs 16, 17, and 18 the sequence (left to right) of plots and their respective number of seedlings is identical). Although Graph 16 represents only Quebrada Demanda, the same pattern was observed for Quebradas Ishinca and Aquilpo as well. A comparison of the

Graph 16



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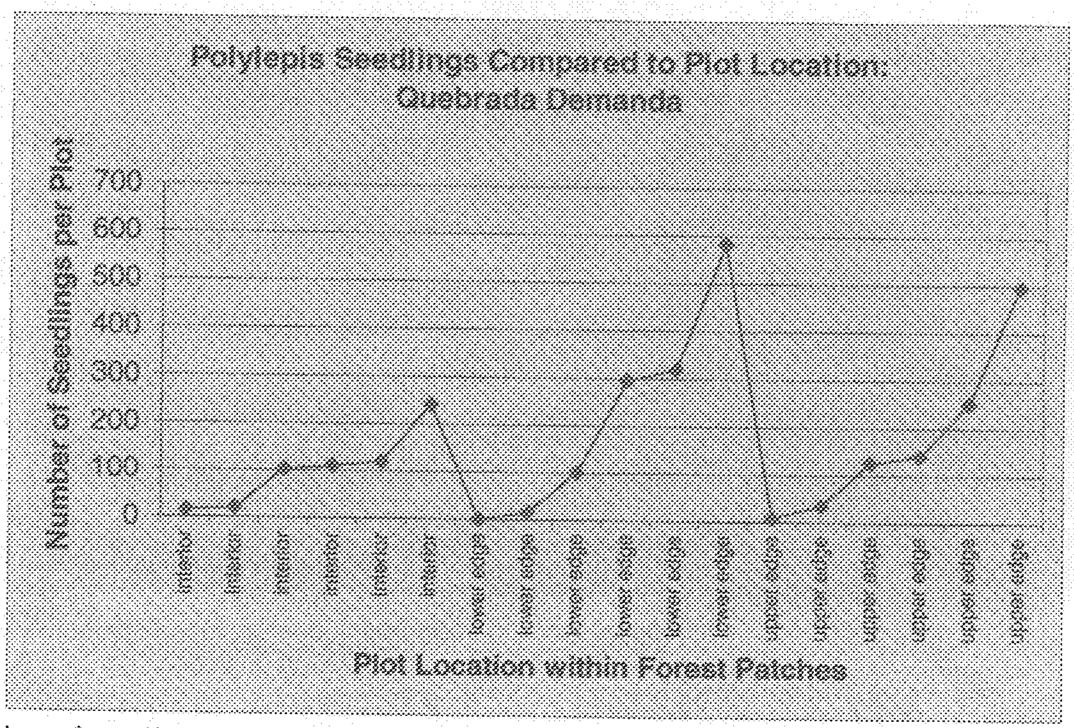

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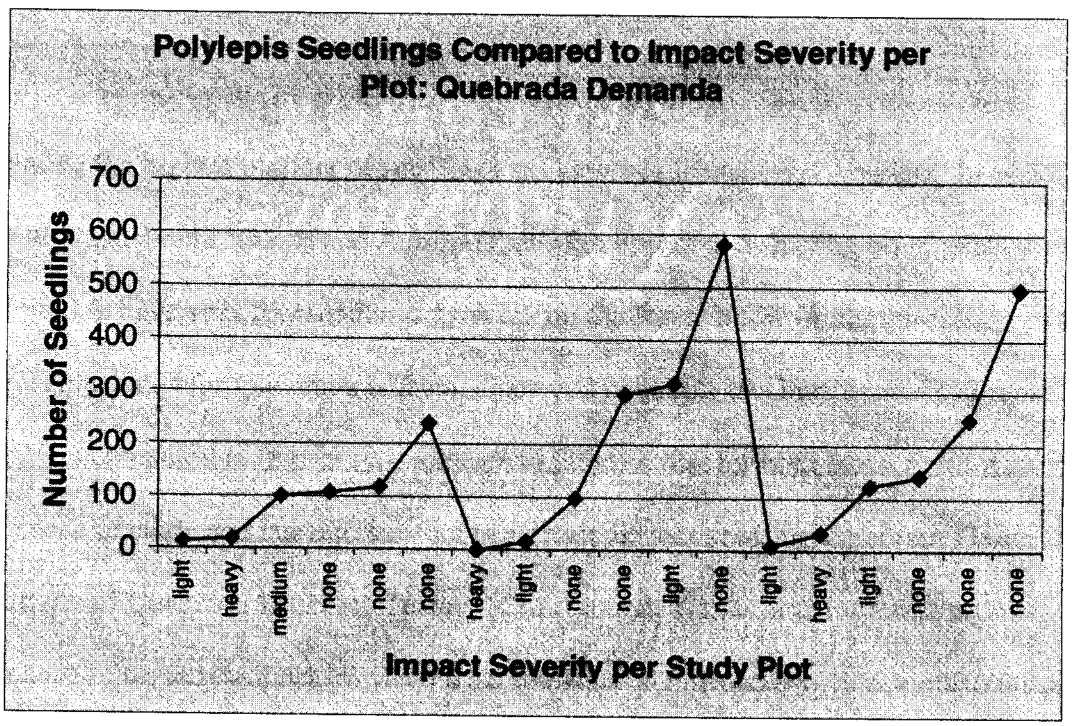
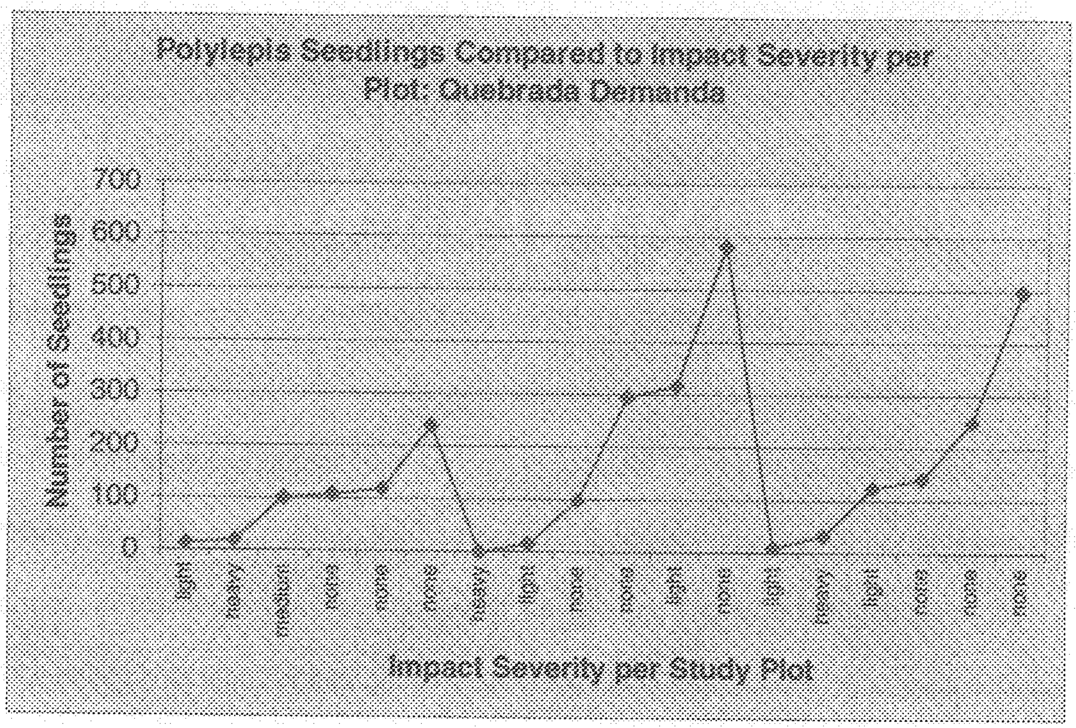
17 and 18). Chi-squared and T-tests of this pattern yielded insignificant results. (Note that this statistical insignificance is likely to be associated with the small sample size of the data set). Even low-magnitude impacts can appear to have a significant affect on the number of seedlings that may be present on the forest floor. In general, the large variation in the number of *Polylepis* seedlings is found in conjunction with plot location, impact severity, and impact type. However, when comparisons of number of seedlings to impact severity and to impact type were completed for Quebradas Ishinca and Aquilpo the results were different as compared to Quebrada Demanda. Surprisingly heavy, medium, and lightly impacted plots

Graph 17

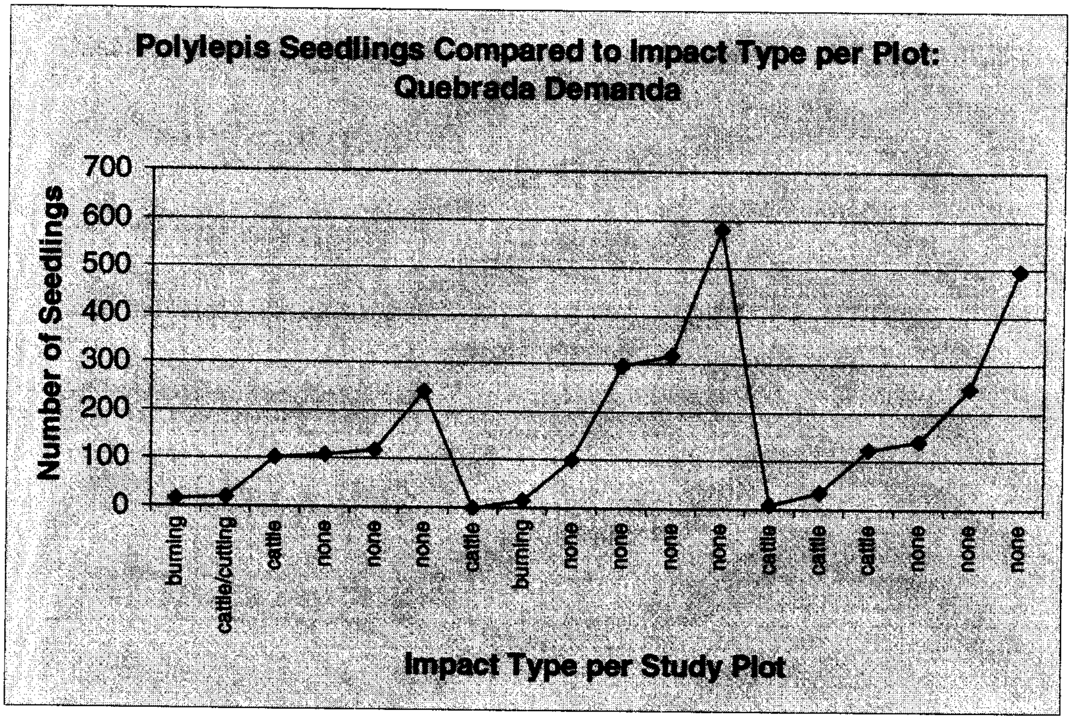


17 and 18). Chi-squared and T-tests of this pattern yielded insignificant results. (Note that this statistical insignificance is likely to be associated with the small sample size of the data set). Even low-magnitude impacts can appear to have a significant affect on the number of seedlings that may be present on the forest floor. In general, the large variation in the number of *Polylepis* seedlings is found in conjunction with plot location, impact severity, and impact type. However, when comparisons of number of seedlings to impact severity and to impact type were completed for Quebradas Ishinca and Aquilpo the results were different as compared to Quebrada Demanda. Surprisingly heavy, medium, and lightly impacted plots

Graph 17

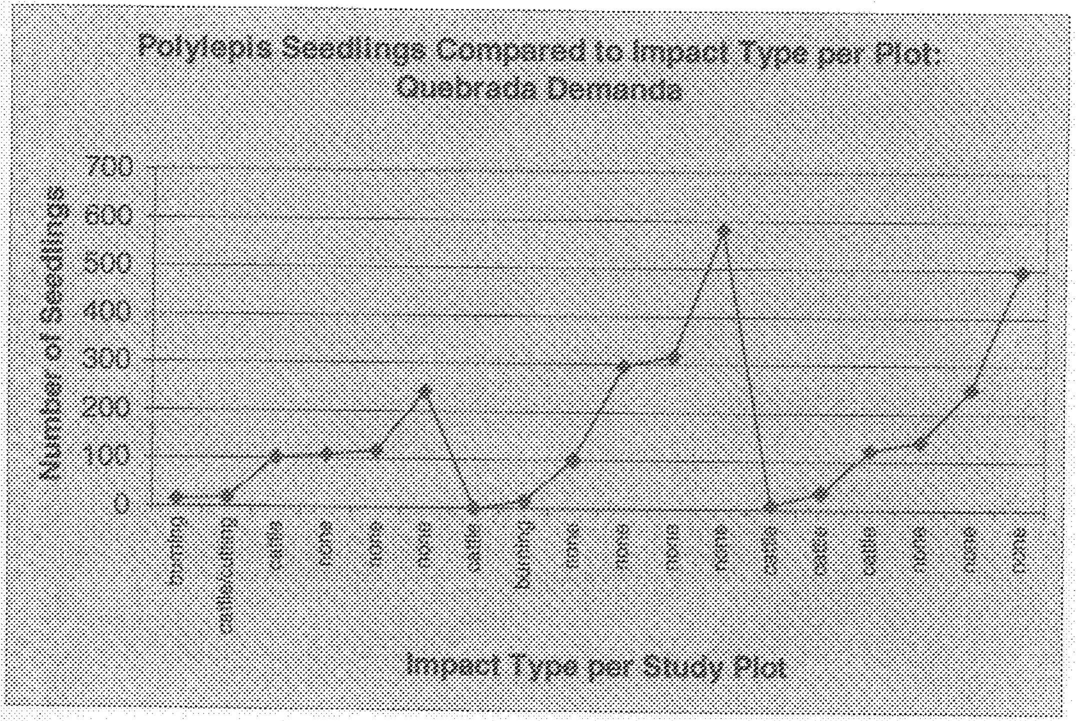


Graph 18



have among the highest number of seedlings in Quebrada Ishinca and Aquilpo. In addition, plots within Quebrada Ishinca and Aquilpo that were observed as having no impacts were often found to have very few seedlings growing on the forest floor. A demonstration of this finding is presented for Quebrada Ishinca, displayed in Graph 19. Furthermore, number of seedlings as compared to impact type appears to indicate that for both Ishinca and Aquilpo the presence of cattle and cutting does not negatively impact seedling vigor (see Graph 20 for the example of Quebrada Ishinca). Testing (Chi-squared, T-tests, and regressions) for significance of these relationships yielded no statistical significance with respect to these findings.

Graph 18



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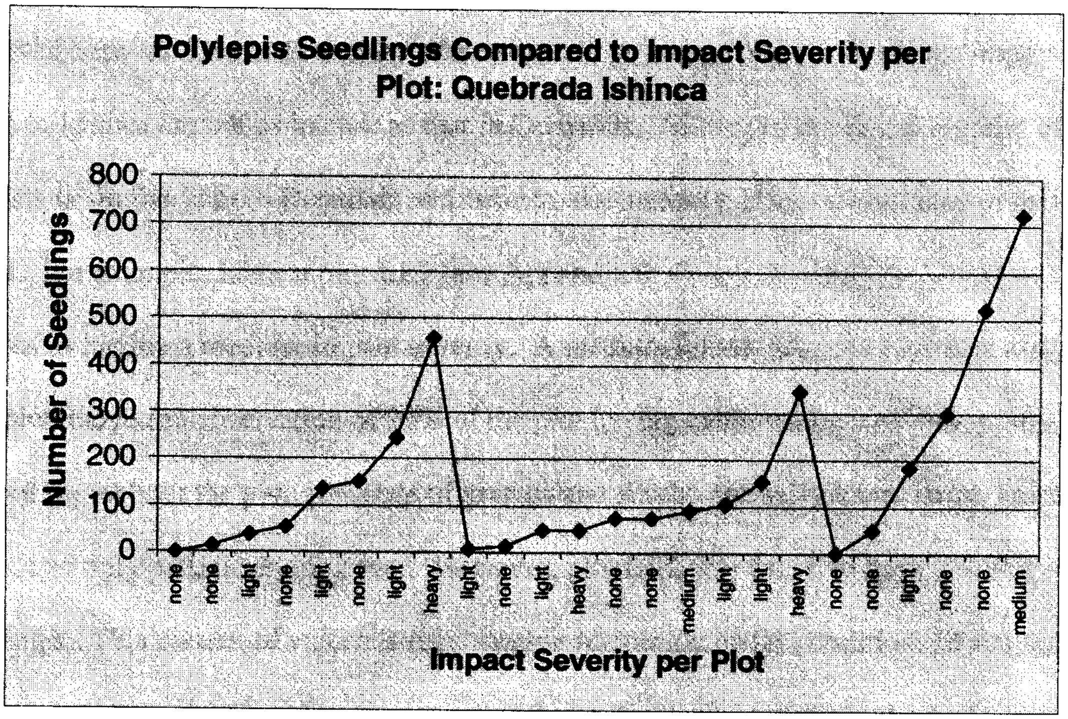
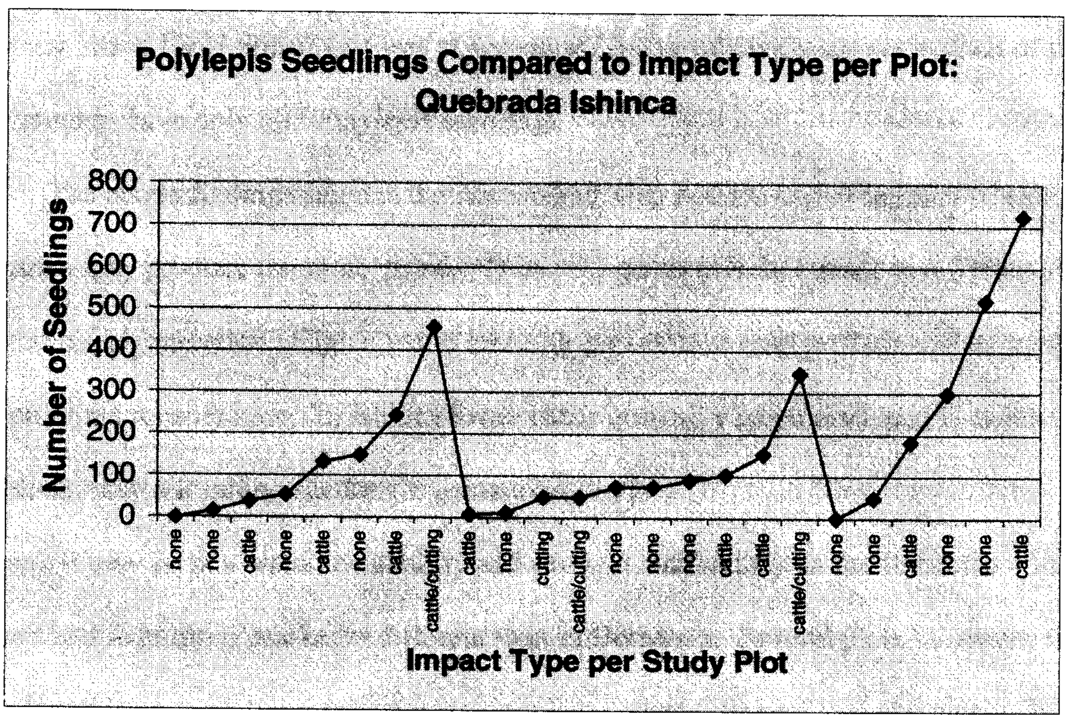
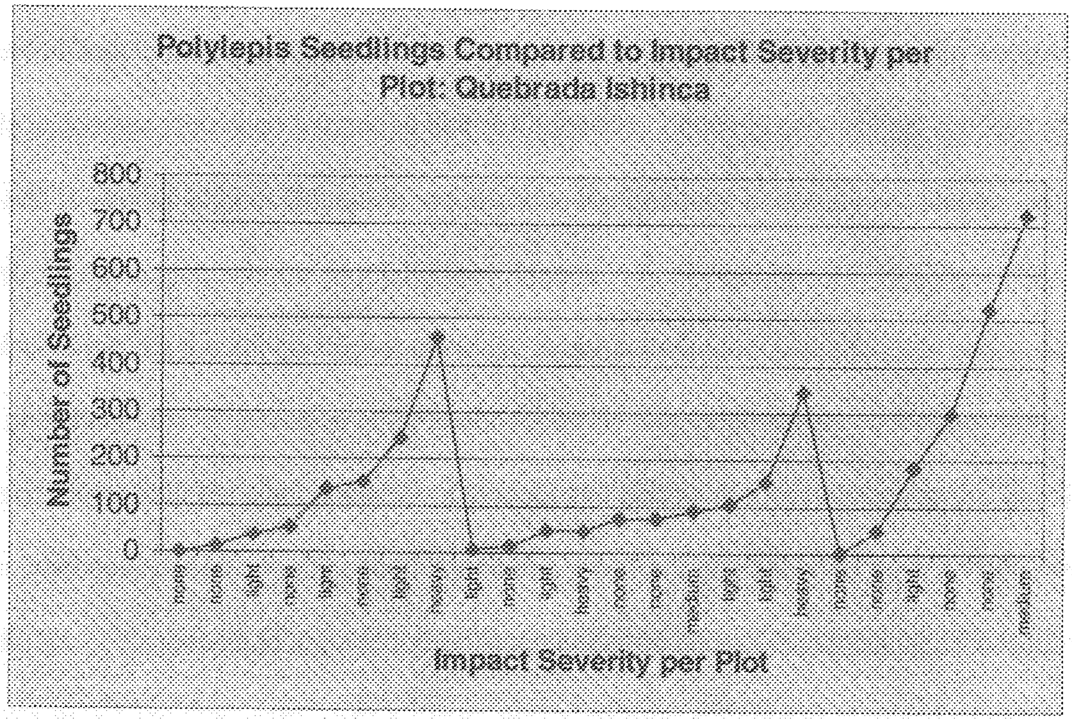
Graph 19



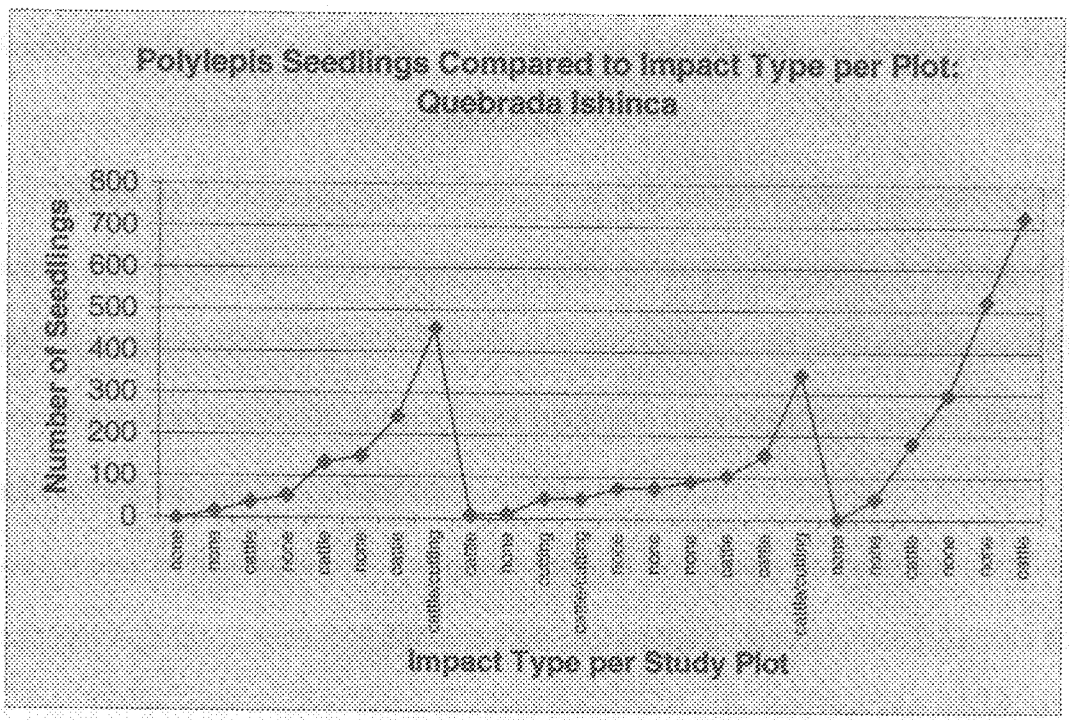
Graph 20



Graph 19



Graph 20



Two potential interpretations for differences in seedling vigor and regeneration observed between Demanda and the other two valleys are as follows. First, the impacts from cattle in Ishinca are not as intense as that in Demanda. Although, the visual severity of cattle impacts is similar in both Demanda and Ishinca, the intensity of the impact may in fact not be equal. For example, Ishinca plot I.1.2 (see Appendix 6: *Forest Stand Field Notes*) was labeled as having a medium impact severity. A medium impact severity type was assigned to this plot due to the observation of 20% of the plot having cattle tracks, cattle droppings littered throughout the plot, presence of grasses and shrubs normally found in the grassland areas, and only partial canopy cover. However, plot I.1.2 was found to have 724 *Polylepis* seedlings. This pattern of vigorous regeneration seemingly under conditions of impact in Ishinca may have developed over a longer period of time with fewer numbers of cattle than a plot given the same impact severity type in Demanda. For example, plot P.4.2 (see Appendix 6: *Forest Stand Field Notes*) that was observed as having relatively the same level of impact was found to have only 102 *Polylepis* seedlings.

The above findings suggest that the smaller area and the higher number of cattle in Demanda may produce the same visual effects on a given plot, but result in different affects on seedling regeneration. Higher cattle intensity for instance may produce soil compaction that prohibits regeneration. In Ishinca fewer cattle grazing a larger area, nearly twice that of Demanda, may not inhibit seedling regeneration.

Second, it may be that water availability and sunlight availability on the forest floor in Ishinca and Aquilpo is markedly different than in Demanda. Several plots in Ishinca that were found to have no impacts and seemingly intact were also very wet and receive little direct sunlight given their aspect and position beneath a cliff. Overall, however, it appears that seedlings may require specific growing conditions, and that if such conditions are achieved then seedlings are to some extent resilient to anthropogenic impacts. This is clearly the case in Quebrada Aquilpo where the some of the highest number of seedling regeneration were observed in plots that had been recently burned.

Valley Level Stand Analysis

Quebrada Demanda – Discussion

In general the ecological data collected from Demanda area reveal a mixed picture. Except for a strong relationship between elevation and basal area, no clear relationships were discovered in conducting linear regressions on major variables. However, a pattern does emerge when seedlings and saplings are compared to impact intensity and type. These findings are made more tractable when considering both the geography and the park management of this valley.

When considering the geography of the valley fundamental characteristics need to be understood. Only those patches that were studied at higher elevations (see Appendix 2: Map 9 patches 1, 2, and 3) in the valley were healthier than those lower in the valley (see Appendix 2: Map 9 patches 4, 5, and 6). Despite the small size (5 – 7 ha) of forest patches in the upper reaches of the valley, trees in these patches are clearly larger, seedling and sapling regeneration is exceptionally vigorous, and seemingly 'pristine' or 'intact' conditions exist (see Appendix 6: all plots associated with P.1, P.2, & P.3). Intact here is understood as: light to no impact of any kind observed, understory vegetation is dominated by mosses, herbs, and succulent plants unable to survive in conditions outside the forest patch, micro-climatic conditions maintained by the patch is distinctly cooler and more moist than outside the patch, and seedling and sapling regeneration is vigorous.

These characteristics are coupled with the fact that all of the higher elevation patches grow on massive boulder fields, helping to maintain a steady state of regeneration within the patch by preventing cattle or humans easy access to the understory. Indeed, where the boulder field ends is typically the location of the forest edge (see Appendix 6: all plots associated with P.1, P.2, P.3, and P.6). The transition from forest to grassland is immediate. With one notable exception, which deserves mention, it is rare to observe seedlings or saplings surviving beyond 5 meters from the forest edge, and grasses and shrubs do not survive beyond just a few meters within the patch edge. However, in one area of grassland, about 20 meters from a patch, very high density of *Polylepis* seedling regeneration was discovered (see Appendix 6: P.1.4). Grasses in this area were mature, 3 – 4 feet tall, and as a result unpalatable to cattle. A lack of fire, cattle impacts, and appropriate growing conditions may be the cause for this exceptional case of regeneration.

Use of this valley by local peoples appears to be limited to grazing of cattle. One informant lamented that the reserve forces local people to graze their cattle at higher elevations. He stated that the reserve "boten las vacas a lugares lo que no son normales… a los alturas donde no hay comida suficiente – livestock are forced into areas that are of high elevation that is not normal for cattle, and where there is not enough fodder for grazing." Interestingly it is precisely those patches that are more impacted and degraded that do not grow on boulder fields. Of these patches two were in fact at exceptionally high elevation (see Appendix 6: all plots associated P.4 and P.6). This suggests two possibilities. First, once cattle can penetrate the forest edge (typically very dense) they can move about with relative freedom from hazard due to injuries, provided that the patch does not grow on a boulder field. Second, because grazing occurs at these higher elevations where fodder maybe scarce, cattle may leave the grassland to seek fodder in forest understory. In fact degraded and impacted forests in Demanda suggest that the primary type of impact was by cattle, and that these impacts were noted along the upper edges of forest patches. This may be the result of management practices by the park that have established barriers to entry. However, once in higher elevation grasses cattle can circumvent these barriers and wander into upper portions of forest patches that permit ease of access.

With respect to extraction of timber from the valley, in interviews with 3 local people who have rights to access grassland resources in the area, all claimed that no wood was extracted. Rather fuelwood and timber resources are satisfied by the cultivation of *Eucalyptus globulus* (*eucalypto* in local parlance) in villages within the buffer and transition zone of the reserve. That only one example of cutting was found in Demanda suggests that locals are not harvesting green timber from the forests because they have an adequate supply of *Eucalyptus* and/or park service staff in the area deter the cutting of timber. According to those *campesinos* interviewed from Humacchuco it is extremely rare when people take native wood from the park. If a family is struggling with their crops and have no income, then on occasion wood will be extracted from the reserve. But this extraction takes place near the boundary between the core area of the reserve and the buffer zone, some 15 kilometers away from Pisco (thus located outside of Quebrada Demanda and Llanganuco).

Finally, except for the one observation of fire in Demanda no other signs of burnig could be found. Although fire impacts disappear rapidly in grasslands they tend to linger much longer on forests. No evidence of fire impacts at the edge of forest or forest interiors were observed. The sole case of fire impact may be several years old and was isolated to burning of specific shrubs (*Puya weberbaueri* thought by locals to snare and kill smaller livestock because of its sharp hook-shaped thorns). Reserve staff claim that no fire has been used as a management tool in area since 1990. Given the lack of evidence of burning the claim appears to be substantiated.

Quebrada Ishinca – Discussion

Patterns within the ecological data collected from Quebrada Ishinca follow closely to the patterns found in the Pisco data set. Two notable exceptions are, first, in addition to the lack of correlation between basal area and elevation, no correlation was found between *Polylepis* seedling, saplings to change in slope or aspect. And second, the lack of a clear pattern in seedling regeneration and severity of impact. As discussed above the differences in edaphic characteristics, light availability, and intensity of cattle impact may be the cause of differential seedling vigor in the two study sites. Regeneration outside of the forest keeps to the same pattern in Pisco, where no regeneration of seedlings or saplings was found beyond 10 meters from the forest edge.

Overall, many of the forest patches in Ishinca appear to be mostly intact. The same pattern of forest formation on boulder fields (see *Quebrada Demanda – Discussion)* holds true in the upper two-thirds of the valley (see Appendix 6: all plots associated with I.1, I.2, I.3, I.4, I.5, and I.6). However, the lower third of the valley is blanketed in a contiguous forest (see Appendix 6: all plots associated with I.7 and I.8). The physiography of the bottom third of the valley is nearly V-shaped. From the river-bed the valley steepens to 30 – 40 degrees within a 100 meters and then tops out in vertical cliff walls. Nevertheless, all but two of the patches studied showed signs cattle impacts. The two patches without cattle impacts were located on extremely steep boulder fields and were bounded on their lower edge by the river – preventing any easy access along the lower edge.

No signs of burning were found in any of the forest patches, however, a number of scars from lightning strikes were noted on the north facing central valley slopes (see Appendix 6: all plots associated with I.2, I.4, and I.5). Interviews with local *campesinos* (2 people from the town of Collón) suggest that active burning in the valley has practically ceased to be a utilized as a grassland management tool for three years. However, one respondent did admit that some burning does take place in the hanging valleys and higher slopes of the Ishinca watershed. When asked why burning is no longer a management tool he responded that, "it is wrong and produces more harm than good to grasses." This is a curious response since the same informant and another both concurred that the biosphere reserve staff have not discussed grassland management with the community in nearly 10 years. The idea that burning is a poor management tool may be filtering into the village by some other mechanism, such as training sessions to obtain tour guide certification in Huaraz and/or conversations with tourists who pass through the village of Collón.

Finally, with respect to anthropogenic fire in the valley, both informants agreed that the celebration of San Juan or the Día de Indio on the 24th of June leads to widespread fires. The celebration is a tribute made for successful agricultural crops that combines Incan and Spanish tradition. According to one informant to burn the landscape is a way to "calintar la tierra – la pacha mama – por la precencia de heladas…la quema para protegir los cultivos." Literally: to heat the land or mother earth in order to prevent night frosts… fire is a way to protect crops. While conducting fieldwork in 1999 during the time of this celebration widespread burning was observed, however, in the Quebrada Ishinca most burning was located outside of the park in the buffer zone of the reserve.

As depicted in Graph 12 most impacts on the forests in Ishinca were due to cattle. But as was also noted above cattle impact did not lead to lower numbers of seedlings, suggesting that regeneration and resilience within forest patches is not adversely affected. Cutting, however, was noted in several plots. Speaking with local informants suggest that peasants from Collón rely entirely on *Eucalyptus* for timber and fuel, but that plows and yokes for agriculture are preferably made from *Polylepis* because it is a stronger wood. Only the poorest of families take timber from the park. Both informants also indicated that the most important source of a family's yearly income, beyond that of even agriculture and cattle, is the sale of *Eucalyptus*. Each family grows their own *Eucalyptus* on private plots as well as receiving income from community plots. Collón as a well-developed community forestry system tied to cooperative carpentry business that sells goods to Huaraz. According to informants, *Eucalyptus* accounts for almost 5000 soles[1] per year for each family in Collón. Given this wealth in timber who is cutting the forests of Ishinca?

According to both informants the mountaineering lodge at the head of the valley is cutting wood for fuel and construction. This observation is corroborated by several sources. First, informal conversations with tour operators in the field suggest that the lodge is to blame. Second, looking around the lodge several large cut and dried plies of *Polylepis* were observed. Third, one staff member from the lodge was observed cutting the top half of a *Polylepis* tree down. Fourth, and most unsettling, along the main valley trail that runs

[1] During the summer of 1999 2.7 soles was equivalent to $1 US.

through the large forest at the mouth of the valley, a transect to count cut trees was conducted. This transect yield a count of 736 cut trees in less than 7 kilometers. In fact several cutting areas were found hidden just off the trail where entire trees were downed and cut for shipping. Clearly it is easier to take timber from forests so close to lodge rather than haul wood up from the lowlands. It is possible that if this activity continues unabated, that as tourism continues to grow in the region these forests will show greater and greater signs of degradation. Enforcement of *Polylepis* forest protect status is not possible at this time because no staff is available to oversee activities at the lodge.

Quebrada Aquilpo – Discussion

Patterns in the ecological data for Quebrada Aquilpo appear to settle in somewhere between those found in Pisco and Ishinca. No clear relationships were found in running correlation tests among ecological variables. The relationship between number of seedlings and impact severity and type does appear to follow more closely the pattern seen in Pisco since some of the highest numbers of seedling regeneration were found in burned areas. Regeneration outside of forest patches is nearly non-existent in this valley, where dispersal of seedlings and saplings beyond the forest edge is less than 5 meters (see Appendix 6: all plots associated with A.1, A.2, A.3, A.4, and A.5).

Except for a near total absence of shrubland areas and dominance of grasslands in the valley, physiographically and ecologically Aquilpo is the twin of Ishinca. Only one patch was found do have no impacts. This patch located in the upper reaches of the valley is formed on an exceptionally steep boulder field.

Burning in Quebrada Aquilpo far exceeded what was observed in either Pisco or Ishinca. Of all study plots with burning impacts, 80% were found in Aquilpo, 20% in Pisco, and 0% in Ishinca. Moreover, observations made over the course of 7 days of field work in the valley indicate that nearly 100% of the grasslands in the upper two-thirds of the valley are regularly burned. Three specific observations lend support to this claim. First, throughout the valley there were very few areas with mature highland grasses. In all but one small area complex burning patterns were observed. Burning wase identified either by the presence of large areas of carbonized grass tufts, and/or by differences in the grass age-class. Differences in the age-class of grasses were easily detected on upland slopes by the presence of distinct linear boundaries. These smooth linear boundaries separating large patches of grass of different height, suggest that fire and not cattle grazing is the cause. Second, along all forest edges, which were explored, not a single area was found without burn scars on living trees, or entire tress and saplings killed by fire. In one patch, along the upper edge, a blaze had actually burned 3 – 4 ha of edge and interior forest. Judging from regeneration and soil, the area had been burned no more than six months prior. Third, over the course of a week in the valley a shepherd was observed twice setting fires in upland grass areas.

Interviews with four *campesinos,* from the village of Jomcopampa, about the use of fire as a management tool produced a mixed set of responses. Two of the four informants claimed unambiguously that fire has not been a management tool in the valley for over three years. However, one of these informants, in the same interview contradicted his earlier claim by stating that, "usamos la quema en la quebrada para rejuvenar pastos – we use fire in the valley to rejuvenate the grasslands." The other two informants both agreed that fire is used in the valley on occasion, and that widespread burning inside and outside the valley occurs during the celebration of San Juan/Dia de Indio. Moreover, it is interesting that all informants claimed that it has been years since the reserve staff has visited with the community. One informant made the point quite clearly, “we are happy that the park is not here, because we get to use the valley as we always have”. When asked to clarify what was meant by ‘park’ the informant said park staff. But when then asked where the park begins he answered, “its in the valley.” The park is obviously a presence to the *campesinos* of Jomcopampa, but it appears that for all intent and purposes it does not drastically change their land-use practices. However, the park is enough of a presence that claims about use of fire as a management tool and the extraction of other resources from the valley fall in line with general park policy.

The impact of cattle and fire on the regeneration of seedlings is variable. The low intensity of grassland fire does kill seedlings and saplings beyond the forest edge, but at the forest edge and just within seedlings and saplings appear vigorous. In addition, in areas where forest edge and interior have burned, seedlings appeared to be reestablishing rapidly, despite the grazing of cattle in those burned areas on grasses, herbs, and succulents that were also reestablishing. As mentioned in the discussion section for Quebrada Demanda and Ishinca, this issue may be one of edaphic characteristics of the valley and to lower intensity of cattle impacts, which promote the favorable conditions to seedling establishment.

Cutting of timber from the valley was not as prevalent as Ishinca, but more so than Pisco. The majority of cut *Polylepis* was found in areas where local people had built wooden bridges to cross the river and at the mouth of the valley. Cutting at the mouth of the valley was of a different type than the cutting seen in Ishinca. In Ishinca whole trees and very large branches were hewn. In contract cutting in Aquilpo took the form of lopping smaller and minor branches, which appears less severe to the condition of a tree. There are only about 300 people who live in Jomcopampa, who according to informants rely mainly on *Eucalyptus* for their fuel and construction wood. When necessary a family will go into the park to cut wood, however, this is seen not only as incorrect but also a sign of poverty. In conversations about this point it seems that the use of *Polylepis* as a fuel source is an indication of ones economic status. In addition, one informant claimed that poor families also use cattle dung as an alternative fuel source when wood in not available. It is rare to hear such a claim in the Cordillera Blanca, but on two occasions I did see families in Jomcopampa using dung as their fuel source.

A community *Eucalyptus* forestry project began in the late 80s, however, it only provides a minimum of timber to the village and at best about 500 soles per year for a family. Agriculture will provide about 4-5000 soles and cattle about 600 soles per year for a family. One informant stated the point quite succinctly, "potatoes are much more important to the village than cattle or timber... we don't have the skills or knowledge to make wood products. We would like to learn but don't know how. All the wood we sell is unprocessed. It goes to villages below ours where chairs, tables, and utensils are made." Clearly it is understood that profit in the cultivation and harvest of *Eucalyptus* is in the creation of items for sale to town in the lowland and the markets in Huaraz. Unfinished timber for construction and fuelwood fetch minimal prices at market.

Questions of Synthesis

The analysis and descriptions of Quebradas Demanda, Ishinca, and Aquilpo suggest a complicated picture of forest stand structure. Where do the findings presented above fall with regard to other research on the biogeography of *Polylepis* forests? How does data on stand structure and land-use/management relate to the findings of Chapter Three on spatial dynamics? Is there a clear interpretation that synthesizes the results of this research? These are the questions that we will turn our attention to in the following chapter.

CHAPTER FIVE
SYNTHESIS AND CONCLUDING REMARKS

Introduction

As revealed in the complexity of findings presented in Chapter Three and Chapter Four the story of *Polylepis* forests in the Huascarán Biosphere Reserve is anything but straight forward. The data and preliminary interpretations of spatial and ecological analyses of forest cover change presents a multifaceted and complex case wherein the overall pattern shows resiliency of *Polylepis* patches in the Huascarán Biosphere Reserve. Findings suggest that the suite of environmental orthodoxies explored in Chapter Two are unsatisfactory. Within the context of a site-specific micro-scale case study the discourses of Declension, Adaptation, and Interaction fail to account for observed phenomena. Until more in-depth analysis and research in the area is completed speculation over the merits of one perspective over another other may ultimately be limited. Moreover, it is not clear whether the acceptance of a single conclusive perspective would promote better management of forests within the reserve. The establishment of single perspective may simply serve to reaffirm an environmental orthodoxy that assumes the malfeasance of ecological villains (a variation on the Declension perspective) or powerlessness of human agency in the face of inevitable natural climatic changes (a variation on the Adaptation perspective). In this final chapter a broader discussion of the analyses offered in Chapters Three and Four explores an interpretation of *Polylepis* forest resiliency that may transcend these issues.

Recall the passage by C. S. Lewis in Chapter Two, specifically that: "No model is a catalogue of ultimate realities, and none is a mere fantasy. Each is a serious attempt to get in all the phenomena known at a given period, and each succeeds in getting in a great many. But also, no less surely, each reflects the prevalent psychology of an age almost as much as it reflects the state of that age's knowledge." In the spirit of this claim it should be understood that this thesis is yet another attempt to understand a phenomena, and as such is itself incomplete. In offering an alternative to the dominant discourses – models – of *Polylepis* forest cover change the intention is simply to amplify what we do and do not know about these forests. Following Forsyth's caveat, the goal here is not to replace one orthodoxy with another, but rather as reiterated throughout this work to offer a different perspective; a perspective that will hopefully aid in improving the management and condition of the Huascarán Biosphere Reserve.

I begin then with a synthesis of the data and discussion from Chapters Three and Four. In this synthesis I will consider the analyses completed here with those of the reserve and conservation groups working in the area, by revisiting discourse on *Polylepis* forest cover change. I will then close with a set of recommendations for management of forests in the park, and lessons learned.

Synthesis of Findings

It should be noted at the outset that the findings presented in this thesis generally support contemporary research on the biogeography of *Polylepis* forests (Byer's 1999; Fjeldså and Kessler 1996; Kessler 1995). In particular, Kessler's ambitious examination of a group of 194 *Polylepis* forest stands in high-land Bolivia reveal that physiographic conditions such as sunny aspects, slopes, rocky slopes, rock faces, streamsides, and proximity to villages have no statistical relationship with regard to location of forest stand establishment, stand conditions, stand fragmentation, or stand degradation. This appears to be the case given the ecological data assessed in Chapter Four. However, Kessler (1995) and Kessler and Fjeldså

(1996) argue extensively that the contemporary pattern of *Polylepis* forests across the Andes is a function of human mis-management of the landscape. Whether this is supported in the work presented here is discussed below. Suffice to say for the moment that the issues Kessler and Fjeldså raise with regard to stand regeneration and seedling establishment outside of forest patches is supported in the findings from the HBR. Fire and grazing exclosure experiments, according to Kessler and Fjeldså, demonstrate the rapid reestablishment of *Polylepis* seedlings in grassland areas. Many areas of seedling establishment outside of forest patches within the HBR appeared in areas devoid of cattle and fire impacts. However, the way in which results of this research differ from the work of Kessler, Fjeldså, and others is an issue to which we now turn our attention.

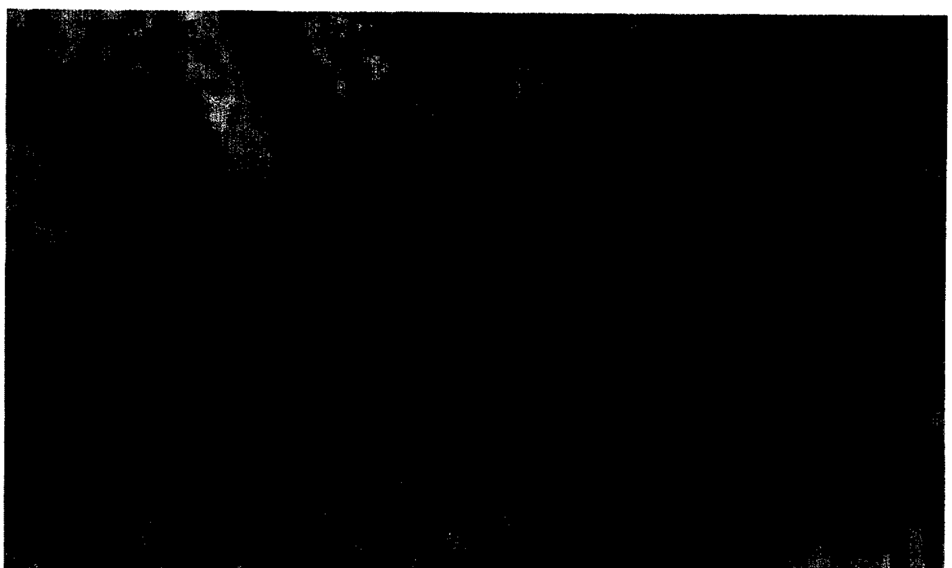
In the discussion of the spatial analysis of *Polylepis* forests two initial interpretations were offered. First, despite the difficulties encountered in attempting to complete a rigorous analysis of forest cover change the qualitative finding suggest no significant change on the landscape. This finding is based on images analyzed over just a ten year time period. Second, in order to achieve greater confidence in findings, more research and better imagery would have to be acquired, but such an investment in time and money may not lead to greater insights than those offered in the present work. The fundamental reason for this claim derives from closer inspection of the Landsat TM imagery and the 1962 aerial photography. Recall that aerial photography was omitted from the formal analysis because unacceptable levels of error in ortho-photo rectification. But can some inkling of a trend be determined from a qualitative analysis of this imagery?

Qualitative here implies a visual analysis, whereby identical patches from 1962 photographs are compared to those in the 1996 Landsat TM image. Because of the tremendous contrast between forest and surrounding grassland matrix it is quite easy to make out the shape of a patch on the landscape. As such it may be possible to visually inspect the same patches across the two images and observe any obvious changes with respect to size and/or shape. In fact such analysis reveals an interesting result. Two brief examples are offered here.

First, when a visual inspection of a patch in Quebrada Aquilpo is completed using the 1962 and the 1996 imagery no discernable changes can be detected (see Image 1 and 2). Image 1 is a zoomed subset image of the 1962 photograph and Image 2 a zoom of similar magnitude is used to isolate the same patch in a 1996 satellite image. It is remarkable to note that the smaller patch in the center right side of both images and that the shape of the forest edge of the larger patch to the left appears identical. In the discussion of Quebrada Aquilpo (see above *Quebrada Aquilpo – Discussion*) it was noted that the use of fire in the valley was nearly ubiquitous. The claim can not be made that the fire regime observed in 1999 resembles that of 1996 or 1962. However, based on interview testimony with local peoples, reserve staff, and conservation groups as well as ecological literature, suggests the widespread use fire in Andean grassland management (e.g. Pérez 1998; Zimmerer and Young 1998; Fjeldså and Kessler 1996, Kessler 1995; Lægaard 1992; Millones 1982; Ellenberg 1979). Given this broader agreement it would not be an unreasonable to assume that fire in each of the study sites has been used by *campesinos* in the past. As such it is intriguing to note the resiliency of these forests over a 34-year time period, and all the more so that the 1962 image predates the establishment of the HBR by 13 years and 22 years before the enactment of the first comprehensive park management plan (*Parque Nacional Huascarán: Plan Maestro* 1990a,b).

Image 1

Image 2



Quebrada Aquilpo – lower/mid section of valley – *Polylepis* forests are dark black (Image 1) and green (Image 2). Note the sharp outline that delineates forest from surrounding grassland and exposed rock surfaces (white – Image 1 and red/pink Image 2).

Image 1

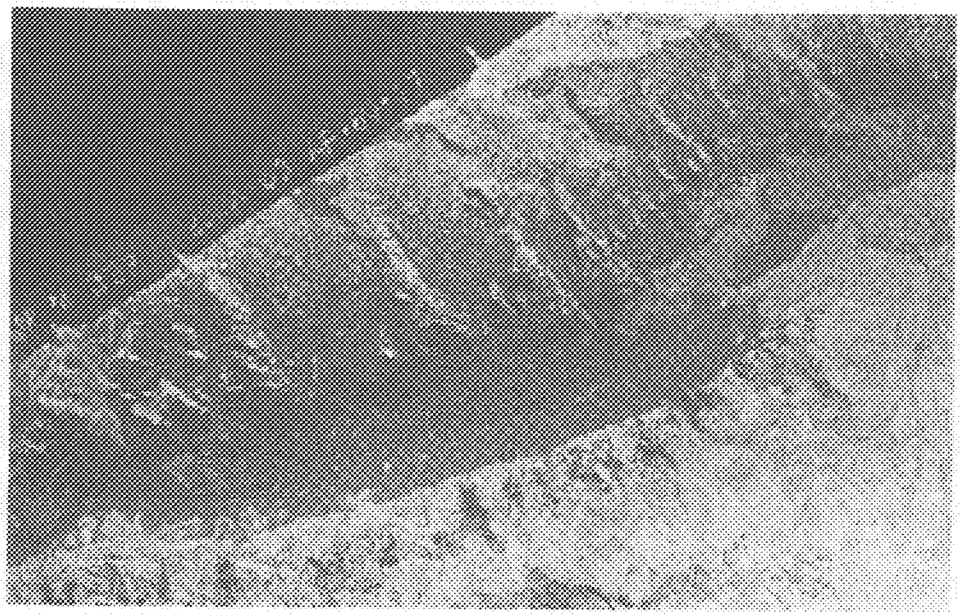


Image 2

Quebrada Aquilpo – lower/mid section of valley – *Polylepis* forests are dark black (Image 1) and green (Image 2). Note the sharp outline that delineates forest from surrounding grassland and exposed rock surfaces (white – Image 1 and red/pink Image 2).

Second, Image 3 and 4, taken from the same set of images depict forest patches from Quebrada Ishinca. Here again the shape and size of forest patches appear quite similar. Also note that in the upper right hand corner of Image 3 and 4 the 1962 glacier has retreated and left in its wake an alpine lake bounded by a moraine, an indication that in spite of climate change forests appear unaffected with respect to their extent. This type of visual analysis was completed for all study patches in the two valleys (note: only 2 pairs of images were presented for demonstration. Those found to be clearly obvious for interpretation are shown here – other comparisons can not be clearly presented without the use of a computer screen and higher resolution graphics). Results of this analysis on other study patches yielded identical findings as those in the aforementioned examples. Again this type of analysis is purely qualitative, but the suggestion is profound; forests in the Aquilpo, Ishinca, and Demanda valleys have not changed dramatically over a 34-year time period. It may well be the case that slight changes in shape or size have occurred, but the point remains that the forest patches display a highly resilient pattern over time, a finding that supports Byers' 1999 repeat photography, landscape change analysis of the biosphere reserve.

The suggestion of no change in forest patterns must be reconciled with the findings of the ecological analysis. Clear in the discussion of findings for each of the study sites are the similarities that the valleys share. Yet differences do exist. Percent of impact severity per site, Graph 21, and incidence of impact type per study site, Graph 22, provide a broad overview of the similarities and differences in the three study areas. In Graph 21 we see that Quebradas Ishinca and Demanda are nearly identical with respect to percentages of impact severity registered in study plots, while a marked increase in

Image 3

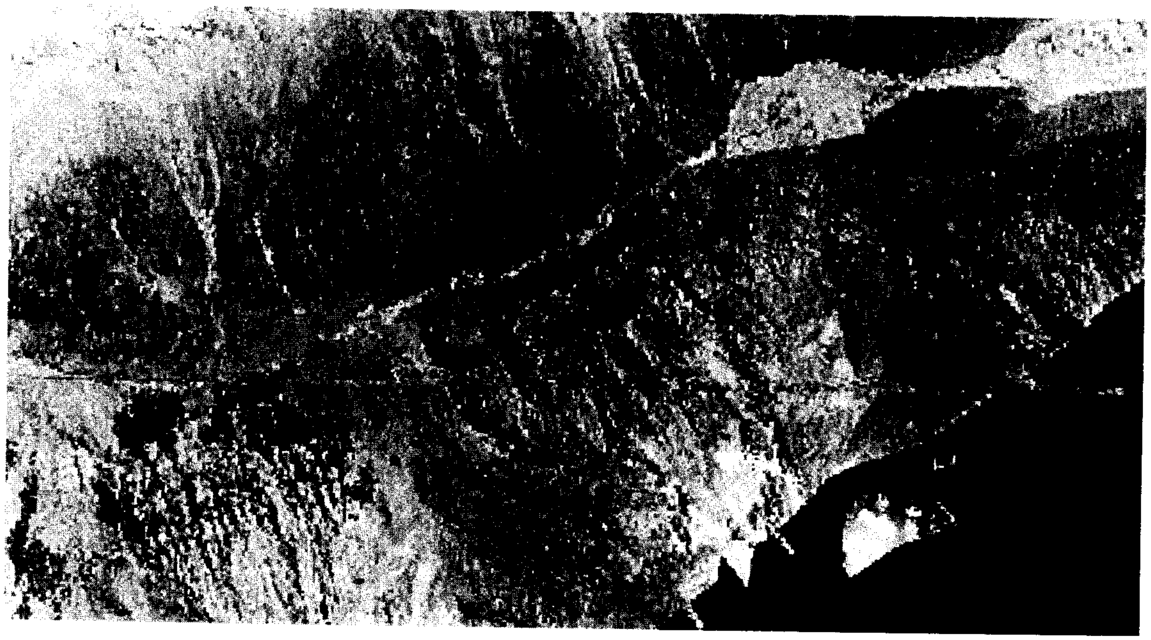
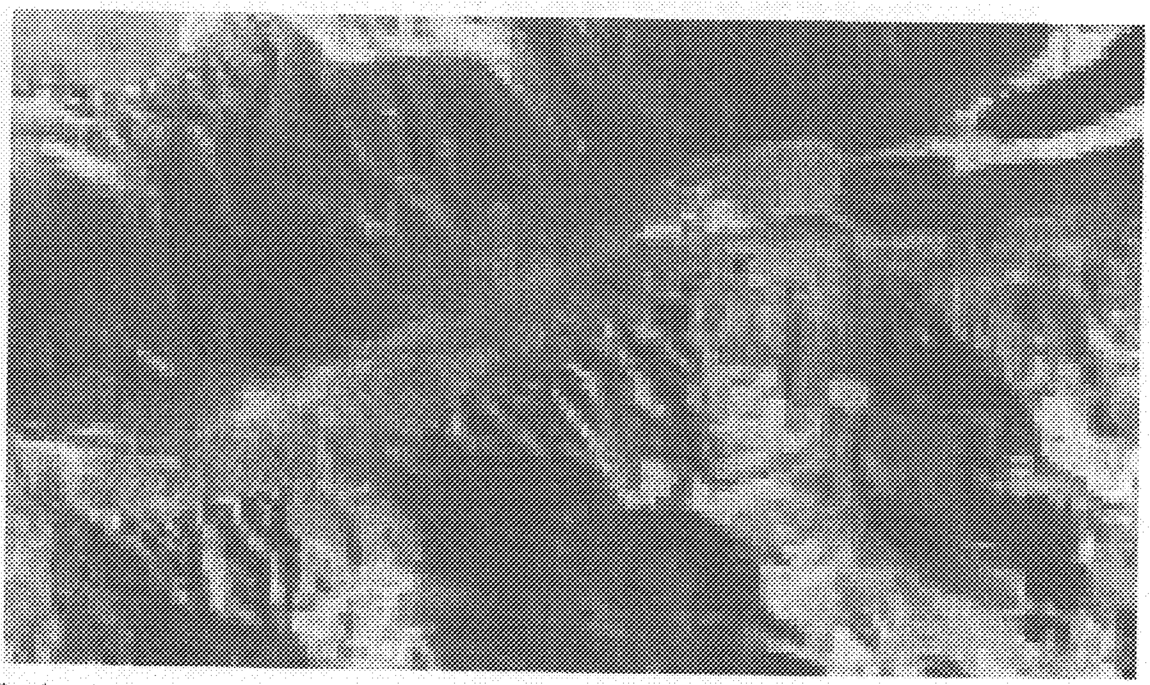


Image 4

Quebrada Ishinca – upper/mid section of valley – *Polylepis* forests are dark black (Image 3) and green (Image 4). Note the sharp outline that delineates forest from surrounding grassland and exposed rock surfaces (white – Image 3 and red/pink Image 4).

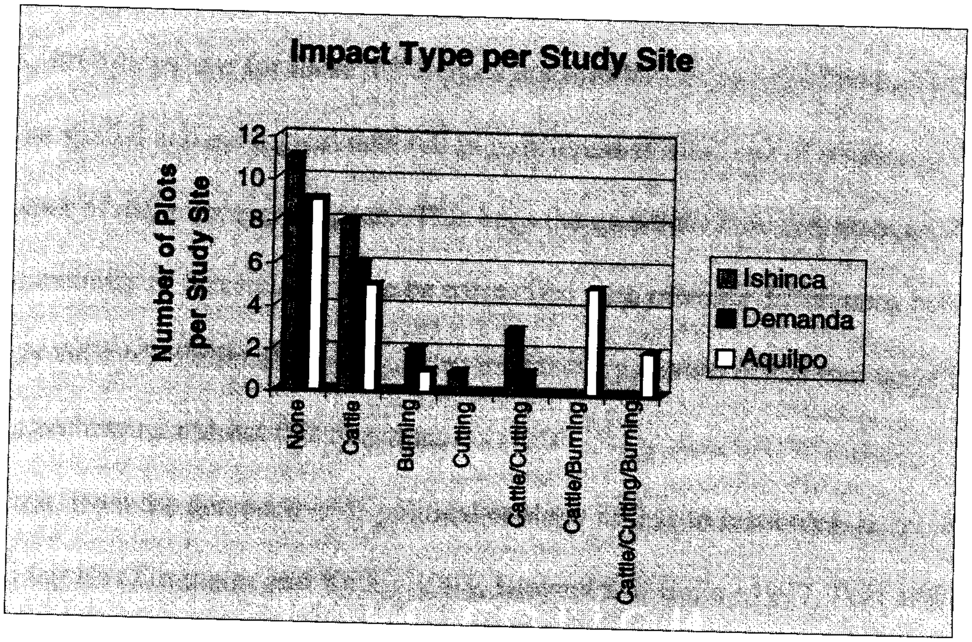
Image 3

Image 4

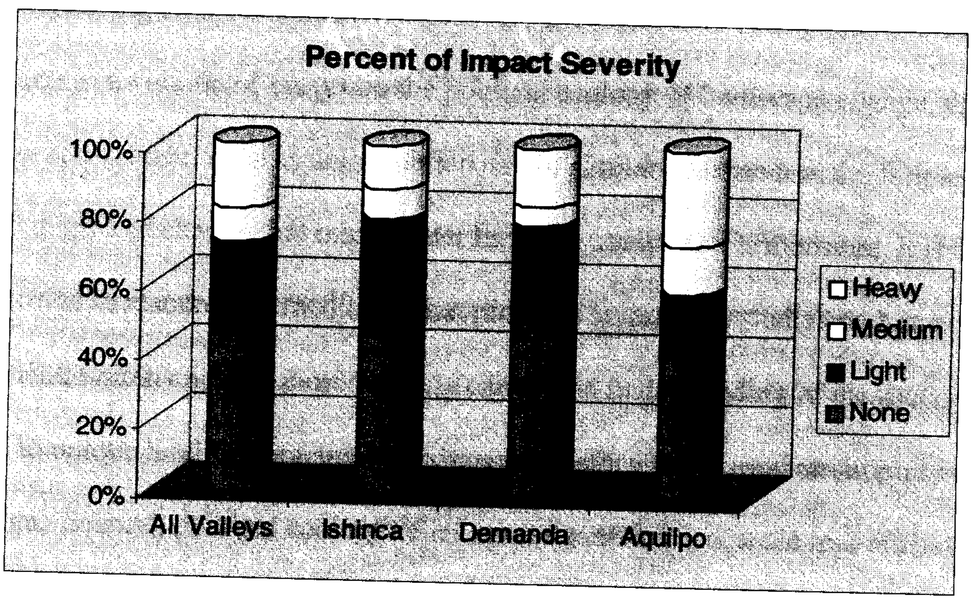


Quebrada Ishinca – upper/mid section of valley – *Polylepis* forests are dark black (Image 3) and green (Image 4). Note the sharp outline that delineates forest from surrounding grassland and exposed rock surfaces (white – Image 3 and red/pink Image 4).

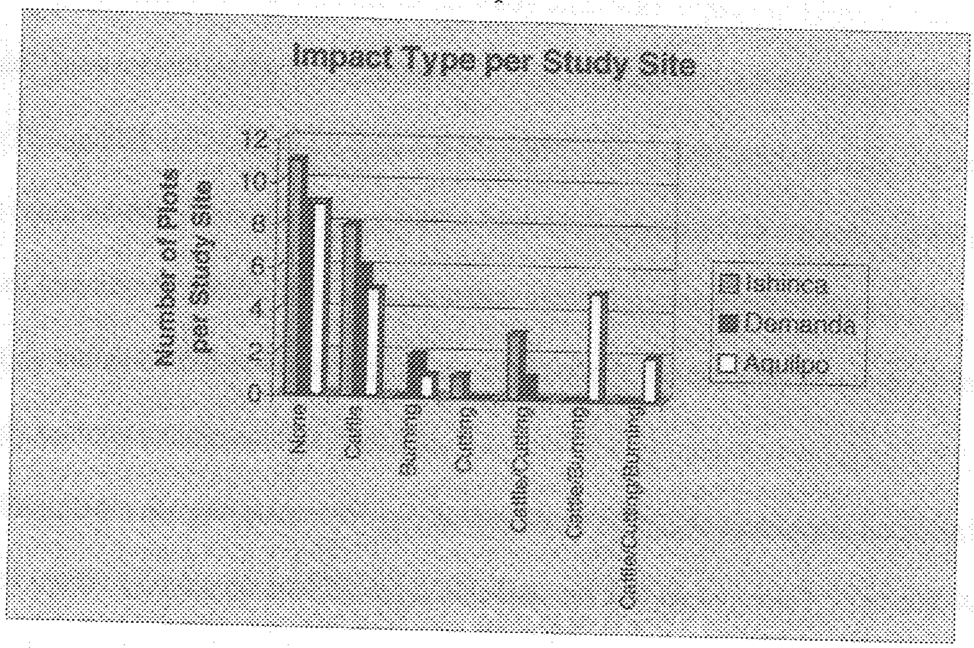
Graph 21



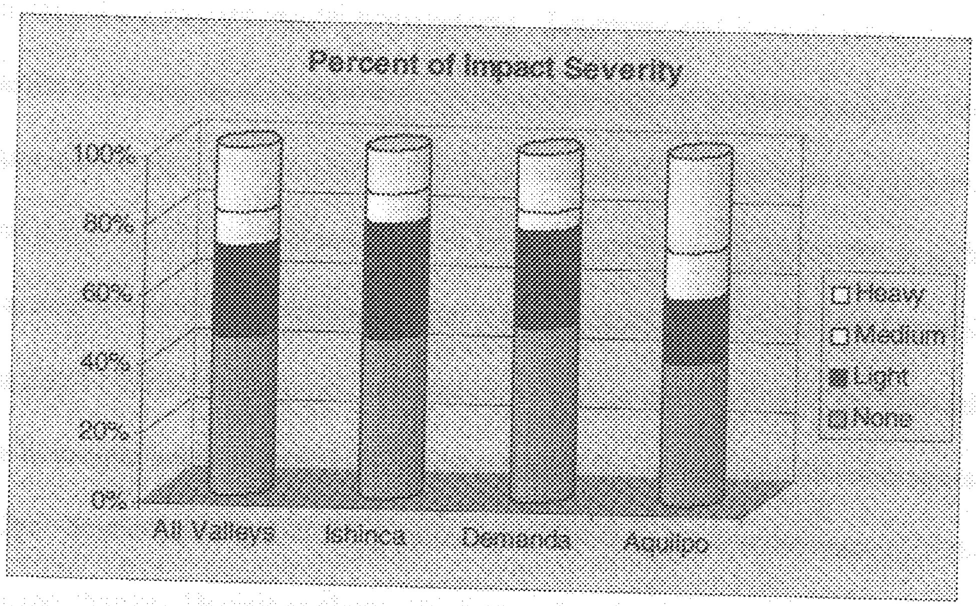
Graph 22



Graph 21



Graph 22



severe impacts are present in Quebrada Aquilpo. In addition, Graph 22 reveals the similarities and difference among the three study sites with regard to types of impacts observed. Interpretations for these differences and similarities are detailed in Chapter Three.

The spatial and ecological data tell two different stories, one of resiliency over time and the other of difference over space. This begs the question: how can an overall similar pattern of stability of forests over time be reconciled with obvious differences between the three study valleys? Political ecology, as an explanatory devise, offers two ways in which to shed light on how to address this question.

First, from the perspective of political ecology access to resources, necessarily a contested terrain (Zimmerer and Young 1998; Brayant and Bailey 1997; Peet and Watts 1996), is the lynchpin of a meaningful analysis of landscape change, degradation, or generally speaking environmental management. Zimmerer and Young (1998) state in their introduction to a volume of essays on the political ecology of landscape change, that environmental change, such as deforestation, is not similar because it is the frequency, rate, kind, and degree of change that must matter in the an analysis. Furthermore, it is the history of how access to resources is meditated that provides leverage in studies on human-environmental interaction, to more robustly capture an understanding of the dynamics that give rise to unique land-use practices, landscape transformations, and environmental knowledge. Second, political ecology relies upon the notion that scale matters in the analysis of landscape change. Decisions about which spatial and temporal scale to examine a phenomenon establish the initial conditions of such study that will fundamentally constrain the possible set of findings. This point, strikingly illustrated in Turner's (1998) exploration of rangeland degradation of Sahelian Africa, reveals the sensitivity of scientific findings to the use of various spatio-temporal scales.

In the case of *Polylepis* forest cover change in the HBR, these two issues are at play. Access to a means of livelihood for Humacchuco, Collón, and Jomcopampa are different. Details of these differences are addressed in the discussion section for each study valley in Chapter Three, however, it is worthwhile here to reiterate some key points. First, Collón – the village below Quebrada Ishinca – is by far the wealthiest of all three villages. Residents of Collón are engaged in not only traditional agricultural and subsistence practices, but also have found ways to capitalize on the tourism industry and forestry projects involving *Eucalyptus* plantations. In addition, due to increased tourism, and specifically the establishment of the mountaineering lodge, a high degree of wood extraction in *Polylepis* forest patches is taking place. Humacchuco lacks access to the tourism industry and to markets for forest products. In addition, Humacchuco must contend with strict regulation of Quebrada Llanganuco and Demanda by the HBR staff. This is markedly different from the situation that people in Jomcopampa face with regard to Quebrada Aquilpo. In Quebrada Aquilpo the presence of the HBR staff is minimal to non-existent. As a result land-use practices in this valley proceed without outside regulation.

Overall then land-use pattern in each valley reflects not only the unique resource requirements of each village, but also the relationship through which each village negotiates with the reserve, its management staff and conservation groups in the region for access to the park. In the each discussion section for the three valleys we see how such differences influence land-use practice.

Regardless of the differences in the frequency, rate, degree, and type of land-use for each of the study sites there appears to be little affect on forest cover at longer time scales. In other words forest stability seems to be the general finding for all three valleys as revealed by the images in the preceding section. However, it may be the case that the degraded forest patches of Quebrada Demanda are poised to disappear if the conditions that promote seedling establishment are not achieved. The difficulty with respect to management is to determine what conditions give rise to regeneration. Given the variability observed in seedling regeneration compared to impact types and severity it is not obvious what conditions will promote *Polylepis* seedling establishment (see Chapter Four: *Seedling and Sapling Regeneration*). In addition, grazing, fire, and/or forest extraction at present do not appear to limit the regeneration and resilience of forest patches in the three valleys.

This suggests a more subtle point that moves us away from the basic questions we ask about forest cover change all together. If we accept the patterns presented in this study, then instead of asking how and why forests are changing over time we should ask how and why forests remain unchanged? This could be a far more fruitful line of questioning with regard to both academic debates over *Polylepis* forest distribution and to management of forests within the biosphere reserve.

Discourse on *Polylepis* Forest Cover Change - Revisited

Environmental discourse has material consequence. To suggest otherwise would be to deny not only the agency of culture on a landscape but also the significance of how environmental policy and management planning is developed. How discourse acquires agency and purchase on the environment is a complex question, requiring investigation into the history, economics, politics, and culture of an area to fully understand. The matter is further complicated in that the environment itself has a degree of agency upon human society. Once established as the dominant interpretation or the most compelling explanation, a discourse assumes a hegemonic role in guiding policy, management, and interpretations of the environment. Discourse at this moment becomes in Latour's perspective naturalized, which is to say logically derived – or caused – by nature. Nature serves as the ultimate arbiter of the truthfulness of a discourse. And as such discourse has an affect not only material world, but may also become so reified as a privileged perspective that its replacement or modification maybe exceptionally difficult (e.g., discourses on evolution, democracy, or classical physics).

Yet as described in Chapter Two Latour cautions that, "since the settlement of a controversy is *the cause* of Nature's representation not the consequence, we *can never use the outcome – Nature – to explain how and why a controversy has been settled*" (1987: 99 emphasis in original). Chapter Two explored the changing story of *Polylepis* forests both in the Andes and in the Cordillera Blanca. The three dominant discourses derived from consideration of these forests are Declension, Adaptation, and Interaction, each of which appeal to a sense of the natural as a powerful, albeit partial, justification.

Each of these perspectives of the Andean highlands results in dramatically differing readings of the landscape. Moreover, it is interesting that within scientific discourse, interpretation of *Polylepis* landscapes is still contentiously debated and remains unsettled; the natural state of *Polylepis* landscapes is yet undetermined. Indeed, this thesis is but more fodder in that polemic. In contrast to the scientific debate, within the discourse of the HBR, the matter is considered for the most part settled; where a natural state of the landscape is actively managed for and understood.

This collapse of multiple discourses into essentially a single perspective among the institutions that manage resources in the reserve is driven primarily by a history of interpreting the landscape as degraded (see Chapter Two: *Discourse and Science: Declension, adaptation, and interaction*). But more pragmatically, it is obvious that even if the HBR staff was to question their assumptions about landscape change/degradation the resources for such an effort are simply not available. In other words the HBR may not have the resources to effectively research environmental issues, design management plans, and then conduct implementation and monitoring activities.

It is beyond the scope of this thesis to engage in a thorough exploration of the complex relationship between environmental discourse and environment change in the reserve. However, it is worthwhile to briefly make some concluding points. First, in the case of the HBR presented here, the suggestion in broadest terms is that the relationship between environmental perception and the environment has fallen out of step. This is made clear in the discussion of findings in Chapter Three, where in many cases the reserve staff is not aware of the kinds of land-use practices that affect each of the study sites. In some instances the HBR position is counter to what was observed on the ground. For example, the HBR is unaware that fire continues to be used as a management tool in Quebrada Aquilpo or that forest extraction in Ishinca does occur with great frequency. In addition, the findings presented here, that forest patches are resilient – neither greatly expanding nor contracting on the landscape – does not align with the HBR perspective that degradation continues in Demanda or with the perspective that Ishinca and Aquilpo are recovering. In short the HBR reliance upon a perspective of Declension appears in some respects unwarranted. Second, conservation groups such as The Mountain Institute assume a discourse of Interaction where the natural state of the landscape is one of coexistence of highland communities and the environment. TMI strives to achieve biodiversity conservation goals within a framework of political ecology, where historical geography, sustainable development, and cultural survival are all considerations in determining which management methods are best suited to the area. Fundamentally TMI assumes that in the HBR people are a part of the equation (see Chapter Two: *Institutional and Campesino Discourse*). In the case of both the HBR staff and conservation groups it is a vision of the 'natural' upon which management decisions are based. Given the complexity of issues involved, which of the three discourses best serves to facilitate more effective management?

The fundamental shortcoming of all three perspectives showcased in Chapter Two is that none deal with the issues of political ecology. From the perspective of Declension, a prominent implication is *Polylepis* as a climax species of the highland Andes. Fjeldså and Kessler (1996, 189: emphasis added) unequivocally posit that: "After the glacial period the highlands were open to colonization by *Polylepis* trees. We now assume that *Polylepis* forests and woodland would constitute *the natural vegetation* in much of the high Andes," but "instead of a mosaic of woodland, scrub, and a variety of grasses we find *vast* and *monotonous* areas of bunchgrass (*ichu*) steppe, of very low productivity" (1996, 39: emphasis added). Centuries of human land-use practices have sculpted the highland Andes we observe today. The subclimax monotonous grasslands and relictual *Polylepis* forest patches, relatively new to the Andes, are symptoms of a degraded landscape created by the highland *campesino*. Ultimately these anthropogenic landscapes are profoundly *un*-natural; implying that human agency on the landscape is also un-natural. This perspective is problematic because it fails to consider the political, cultural, and economic dynamics. As such the management implication is simply to remove people from the landscape. This is apparent in HBR policy of limited access to natural resources and land-use practices (such as agriculture and plant collection) within the core area of the reserve.

The perspective of Adaptation informs us that patchy distribution of *Polylepis* occurred long before human agency could have had a major impact on the landscape. Evidence of long term fluctuations in geology and climate, and concomitant *Polylepis* speciation and specialization as adaptive response, draws our attention to a different reading of the landscape. While anthropogenic disturbance may have been superimposed upon the landscape, current forest patterns show remarkable stability. However, today it would be an impossibility to tease apart human and natural forces that drive contemporary landscape patterns, in order to create a compelling argument for the 'natural' phylogeny of *Polylepis*. A main implication given this perspective is that, human agency is not a central part of the *Polylepis* story and that the political ecology of the region has not influenced the geography of species. Recall Simpson's (1986: 304) claims that: "superimposed on these natural geologic and climatologic events," which led to uneven distribution of *Polylepis* forest, "have been human actions... [and]... because of these human influences, it is unfortunately impossible precisely to reconstruct the evolutionary history of the genus." The main point remains the same, that only recently has human agency negatively impacted the landscape, and that this effect has created conditions which has rendered the landscape inaccessible to understanding its natural state.

The perspective of Interaction as characterized by Young and León (1995: 659) suggests that: "habitat fragmentation is a natural consequence of the distribution of ecosystems in a complex topography... thus it is critical to understand the degree and impact of this natural fragmentation when evaluating the additional fragmentation caused by human activity." Due to the verticality of the Andes, fantastic micro-climatic change can occur over short distances (Brush 1977; Gade 1992). This verticality creates natural conditions, which favor discontinuous distribution and apparent fragmentation of vegetative cover. Moreover, interpolation of climatic condition over small-scale distances can be exceedingly difficult in many areas, especially in the steep high altitudinal habitats of *Polylepis* forests. This variability in microclimates may serve to undermine attempts at projecting potential distribution of vegetative cover over large areas.

Anthropogenic forces on the landscape also no doubt play an important role in understanding how and why contemporary landscape patterns appear as they do. However, human agency on the landscape is not evenly distributed, thus complicating our understanding of its relative importance on a regional landscape scale. Furthermore, the interplay of natural and anthropogenic patterns themselves vary locally with respect to their relative dominance over one another. There can be places on the landscape where anthropogenic dynamics greatly outweigh natural dynamics (Denevan 1992), while in other places natural dynamics mask the expression of anthropogenic dynamics (Vale 1998). Within the HBR there are areas, which come under greater influence of biotic and abiotic factors, while in other areas human agency is undeniably the driving force on the landscape. While this perspective comes close to considering the political ecology of forest dynamics, it simply suggests the variability of human agency on the landscape. It does not directly address the political and economic context of neither how landscapes degrade nor how and why they are deemed degraded in the first place.

Finally, the perspective offered in this thesis is itself a discourse about *Polylepis* forest cover change. It could be categorized as a form of the Interaction perspective, but it goes further in that it recognizes the import of economics and the local context of management for each of the valleys. In addition, the thesis is also caught in the process of science as conceived of by Latour. Recall Latour's (1999, 30) claim that researchers, "do not speak of the world but, rather, construct representations that seem to push [the world] away, but also bring it closer." The production of this thesis and the perspective offered here is an appropriation of nature through abstractions and symbols that come to represent the forests of the HBR (not unlike Latour's (1999) description of ecological research completed in Brazil in *Pandora's Hope*). Furthermore, the progressive abstraction of *Polylepis* forests into charts, graphs and maps become part of the *Polylepis* debate, wherein the 'nature' of *Polylepis* forests has yet to be settled. As a part of the ongoing controversy in defining what is a natural *Polylepis* landscape the thesis will be challenged on the basis of assumptions made, methodologies chosen, and results presented and not on the nature of the forest *per se*. The work presented here then is not intended to be a complete picture, but rather an indicator or orientation for future research to consider.

Recommendations for Management

The interpretation that forest patches within the HBR are resilient is not a call for a relaxation of conservation efforts. Instead many of the assumptions about forest cover change, and the role of anthropogenic impacts in such change must be reconsidered.

- *Polylepis* forest patches in the three study areas investigated appear to be remarkably resilient. This suggests a de-emphasis on what causes fragmentation in favor of a different question: why are forests not establishing and/or expanding across the landscape?
- Given the stability of forest patches in the study areas, especially in terms of size, shape, and regeneration investigation into what impacts cattle have on soil structure and regeneration in grassland areas should be undertaken to better understand why *Polylepis* seedling and sapling establishment outside beyond forest edges is rare.
- Analysis of threats to forest health and regeneration ought to reconsider the idea of impact severity (as defined in this thesis) as a predictive tool to the condition of a forest.
- Providing user-groups who access resources assistance in forestry projects may further offset anthropogenic impacts on the reserve. *Eucalyptus* should not be demonized as a threat to livelihood. Plantation techniques for *Eucalyptus* need to be improved with respect to agricultural needs of the area, training provided in the processing *Eucalyptus* into finished products, and markets for such wood products further expanded to support communities who live along the boundary of the reserve core area in the buffer zone. In addition expanding wood production into the livelihood practices of communities along the reserve core area may help reduce the number of cattle that are grazed in park.

- Identify communities who most heavily rely upon the resources of the core area and determine if current land-use practices do in fact have deleterious impacts on forest patches.
- Reforestation techniques should work with existing stands of *Polylepis*. Planting same species type along and near current forest edges may better support forest expansion.

Conclusion

This thesis has explored the various interpretations about *Polylepis* forest cover change in the HBR. The use of GIS and remote sensing technology, coupled with ecological and qualitative data can provide insight on the dynamics of forest cover change or resiliency. Difficulties and challenges involved with these techniques were detailed. The overall analysis points strongly toward the resiliency of forest patches in the HBR.

The case study of the HBR reveals quite vividly how the Andean landscape is an expression of the intimate relationship between humanity and mountain biogeography. In addition it has been argued that given this historic relationship, human agency on the landscape should be interpreted as natural as that of *Polylepis*. The assumption here is that the Andean landscapes is Andean, precisely because it is the marriage of anthropogenic and natural dynamics: the material, aesthetic, and cultural expression of historical and contemporary human-environmental interactions.

Embracing this assumption, the work of conservation and sustainable development implies either an extant characteristic of a place, or a possible future state of being is a guiding perception that requires careful thought and consideration. What are we conserving and for whom? Does our vision of an Andean landscape lack the presence of people? How do we negotiate between the materiality of the landscape and the ideology implied within our discourse over conservation and development? These types of questions suggest that it is important to unpack what we understand to be a natural landscape, because environmental perception and discourse have material impact on landscapes and people. The discourses that have been reviewed here appear to be unsatisfactory in addressing the HBR case study. It may be that no single discourse – environmental orthodoxy (see Chapter One: *Discourse Analysis*) – will be able to account for the full range of phenomenon observed on *Polylepis* landscapes, given the complexities of spatio-temporal scale, economics, and politics that influence environmental change.

The suite of land-use practices of highland *campesinos* has not affected the landscape equally in all places. Contemporary pressure from fuelwood gathering and timber extraction coupled with livestock grazing may degrade remaining *Polylepis* stands. However, we have seen that changes in production practices in the remote highlands, and the advent of forest plantations of alternative species (e.g. *Eucalyptus globulus*) at lower elevations appear to reduce pressure on *Polylepis* forests. The lesson here is that local socio-environmental interactions influence landscape patterns in the reserve. Thus we have seen in this thesis that to vilify *campesinos* and their land-use practices may be inappropriate with regard to the contemporary condition and health of *Polylepis* forests. How highland peoples interact and effect landscape pattern and process at local scales will be important to informing conservation action and policy for *Polylepis*.

The challenge before us should not be conceived of as a choice between human or natural values as being more or less important, but rather how we can conserve what is believed to be Andean, both culturally and ecologically.

Appendix – 1

Figures

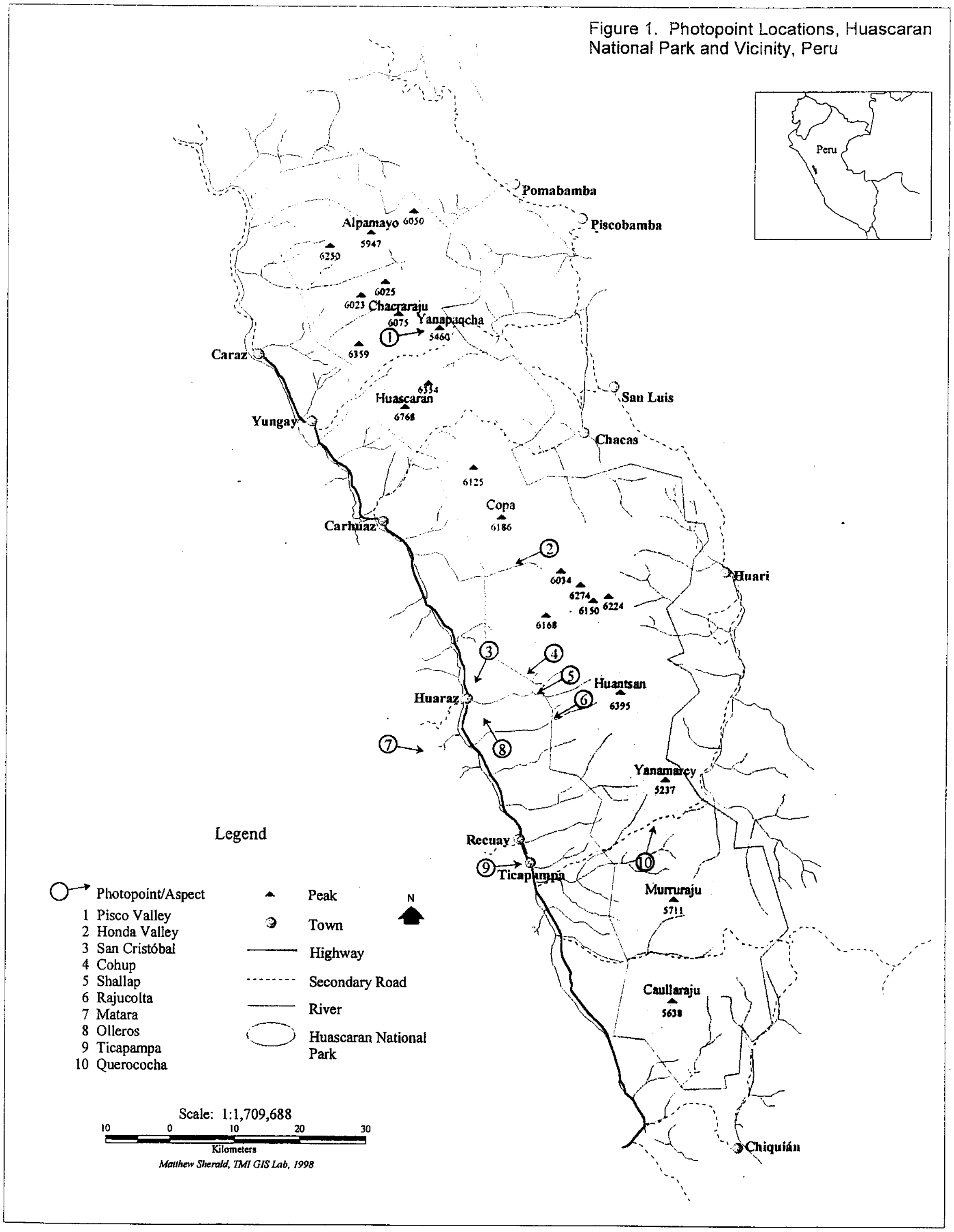


Figure 1. Photopoint Locations, Huascaran National Park and Vicinity, Peru

Figure 1 Photopoint Locations, Huascaran National Park and Vicinity, Peru

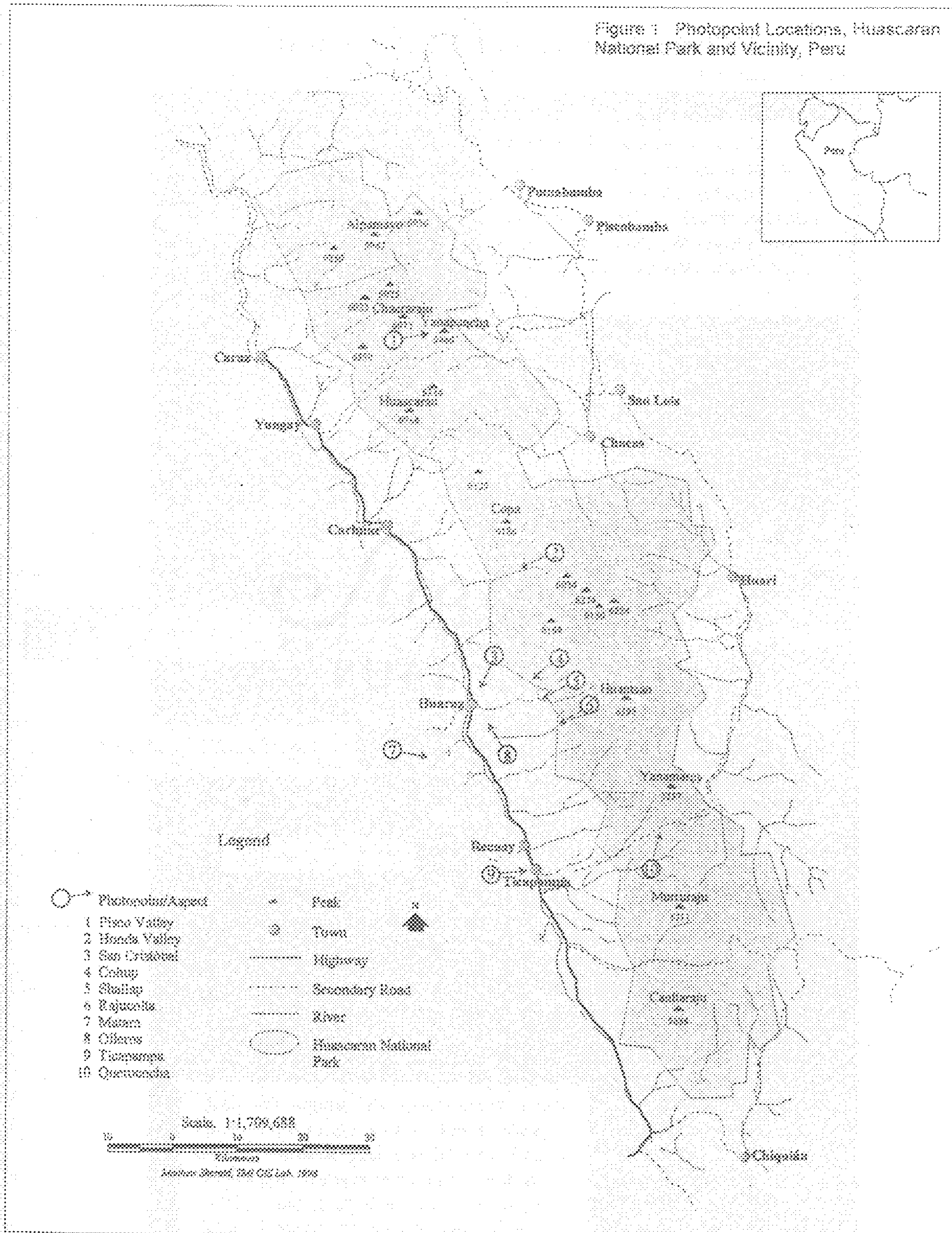
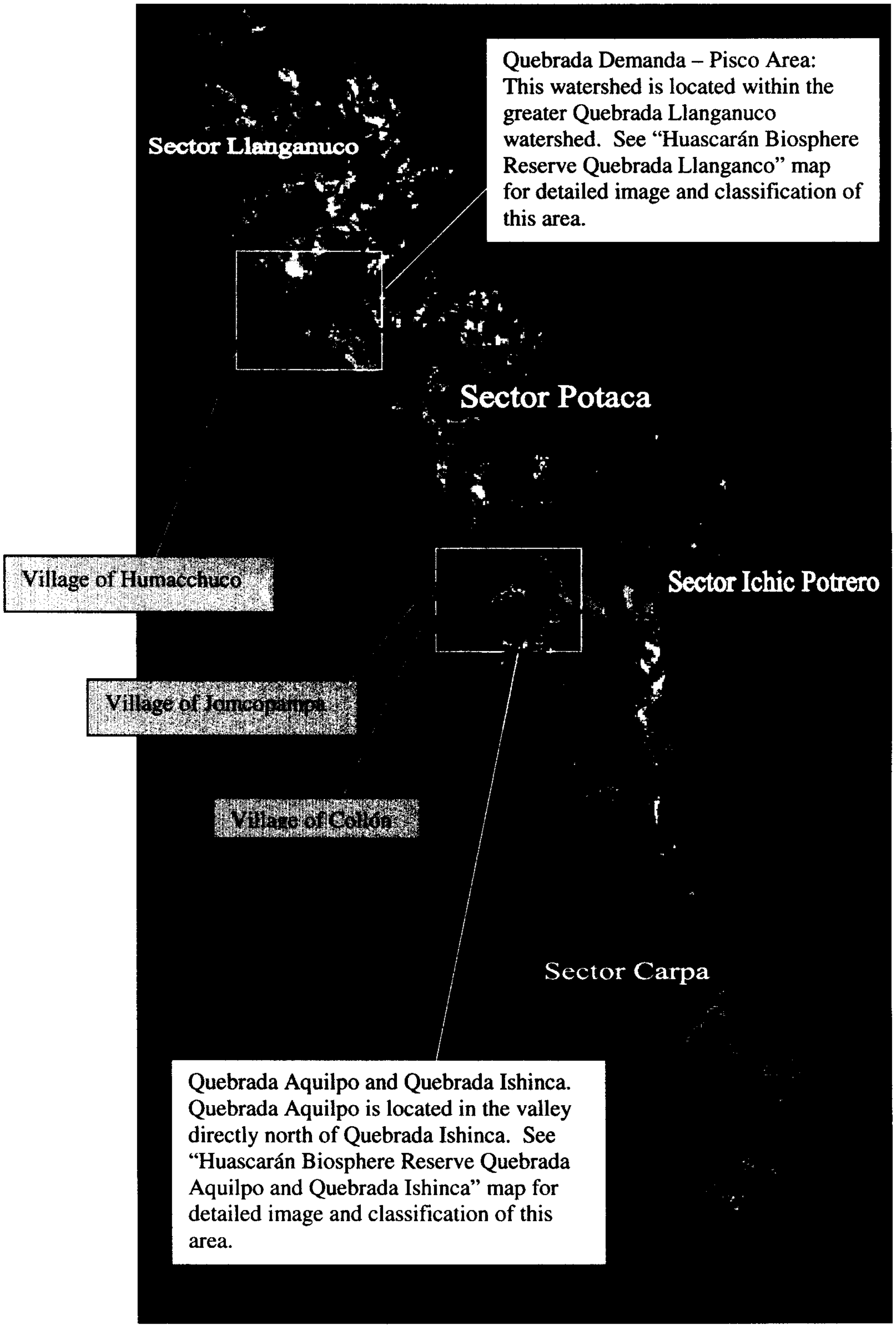


Figure 2
Huascarán Biosphere Reserve
(1996 Landsat TM image of national park/core area: bands 5, 4, and 3 false color composite)



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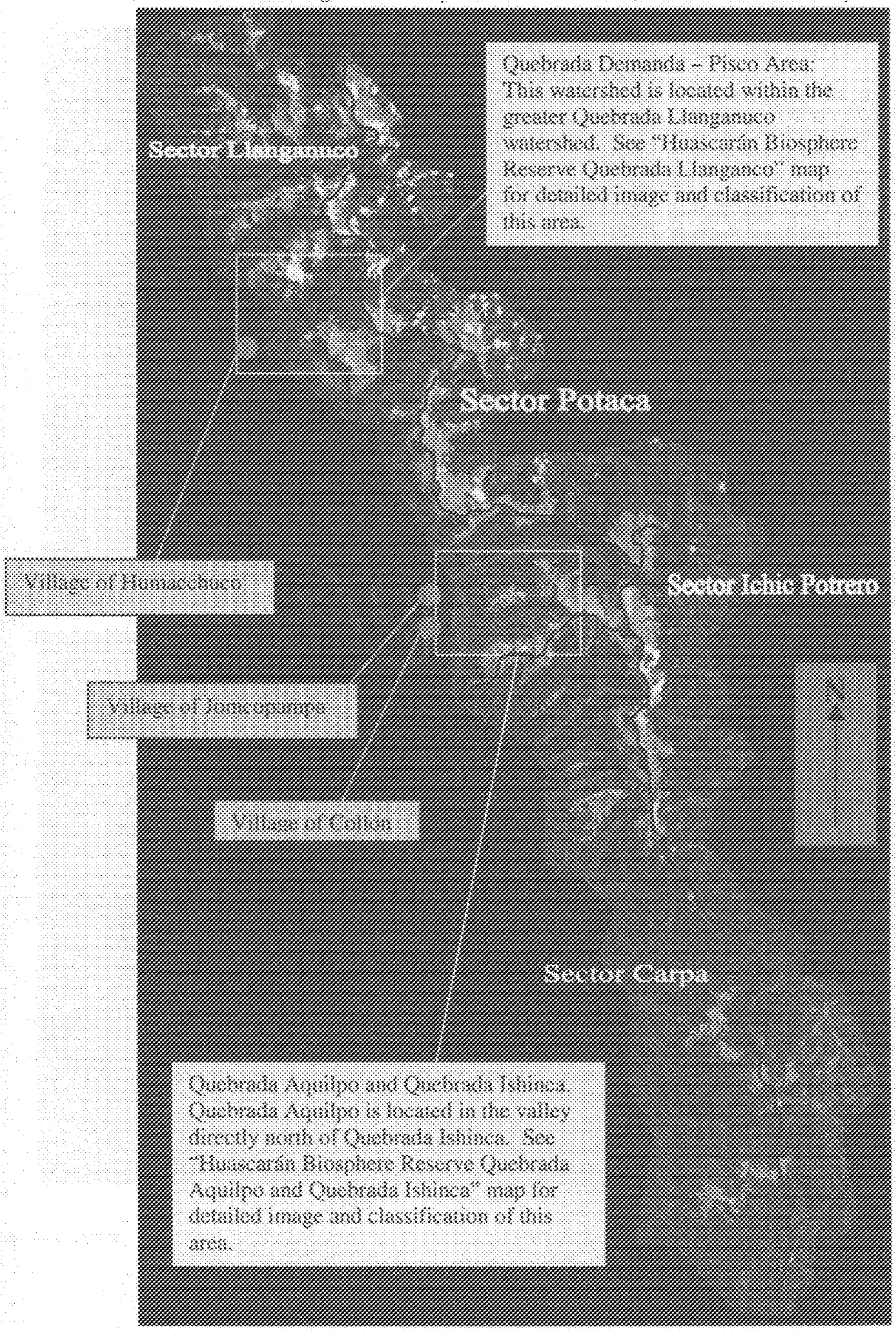


Polylepis Forest Classifications

Figure 3

1996

1986

Here two Landsat TM images have been classified as Polylepis Forest and non-forest for two valleys, Quebrada Aquilpo and Quebrada Ishinca within the Huascarán Biosphere Reserve. These classified images have been overlaid with vector polygons that represent forest cover. Polylepis forest polygons were visually interpreted from the original Landsat TM images prior to their classification as forest/non-forest. Interpretation was based on ground truth data collected from fieldwork completed in the biosphere reserve during the summer of 1999 and from aerial photos of the area.

Interesting to note is the close correspondence between forested areas that were visually interpreted and those classified via a computer automated process in Erdas Imagine. Differences and discrepancies between the classifications result from errors in visual interpretation for polygons and atmospheric disturbances (shadows, haze, and mis-classification of pixels at boundaries between cover types) for automated classification. One qualitative interpretation offered here is that forest cover from 1986 to 1996 has not changed dramatically.

Legend

Land Cover Types

All Land Cover Types

Polylepis Forest

Polylepis Forest Polygons

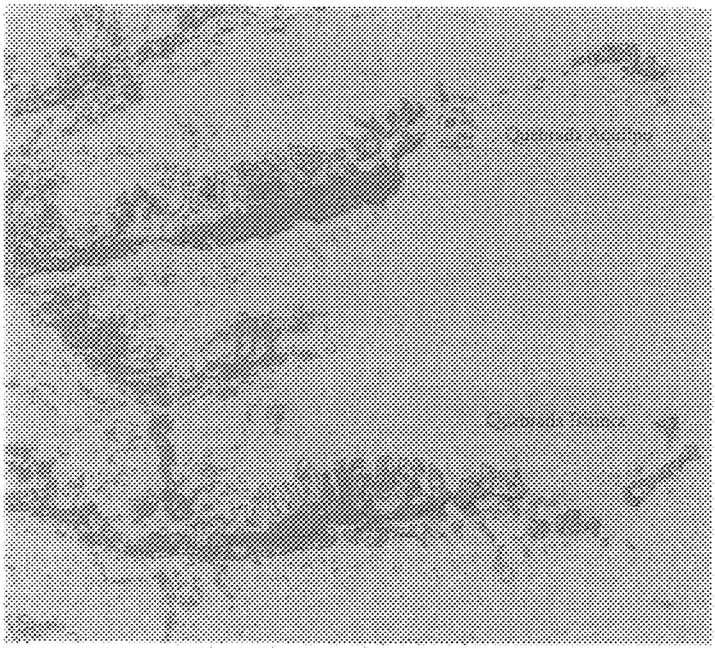
Scale

1000 0 Meters

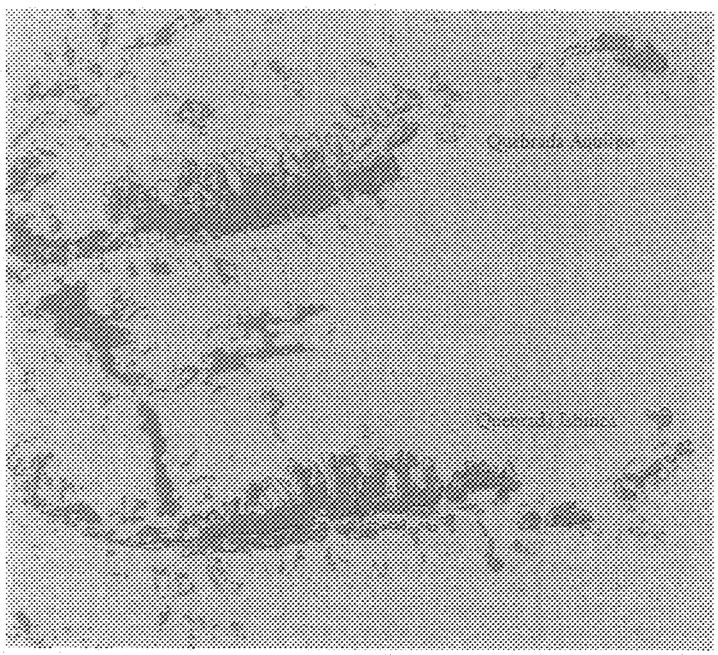
Ankur Tohan 5/9/2000

Polylepis Forest Classifications

Figure 3



1996



1986

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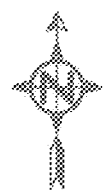


Legend

Land Cover Types

All Land Cover Types

Polylepis Forest

Polylepis Forest Polygons

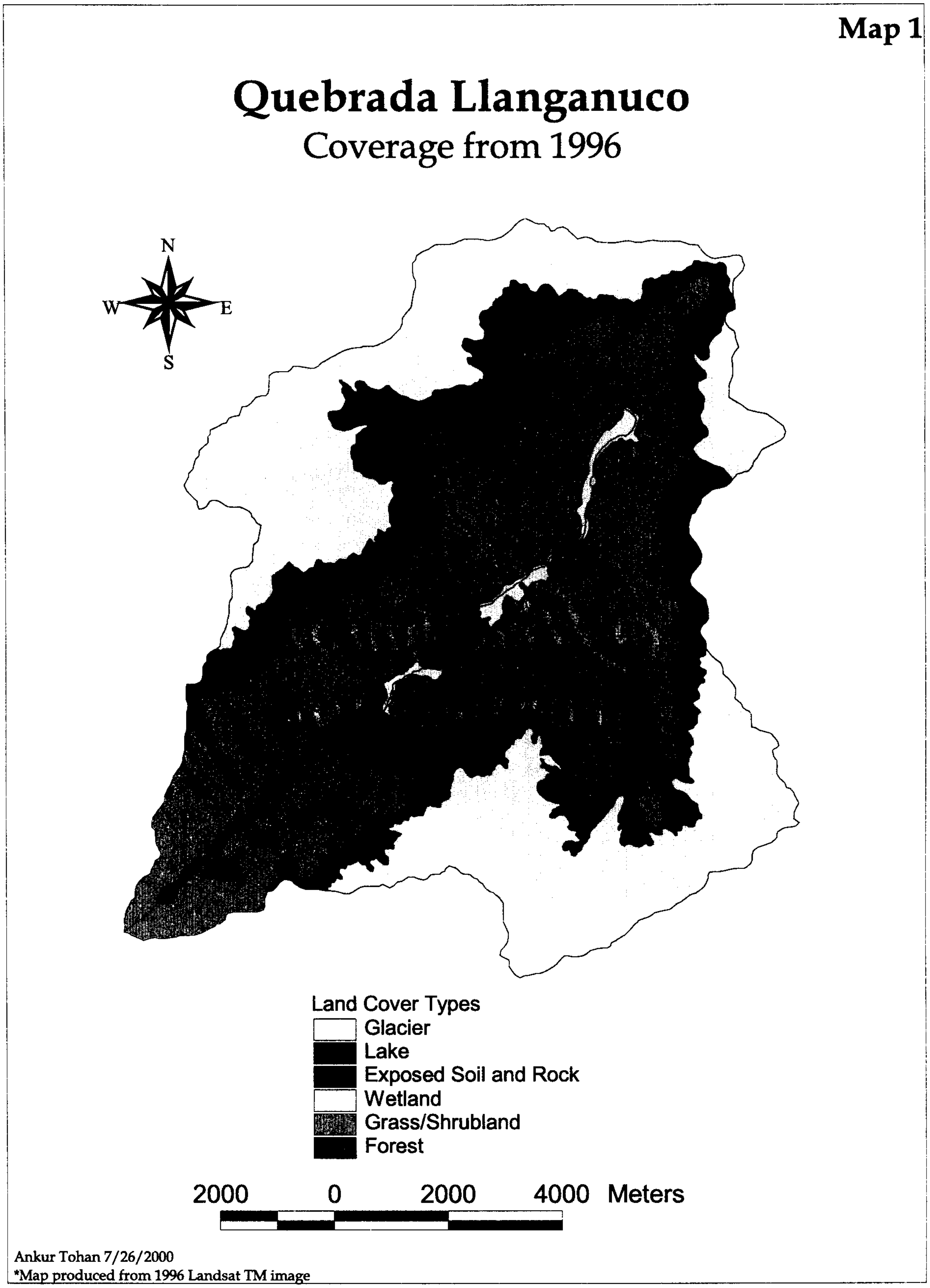
Scale

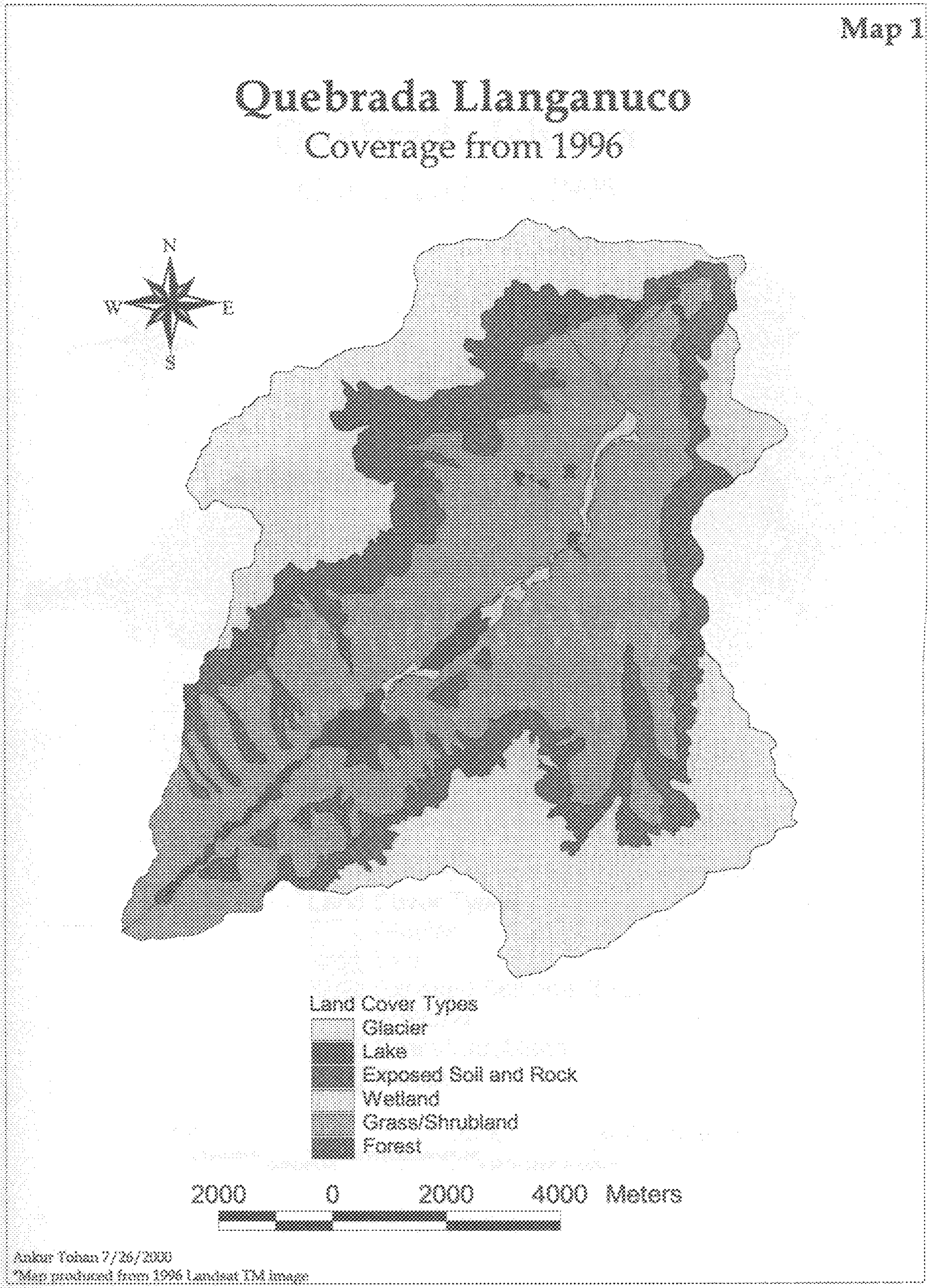
Meters

Ankur Tobias 3/9/2000

Appendix – 2

Maps


Map 1
Quebrada Llanganuco
Coverage from 1996
N
W
E
S
Land Cover Types
Glacier
Lake
Exposed Soil and Rock
Wetland
Grass/Shrubland
Forest
2000 0 2000 4000 Meters
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image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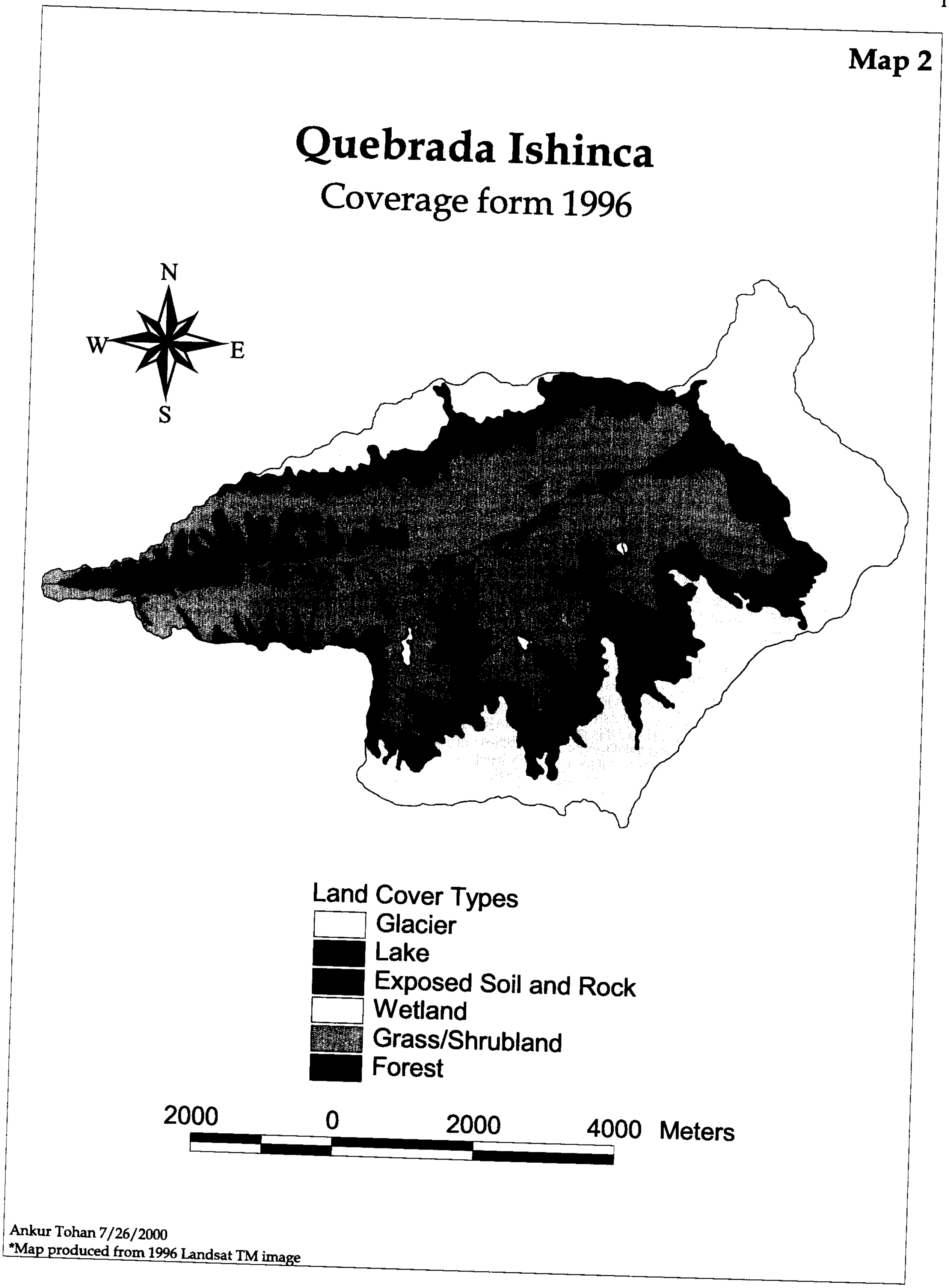
Map 2
Quebrada Ishinca
Coverage form 1996
N
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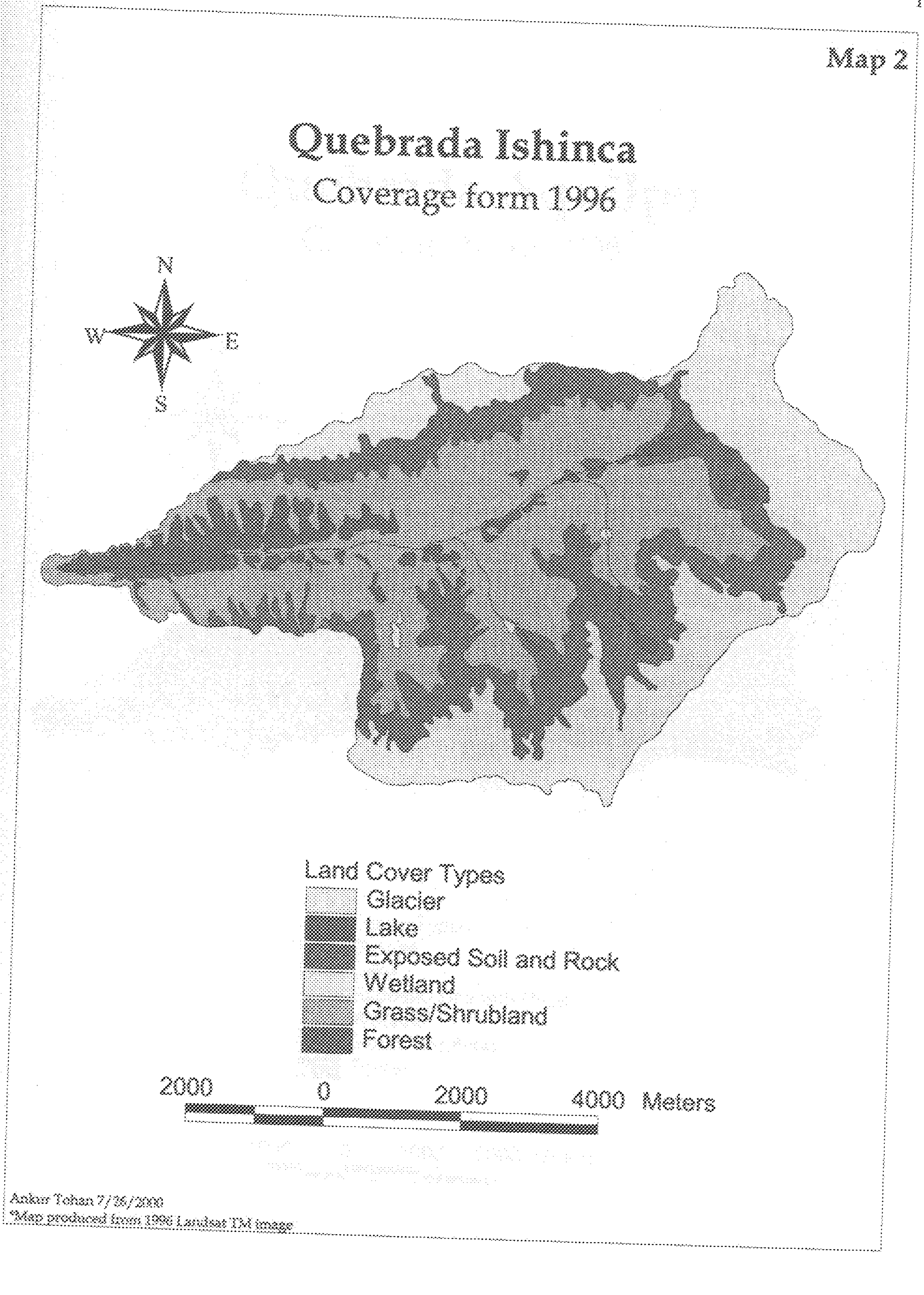
Land Cover Types
Glacier
Lake
Exposed Soil and Rock
Wetland
Grass/Shrubland
Forest
2000
0
2000
4000
Meters
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image


Map 2
Quebrada Ishinca
Coverage form 1996
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Land Cover Types
Glacier
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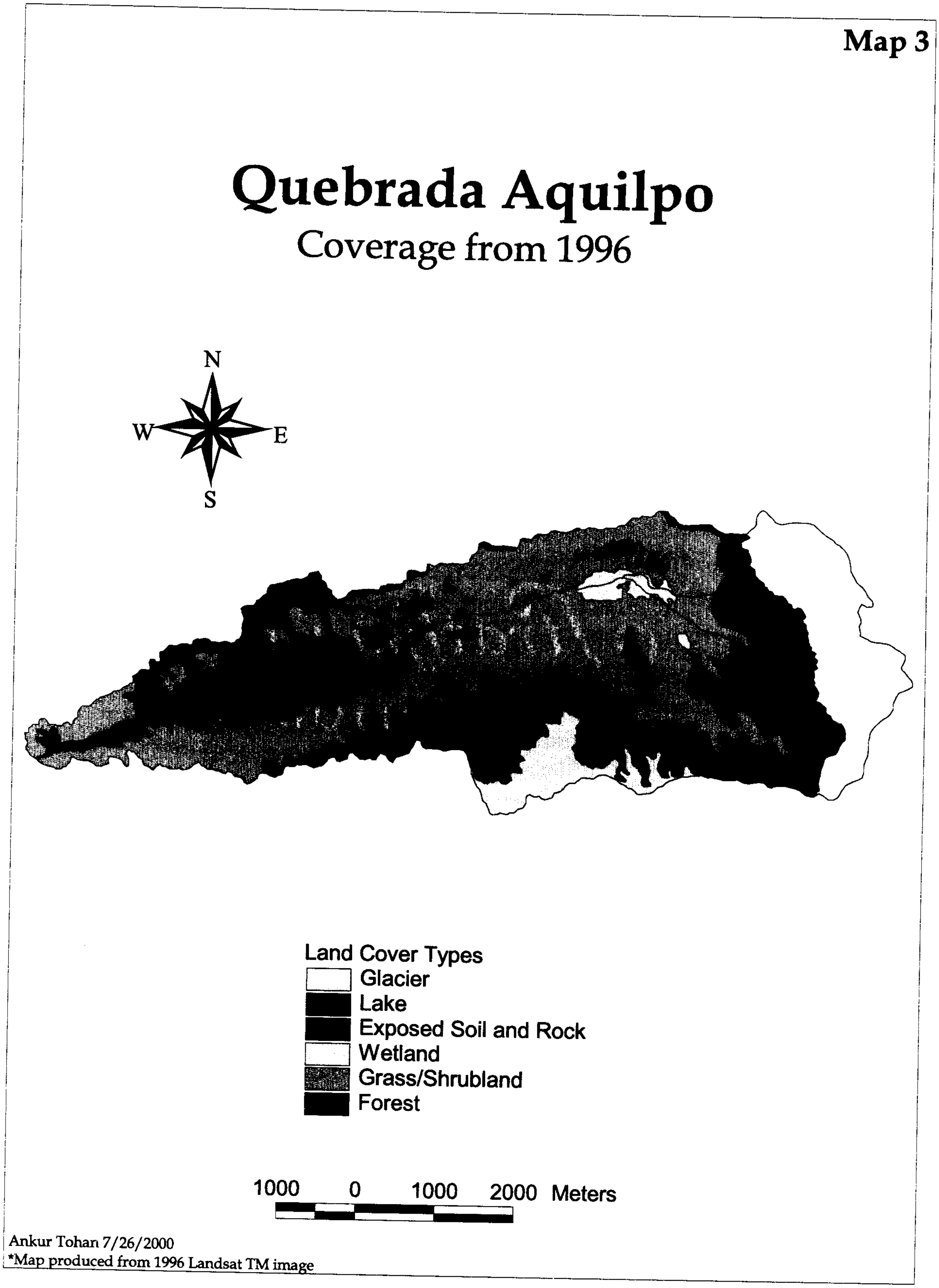
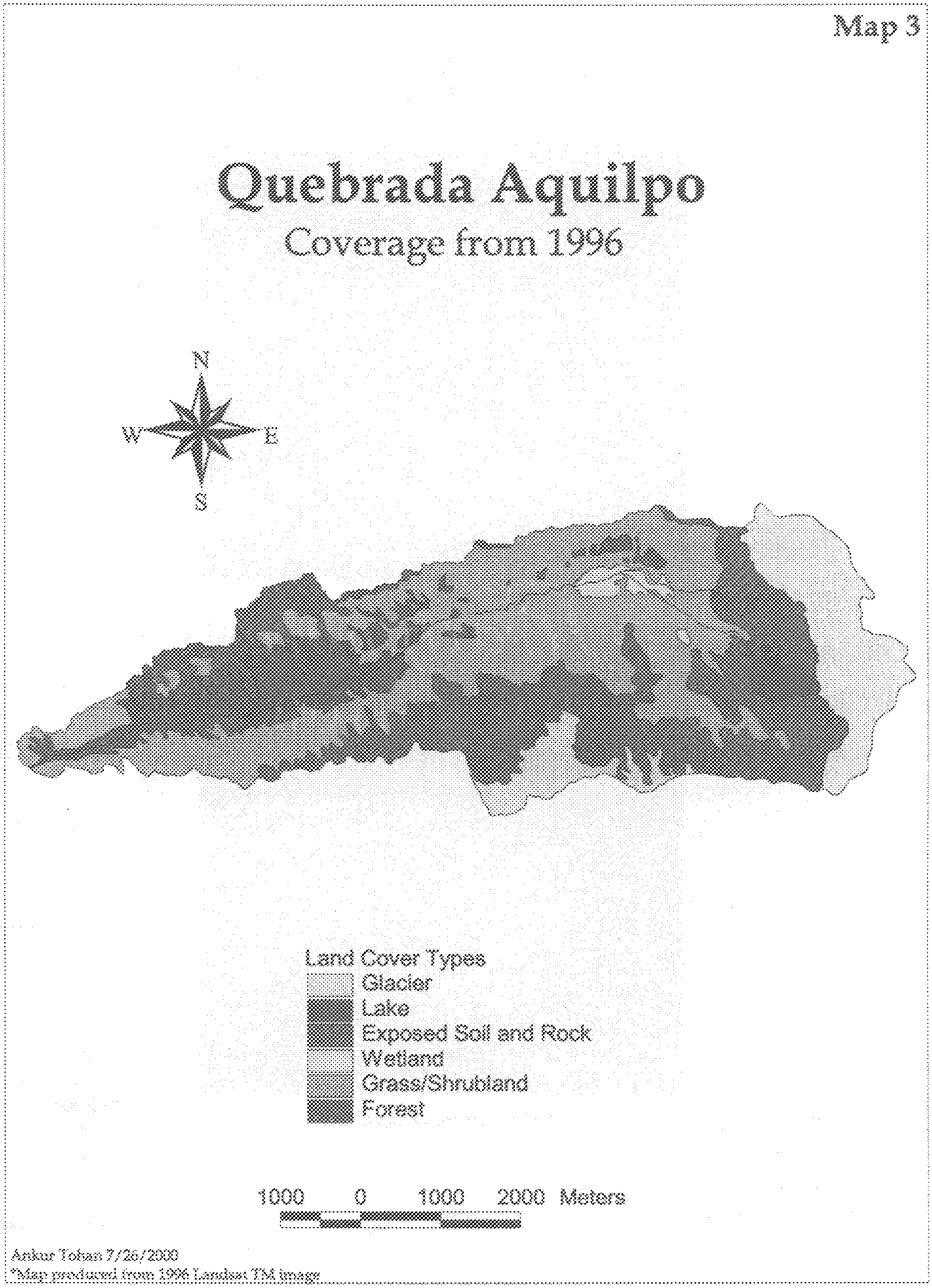
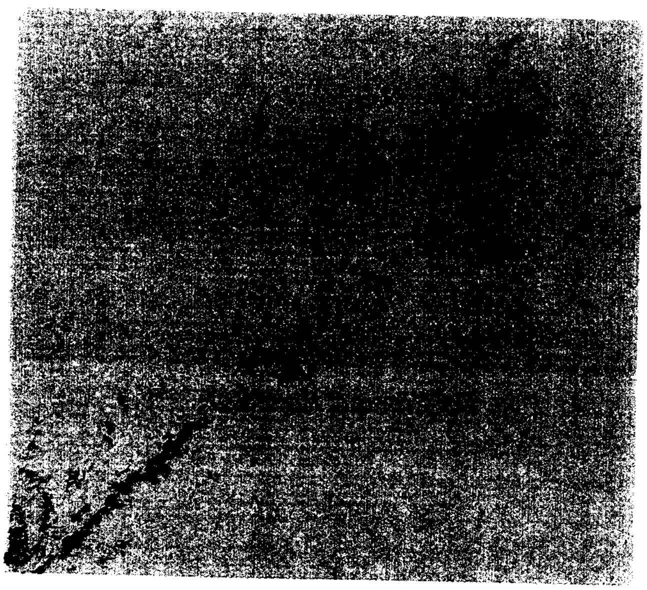

Map 3
Quebrada Aquilpo
Coverage from 1996
N
W
E
S
Land Cover Types
Glacier
Lake
Exposed Soil and Rock
Wetland
Grass/Shrubland
Forest
1000 0 1000 2000 Meters
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image


Map 3
Quebrada Aquilpo
Coverage from 1996
N
W
E
S
Land Cover Types
Glacier
Lake
Exposed Soil and Rock
Wetland
Grass/Shrubland
Forest
1000 0 1000 2000 Meters
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image

Pattern of Polylepis Forest Cover Change
Quebrada Llanganuco

Map 4

Quebrada Llanganuco 1996



Quebrada Llanganuco 1986

Legend

Land Cover Types

All Land Cover Types

Polylepis Forest

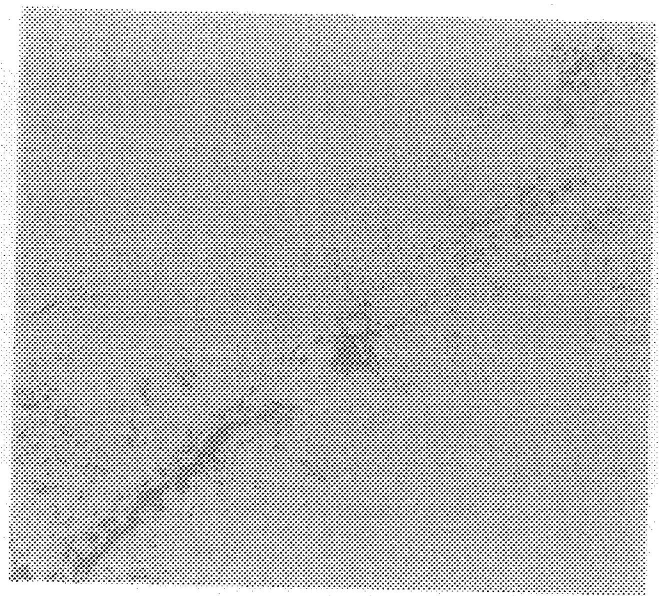
Scale

2000 0 Meters

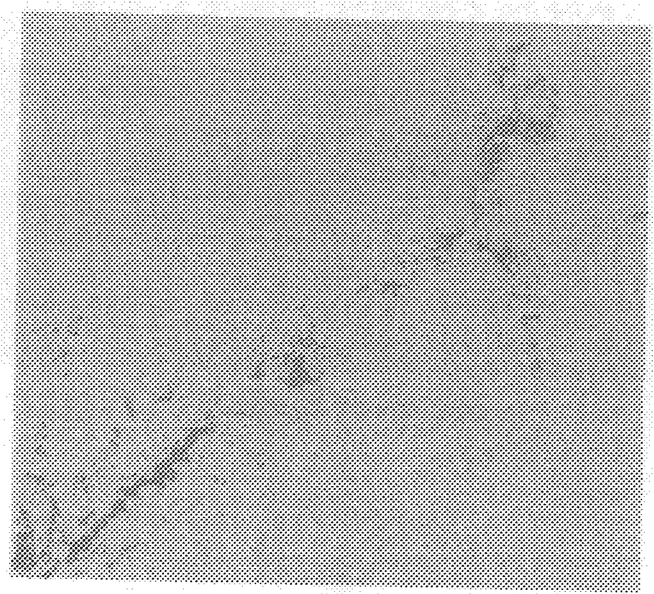
Ankur Tohan 5/7/2000

Pattern of Polylepis Forest Cover Change
Quebrada Llanganuco

Map 4



Quebrada Llanganuco 1996



Quebrada Llanganuco 1986

Scale

Meters

0

Legend

Land Cover Types

All Land Cover Types

Polylepis Forest

Pattern of Polylepis Forest Cover Change
Quebrada Ishinca

Map 5

Quebrada Ishinca 1996

Quebrada Ishinca 1986

Legend

Land Cover Types

All Land Cover Types

Polylepis Forest

Scale

1000 0 Meters

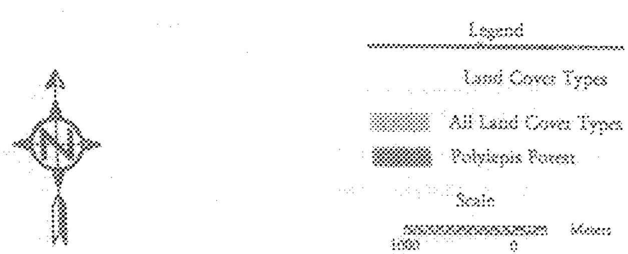
Ankur Tohan 5/10/2000

Pattern of Polylepis Forest Cover Change
Quebrada Ishinca

Map 5

Quebrada Ishinca 1996

Quebrada Ishinca 1986

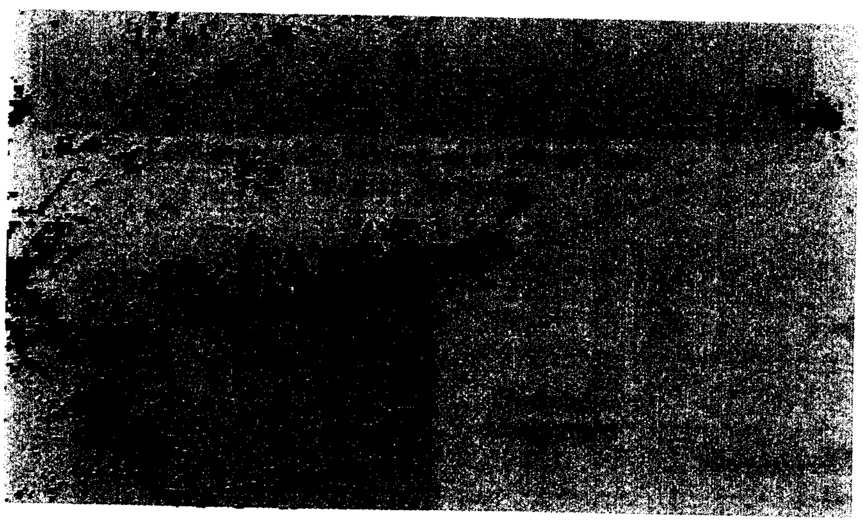


Ankur Yohan 5/10/2000

Pattern of Polylepis Forest Cover Change
Quebrada Aquilpo

Map 6

Quebrada Aquilpo 1996



Quebrada Aquilpo 1986

Legend

Land Cover Types

All land Cover Types

Polylepis Forest

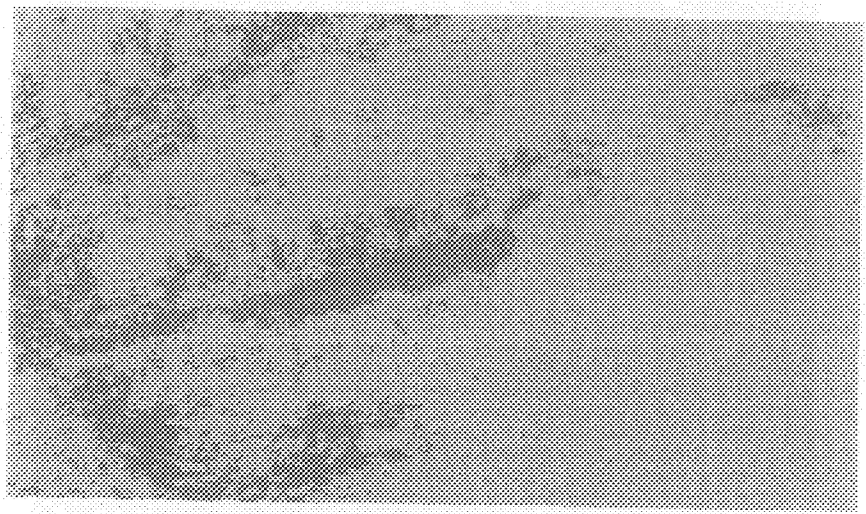
Scale

1000 0 Meters

Ankur Tohan 5/4/2000

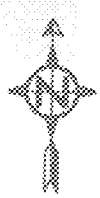
Pattern of Polylepis Forest Cover Change
Quebrada Aquilpo

Map 6



Quebrada Aquilpo 1996

Quebrada Aquilpo 1986



Legend

Land Cover Types

All land Cover Types

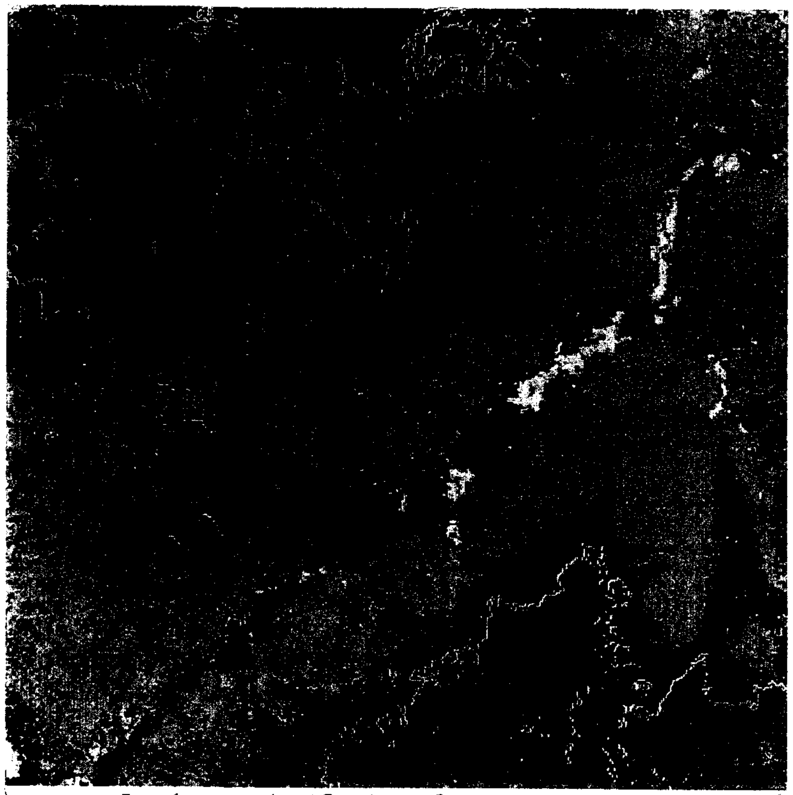
Polylepis Forest

Scale

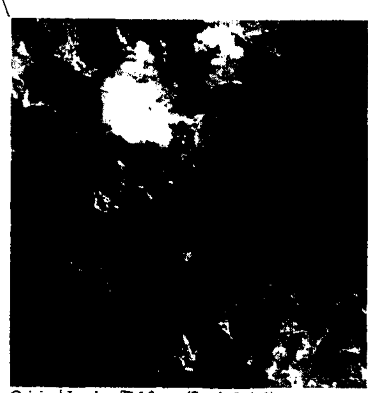
1000 0 Meters

Huascarán Biosphere Reserve
Quebrada Llanganuco

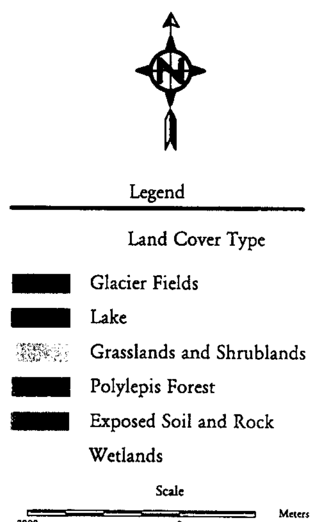
Map 7



Land-cover classification of a 1996 six band Landsat TM image.



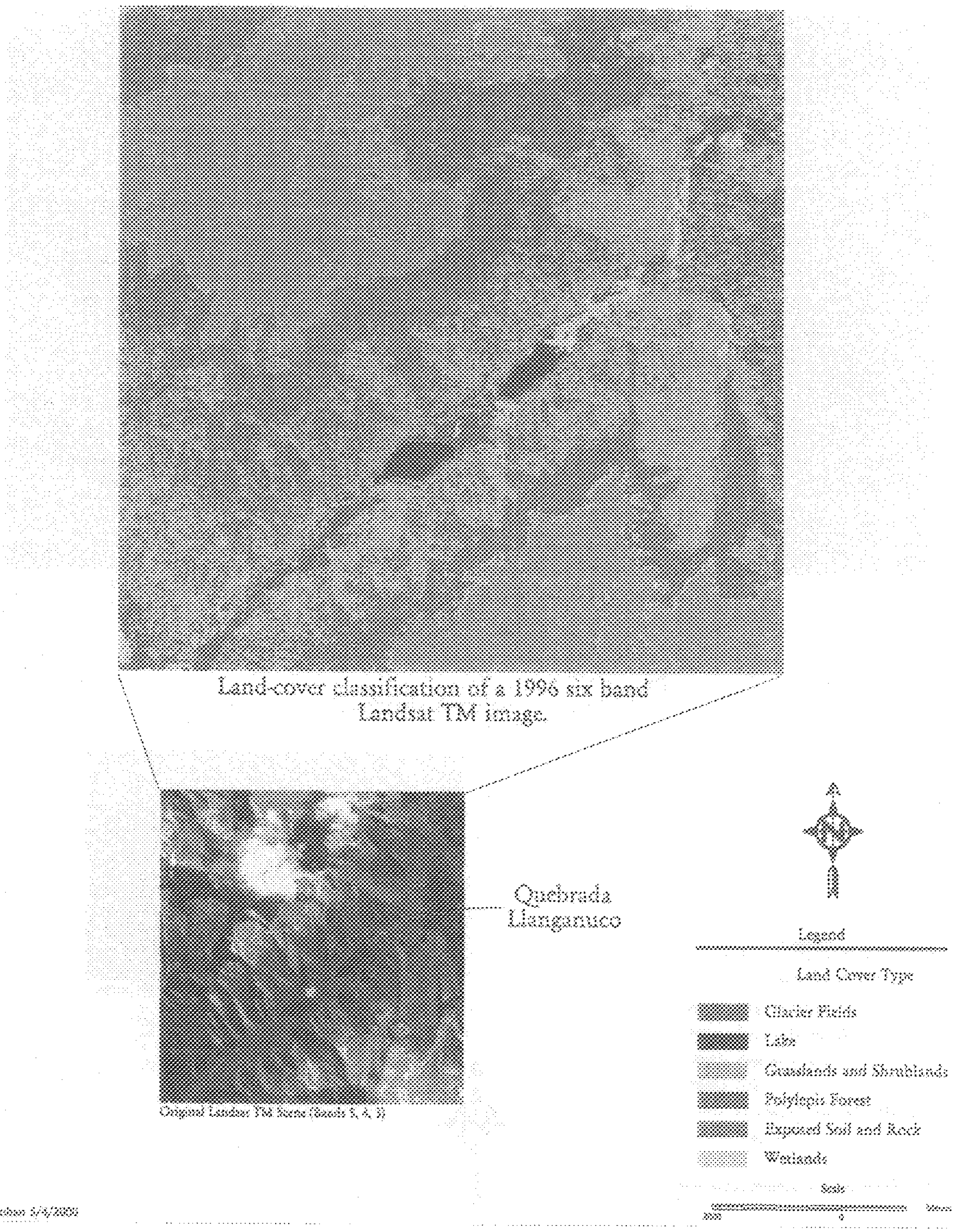
Original Landsat TM Scene (Bands 5, 4, 3)



Ankur Tohan 5/4/2000

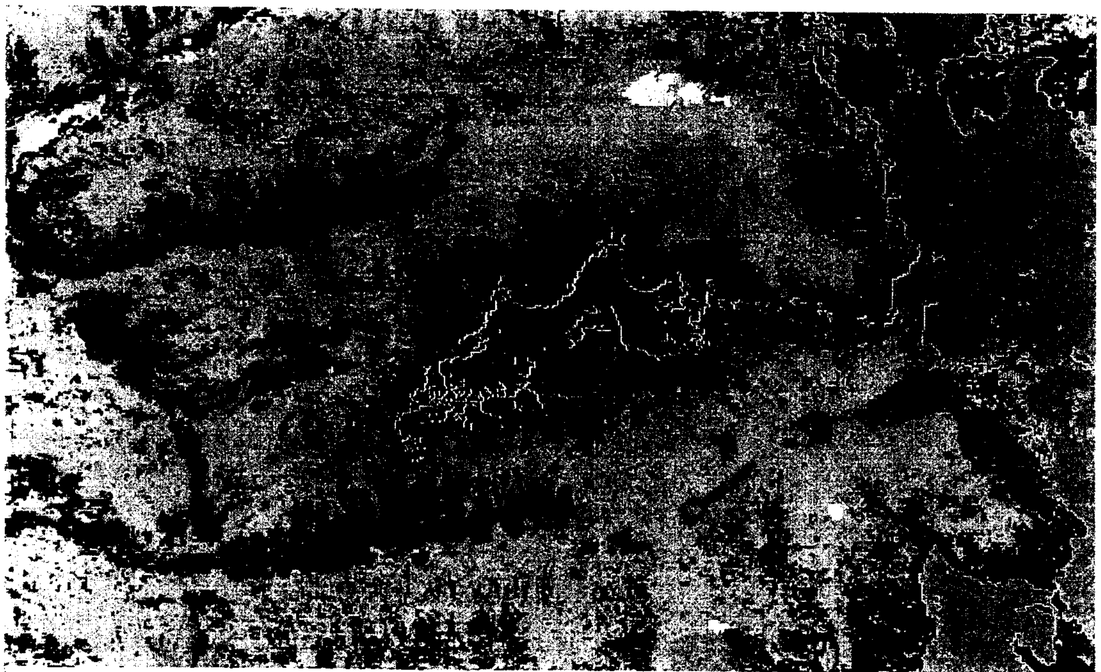
Huascarán Biosphere Reserve
Quebrada Llanganuco

Map 7

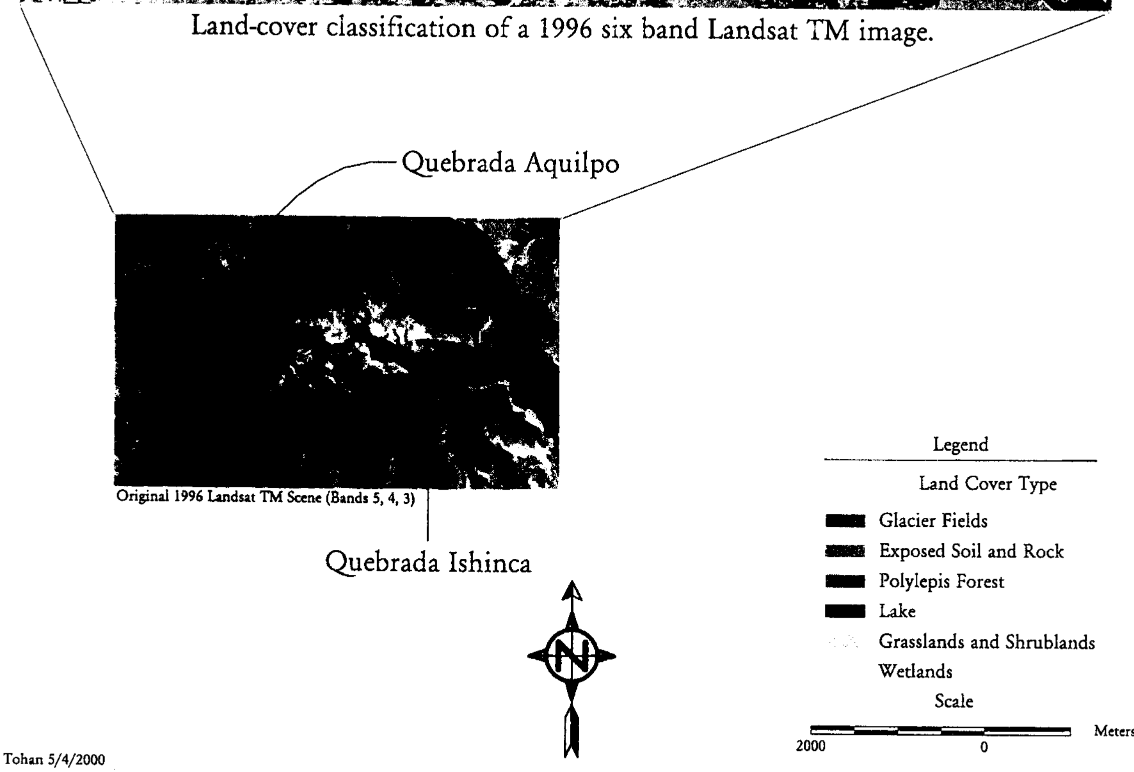


Huascarán Biosphere Reserve
Quebrada Aquilpo and Quebrada Ishinca

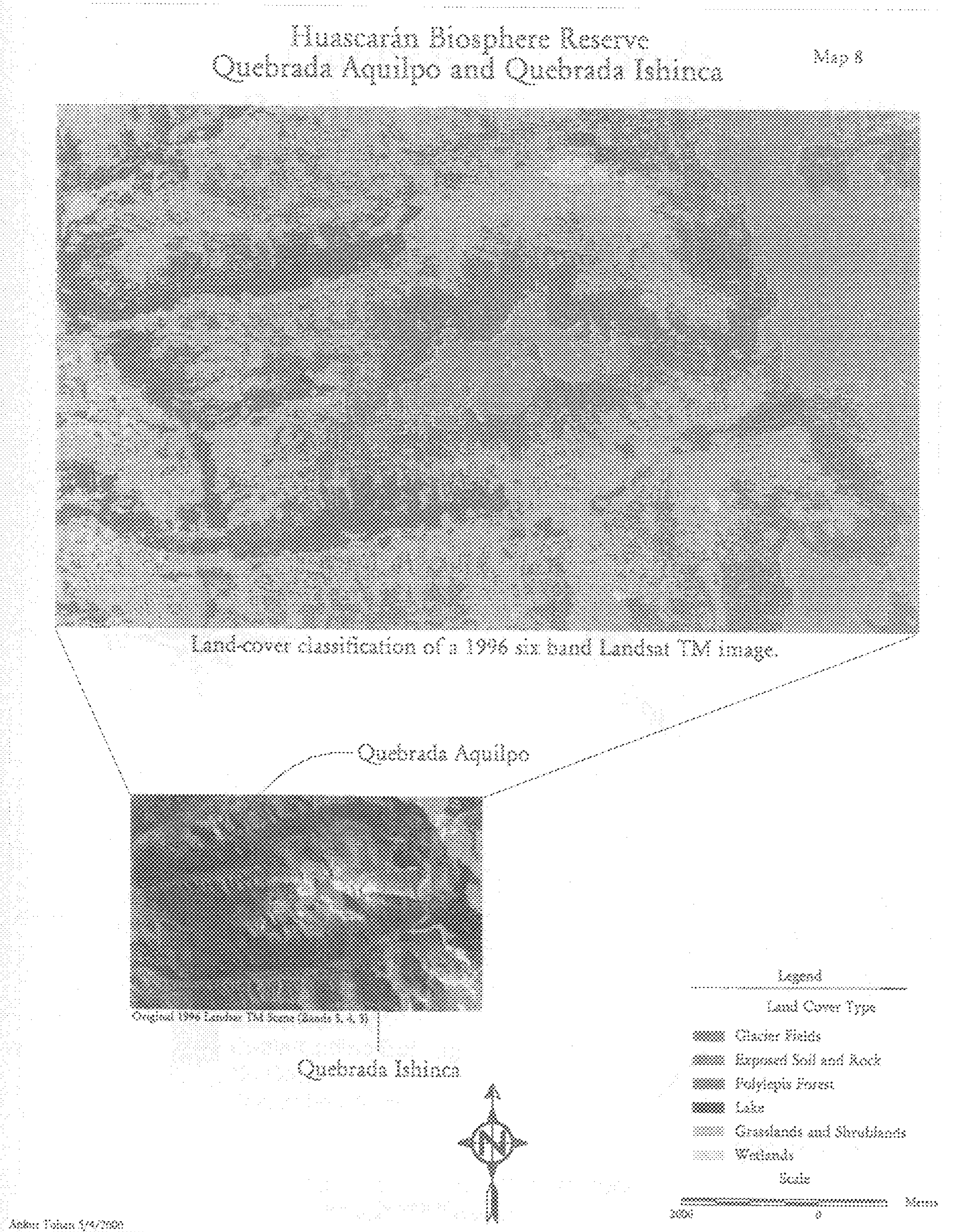
Map 8



Land-cover classification of a 1996 six band Landsat TM image.

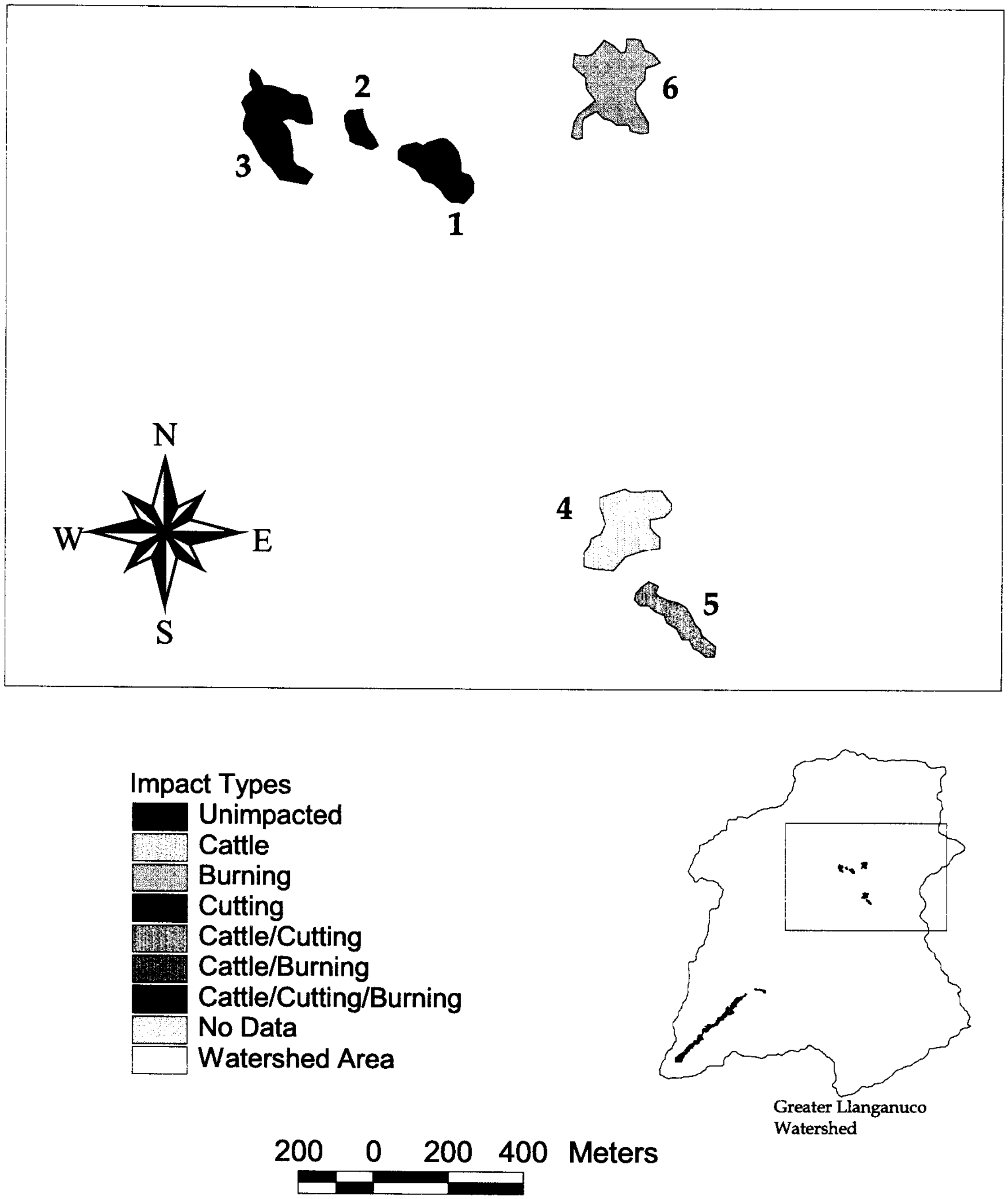


Ankur Tohan 5/4/2000

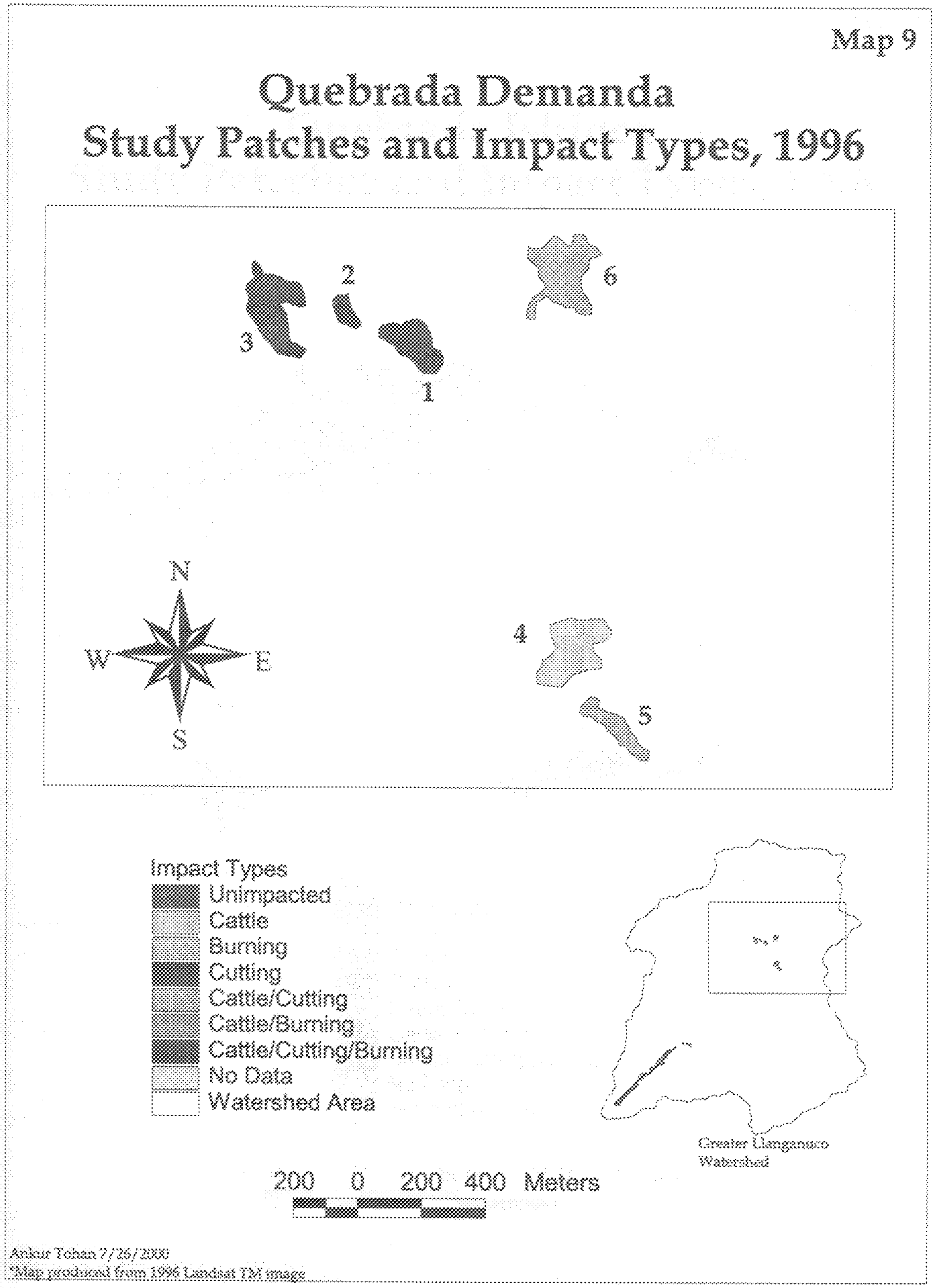

Huascarán Biosphere Reserve
Quebrada Aquilpo and Quebrada Ishinca
Map 8
Land-cover classification of a 1996 six band Landsat TM image.
Quebrada Aquilpo
Original 1996 Landsat TM Scene (Bands 5, 4, 3)
Quebrada Ishinca
N
Legend
Land Cover Type
Glacier Fields
Exposed Soil and Rock
Polylepis Forest
Lake
Grasslands and Shrublands
Wetlands
Scale
0

Map 9

Quebrada Demanda
Study Patches and Impact Types, 1996

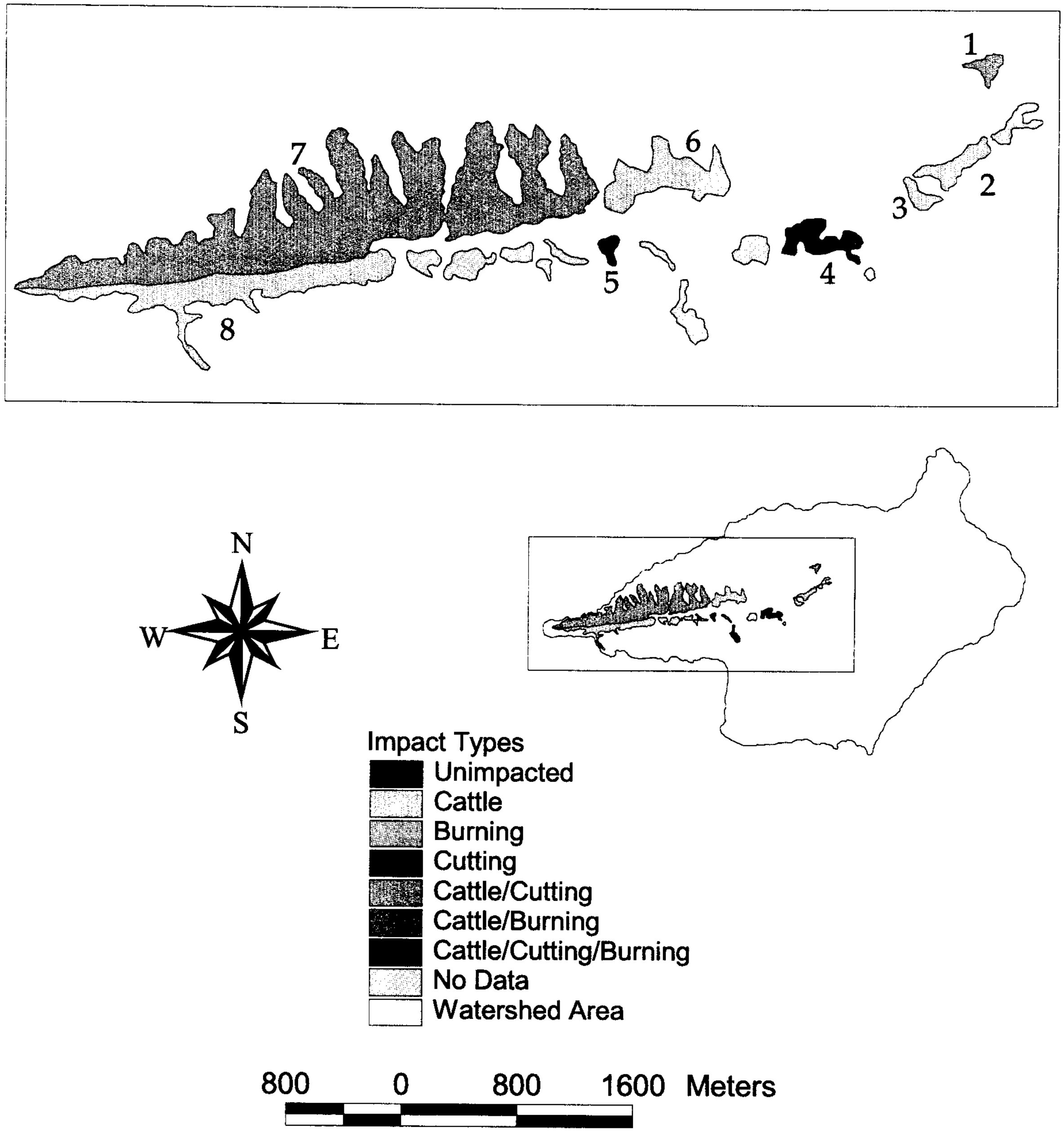


Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image


Map 9
Quebrada Demanda
Study Patches and Impact Types, 1996
2
6
3
1
N
W
E
S
4
5
Impact Types
Unimpacted
Cattle
Burning
Cutting
Cattle/Cutting
Cattle/Burning
Cattle/Cutting/Burning
No Data
Watershed Area
Greater Llanganuco
Watershed
200 0 200 400 Meters
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image

Map 10

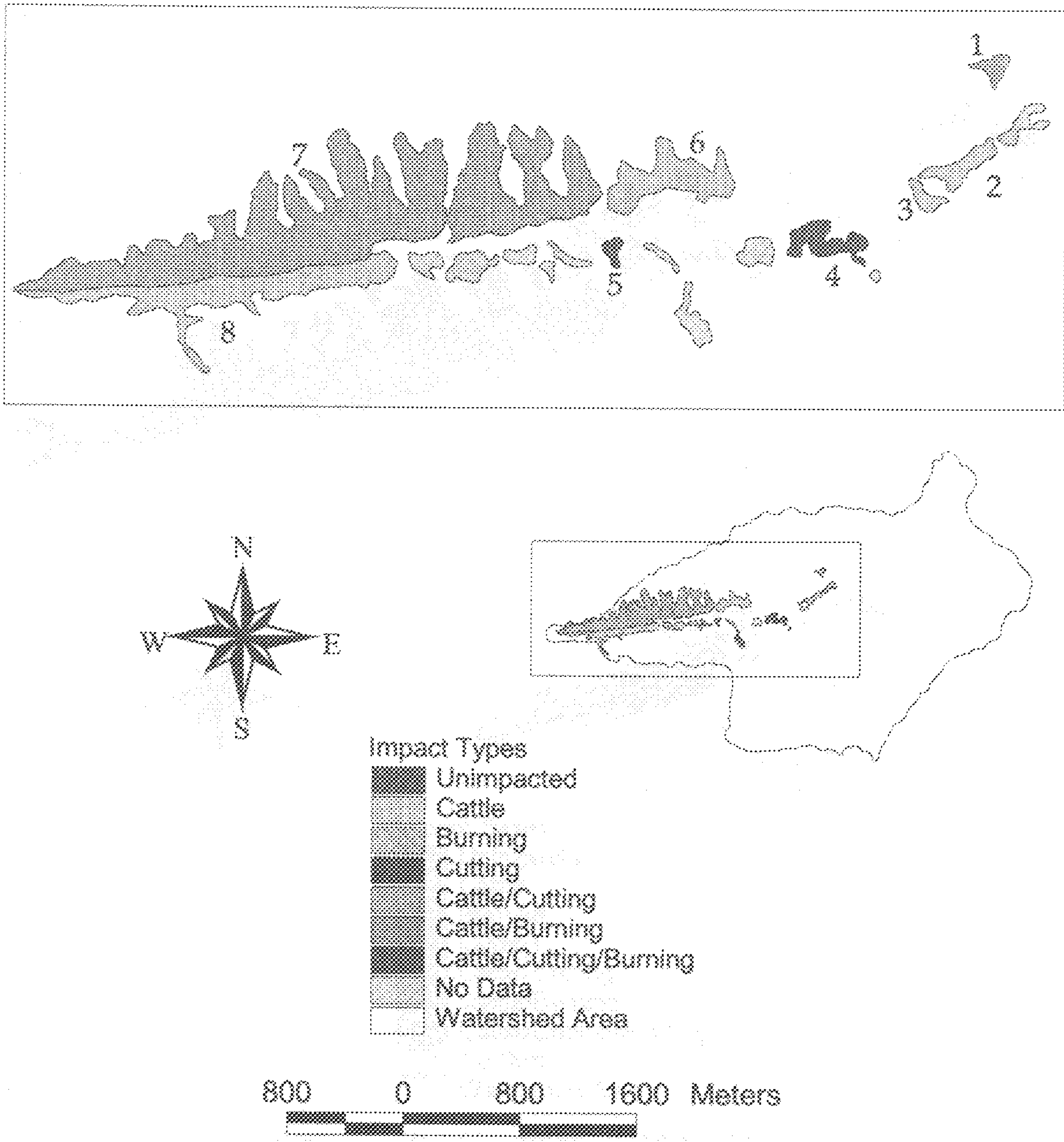
Quebrada Ishinca
Study Pataches and Impact Types, 1996



Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image

Map 10

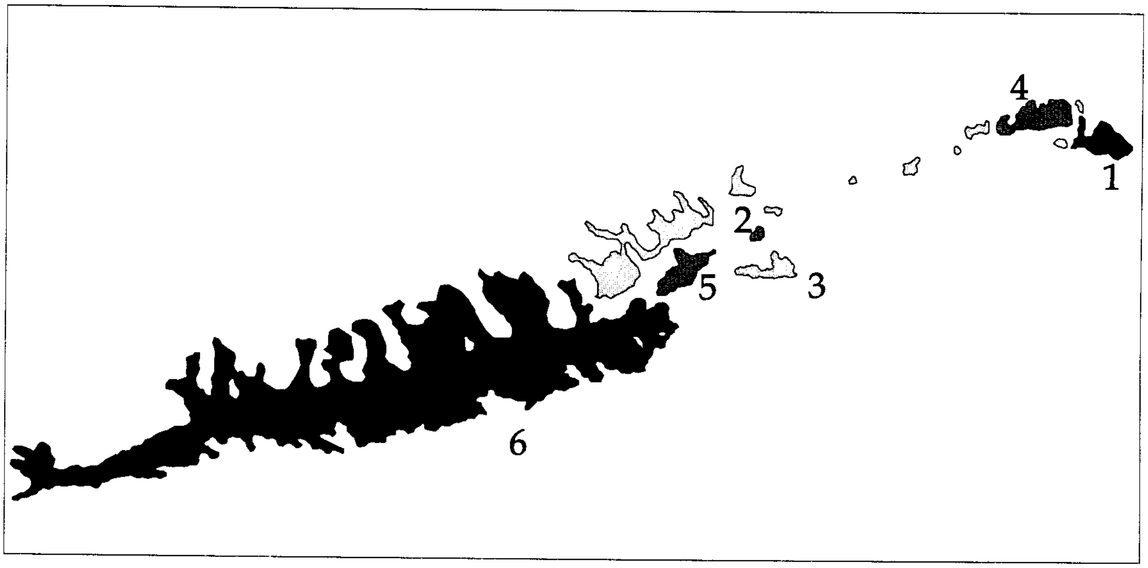
Quebrada Ishinca
Study Pataches and Impact Types, 1996

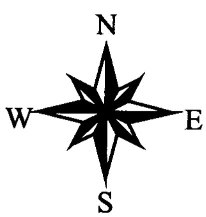


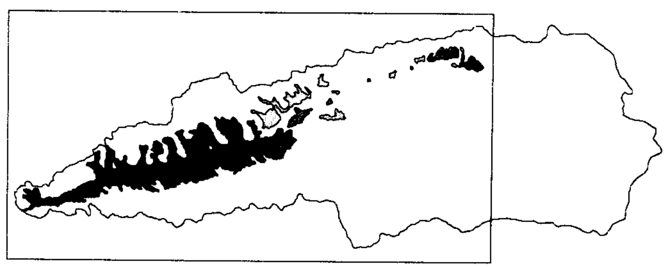
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image

Map 11

Quebrada Aquilpo
Study Patches and Impact Types, 1996





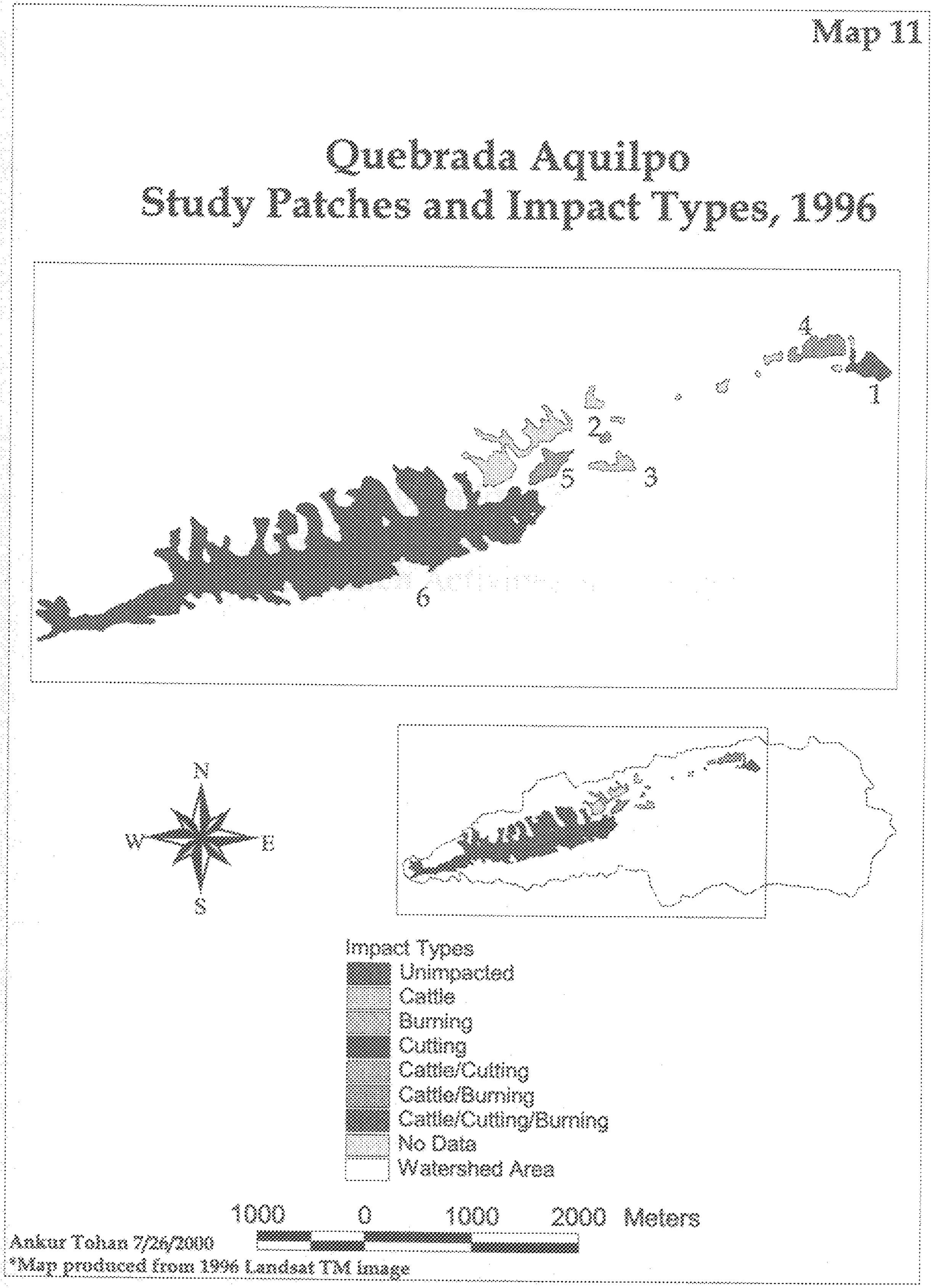


Impact Types
- Unimpacted
- Cattle
- Burning
- Cutting
- Cattle/Cutting
- Cattle/Burning
- Cattle/Cutting/Burning
- No Data
- Watershed Area

1000 0 1000 2000 Meters

Ankur Tohan 7/26/2000

*Map produced from 1996 Landsat TM image


Map 11
Quebrada Aquilpo
Study Patches and Impact Types, 1996
1
2
3
4
5
6
N
W
E
S
Impact Types
Unimpacted
Cattle
Burning
Cutting
Cattle/Cutting
Cattle/Burning
Cattle/Cutting/Burning
No Data
Watershed Area
1000 0 1000 2000 Meters
Ankur Tohan 7/26/2000
*Map produced from 1996 Landsat TM image

Appendix – 3

Field Research Activities and Design

Field Research Activities and design:

1) Determine with The Mountain Institute (TMI)(the main conservation NGO working with the HBR) and Reserve staff which valleys to evaluate. Each valley will have a different degree of "degradation". Selected sites are Quebrada Demanda (degraded) Quebrada Ishinca (impacted), and Quebrada Aquilpo (pristine).
2) Valleys were chosen to represent forests that are under pressure from a variety of impacts; cutting, burning, and grazing. In addition an Impact Severity variable was developed (see Appendix 7: *Interval and Descriptive Variables*)
3) Conducted forest structure assessment that provides data on the basal area, average DBH, number of seedlings, number of saplings, percentage of canopy cover, and relative dominance of tree species. These metrics were assessed within study plots (3/patch) representing a range in altitude, aspect, slope, and livestock use variable (see Appendix 5: *Forest Stand Structure: Field Methodology*).
4) Interviews with local *campesinos* within villages located at the mouth of each of the study valleys to obtain numbers of livestock grazed in study area. In addition, data was collected to reflect forest use by species (i.e., are villagers using *Polylepis* or *Eucalyptus* for fuel/timber - if *Polylepis*, then which patches within study area; if *Eucalyptus* how much per family per year). Finally, interviews allowed me to determine if *campesinos* are engaged in burning grasslands around forest patches.
5) Data collected on the structure of *Polylepis* forest supports the time series spatial analysis of forest cover change in a GIS from 1962 to 1996 (see Appendix 4: *Methodology for Spatial Analysis*). Fieldwork completed to facilitate this analysis

required collecting ground control points within valley study area and within villages. In addition, training sites of forest cover (*Polylepis* and *Eucalyptus*), shrublands, grasslands, agricultural plots, lakes, and villages were identified in order to determine their spectral signature for classification of remotely sensed digital images. Classification of remotely sensed imagery allowed for land-cover maps to be produced for the HBR and TMI.

6) Collection of planning documentation for the national park and socio-economic data for the region. Interview with the Reserve and TMI staff were completed to obtain information on the perceived threats to *Polylepis* patches within the park, and policy currently in place to address their protection.

Appendix – 4

Methodology for Spatial Change Analysis

Methodology for Spatial Change Analysis

Conceptualization

The primary objective of the project with regard to spatial analysis is to determine whether there has been a change in the spatial distribution, size, and shape of *Polylepis spp.* forest patches in three valleys (Quebrada Ishinca, Quebrada Aquilpo, and Quebrada Llanganuco) that are the study sites within the Huascarán Biosphere Reserve between 1962 and 1996. The change in spatial distribution of forest patches was detected by comparing aerial photographs from 1962 (1:50,000) with Landsat TM 30m images from 1986 and 1996. In addition to qualitative visual interpretation of the data, these three layers were overlaid in a GIS to detect changes in forest patch distribution. Changes in forest patch size were calculated by comparing the area of twenty study patches through each of the three time periods. Change in the area of forest cover at the valley level was detected by comparing the total area of forest in each of the three valleys during each of the three time periods. Change in forest patch shape was detected by comparing the area weighted mean fractal dimension and the corrected perimeter ratio for each of the patches in each time period. Fractal dimension is a measure of the complexity – 'edginess' – of patch perimeter, and perimeter/area ratio is a measure of shape complexity (Baker and Cai 1992). These indices will also be applied at the valley scale to determine landscape level changes in forest cover.

The primary data layers for the first part of the project are 1962 aerial photographs (1:50,000) obtained from the Instituto Geografíco del Peru; 1986 and 1996 Landsat TM (30m) un-rectified images obtained from EROS/USGS; 1987 Landsat TM 30m rectified image obtained from Berrik Mining; 1:25,000 base maps of the study area obtained from the Instituto Geografíco del Peru; and ground truth and training areas for classification.

The secondary goal of the project is to determine whether detected change can be correlated to ecological data from 1999 on the structural characteristics of forest patches. These ecological variables include diameter at breast height, basal area, relative density, relative dominance, number of trees, importance value ranking, and number of seedlings and saplings. Patches are also characterized by slope, aspect, and elevation. Data was collected for 64 plots in 20 forest patches during fieldwork in the summer of 1999.

Implementation

Data Layer Preparation

The first implementation step is preparation of the three primary data layers (1962 aerial photographs, 1986 and 1996 Satellite TM Imagery) for analysis.

1962 Aerial Photographs

Aerial photographs need to be ortho-rectified in order to be able to use them for change change analysis relative to Landsat TM imagery. The protocol for preparation of ortho-rectified photographs is as follows. Step one is to create elevation contour maps in vector format for each of the three study valleys using base maps of the area in Arc/Info. The elevation contour maps are then used to build a Digital Elevation Model (DEM), also in Arc/Info. Finally, the DEM is combined with the rectified Landsat TM 1987 image in OrthoMapper to perform photo ortho-rectification. Once the ortho-rectification is complete, one coverage for each valley is digitized to create a forest/non-forest maps.

Landsat TM Imagery 1986 and 1996

The first step in preparing the Landsat TM imagery is geo-rectification (similar to ortho-rectification in principle). There is one image from 1987, which is geo-rectified in bands 1,3, and 7. This image will be used to geo-rectify the Landsat TM 1986 and 1996 seven band images. The protocol is as follows. Using Erdas-Imagine, the non-rectified 7 band images from 1986 and 1996 images are geo-rectified to the 3 band 1987 image. Rectification employs a first order polynomial transformation for geometric correction and a bilinear transformation for radio-metric correction. Following rectification the three study sites are then subsetted out of the larger image in bands 1,2,3,4,5, and 7. Because band 6 is a thermal band, standard operational procedure for satellite image classification does not use band 6.

The second step involves standardized radiometric normalization of the 1986 to the 1996 images. Normalization, a standard technique used to identify land cover change over time in remote sensing applications, reduces the effect of differing atmospheric and other non-surface effects across time which may result in the false interpretation of land cover change (Heo and FitzHugh 2000). The procedure is as follows: in each study valley pixels are selected that have the same location in both scenes, and that are considered to be unchanged over time with respect to spectral signature. 30 points are selected for each scene. Spectral values for 1986 are regressed linearly onto spectral values from 1996. Regression is completed on a point by point and band by band basis. Each point is assessed as to its R-squared value. Points with a low R-squared (> 0.95) are thrown out while those with higher values are attained. Once an R-squared of .95 or higher is achieved with a set of common points, the 1986 image is regressed to the 1996 image. Once the 1986 image is normalized to 1996, the spectral signatures of land cover classes used to classify the 1996 image can be used to classify the 1986 image. Changes in classification using the same set of spectral signatures allows for change detection of land cover types.

Third, as an alternative method to the standardized radiometric normalization of images to one another, single image band ratio normalization is completed (Jenson 1996; Lillesand and Kiefer 1994). This normalization process is standard procedure when atmospheric and other non-surface effects must be mitigated against in order to perform effective land cover classification. In the case of mountainous areas, shadows cast by clouds, topographic relief, and atmospheric disturbance can be lessened. The normalization procedure is as follows: utilizing a normalized difference ratio algorithm all 6 bands of spectral data for each scene are normalized in a pair-wise manner (e.g., band 1 and 2, band 2 and 3… band 6 and 1). Band ratio normalization is completed for each of the three valleys followed by land cover classification using distinct spectral signatures for each site.

Classification of each study site is completed using an unsupervised classification method, the ISODATA algorithm (Jenson 1996; Lillesand and Kiefer 1994), for 600 and 350 classes. The 600 class image is used to isolate the spectral signatures for *Polylepis* forest. Once the forest signatures have been identified the remaining spectral signatures are set to zero. These signatures are then re-applied to the original image using a Maximum Likelihood Classifier to produce a forest and non-forest classification. The same procedure is followed for each image using 350 classes. However, the final classification results here are used to create a coverage of 6 land-types by defining land-cover types to specific spectral signatures. Land-cover types used were glacier fields, exposed soils and rock, grassland and shrubland, wetlands, lakes, *Polylepis* forest.

In addition to the use of automated classification of imagery, visual interpretation of each study site is completed. This is accomplished through a process of on-screen digitization of land-cover types. For each of the three study sites a vector-coverage is created for forest/non-forest and for the 6 classes (glacier fields, exposed soils and rock, grassland and shrubland, wetlands, lakes, *Polylepis* forest) from the original 1986 and 1996 imagery.

Change Analysis

Once the data layers are prepared, the second step is to analyze change between the three time periods. Change analysis takes place in two steps. First, each of the data layers is overlaid in Arc/Info to visually identify change. Change in spatial distribution is determined by overlaying the three coverages in a GIS environment and qualitatively analyzing changes in patch location, shape, and size. A coverage is created for patches that have changed and those that have not in each valley. Second, change in patch size and patch shape is calculated using the Patch Analyst extension of Arc/View. Patch size is measured by patch area. Patch shape is calculated using the corrected perimeter/area ratio and area weighted mean fractal dimension.

Corrected perimeter/area ratio[1] varies from a value of 0.0 for a circle to infinity for an infinitely long and narrow shape (Baker and Cai, 1992). An increase in the corrected perimeter/area ratio over time indicates an increase in patch edge. Area weighted mean

[1] Corrected Perimeter/Area ratio = $(.282* \text{perimeter})/(\text{area})^{1/2}$

fractal dimension[2] measures complexity of the patch borders. Mean fractal dimension approaches one for shapes with simple perimeters, and two when shapes are more complex (Elkie *et. al.* 1999). To track change between the three time periods, each of the twenty study patches is assigned an ID in Arc/Info, and patch size and shape values are quantitatively compared over time. The change analysis will combine both landscape scale and patch level indices to generate evidence of spatial change

Correlations of Change with Ecological Data

Finally, evidence of spatial change is compared to the ecological data. Average DBH, relative density, relative dominance, number of trees, importance value ranking, number of seedlings and saplings, and patch slope, aspect and elevation will be calculated from 1999 field data to generate data on stand structure. We will then determine whether there is a relationship between evidence of ecological impact in 1999 and the amount of spatial change in a patch over the three time periods.

[2] Fractal Dimension (d) = (2 *s) where s is the slope of the regression of the log of the patch perimeter versus the log of the patch area.

Appendix – 5

Forest Stand Structure: Field Methodology

Forest Stand Structure: Field Methodology

Forest patches within each study site were pre-selected before entering the field. Through utilizing elevation maps of the study site in conjunction with aerial photography patches were selected throughout the entire length of a valley. In addition to keeping the number of patches studied within each valley similar several other criteria were employed in patch selection to capture the variation in patch structure throughout the study site. In order to capture this variability within each study site patches were selected from the head to the mouth of the valley, from their upper to lower elevation limit, at varying degrees of slope and aspect, proximity to grassland and shrubland, and at varying degrees of accessibility from trails and roadways. Once pre-selected patches were studied in the field.

Field study of patches involved the selection of study plots within each patch. These plots were selected in order to capture as best as possible the variation of within patch characteristics. As such plots were selected from the upper edge (upland), lower edge (lowland), and interior (center) of each patch. In general only 3 plots per patch were completed, however, for larger patches a greater number of plots were completed in order to better account for its structure.

Plot selection was randomized in the following manner. At the upper edge, lower edge a number from 1 – 20 was selected at random. This number would represent the number of minutes to walk along an edge to a plot. In order to avoid bias in terms of number of minutes walked (i.e. picking lower numbers means walking for fewer minutes), after the number was selected a coin was flipped to determine if that number was added to zero or subtracted from 20 (e.g., selecting 18 could mean walking for 18 minutes or walking for 2 minutes). Interior plots were selected in the same manner, however, walking to a plot would begin from within at least 10 meters of the edge of the patch in an area that is considered to be about the middle of the patch.

Once a plot was located a 10 x 10 m square boundary was created using measuring tape, flags, and compass coordinates. This 10 x 10 m plot was then subdivided into smaller subplots or quads of 5 x 5 meters. Each quad was labeled 1 through 4 starting with the lower (down slope) up-valley (corner of plot that was closer to head of valley than mouth) quad. Once the elevation, slope, aspect, and species of *Polylepis* of the plot was recorded for following data within each quad was collected:

1) # of live *Polylepis* and basal area for each tree (a tree was defined as having a DBH of greater than or equal to 4 cm.
2) # of live *Gynoxis* trees and the basal area of each.
3) # of live *Polylepis* and live *Gynoxis* trees.
4) # of dead *Polylepis* and live *Gynoxis* trees.
5) # of *Polylepis* and *Gynoxis* seedlings and saplings.
6) Height, length, and canopy of each *Polylepis* and *Gynoxis* tree (note that on very steep slopes the length of a tree does not necessarily equal the height that tree, because many trees would close to the ground but to long distances.

This data allowed for the following calculations:

1) Plot basal area
2) Relative Dominance
3) Relative Density
4) Importance Ranking of species within plot

Appendix – 5

Forest Stand Field Notes

Forest Stand Field Notes

Descriptions of Study Plots (all plots are 100 m²).

Naming convention:

1st **letter** indicates which **area** plot is located: **I** = Quebrada Ishinca, **P** = Pisco area, **A** = Quebrada Aquilpo.

1st **number** indicates the **patch number** for a given area.

2nd **number** indicates the **plot number** for a given patch.

For example: **A.5.2** is Quebrada Aquilpo, patch number 5, plot number 2.

QUEBRADA ISHINCA

Plot I.1.1

Aspect:	186 SW
Slope:	36°
Elevation:	4425m
Date:	May 26, 1999
Category:	Impacted (cattle)

Plot is located on steep boulder field at center of patch. 40% canopy cover. 50% boulders. 20% grasses. 20% cattle trails. 5% herbaceous plants. 5% shrubs. Abundant impacts from cattle grazing are apparent. No signs of burning. 200 meters to trail. Close to new Italian tourist lodge that has a woodpile of *Polylepis spp.* — used for fuel. Signs of recent cutting along eastern edge of patch. Appearance of runnells/gullies and washes break up forest. Gullies are covered in *Stipa ichu* grasses and herbs – significant signs of regeneration are apparent. Moss in areas and humus present. Bird species are abundant.

Plot I.1.2

Aspect:	198 SW
Slope:	46°
Elevation:	4500m
Date:	May 26, 1999
Category:	Impacted (cattle)

Plot is located on steep boulder field at the upper reached of patch, just below a cliff face. 40% canopy cover. 50% moss covered boulders. 20% grasses. 20% cattle trails. 5% herbaceous plants. 5% shrubs. Signs of cattle droppings are present. No signs of wood cutting. Abundant regeneration is visible. Bird species are abundant.

Plot I.1.3

Aspect: 210 SW
Slope: 15°
Elevation: 4375m
Date: June 26, 1999
Category: Impacted (cattle and cutting)

Plot is located on boulder field at lower edge of patch 20m from trail. 50% moss covered boulders. 1% woody shrubs reaching 4m in height. 25% herbaceous plants. 5% grass cover. 19% cattle tracks. Cattle are present – approximately every meter there are signs of cattle droppings and tracks. 35% canopy cover. Regeneration is present where sunlight reaches forest floor. Multiple signs of cutting are observed. Abundant amount of timber rot. Bird species are abundant.

Patch I.1 - General

Is not intact and shows signs of heavy grazing. Taya (*baccharis* (genus)) and nettle (*ortiga* (genus)) are abundant in heavily trampled areas. Abundant signs of cutting – suggesting the Italian tourist lodge as source of this impact given that patch is far from any villages and piles of wood at lodge. Regeneration is tremendous in areas (near the top of patch).

Plot I.2.1

Aspect: 304 NW
Slope: 25°
Elevation: 4250m
Date: May 25, 1999
Category: Not impacted

Plot is located in a riparian on boulder field at lower western edge of patch. 70% canopy cover. 80% moss covered boulders. 20% herbaceous cover. Extremely rocky and moss-covered. Deep humus and litter fall. No signs of cattle or cutting. Stream running directly to the east of patch appears to serve as a barrier to access. Bird species are abundant.

Plot I.2.2

Aspect: 310 NW
Slope: 35°
Elevation: 4350m
Date: June 26, 1999
Category: Impacted (cattle)

Plot is located on steep boulder field at center of patch. 50% canopy cover. 30% moss covered boulders. 20% herbaceous plants and *ichu* grasses, 20% rock/soil mix. 20% cattle tracks. Rocky boulder field with very deep, stable humus. Litter fall is abundant. Dead *Gynoxis spp.* and *Polylepis spp.*. No signs of cutting, but cattle tracks are abundant. Trees here have a more shrub-like morphology. The surrounding area is characterized by dense patches of *Polylepis spp.* and *Gynoxis spp.*. Bird species are abundant.

Plot I.2.3

Aspect:	330 NW
Slope:	36°
Elevation:	4250m
Date:	June 26, 1999
Category:	Not impacted

Plot is located on steep boulder field at upper reaches of patch. 30% canopy cover. 40% moss covered boulders. 20% herbaceous plants. 10% rock/soil mix, no grasses. One sign of lightning strike. No signs of cutting or cattle. Abundant regeneration of *Polylepis spp.* and *Gynoxis spp.* is observed. Litter fall, deep humus and abundant bird species are present.

Patch I.2 - General

This patch has deep undergrowth, little herbaceous plants, near 100% moss cover, shrub-like *Gynoxis* and *Polylepis spp.* trees (i.e. entire patch is extremely dense and difficult it navigate). Appears that larger *Polylepis spp.* occur in areas where canopy is higher and area is less densely stocked. In general, this patch is more open at edges – where impacts from cutting and cattle grazing are present. Three Italian workers were seen climbing and cutting *Polylepis spp.* treetops in this area. Many *Polylepis spp.* saplings in this area.

Plot I.3.1

Aspect:	340 NW
Slope:	30°
Elevation:	4400m
Date:	June 27, 1999
Category:	Impacted (cattle)

Plot is located on a boulder field at the upper reaches of patch. 10% canopy cover. 80% herbaceous and *ichu* cover. 10% rock/soil mix. 10% cattle trails. Signs of cattle excrement and trails penetrate patch from surrounding grasslands. Stable ground cover of grass/soil mix. Dominated by *Polylepis spp.* shrubs and seedlings. Abundant regeneration is present. Bird species abundant.

Plot I.3.2

Aspect:	320 NW
Slope:	45°
Elevation:	4325m
Date:	June 27, 1999
Category:	Not impacted

Plot is located on steep boulder field in the center of patch. 95% forest cover, 90% large boulder and moss cover, 10% deep debris and soft humus. No signs of cattle or cutting. Dense undergrowth and debris. No grasses or herbaceous plants present. Bird species abundant.

Plot I.3.3

Aspect: 330 NW
Slope: 15°
Elevation: 4275m
Date: June 27, 1999
Category: Impacted (cattle)

Plot is located on flat boulder field at edge of patch next to river. 60% canopy cover. 50% moss covered boulders. 10% exposed. 20% herbaceous plants. 20% cattle trails. Large trees. Little regeneration. Heavy cattle tracking and impaction – soil not deep and springy. Grasses present but not *ichu spp.* type – wild potato variety is also present. Highland woody shrubs, nettles, and other roseate herbs are abundant. Bird species abundant.

Patch I.3 - General

Thin, long patch. Majority of cattle penetration is at top and bottom – little along lateral edge. Similar to other patches on this side of valley. Regeneration stops abruptly at patch edge – very few saplings and seedlings are present outside of patch, and those which occur are within 20m of edge. This may be due to frequent low intensity fires which wipe out *Polylepis spp.* seedlings. However, no signs of recent fires have been noted, nor are fire scars apparent on trees at forest edge. Two possible interpretations for this lack of seedlings and saplings are, 1) sever soil compaction, which may inhibit the establishment of *Polylepis spp.* outside of patch, and 2) microclimatic conditions outside of patch unsuitable for *Polylepis spp.* establishment. The presence of taya (*Baccharis spp.)*, wild potatoes, nettles (*Ortiga spp.*) and rosette herbs (*Pinata spp.*) seem to be abundant at patch edges where cattle pressure is greatest. Forest interior seems intact with little to no obvious human or grazing impacts observed. *Polylepis spp.* regeneration within patch occur where gaps in canopy are present.

Plot I.4.1

Aspect: 332 NW
Slope: 41°
Elevation: 4225m
Date: May 26, 1999
Category: Not impacted

Plot is located on steep boulder field at lower edge of patch next to river. 95% canopy cover. 90% moss covered boulders. 10% herbaceous plants. No signs of cattle or cutting are observed. River seems to serve as a natural barrier to cattle and people. Deep spongy humus and litter fall between rocks. *Gynoxis spp.* seedlings are plentiful – very little *Polylepis spp.* regeneration. Bird species abundant.

Plot I.4.2

Aspect: 346 NW
Slope: 42°
Elevation: 4300m
Date: June 27, 1999
Category: Not impacted

Plot is located on steep boulder field in center of patch. 90% canopy cover. Little to no herbaceous cover – less than 1%. 80% moss cover. 20% debris and litter fall. Deep spungy soils between boulders. No signs of cattle or cutting. Not much regeneration – seedlings or saplings. Bird species abundant.

Plot I.4.3

Aspect: 330 NW
Slope: 60°
Elevation: 4450m
Date: June 27, 1999
Category: Not impacted

Plot is located on steep boulder field at the upper reaches of patch. 95% forest cover. 90% moss covered boulders. 1% herbaceous plants. 9% exposed rock/humus mix. Steep slope appears to be consolidated by deep, dark, stable humus (springy). Dominated by *Polylepis spp.* – shorter and more densely stocked than other plots thus far. Very little regeneration – but *Gynoxis spp.* regeneration is abundant. No signs of cattle or cutting. Abundant litter fall and large woody debris. Bird species abundant.

Patch I.4 - General

Patch is located on a very steep valley wall (40 to 70°). Steepest areas have extremely dense understory – due perhaps to abundant tree fall (*Polylepis spp.* and *Gynoxis*). Trees toward stream – on valley floor appear to be among the largest trees in the plot. Several signs of lightning scars/strikes on trees in this patch. Regeneration stops within 10m of outside forest edge. Several deer trails and scat are present. Bird species abundant.

Plot I.5.1

Aspect: 356 NW
Slope: 32°
Elevation: 4125m
Date: June 28, 1999
Category: Not impacted

Plot is located on boulder field. 75% canopy cover. 80% moss covered boulders. 10% herbaceous plant cover. 10% exposed humus and soft debris cover. No signs of cattle or cutting. *Gynoxis spp.* regeneration abundant. Few *Polylepis spp.* seeds or saplings are present. Large trees open understory. Abundant deadfall. Plot is located on bottom edge of patch with river at NW plot edge. Bird species abundant.

Plot I.5.2

Aspect:	358 NW
Slope:	45°
Elevation:	4325m
Date:	June 28, 1999
Category:	Not impacted

Plot is located on a steep boulder field at the upper reaches of patch. 35% canopy cover. 60% herbaceous plants. 40% moss-covered boulders. Large number of dead trees. Plot is located in a gap in the patch where most down and dead trees appear to have recently fallen – mass wasting from upland rock wall is unlikely because no new boulders are present and no damage from such an event is seen in forest patch directly above plot. Tree fall may be a result of high winds coupled with a steep rocky slope with thin soils. Little *Polylepis spp.* regeneration is present. Signs of burns and lightning strikes – though it is unlikely given the location of this plot (high on valley wall, steep slope, and center of patch) that burns are anthropogenic in origin. No signs of cattle or cutting. Grasses growing and many new herbaceous plants at this elevation – maybe due to the high amount of sunlight striking valley floor. Kaluvial fan on opposite slope. Bird species abundant.

Patch I.5 - General

Large trees dominate this patch with a mix of old *Polylepis spp.* and *Gynoxis spp.* Patch is located on a steep slope – 45° to 60° throughout. Patch is characterized by a high canopy and open understory; trees become sparce as elevation gains, and signs of major tree fall are abundant. Little *Polylepis spp.* regeneration in open areas within patch – maybe microclimatic condition at lower elevation on north face preclude establishment of seedlings due to water stress. Seedlings and saplings are rare outside of patch and those which are found are with 10m of patch edge. Eastern side of patch is bounded by an active kaluvial fan where signs of recent mass wasting have destroyed sections of the forest patch. Two large sections of the southern cliff bounding this patch are actively wasting rock and dirt. Debris from these two sites of mass wasting is not present in the 1963 photo. Patch looks considerably smaller – more triangular in 1999.

Plot I.6.1

Aspect:	160 SE
Slope:	30°
Elevation:	4200m
Date:	June 29, 1999
Category:	Impacted (cattle)

Plot is located on a steep boulder field at lower edge of patch. 60% canopy cover. 60% moss-covered boulders. 20% herbaceous plants. 20% debris/humus/soil mix. Plot located on edge of patch. Signs of cattle present. Large woody shrub species present: *Astereae* (tribe), *Diplostephium*?? (genus) (there are 90 spp.). 5 such shrubs were found in plot. Much down, woody debris present. Ferns present. One *Polylepis spp.* found near plot with

DBH of 110cm. *Polylepis spp.* species in this plot are very straight and tall. Bird species abundant.

Plot I.6.2
Aspect: 180 S
Slope: 42°
Elevation: 4300m
Date: June 29, 1999
Category: Impacted (cattle)

Plot is located on a steep boulder field at center of patch. 80% canopy cover. 50% moss covered boulders. 20% exposed soil. 15% grass. 5% herbaceous plants. 10% cattle trails. Tall, relatively straight *Polylepis spp.*. Open understory. Moss dominate plot floor. Areas have *ichu spp.* (2 types). Abundant dead wood, trees, and litter fall. Few herbs. Abundant signs of deer. No signs of cutting. Some cattle trails though no droppings. Little regeneration. Bird species abundant.

Plot I.6.3
Aspect: 160 SE
Slope: 50°
Elevation: 4400m
Date: June 29, 1999
Category: Not impacted

Plot is located on a steep boulder field at top of patch. 50% canopy cover. 80% moss-covered boulders. 10% herbaceous plants. 10% debris/loamy soil. Much *Polylepis spp.* and *Gynoxis spp.* regeneration visible. Many fallen trees. No signs of cattle. Deer tracks abundant. Thick moss covering ground (springy). Plot located near top of patch. Bird species abundant.

Patch I.6 - General
Taya and holly and diplostephium(?) – highland shrubs abundant at forest edge with *ichu* cover dominating large areas. *Polylepis spp.* regeneration is nearly non-existent outside of patch, but where the species has established is within 10m of patch edge. Large *Gynoxis spp.* are found growing in the matorral area bounding this patch (not grasslands). The eastern and western boarder of this patch is bounded by two kaluvial fans. Both kaluvial areas are being colonized by matorral species including lupins.

Plot I.7.1
Aspect: 174 SE
Slope: 18°
Elevation: 3900m
Date: May 24, 1999
Category: Not impacted

Plot is located on a boulder field at center of patch near walking trail. 80% canopy cover. 75% moss covered boulders. 25% herbaceous plants. Relatively open riparian *Polylepis spp.* forest. Several large trees. Soil is deep and loamy. No grasses – but *Gynoxis spp.* dominate plot. Close to trail with signs of loping and one whole tree cut (13 m in height). No signs of cattle droppings. The surrounding area is basically the same up slope – steep dense *Polylepis spp.* and *Gynoxis* present. No signs of cutting in this plot, but cutting is observed nearby all along trail. Bird species abundant.

Plot I.7.2

Aspect:	155 SE
Slope:	19°
Elevation:	4175m
Date:	June 30, 1999
Category:	Impacted (cattle)

Plot located on a boulder field at the lower eastern edge of patch. 40% canopy cover. 60% herbaceous plants. 15% moss covered boulder. 10% shrub (taya - *baccharis spp.* and holly - *ortiga spp.*). 5% grasses. 10% exposed soils and cattle tracks. East edge of plot is bounded by a kaluvial fan that is reestablishing vegetation with matorral type plants. Transition at edge is abrupt with a total loss of matorral type plants 5m inside patch. Few *Polylepis spp. spp.* survive in kaluival fan and no regeneration is found beneath them nor just outside of forest. Inside this plot there are multiple signs of cattle tracks, trails, droppings. Taya, holly, and other puna vegetation are somewhat abundant (e.g. 14 taya counted in plot). Ground is relatively flat here but steepens quickly to 60° and steeper to the top of plot (north). Ground is also soft and springy with abundant leaf litter and woody debris. High *Polylepis spp.* regeneration despite cattle grazing in area (4 cattle seen grazing in plot). The forest to the north (top of plot) rapidly becomes more dense with seemingly smaller (thinner and shorter) trees. No signs of cutting. Very few puna grasses. Bird species abundant.

Plot I.7.3

Aspect:	180 S
Slope:	40°
Elevation:	4000m
Date:	July 1, 1999
Category:	Impacted (cutting)

Plot located on a steep boulder field 15m from trail (near cattle gate – lower eastern edge of patch). 70% canopy cover. 80% moss-covered rocks. 5% herbaceous plants. 5% tree that looks like *Gynoxis spp.* (leaf yellow bottom and green leathery top (82 in plot)). 10% compacted exposed soil. Abundant signs of cutting in the area – flagging found (maybe a marker for a cutting area). No cattle tracks or droppings found. Very moist and cold. To the north, the forest becomes much more dense and overgrown and seemingly smaller. Trees here seem smaller in diameter in general. Not much regeneration. No grasses or puna plants. 80m diamter (10 x 8) gaps created in canopy where cutting has taken place.

Obvious signs of campsite near plot (Italian and Peruvian trash, burned logs, etc.) from where supposed log cutters camped. 13 cut *Polylepis spp.* counted. No birds seen nor heard.

Plot I.7.4

Aspect:	238 SW
Slope:	3°
Elevation:	3950m
Date:	July 1, 1999
Category:	Impacted (cutting and cattle)

Plot located in a flat riparian area in middle of patch — southern edge of plot is bounded by walking trail. 50% canopy cover. 20% moss covered boulders. 60% herbaceous plants. 20% debris of fallen and cut trees/soil mix. Heavy signs of cutting and cattle presence. Abundant *Polylepis spp.* regeneration in plot — especially at trail/plot edge and where gaps in canopy occur. Many dead *Polylepis spp.* seedlings in quad 2 (at least 20) from trampling. Cutting is a major factor west of plot and in surrounding areas. To north of plot, slope steepens dramatically and becomes a boulder field with no signs of cutting (about 45° slope) whereas this plot is on valley bottom. 18 *Polylepis spp.* cuts and 1 *Gynoxis* cut counted. 28 *Gynoxis*-like tree counted. Few bird species observed.

Plot I.7.5

Aspect:	250 SW
Slope:	7°
Elevation:	3900m
Date:	July 1, 1999
Category:	Impacted (cutting – and cattle)

Plot located in a flat riparian area with few boulders, near trail in the lower middle section of patch. 15% canopy cover. 80% grasses and herbaceous plants. 10% cattle trail. 10% boulders and moss. Abundant signs of cattle (trails, droppings, etc.). Open and exposed plot that is easily accessible to both humans and cattle. Little *Polylepis spp.* or *Gynoxis spp.* regeneration present. 7 cut *Polylepis spp.* counted. Some bird species observed.

Plot I.8.1

Aspect:	340 NW
Slope:	50°
Elevation:	4025m
Date:	June 30, 1999
Category:	Impacted (cattle)

Plot located in the eastern middle of patch on a steep boulder field adjacent to rock bed/mass wasting/erosion gully near mouth of valley. 60% canopy cover. 70% moss-covered boulders. 20% herbaceous plants, 10% debris/humus mix. Deep soil surrounding boulders. Much dead matter in plot. Old, large trees down. Some seem to have fallen from boulders giving way – many in the plot are loose. Very active erosion gully (see slide). Located halfway up from river. Few signs of sign of cattle, but in area surrounding plot cattle presence is abundant. *Polylepis spp.* regneration in surrounding forest is visible, but not much is observed in this plot. Below and east of plot massive deforestation caused by a recent mass wasting. Some bird species observed.

<u>Plot I.8.2</u>

Aspect:	348 NW
Slope:	50°
Elevation:	4100m
Date:	June 30, 1999
Category:	Impacted (cattle)

Plot located on a steep boulder field in the western middle of patch. 50% canopy cover. 60% herbaceous plants. 30% moss-covered boulders. 5% debris/humus mix. 5% cattle trails. Signs of cattle trails present. Many *Polylepis spp.* bowled over but still growing, possibly due to larger boulder erosion from uphill or loose boulder substrate on steep slopes. Very dry on this side of the valley. No grasses, but ortega is present – grazing seems abundant in the area. *Gynoxis spp.* seems more prevalent and larger than in other plots. Abundant litter fall. Bird presence is minimal.

[From cattle gate to edge of HNP, in the Ishinca valley, the number of signs of Polylepis cutting just off trail or on trail is 686.]

<u>QUEBRADA DEMANDA (The Pisco Area)</u>

<u>Plot P.1.1</u>

Aspect:	146 SE
Slope:	30°
Elevation:	4300m
Date:	June 19, 1999
Category:	Not impacted

Plot is located on a boulder field, 20m from patch top below cliff face. 70% canopy cover. 85% moss-covered boulder. 5% herbaceous plants. Relatively large *Polylepis spp.*. Regeneration is intense in areas where large gaps in canopy are present. No signs of cattle or cutting. Soil deep in areas between boulders. Litter and duff from *Polylepis spp.* is intense. Area and plot appear to be the same with several very large *Polylepis spp.* nearby (60 – 90 cm in DBH). Bird species are abundant.

<u>Plot P.1.2</u>

Aspect:	140 SE
Slope:	50°
Elevation:	4250m
Date:	July 11, 1999

Category: Not impacted

Plot is located on a steep boulder field at south center of patch. 85% canopy cover. 15% herbaceous plants. 85% moss-covered boulders. Little regeneration. No signs of cattle or cutting. No grasses or puna shrubs. Deep, dark, springy and loamy soil. Bird species abundant.

Plot P.1.3

Aspect:	180 S
Slope:	20°
Elevation:	4150m
Date:	July 12, 1999
Category:	Not impacted

Plot located at lower southern edge of patch on a boulder field. 75% canopy cover. 80% moss-covered boulders. 10% debris and exposed soil. 10% herbaceous plants. Massive boulder field at extreme lower edge of plot (7m drops between boulders). Grasses border western edge of plot. Moss is deep and springy. Bird species are abundant.

Plot P.1.4

Aspect:	180 S
Slope:	48°
Elevation:	4200m
Date:	July 12, 1999
Category:	Impacted (cattle)

Plot located outside of patch, but bounded on the southern and western sides by trees from P.1. Plot itself is about 20m from patch in an open grass field. 2% canopy cover. 95% dominated by herbaceous plants: *ichu* grasses and rossette-type herbs growing between *ichu*. Much regeneration visible. Area is steep with no boulders, though soil appears quite rocky. Signs of deer scat and cattle trails (5%) visible. Birds are abundant in the area but none appear to be roosting in the plot itself.

Patch P.1 - General

Similar to P.2 and P.3. Small intact/undisturbed patch. Edges at top, bottom and sides show no signs of cattle or cutting. Regeneration seems highest at forest edge. Very little regeneration outside of forest (no more than 20 m from edge but in general, regeneration of seedlings and saplings are within 5 m from forest edge – however, P.1.4 is an exception). Outside forest hill slope is very steep (up to 65 degrees) and dominated by *ichu* grasses. Many *Gynoxis spp.* are found outside forests – especially where small rocky/boulder fields are located – here we also find some taya (*Baccharis spp.*) and *Puya Raymundii.* Otherwise, grasses between patches P.1, P.2 and P.3 have very few puna shrubs of the matorral type.

Cows were present in valley floor (about 25) though none were seen on valley slopes near or between patches P.1, P.2 or P.3. Three deer were sighted (Taruka or *Hippocamelus antisensis*), 2 female and one large male with 8-points on it's antlers. All three were seen exiting from eastern edge of patch P.1, however, tracks were identified in all three patches. The fourth patch, between P.2 and P.3, has a 75% canopy cover, is about 15m wide at its widest, and a dry windy understory. Very few grasses inside this patch but some do exist along with taya (*Baccharis spp.*), and there was little regeneration of *Polylepis spp.* observed. Boulder fields seem to define the shape of all 4 patches in this area.

<u>Plot P.2.1</u>

Aspect:	167 SE
Slope:	37°
Elevation:	4300m
Date:	July 11, 1999
Category:	Not impacted

Plot is located on a steep boulder field at top of patch. Patch is narrow here, about 60m wide, though signs of cattle are observed penetrating patch edge. 85% canopy cover. 70% moss-covered boulder. 10% herbaceous plants. 20% debris/moss-soil mix that is very deep and loamy. Deer tracks in area. No signs of cattle. Much *Gynoxis spp.* and *Polylepis spp.* regeneration visible. Abundant unidentified herbaceous plants growing throughout plot. Mice and hawks present in area. Bird species are abundant.

<u>Plot P.2.2</u>

Aspect:	150 SE
Slope:	40°
Elevation:	4200m
Date:	July 11, 1999
Category:	Not impacted

Plot is located at bottom edge of patch on a steep boulder field. Deep, springy moss cover. 70% forest canopy. More open and dry than P.2.1. 80% moss-covered boulders. 10% herbaceous plants. 10% debris and exposed soil. Signs of deer scat visible. Grasses on eastern edge of patch, *ichu*, are invading into quads 1 and 4. No signs of cattle. Two taya (*Baccharis spp.*) present. Bird species abundant.

<u>Plot P.2.3</u>

Aspect:	150 SE
Slope:	40°
Elevation:	4250m
Date:	July 11, 1999
Category:	Not impacted

Plot is located at center of patch on a steep boulder field. Deep, springy moss cover. 80% forest canopy. 90% moss-covered boulders. 10% herbaceous plants. Deer scat visible. No signs of cattle. Bird species abundant.

Patch P.2 - General

Narrow patch and very similar to patch 1. Steep, rocky and moss-covered. Relatively open understory except at edges when *Polylepis spp.* regeneration is very high.

Plot P.3.1

Aspect: 144 SE
Slope: 42°
Elevation: 4225m
Date: July 12, 1999
Category: Not impacted

Plot locate on steep boulder field on southeastern edge of patch. 90% canopy cover. 80% moss-covered boulders. 10% debris and exposed soil. 10% herbaceous plants. Deep, loamy humus present. *Polylepis spp.* regeneration is thick along edge, especially in quads 1 and 4. Where there are no gaps in canopy regeneration is greatly reduced. Outside of patch regeneration stops abruptly and seedlings and saplings are sparse within 4m or 5m from edge, beyond which they do not occur. 5 taya (*Baccharis spp.*) counted in quad 4. Bird species are abundant.

Plot P.3.2

Aspect: 180 S
Slope: 45°
Elevation: 4275m
Date: July 12, 1999
Category: Not impacted

Plot located on a steep boulder field at center of patch. 95% canopy cover. 5% herbaceous plants. 95% moss-covered boulders. Deep, springy moss and dark, loamy soil beneath moss between boulders. No grasses. No signs of cattle. Surrounding area is similar – very tall, relatively straight trees that are densely packed. Bird species are abundant.

Plot P.3.3

Aspect: 130 SE
Slope: 48°
Elevation: 4350m
Date: July 12, 1999
Category: Not Impacted

Plot located on a steep boulder field at top of patch. 90% canopy cover. 90% moss-covered boulders. 10% herbaceous plants. Deep springy moss and loamy soils dominate the plot. Very little regeneration is observed. Bird species are abundant.

Patch P.3 - General
Similar to P.1 and P.2..

Plot P.4.1

Aspect:	90 E
Slope:	50°
Elevation:	4000m
Date:	July 13, 1999
Category:	Impacted (cattle)

Plot located on a steep consolidated slope at eastern edge of patch. Slope is open and covered with grasses with sparse tree cover – savanna like. 10% canopy cover. 75% herbaceous plants and grasses. 10% rocks (medium-sized boulders). 15% cattle trails. Abundant herbaceous plants present, including *lupin*, *ichu*, *puya*, some rossette herbs and other grasses. Very dry, no moss and no succulent plants present. No litter fall. Multiple cattle tracks and droppings. Very open and exposed plot, south-facing slope. National park reforestation project encompasses this area: planting *Polylepis rasamosa* (7 in total – one planted in middle of trail). Holly present in quads 1 and 2. Ten *lupins* counted, 3 *puyu* counted and *Baccharis spp.* present throughout plot. Natural regeneration is *Polylepis sericeae* while planted species are *rasamosa.* Bird species are present.

Plot P.4.2

Aspect:	100 SE
Slope:	40°
Elevation:	3950m
Date:	July 13, 1999
Category:	Impacted (cattle)

Plot located at center of patch on a steep rocky slope. 50% canopy cover. 40% moss-covered boulders. 35% shrubs and herbaceous plants. 10% exposed soil. 15% cattle trails. Numerous *Baccharis* species present, as well as Quiswar (?*spp.*), *Puyu spp.*, and multiple-stem taya (*Baccharis spp.*), 4 to 5m tall with DBH between 3 and 7 cm. Plot is dry. Ferns and holly are also present. Signs of cattle (excrement and trails). No litter fall present. 22 Taya, 58 Quiswar, and 6 *Puyu waberbauerii* counted throughout plot – it was difficult to distinguish between Quiswar (?*spp.*) and *Gynoxis spp.* seedlings. Few bird species observed.

Patch P.4 - General
Patch is characterized as highly impacted, with an open dry understory and savanna-like structure. Cattle trails and excrement are abundant throughout patch. Very little regeneration of *Polylepis spp.* and *Gynoxis spp.* is present. National Park staff is attempting to replant the area with a different species of *Polylepis spp.* than that which occurs in the area naturally – many appear not to be taking root.

<u>Plot P.5.1</u>
Aspect: 340 NW
Slope: 5°
Elevation: 3900m
Date: July 13, 1999
Category: Impacted (cattle)

Plot located at lower northwest edge of patch, adjacent to river, just east of bridge and north of the park storage house. 20% canopy cover. 15% cattle trails. 40% grasses. 20% herbaceous plants. 25% moss-covered boulders. Open understory and much dryer than patches at higher elevations. Abundant in grasses, holly, taya and many puna rossette-type plants. Taya (*Baccharis spp.)* and holly assume a tree/shrub morphology. 24 taya counted throughout plot. Abundant cattle tracks and excrement. Abundant human fecal matter and trash. Little litter fall, perhaps due to collecting (campfires with *Polylepis spp.* are nearby). Few bird species observed.

<u>Plot P.5.2</u>
Aspect: 340 NW
Slope: 4°
Elevation: 3925m
Date: July 13, 1999
Category: Impacted (cattle and cutting)

Plot located near trail in the center of the patch next to a stream (directly on eastern edge of plot, bordering quads 2 and 4). 60% canopy cover. 60% small rocks, moss-covered field. 30% herbaceous plants. 10% cattle trails. Signs of cattle present (excrement and tracks). Multiple signs of cutting and breaking of *Polylepis spp.*. Cutting possibly due to proximity to trail. Canopy is relatively open and soil/moss is dry and not loamy or deep. 16 taya counted throughout plot. 24 signs of cutting counted throughout plot. Some bird species observed.

<u>Plot P.5.3</u>
Aspect: 325 NW
Slope: 3°
Elevation: 3950m
Date: July 13, 1999
Category: Impacted (cattle)

Plot located at top of patch near to where stream enters patch. 40% canopy cover. 10% herbs (includes some grasses but no ichu is observed). 20% stones (no boulders). 70% moss. Some taya present (34 counted throughout plot). 4 lupins counted. Not much litter fall. No signs of cutting. No cattle trails but excrement is present. Beyond patch edge *ichu*, *puyu* and other matorral-type vegetation transition quickly into puna grassland. Bird species abundant.

Patch P.5 - General

This patch is defined as a riparian forest: it follows the course of a stream and is bounded on its eastern and western flanks by steep walls. Walls are approximately 20m in height and appear to have been formed from water processes. Some trees are seen on creek walls but very few (90 to 80 degree slope of walls). Beyond creek walls no forest seen. Area is flat and densely packed wtih young trees. Cattle presence is noted by excrement but not many pronounced trails. Some cutting is observed, however, it is limited to those areas close to the trail. *Lupin* and other matorral type vegetation are abundant.

Plot P.6.1

Aspect:	120 SE
Slope:	49°
Elevation:	4300m
Date:	July 27, 1999
Category:	Impacted (cattle)

Plot located on a steep boulder field at top of patch — 50m below cliff face to north and about 300m above stream in valley bottom. 20% canopy cover. 65% grasses - *ichu.* 28% lichen-covered loose rocks. 2% herbaceous plants. 5% moss. Plot is open with abundant grasses and shrubs present: *ichu*, *ortiga*, *baccharis*, holly, *Lupin* are present, and *Puya weberbauri*. Small ferns are also present. No signs of cattle in this plot, though trails and excrement are in surrounding area. In all directions surrounding plot, vegetation cover looks similar with abundant *ichu* grasses, few large *Polylepis spp.* trees and abundant *Gynoxis spp.*. *Gynoxis spp.* regeneration is abundant while *Polylepis spp.* regeneration is not. No deadfall or *Hypochuerius* species present. Soil is not loamy or deep, but relatively compacted with some litterall present. 28 holly counted in entire plot and 1 taya. Deer scat was noted. Few bird species observed.

Plot P.6.2

Aspect:	110 SE
Slope:	45°
Elevation:	4250m
Date:	July 27, 1999
Category:	Impacted (burning)

Plot located in center of patch on a steep boulder field. 20% canopy cover. 60% moss-covered boulders. 10% herbaceous plants. 5% *Puya weberbaureri.* 25% grasses – *ichu* (2 types). Some holly is present. No signs of cattle or cutting. Some burning of *puya* in and around plot. Plot is very dry and open. Abundant *Polylepis spp.* and *Gynoxis spp.* regeneration in surrounding area. Plot has several large trees though is distinct from others in this valley. It is much more open and is dominated by matorral type plants and shrubs in the understory. Moreover, where the patch ends a sharp ecotone exists between the patch and the grasslands which are less rocky and have fewer shrubs. However, seedlings and saplings of *Polylepis sericea* are found up to 100m from edge of this patch in the grasslands

– existing in a different manner than the Aquilpo regeneration in the grasslands. Most *Polylepis spp.* regeneration outside of forest patch is *sericea* even where *weberbaueri* dominate. Few bird species observed.

Plot P.6.3
Aspect: 110 SE
Slope: 45°
Elevation: 4150m
Date: July 27, 1999
Category: Impacted (burning)

Plot located at the lower edge of patch on a steep boulder field. 25% canopy cover. 50% moss-covered boulders. 20% herbaceous plants. 5% *Puya weberbaureri.* 25% grasses – *ichu* (2 types). Some holly is present. No signs of cattle or cutting. Some burning of *puya* in and around plot. Plot is very dry and open. This patch is very similar to P.6.2. Few bird species observed.

Patch P.6:
See description for plot P.6.2..

QUEBRADA AQUILPO

Plot A.1.1
Aspect: 190 SW
Slope: 32°
Elevation: 4450m
Date: July 18, 1999
Category: Not impacted

Plot located at lower edge of patch on a steep boulder field. 40% canopy cover. 90% boulders – very little moss in this plot. 8% dried and dead matter – litter fall is high. 2% herbaceous plants. Debris and deadfall abundant. No grasses present. No signs of cattle. Birds are abundant. Plot is located close to edge. Abundant scat and cattle tracks outside of patch. Very open and dry plot. In general, this whole patch appears to be the same. *Polylepis spp.* have shrub-like morphology with multiple, small branches from base of tree. *Gynoxis spp.* is abundant. Few bird species observed.

Plot A.1.2
Aspect: 210 SW
Slope: 35°
Elevation: 4400m
Date: July 18, 1999
Category: Not impacted

Plot located at the center of patch on a steep boulder field. 45% canopy cover. 5% herbs. 95% moss covered boulders and dirt/debris between rocks. Boulder field, steep with not very much soil or organic matter – not loamy like other plots. No signs of cattle nor grasses or puna plants. *Gynoxis spp.* regeneration is more abundant here than in lower sections of plot. Surrounding area seems similar – steepening quickly to the north. Abundant deadfall and several very large trees are dead (one in plot). Up slope appears very dense with shrub-like *Polylepis spp.* when breaks in the canopy appear. Bird species are abundant.

Plot A.1.3

Aspect:	210 SW
Slope:	40°
Elevation:	4500m
Date:	July 18, 1999
Category:	Not impacted

Plot located at top of patch on a steep boulder field. 30% canopy cover. 75% moss-covered boulders. 20% herbaceous plants. 5% soil/humus mix. Grasses on eastern edge of plot, along quads 1 and 4, where the canopy opens. Abundant regeneration of both *Polylepis spp.* and *Gynoxis spp.* present. Abundant litter fall – mainly branches. Bird species are abundant.

Plot A.1.4

Aspect:	180 S
Slope:	50°
Elevation:	4600m
Date:	July 20, 1999
Category:	Not impacted

Plot located on a steep boulder field in the middle of patch, 60m in from western edge and 100m from northern edge. 75% canopy cover. 5% grasses. 5% herbaceous plants. 60% moss-covered boulders. 30% loose soil/debris. Extremely high amount of debris is present – down *Polylepis spp.* branches and trunks. *Ichu* is present. No cattle tracks or excrement or cutting was observed in plot. Surrounding plot to the west has cattle tracks and excrement. Signs of buring are notably high in the area, yet much *Polylepis spp.* regeneration is visible. Large boulders flank this plot. Soil in this plot is more compacted than other sites – not springy or loamy, though very moist and damp. Plot is typical of the interior. One dead Polylepis with a DBH of 44.5cm and another dead with a DBH of 34.5cm was observed. Bird species are abundant.

Patch A.1 - General

Over 50 cattle seen grazing in the wetland below patch. Signs of burning on edge and in openings of this patch are abundant. On western edge, effects of burning are dramatic, present 60m within forest from edge. Large emergent (greater than 120 cm in DBH) *Polylepis spp.* (20-25m in height). Abundant signs of cattle (trails and excrement) along the edges of patch. Forest rapidly becomes very dense and lush the eastern side of the patch and in patch interior. Grassland/savanna like transition from grasses to forest interior. All grasses and trees exhibit signs of burning – only the very large trees seem to survive on rocky-boulder patches. Very little regeneration seen walking across the grasses and savanna areas (some found under canopies of large trees). Along western edge of patch soil is relatively stable – not a boulder field. Clearly this forest would make for prime grasslands if it were completely cleared

Plot A.2.1

Aspect:	170 SE
Slope:	22°
Elevation:	4200m
Date:	July 19, 1999
Category:	Impacted (cattle)

Plot located at lower edge of patch next to stream on a boulder field. 30% canopy cover. 80% moss-covered boulders – semi-loamy soils and deep mosses. 5% herbaceous plants. 10% deep, dry moss/humus. 5% cattle trails. Taya and holly are present. Grasses, such as *ichu* are abundant, especially on southern edge of quads 1 and 2. Large saplings of both *Polylepis spp.* and *Gynoxis spp.* are present. Abundant regeneration of *Gynoxis spp.*. Signs of cattle at lower edge of plot (trails and excrement). Plot is very open. Much regeneration observed of *Polylepis spp.* and *Gynoxis spp.* along eastern edge of plot – mostly outside of plot, along quads 1 and 4. To the west, flat parts of forest have been cut away. Deadfall is abundant. 80 to 90% of grasses have been burnt and some burnt trees (7m tall, 6 – 7cm in DBH). Very dense patch looking northward. Several large emergent trees are visible. Bird species are abundant.

Plot A.2.2

Aspect:	150 SE
Slope:	42°
Elevation:	4250m
Date:	July 19, 1999
Category:	Impacted (cattle and burning)

Plot located at top of patch on a steep slope which has recently been burned. 5% canopy cover. 20% grasses. 1% herbaceous plants. 30% boulders. 49% moss covered boulders. About 4 ha of forest has been burned in this area. All mosses are dead and black exposed soil is abundant. Area above burned trees also shows signs of having been burned. Grasses outside of patch are burned. A thin strip of forest separates burned forest interior from burned grasses. Upper slope of this patch seems less rocky (less large boulders). It is possible that trees are being cleared for these grasses. *Gynoxis spp.* regeneration appears more abundant than *Polylepis spp.* regeneration. Abundant *ichu* – green and recently sprouting after burn. Cattle tracks present inside and outside of plot. Large trees survived – seems like fire did not reach canopy. *Ortiga spp.* and holly present. All *Polylepis spp.* trees in this plot were severely burned. 12 *Gynoxis spp.* and 6 *Polylepis spp.* in plot were destroyed by fire – DBH ranged from 4 to 12.6cm and heights ranging from 2 to 7m. Two living Polylepis trees had large branches that were dead from the fire with DBH range from 3.5 to 8.6cm and heights from 1 to 4m. Very few bird species observed.

Plot A.2.3

Aspect: 160 SE
Slope: 42°
Elevation: 4240m
Date: July 19, 1999
Category: Impacted (cattle and burning)

Plot located in middle of patch on a steep boulder field. 20% canopy cover. 40% moss-covered boulders, 5% herbaceous plants. 20% grasses. 20% cattle trails. 15% exposed soil. Open, dry and burned plot. Ferns, taya and grasses present. Severe burns visible on some of the *Polylepis spp.* in this plot (Quad 2 had *Polylepis spp.* saplings with burns). Soil is not loamy. Little moss present – most appears to have been killed by the fire. The surrounding area, to the north and west has severely burned *Gynoxis spp.* and *Polylepis spp.*. Area appears to be have been burned repeated owing to the lack of *Gynoxis spp.* trees or saplings, and that most shrubs (*Baccharis spp.*) have been burned and killed – little regeneration of these shrubs were observed. Few bird species observed.

Patch A.2 - General

Entire northern edge has been burned. Burned grasses and shrubs seem to indicate repeat burning. Signs of burning penetrate forest edge about 40m. The eastern edge appears to be the most intact – undamaged *Polylepis spp.* and *Gynoxis spp.*. Very few large trees present.

Plot A.3.1

Aspect: 5 N
Slope: 25°
Elevation: 4275m
Date: July 19, 1999
Category: Impacted (cattle)

Plot located on lower edge of patch next to stream on western side. High cattle grazing pressure. 20% canopy cover. 20% rock. 20% grasses. 10% herbs. 30% moss. 20% cattle trails. Highly compacted soils in this plot. Signs of cattle but no trials, only excrement. High ridge on stream - both sides - suggests was once a major route for mass wasting up slope. Probably burned regularly at one point, though today no signs of burns on trees. Open understory (easy to move about) 94 holly, 2 lupin and 4 taya (*baccharis spp.*) counted in plot. Few bird species observed.

Plot A.3.2

Aspect: 20 NE
Slope: 29°
Elevation: 4275m
Date: July 19, 1999

Category: Impacted (cattle)

Plot located in center of patch east of stream. 60% canopy cover. 30% moss-covered boulders. 30% grass. 20% herbs. 20% cattle trails. Highly compacted soils on a rocky slope. Rocks are highly consolidated. Intense cattle pressure. Very open understory. Holly and taya are abundant. Some burning scars noted on trees surrounding plot but no signs of cutting. Surrounding forest is very similar; to north, east and west, forest turns to a matorral-type ecosystem. 34 holly counted in this plot. One dead *Polylepis spp.* recorded in quad 1 with two branches having 14 and 16.5 cm DBH. Few bird species observed.

Patch A.3 - General

Small patch located on an ancient kaluvial fan. Intact interior *Polylepis spp.* forest conditions not found. Abundant signs of cattle (trails and excrement) – cattle seen grazing inside patch. Matorral type shrubs are abundant throughout patch. Patch is open and easy to walk.

Plot A.4.1

Aspect: 203 SW
Slope: 55°
Elevation: 4600m
Date: July 20, 1999
Category: Impacted (cattle and burning)

Plot located at the top of patch on a steep slope, 25m from eastern edge. 20% canopy cover. 50% grasses. 5% herbs. 10% rock. 15% moss. 20% cattle trails. Savanna-like formation. Consolidated rocks with ample grass and mosses. Cattle tracks and excrement are abundant. Vines are abundant. Dry and open understory. All trees show signs of severe burn scars and some of the lower branches have been killed from fires. Recent burning of grasses in this area are apparent just below (west) plot – in this area there are large trees like plot A.4.1 but no regeneration of *Polylepis spp.* or *Gynoxis spp.* were observed. Abundant birds species observed.

Plot A.4.2

Aspect: 220 SW
Slope: 59°
Elevation: 4550m
Date: July 20, 1999
Category: Impacted (cattle and burning)

Plot located on an open, steep and grassy, savanna-like field – in a small, isolated forest-island on eastern edge of patch 4, about 20m from patch. 5% forest canopy. 10% boulders. 70% grasses. 10% moss. 10% cattle trails. All regeneration in quads 1 and 4 is clumped around one tree. *Ichu* grasses dominate. One *Polylepis spp.* shows signs of burns. Quads 2 and 3 appear to have been burned in the past two or three years. Grasses in surrounding area have all been burned and show no signs of regeneration. Cattle tracks and excrement are present. In general, regeneration in quads 1 and 4 is due to possible low-intensity, low-severity fires. Burning grasses and perhaps singeing edges of *Polylepis spp.* forests (not completely penetrating). Lack of any matorral-type plants (reducing fuel load), i.e. no taya present. Located about 500m from valley floor. In general, the entire area between patches 1 and 4 is steep, with regularly burned grasses and small islands of *Polylepis spp.* forests (with regeneration present but only under the canopy of older large trees) in a savanna-like formation. Bird species are abundant.

Plot A.4.3

Aspect:	172 SE
Slope:	28°
Elevation:	4500m
Date:	July 20, 1999
Category:	Not impacted

Plot located in the center of patch. 85% canopy cover. 20% herbs. 40% moss-covered rocks. 40% mosses and soils. Soils are not loamy. No burned trees in this plot. No grasses. No signs of cattle or cutting. Densely stocked and seemingly intact. Boulders here are very large and semi-consolidated. No *puna* plants or shrubs. Abundant bird species observed.

Plot A.4.4

Aspect:	190 SW
Slope:	15°
Elevation:	4480m
Date:	July 20, 1999
Category:	Not impacted

Plot located along the lower southwestern edge of patch on a boulder field. 80% canopy cover. 60% moss-covered boulders. 5% grasses. 5% herbaceous plants. 30% moss and soil. Densely stocked. High regeneration present. Southwestern edge of patch is 10m from outside. Boulders along edge may serve as fire break. Outside of patch fire signs are evident. Few cattle droppings. Possible burn or lightning strike in quad 4. Steep and rocky to north, appears similar to this plot. This plot is a good representation of forest interior conditions of this patch. No signs of cutting present. Abundant bird species observed.

Patch A.4 - General

Patch seems highly impacted along all edges. Interior is intact, but edge effects penetrate to about 20m. See descriptions for individual plots for this patch.

Plot A.5.1

Aspect:	140 SE
Slope:	38°
Elevation:	4175m
Date:	July 21, 1999

Category: Not impacted

Plot located near the center of patch on boulder field. 98% canopy cover. 70% moss-covered boulders with deep, loamy, springy soil in between. 5% herbaceous plants. 25% moss. No signs of cattle or cutting. Litter fall is abundant and plot is relatively open and easy to walk. Appears that due to little sunlight reaching forest floor, only those trees survive that have canopy exposure. Little *Polylepis spp.* regeneration – only in quad 4 are any seedlings abundant. Appears that dead trees in this plot were out competed for sunlight. Plot is located 300m in from eastern edge and 50m from southern edge. Eastern edge, north and south of plot of patch 5 are densely packed with both *Gynoxis spp.* and *Polylepis spp.* although west of plot appears to open up into boulder field. Surrounding this plot the patch has dense understory/thick. No grasses present. Abundant bird species observed.

Plot A.5.2

Aspect: 120 SE
Slope: 48°
Elevation: 4225m
Date: July 21, 1999
Category: Impacted (cattle and burning)

Plot is located along the northern edge of patch abutting grasslands; just below northern arm of patch where it bends to the east. 30% canopy cover. 20% grasses. 5% herbs. 20% rocks/boulders. 65% moss and dirt. Grasses end abruptly, running across quads 3 and 4. Tremendous amount of regeneration of *Polylepis spp.*, both seedlings and saplings. All seedlings and saplings show signs of severe burning but the intensity of fire did not kill the majority of the saps (this may be due to the lack of fuel to completely burn the crown of saps and seeds). All large trees in this plot show signs of severe burns as well. Cattle tracks and excrement are abundant. No signs of cutting. 18 holly counted in quad 1. Abundant charcoals from a recent burn found in all quads. Just south of plot, forest opens with large trees, both Polylepis and Gynoxis. Abundant mosses and regeneration. Grasses to the north and east of here are about 10cm tall, suggesting that the area has not burned in a couple of years. The majority of the dead *Polylepis spp.* found in this plot are saplings. Few bird species observed.

Plot A.5.3

Aspect: 161 SE
Slope: 24°
Elevation: 4175m
Date: July 21, 1999
Category: Not impacted

Plot located along lower edge of patch, 10m from stream (to south) and 10m from northern edge. 85% canopy cover. 60% boulders. 5% herbs. 35% soil/moss mix. Deep, springy, and loamy moss and soil mix. Large down branches and trees. Understory is very open. To the east, understory becomes dense, with abundant *Gynoxis spp.* and *Polylepis spp.*

saplings abundant. No grasses, no puna shrubs, no signs of cattle or cutting. Southern, northern and western edges all show signs of burning. Few bird species observed.

Patch A.5 - General

The whole northern edge of this part of patch shows increased sapling and seedling concentrations at edge with few large trees. All show signs of burning – but the patch seems to be expanding. Saplings and seedlings at edge extends about 10 to 15m into patch where forest gives away to large trees and a more intact structure. Patch, in general, occupies a rather rocky/boulder area. The matorral formations surround sections of this patch, which are quite rocky perhaps occluding cattle and allowing *baccharis spp.* and other species to establish.

Plot A.6.1

Aspect:	150 SE
Slope:	30°
Elevation:	4175m
Date:	July 21, 1999
Category:	Impacted (burning)

Plot located along the eastern edge of patch. 70% canopy cover. 10% grasses. 20% herbaceous plants. 30% rock. 40% moss and dirt. Semi-loamy and mossy. Open understory. Next to trail and grasslands (burned) to the north. No signs of cattle or cutting. Large trees in quads 3 and 4 show signs of scars from burns. Abundant deadfall. 70m up from river. Grasses are invading from the north, but are not seen beyond the plot further to the south. No puna plants or shrubs. Surrounding area seems similar to the east, west and south – boulders and mossy. Few bird species observed.

Outside of patch 6 in grasslands, very little regeneration or *Polylepis spp.*or *Gynoxis spp.* – some saps/seeds found but no more than 5m away from edge and usually protected in some fashion, e.g. a small slippage due to soil exfoliation created a pocket whereby *Polylepis spp.* established and grasses are about 1m away.

Plot A.6.2

Aspect:	340 NW
Slope:	24°
Elevation:	4150m
Date:	July 21, 1999
Category:	Impacted (cattle)

Plot located along the eastern edge of patch, 20m north of stream. 85% canopy cover. 70% boulders with moss cover. 10% herbaceous plants. 20% moss. *Ortiga* present. Deep, loamy, springy soil. No signs of cutting. Abundant deadfall (one dead *Polylepis spp.* with DBH of 60cm). To east, patch ends and grass/rocky savanna begins (on south-facing slope), with burned grasses visible. Some flowering plants present. Very large boulders bordering plot to south. Patch is similar to the north, though to west understory becomes more dense, with *Gynoxis spp* saplings becoming more abundant. Cattle tracks are abundant in and around the plot. Small saplings have been browsed on in this plot (by cattle or deer?). Very large fallen *Polylepis spp.* tree to the eastern edge of plot (5m) with DBH of close to 100cm. Few bird species observed.

Plot A.6.3

Aspect:	340 NW
Slope:	46°
Elevation:	4125m
Date:	July 21, 1999
Category:	Not impacted

Plot located in the center of patch on a steep boulder field, about 200m up from trail on south-facing slope of patch 6, about 50m to north cliff face. 60% canopy cover. 50% moss-covered boulders. 30% herbaceous plants. 20% moss. Soil is deep and loamy. Dense undergrowth of clover, *ortiga* and *Gynoxis spp.* seedlings. Abundant deadfall. No signs of cattle or cutting. Areas to west open up dramatically with strip of downed *Polylepis spp.* trees – perhaps due to wind fall. To the east, forest remains dense, looking similar in tree morphology and dense herbaceous undergrowth. To the north, also appears similar. Much undergrowth present where canopy opens up. Many old, dead trees also present and very large and tall live Polylepis and Gynoxis trees. Slope steepens above and below this plot. Hypochuerius species are present. In surrounding areas, high amount of Polylepis regeneration, interspersed with herbaceous plants (clover, Hypochuerius species, etc.). Gynoxis A present in area but not plot. No ichu nor puna plants or shrubs. Abundant bird species observed.

Plot A.6.4

Aspect:	139 SE
Slope:	11°
Elevation:	4000m
Date:	July 21, 1999
Category:	Impacted (cattle)

Plot located in center of patch in riparian area next to trail; 5m from stream set up on a flat bench. 60% canopy cover. 40% herbs and grasses (not *ichu*). 20% moss-covered boulders. 10% moss. 30% exposed soil and debris. Abundant deadfall. No signs of cutting, burning. Few signs of cattle. Open understory. To the north, steepens quickly, more boulders and a dense understory of *Gynoxis spp.* and *Polylepis spp.*. Much warmer than upper valley. Moist but not loamy. Taya and holly are present here (one of each in quad 2). Abundant bird species observed.

Plot A.6.5

Aspect:	340 NW
Slope:	65°
Elevation:	3890m

Date: July 21, 1999
Category: Impacted (cattle, burning, and cutting)

Plot located on a steep slope along the western edge of patch – at the at the mouth of valley and next to trail. 30% canopy cover. 25% shrubs (taya, holly, etc.). 20% moss. 15% grasses (*ichu*, *Puya weberbaueri*). 15% rocks. 25% cattle trails. Abundant deadfall – all trees have burn scars. Cattle tracks running through plot. Surrounding area is similar with evidence of cutting. To the north, slope steepens, grasses increase. In this part of the forest (since plot A.6.4) there has been a mix of *Polylepis* – both *sericea* and *weberbaueri*. There are 35 holly and 7 taya in this plot. Few bird species observed.

Plot A.6.6
Aspect: 318 NW
Slope: 35°
Elevation: 3860m
Date: July 21, 1999
Category: Impacted (cattle, burning, and cutting)

Plot located along western edge of patch. 15% canopy. 20% trail (cattle), 10% rock, 5% moss, 40% grasses (*ichu*), 15% shrubs, 10% herbs. All trees in plot show signs of burns. Signs of cutting in plot are abundant (15 in total). Abundant signs of cattle (trails and excrement). Regularly burned. Savanna/desert like – extremely dry and dusty. 60 *Baccharis spp.* and other shrub types. All trees have a stunted, shrub-like morphology and appearance except for 3 or 4 large ones. The surrounding area is similar. Severe burns all along this outter edge – especially after last plot 500m to the east. Few bird species observed.

Patch A.6 - General
This patch is the largest in the valley. Impacts appear to be most abundant along the eastern and western edges. Interior is intact except for areas along trail, which run through the middle of patch. See descriptions for each of the plots.

Appendix – 7

Interval and Descriptive Variables

Interval and Descriptive Variables

The following categories were derived from the *Forest Stand Field Notes* (see Appendix 6):

1) Impact Type and ID: a descriptive label for human impact type – None (0), Cattle (1), Burning (2), Cutting (3), Cattle and Cutting (4), Cattle and Burning (5), Cattle, Cutting, and Burning (6).
2) Impact Severity and Severity ID: Impact severity, interval variable, was defined as None (0), Light (1), Medium (2), and Heavy (3). These distinctions were made on the basis of careful review of the totality of empirical observations made in each plot and patch.
3) Plot Location and ID: a descriptive variable defined as Lower Edge (0), Interior (1), and Upper Edge (2).
4) Edge – Interior ID: a descriptive label for each plot defined as Edge (0) or Interior (1).
5) Plot Proximity to High Grasslands and ID: a interval variable used to describe a plots distance to areas that a typically burned and grazed, defined as Directly Adjacent (1), Nearby – within 10 meters (2), and Distant – beyond 10 meters (3).
6) Plot Proximity to Trails and ID. This variable is an attempt to define social distance rather than absolute distance to villages. By social distance I mean ease of accessibility. It is an interval variable used to describe a plots distance to trails and other areas regularly accessed by locals, defined as Adjacent (1), Very Close – within 10 meters (2), Close – 20 to 100 meters (3), Somewhat Far – 100 to 400 meters (4), and Very Far – greater than 400 meters (5).

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