REASSEMBLING THE LANDSCAPE: A HOLISTIC STUDY OF POLYLEPIS FOREST COVER CHANGE IN COLINA, TUNARI NATIONAL PARK, BOLIVIA

A Thesis in Geography

by

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ABSTRACT

This thesis project is a mixed methods study of changes in *Polylepis* forest cover in the community of Colina, Tunari National Park, Bolivia from 1991-2011. The project combines a time-series analysis of Landsat 5TM images with semi-structured interviews and ethnographic-style observations to explore changes in *Polylepis* forest cover in a holistic, landscape framework that places change in the context of multiple interacting processes. This approach to *Polylepis* forest research challenges dominant discourses in Andean biogeography that link the current distribution of *Polylepis* forest to simple cause-and-effect relationships with anthropogenic fire and grazing. Through a synthesis of multiple methods, this thesis argues that the deficiency of this dominant narrative is not scientific fallacy, but a spatial mismatch that results from a construction of these forest systems as discrete systems in the landscape. The thesis offers a new framing of the landscape that places *Polylepis* forests in an interconnected web of relations. This alternate framing highlights connections between social and ecological processes like changing climate, grassland productivity, regional and local economy, and peasant livelihoods that offer new possibilities for understanding the complexities of change in humanized landscapes like the Andes. Through a multi-scalar landscape level approach, this study finds that blaming grazing and fire for observed decrease and thinning of *Polylepis* forest in Colina is an over simplification that has led to conservation efforts that will likely harm local residents and fail to stop forest loss in the long-term. Based on the findings of this case study and an engagement with current scholarship on *Polylepis* and related systems, this thesis offers the hypothesis that *Polylepis* cover change in Colina is the result of a combination of ecological change and a lack of economic opportunity that has led to heavier reliance on forest resources. The research also
develops methods for the use of Landsat imagery in the study of *Polylepis* systems, and identifies key areas of focus for future research in these systems.
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Chapter 1

An Introduction to Holistic *Polylepis* Forest Cover Change Analysis in the Community of Colina, Tunari National Park, Bolivia

1.1 Introduction

Landscapes have so many different stories to tell. This is especially true in Tunari National Park, just north of Cochabamba, Bolivia. The park is a fascinating and intricate patchwork of rivers, alpine lakes, endangered *Polylepis* woodland relicts, potato fields, bunchgrass lands, and Quechua communities that have lived in the region for a millennia. Since European observers and scientists first began traveling through the greater tropical Andean highland there has been considerable debate over the extent of past forest cover and processes that produced the current distribution of forest systems in the region. As Young (1998) notes, however, the story of Andean deforestation is a story that is, in many ways, yet untold. This is partly due to the fact that the history of human habitation in the region reaches back to the beginning of the Holocene (approximately 12,000 years before the present (yrs B.P.)) (Baied & Wheeler, 1993; Young, 1998). In the case of *Polylepis* forest systems, which are of central importance to this case study, this is also due to the fact that there is relatively little known about the ecology of these systems.

The genus *Polylepis* (or *kewiña*, as they are known in Bolivia) is collection of roughly 28 species of arboreal angiosperm that are endemic to the central and northern Andes from central Argentina to Venezuela (Kessler & Schmidt-Lebuhn, 2006). Isolated patches of relatively closed canopy forest dominated by one or a few species of the genus are found within the alpine grassland communities, often 500-1000m (or more) above the continuous forest line. This rather
unique distribution, along with the extreme conditions in which these systems are often found (contiguous patches of *Polylepis tarapacana* are found in excess of 5200m on the slopes of Sajama volcano in western Bolivia, making them the highest altitude treeline community in the world) has led to considerable theorization on the genesis of current distribution. Some have argued that the patchy distribution is due to specific adaptation to microsite conditions, while others have argued that the tropical highland was once significantly forested – predominantly by *Polylepis* spp. – and that thousands of years of human activity have led to drastic declines in forest cover (Körner, 2003). A thorough discussion of these debates is included in chapter 2, so I will not reiterate it here. However, in the last twenty years, the latter, human driven, hypothesis of *Polylepis* forest distribution has risen in prominence, and had significant influence on conservation practice. Yet the reality is that little is known about the actual response of *Polylepis* forest systems to fire and grazing, which are identified as the predominant drivers of forest loss. Furthermore, there have been very few studies that have actually quantified changes in *Polylepis* forests over time (and it should be noted that neither of the three studies that I am aware of found significant decreases in cover (Byers, 2000; Jameson & Ramsay, 2007; Tohan, 2000)).

This case study seeks to respond specifically to that lack of knowledge, and to find a more holistic approach to the study of *Polylepis* forest systems that better captures the myriad social and biophysical processes that shape the Andean landscape.

1.2 Purpose of the Study

Despite several decades of scholarship in political ecology and related fields, there are still numerous cases in which the various components of the landscape are bracketed apart, and the holistic essence of the landscape is lost. In Tunari National Park, and the Andean highland in
general, this story has frequently taken the narrative form of human vs. *Polylepis* forest (Fjeldså & Kessler, 1996; Hensen, 2002; Kessler, 2002) that results is an uncritical presentation of campesino communities and potentially ineffective conservation strategy.

I argue that these simplified narratives are a product of modernity (Merchant, 1990), and a lingering bad habit in human-environment scholarship (Field, Voss, Kuczenski, Hammer, & Radeloff, 2003; Nassauer, 1995; Naveh, 2000; Robbins, 2001). An example of this in Tunari National Park (and one that is central to this proposed research) is that of livestock herding and *Polylepis* forest. This relationship is frequently portrayed as adversarial, with herding posing the greatest threat to the future of *Polylepis* forest in the region (Ellenberg, 1979; Fjeldså & Kessler, 1996; Fjeldså, 2002a; Kessler, 2002). And there is empirical evidence supporting this position. But herding is an integral part of the landscape (Gade, 1992), and cannot be removed or significantly modified without causing ecological alterations—some of which may be severe and poorly understood. Furthermore, herding practice is much more than a biophysical calculus; it is a complex social, cultural, and economic process as well. Understanding how livestock herding affects *Polylepis* forest in the region necessitates engaging with the ways in which these socio-cultural factors are integrated into herding practice. These human/social processes are landscape processes that affect, and are effected by myriad other social and biophysical processes in the landscape. Yet little research on the subject *Polylepis* forest cover change has taken this approach.

What is needed, then, is a holistic framework for landscape research that can integrate the human and the biophysical together to provide more complex and accurate assessments to inform development, conservation, and land change analysis. A considerable amount of excellent theoretical work already exists that aims to break down the division between nature and culture
in western thought (Braun, 2006; Braun & Castree, 1998; Braun, 2008; Cronon, 1996; Whatmore, 2001). More empirical research is now necessary to support this theoretical work and advance progress toward a more holistic approach to human-environment scholarship. Pursuant to this goal, this case study adopts a holistic landscape framework that integrates methods from landscape ecology and environmental social science to better understand the complexities of *Polylepis* forest cover change in the community of Colina\(^1\) in the Tunari Mountains just north of the city of Cochabamba, Bolivia.

The empirical work that follows accomplishes two principal goals, which I argue are the major contributions to scholarship made by this case study. First, this case study better places *Polylepis* forest cover change in the context of the Andean highland landscape. From this holistic perspective, observed changes in *Polylepis* forest cover are understood as the product of interacting biophysical and social processes, rather than the unidirectional result of anthropogenic disturbance. This perspective challenges the dominant discourse of *Polylepis* forest distribution and conservation (see chapter 2) that uncritically identifies peasant agropastoral practices as the primary drivers of forest loss. The holistic landscape perspective generated by this case study then creates new opportunities for *Polylepis* forest conservation that can be more socially just and ecologically effective. More generally, this work also makes important contributions in extending the work of political ecology into Andean forest systems.

This case study also makes several contributions to the study of Andean biogeography. There have been relatively few studies in the literature on *Polylepis* forests that conduct forest cover change analysis, and none that I am aware of that use satellite remote sensing. This case study therefore makes an essential contribution to scholarship on *Polylepis* forest systems by

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\(^1\) Colina is a pseudonym for the name of the actual community where I conducted this research. This is used both to comply with the parameters of my IRB approval, and to protect the residents of the community from any legal action – either by the authorities at Tunari National Park or in the local Agrarian Syndicate.
documenting forest cover change in Colina from 1991-2011. And by synthesizing this change analysis with qualitative data, this case study provides critical insight into potential drivers of Polylepis forest cover change that can then become the focus of future research. Additionally, by successfully using satellite remote sensing for change detection in Polylepis systems, this case study makes methodological contributions to high altitude forest cover monitoring, both in the central and northern Andes, and potentially to other regions of the world.

1.3 Conceptual Frameworks

This case study seeks integrate perspectives and methods from the fields of landscape ecology, biogeography, political ecology, and human ecology. The goal of this synthesis is to draw on the strengths of all these fields to construct a holistic framework for landscape research. While each of these fields is distinct in scope and perspective, there remains significant overlap at the margins that allows for fruitful dialogue in support of this project.

1.3.1 Landscape Ecology and Biogeography

Landscape ecology was established in the United States in the early 1980’s, introducing critical concepts of scale to the study of ecological processes with attention to how processes relate to patterns in space (Turner, 2005). Landscape ecology is, in a sense, a relational network approach to the study of ecological processes, with special attention to connectivity across space (Goetz, Jantz, & Jantz, 2009; Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005), and the flux of energy and nutrients through the landscape network (Forman & Godron, 1981). As a field of study landscape ecology analyzes all relevant processes – both human and non-human in origin – that shape the landscape. Text books are devoted to the tools and theories of this science, but three components of the field are of particular importance to this case study: 1) spatial and temporal connection, 2) hierarchical structure, and 3) the incorporation of humans.
Spatial connectivity in landscape ecology is readily apparent. Forman and Godron (1981) define a landscape as a physical space comprised of smaller patches (distinct ecological units) that are linked in space through shared processes. They describe the spatial pattern of patches in the landscape changing as species, nutrients, and disturbances travel through the network of the landscape mosaic. The study of nutrient cycling and disturbance regimes has a necessary temporal component, but there is another sense in which the ecological study of landscapes stresses temporal connection. The “shifting-mosaic steady state” concept stresses the importance of spatial and temporal scale in landscape change (Bormann & Likens, 1979, p. 667). This theory suggests that temporally dynamic patches in a spatially and structurally connected landscape mosaic produce long-term stability at the landscape scale (Bormann & Likens, 1979; Perry, 2002; M. G. Turner, Romme, Gardner, O’Neill, & Kratz, 1993). Furthermore, the non-equilibrium paradigm in ecology understands landscapes to be in flux between many different states, all of which can be considered a ‘steady-state’ if framed at the appropriate temporal scale (Turner, Gardner, & O’Neill, 2001; Turner, 2010; Zimmerer, 1994). At any moment in time, then, a landscape is connected in a temporal network linking nodes that represent its many states of existence. Understanding landscape connectivity is crucial to Polylepis conservation because it puts the myriad ecological processes and member communities in dialogue and draws attention to long-term trajectory.

Hierarchical landscape models, too, present a relational network in which “minimal structures” at smaller scales link together through shared processes to form complex “configurational structures” at larger scales that comprise the landscape (Pickett, Kolasa, Armesto, & Collins, 1989). These networks are framed as open systems that disassemble and

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2 I follow this definition of landscape for this thesis, and unless otherwise note in the text, I do not engage significantly in theoretical discussions stemming from the area of scholarship known as Cultural Landscape Studies.
reassemble in new configurations as landscape processes change. Hierarchy in the ecological sense is not a linear hierarchy of value or power, but rather a tree-like structure in which components increase in complexity as they converge, and through which all are connected. This case study adopts Naveh and Lieberman’s (1994) systems approach to landscape hierarchy that integrates humans and social processes into the higher levels of the landscape hierarchy. This understanding of the landscape necessitates a holistic view of *Polylepis* forest cover change in which ‘human’ and ‘natural’ processes mutually affect each other and must be considered in concert.

In fact, landscape ecology has a tradition of recognizing humans as part of the landscape (Forman & Godron, 1981; Naveh & Lieberman, 1994; Turner et al., 2001).³ In addition to a commitment to understanding the relationship between humans and the biophysical landscape, there have been increasing calls from within the field to explicitly engage with human/social processes. Nassauer (1995), for example, argues that cultural processes are equally important in shaping the landscape as biophysical processes. Furthermore, she argues that landscape ecologists must develop “normative models for managing landscapes” that can work with culture to improve ecological function (p. 236). Field et al. (2003) argue that landscape ecology must pay more attention to the fact that social processes are “an integral part of landscape change” (p. 351), and that human/social and biophysical/landscape systems interact and co-produce each other. There have also been recent calls from within the field of landscape ecology for practitioners to direct their research toward alleviating poverty (Pijanowski et al., 2010), which may suggest a definitive shift in the field toward dissolving dualistic ontologies of nature and

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³ To what extent landscape ecology in practice considers humans (and socio-cultural processes) to be integrated components of the landscape is a point of debate that is beyond the scope of this study.
culture. This is an important trend that creates an opportunity for research like this case study to critically synthesize social and ecological research.

This case study also draws on, and contributes to, landscape ecology and biogeography research in the Andes. While land cover change analysis has been an active area of scholarship for several decades, relatively little of this work has been done in the tropical Andes. This is due in part a lack of long-term monitoring sites in the region, and to topographic and climatic challenges that make the use of remotely sensed images and photographs comparatively more challenging (Echavarria, 1998; Keating, 2007). This study builds on the work of Echavarria (1998), Kintz et al. (2006), Brandt and Townsend (2006), and Postigo et al. (2008) in adapting methods for satellite remote sensing image analysis to the difficult terrain of the Andes in order to better monitor land cover change. More specifically, this case study seeks to expand on the work of Byers (2000), Tohan (2000), and Jameson and Ramsay (2007) in *Polylepis* forest cover change analysis. These studies – the only forest cover change analyses in *Polylepis* systems of which I am aware – utilize repeat photography and aerial photo analysis to track changes in extent and quality of *Polylepis* cover in the Peruvian Andes. Tohan (2000) also uses Landsat imagery, but the analysis is much simpler than that of this study. This case study expands the reach and methodology of their work by exploring the Bolivian Andes and utilizing multiple satellite remote sensing images and detailed spectral analysis. This greatly expands the potential for future *Polylepis* forest system research by demonstrating the effectiveness of methods and tools commonly used by landscape ecologists in other regions (Naveh & Lieberman, 1994; Turner et al., 2001).

This research is also situated in the literature on *Polylepis* forest systems. Specifically, this research seeks to add complexity to the human-*Polylepis* narrative that tends to emphasize
unsustainable human land use (Fjeldså & Kessler, 1996; Fjeldså, 2002a; Hensen, 2002; Kessler, 2002). This research will make an important contribution to recent literature that explores the relationship between livestock grazing and Polylepis forest patches. Several recent studies have had mixed findings on the effects of browsing, trampling, and fire (all associated with herding in the Andes) on Polylepis forest regeneration (Cierjacks, Rühr, Wesche, & Hensen, 2008; Cierjacks, Salgado, Wesche, & Hensen, 2008; Pollice, Marcora, & Renison, 2012; Torres, Renison, Hensen, Suarez, & Enrico, 2008; Zimmermann, Renison, Leyer, & Hensen, 2009). By combining a qualitative study of livestock herding practice with Polylepis forest cover change analysis, this case study provides a greater context for extant research, and identifies directions for future research on these important relationships. This case study also responds to paleoecological research on Polylepis forest cover, and highlights the need for greater attention to long-term climate trends in future research on the dynamics of these highland forest systems (ex: Gosling, Hanselman, Knox, Valencia, & Bush, 2009; van der Hammen, 1974; Williams, Gosling, Brooks, Coe, & Xu, 2011). A much more thorough engagement with this and other research on Polylepis forest systems can be found in the next chapter.

1.3.2 Political Ecology and Human Ecology

Landscape ecology provides a lens for integrating ‘human’ and ‘natural’ communities and processes into a research framework, but it pays insufficient attention to power and discourse. To address this issue, this research incorporates ideas from political ecology.

Political ecology has grown since the 1980’s to encompass a majority of the research now conducted in the nature-society subfield of geography (Turner, 2009). While there is a diverse range of research foci under the banner of political ecology, the field can be succinctly defined following the classic description offered by Blaikie and Brookfield (1987) as a synthesis of
“concerns of ecology and a broadly defined political economy” (p. 17). Within the diverse field of political ecology, this case study is situated within the subset of work that explicitly engages with biophysical science (Turner, 2009; Walker, 2005). This research follows Zimmerer (2003) in understanding the landscape of Colina in Tunari National Park to be a product of the biogeophysical characteristics of the region and the specific livelihood strategies of local residents. This political ecological position is particularly important when considering the geographic distribution of Polylepis forest stands in the landscape, providing a useful foil to apolitical ecological accounts that suggest that the landscape would be (or should be) largely forested but for human disturbance (e.g. Fjeldså & Kessler, 1996).

This research also benefits from political ecological research on scale. Ecological and socio-political processes operate at multiple scales and interact to produce complex spatio-temporal patterns and processes in the landscape (Sayre, 2005; Zimmerer & Bassett, 2003). Of central importance to better Polylepis forest cover change analysis is understanding not only the scale interactions of complex landscape processes, but the power dynamics across and between scales that produce certain narratives of environmental change (Neumann, 2009).

A critical engagement with environmental change narratives observes where power lies in the process and how narratives compare to empirical observation. In so doing, this research engages with the political ecology of scale in two distinct ways. First, following Sayre (2005) care must be taken to ensure that the ‘epistemological’ and ‘ontological’ moments of scale align. In other words, are observations of the environmental change in question taking place at a level that sufficiently captures the processes involved? This line of analysis compliments the hierarchical systems approach outlined above by acknowledging that processes at one scale are often driven by and manifest themselves at multiple other scales of analysis.
Also important to this study is what Rangan and Kull (2009) refer to the translational moment of scale. The translational moment describes the process by which observations become discourse. Engagements with discourse analysis in this case study also benefit considerably from research that combines political ecology and Science and Technology Studies (STS) (Forsyth, 2003; Goldman, Nadasdy, & Turner, 2011). This scholarship provides a lens for analyzing the ways that scientific knowledge is produced, contested, and mobilized for certain purposes. In the next chapter, I use the tools of STS to analyze the process by which some of the research on *Polylepis* forest systems developed into a discourse on the Andean highland landscape, producing spaces for *Polylepis* conservation that are mismatched to many of the processes that are likely influencing change. Drawing on these critical tools from political ecology and STS, this case study is able to effectively challenge dominant discourse in *Polylepis* forest systems and, following Forsyth (2008), reconstruct a more holistic explanation of *Polylepis* forest cover change that might lead to more socially just and ecologically effective conservation.

This case study is also situated within the extensive literature in human ecology that explores human pastoral practice. Human ecology – often discussed as a precursor to political ecology – is a field of human-environment research that explores either human adaptation to hazards, or the relationship between human culture and the biophysical environment (Turner & Robbins, 2008). Stott and Turner (1998), and Butt (2010) are excellent examples of human ecology literature that explores the ecological effects of spatio-temporal variation in peasant herding practice in Mali, and Kenya, respectively. Human ecology research has also demonstrated in the past that the management of livestock in rural communities is based not only on biophysical resources, but on political economy, social necessity, and situated environmental knowledge (Robbins, 2003; Turner & Hiernaux, 2008; Turner, 2003). This research project will
augment this body of literature by focusing on the central Andes, and *Polylepis* forests in particular, which have received much less attention from scholars studying pastoral ecology (Postigo et al., 2008).

There is also an established practice of incorporating remote sensing and GIS in human ecological research on pastoral practice (Butt, 2010; Postigo et al., 2008; Robbins, 2003; Turner & Hiernaux, 2002). This proposed research will expand upon this practice by integrating participatory qualitative methods with remote sensing analysis to draw connections between the socio-cultural aspects of herding and changes in the patch characteristics of *Polylepis* forest.

1.4 Study Area

Originally created in 1962, Tunari National Park (TNP) is the second oldest protected area in Bolivia (Boillat, Rist, Serrano, Ponce, & Delgadillo, 2008). The park was originally created as a means for reforestation and erosion control in response to severe floods that occurred in Cochabamba in the late 1950’s. Greatly expanded in 1991, the park now encompasses a majority of the Tunari Mountain Range and the mountainous territory that stretches northward away from the city of Cochabamba totaling over 300,000 ha in area (see figure 1.1) (Boillat, 2007). There is some contestation within the country as to whether the park actually meets the biodiversity requirements stipulated by Bolivian law for designation as a national park, and strict enforcement of environmental regulations is currently only enforced within the original 1962 borders adjacent to Cochabamba (Boillat et al., 2008). Despite these national debates, researchers report that the region of Tunari National Park is an important area for biodiversity in highland Bolivia, particularly for numerous threatened *Polylepis* tree species and the endemic flora and fauna that are associated with these forest systems (Fjeldså 2002;)

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4 The designation of ‘National Park’ is the most restrictive level of protection in Bolivia, and is supposed to be based on the results of ecological and biodiversity surveys, which were not conducted in the Tunari case (Boillat, et al., 2008).

The Park is also home to approximately 350 Quechua peasant communities that have been living in the region since the pre-colonial era (Boillat, 2007). These communities range in size from fifteen to twenty families to in excess of one hundred family units. The primary livelihood strategy consists of agro-pastoral production. A variety of crops are cultivated along an altitudinal gradient, with maize, barley, wheat, and other grain crops cultivated at the lowest
elevations, and beans, potatoes, and other root crops like oca and papa lisa cultivated at higher altitudes. Mixed herds of cattle, sheep, llama, and alpaca are kept as well, though individual herd size varies significantly from family to family depending on resources (both labor and capital). Livestock are both extensively grazed in highland pastures and fed a mixture of cultivated fodder such as oats and barley during the dry season. Livestock in these communities are a means of asset storage as well a source of meat and dairy for consumption. Manure is carefully distributed to fertilize agricultural plots, and cattle are frequently used as draft animals.

There is a significant amount of labor migration to the city of Cochabamba, primarily in the southern region of the park that borders city. As in other parts of the Andes (Bebbington, 1998; Preston, 1998), it is also quite common for residents to migrate out of the region on a more permanent basis to other Bolivian cities or the eastern lowlands, as well as to Chile, Argentina, Spain, and the United States.

Communities were organized into agrarian syndicates under the Agrarian Reform of 1952, and these civic forms of organization are often blended with traditional Quechua forms of communal governance. Over ninety percent of the population within the park lives below the national poverty line (Boillat et al. 2008).

The community of Colina were this case study is set is located on the southern slope of the Tunari Mountains facing the Cochabamba valley. The territory of Colina covers an altitudinal range spanning from approximately 3000-4100m above sea level (asl). There are somewhere between thirty and fifty families in the community (though I was told quite contradictory things by various people). I spoke with people from about twenty different families while in Colina. Nearly everyone in Colina engages in off-farm work in Cochabamba or elsewhere, as is typical in TNP. It is possible that the rate of migration and off-farm employment in Colina is higher than
average, however, given its proximity to the city and to a major trucking route that makes transportation more feasible.

Colina has relatively no modern amenities. Many, but not all, homes have a gravity-fed water spigot that is supplied from a local spring, but there is no modern sanitation, save for one bathroom at the school. A project was under way while I was in the field to construct communal bathroom facilities, though it was unclear what the timeline was for completion. There was no electricity in the community save for a few small solar arrays at the school building. The school itself is the center of the community, and it is staffed by three teachers that travel back and forth from Cochabamba on a weekly basis. As of 2012 the school did not offer a high school diploma.

Colina is home to one of the largest remaining Polylepis forest stands in TNP. The community also has much smaller stands of native Aliso, as well as exotic Eucalyptus and Pine, but the Polylepis is the primary source of fuel wood for the residents of Colina. Colinanos also practice agroforestry in parts of the Polylepis forest, and actively graze livestock on the grass understory. The presence of a significant Polylepis forest in conjunction with extensive and historic human use makes Colina an excellent site for this case study.

1.5 Methods

This case study was designed to synthesize data from multiple sources to capture a more complete accounting of the processes involved in Polylepis forest cover change. Collecting data from numerous sources and analyzing it through different means provided multiple points of triangulation. As will be demonstrated in the chapters that follow, this means of verification provided this case study with an internally valid data set, which adds strength to the findings.
Forest cover change was analyzed through a comparison of satellite remote sensing images from the Landsat 5TM platform that were classified with ground truth data collected in the study area during July of 2012. Ground truth points collected in situ were then augmented when necessary using high spatial resolution imagery obtained from ESRI and Google Earth (Witmer, 2008). Polylepis forest cover change was analyzed at five year intervals beginning in 1991 and ending in 2011. This strategy increased the computational time needed for analysis, but it allowed me to capture more fine-grained temporal detail in forest cover change, and query the extent to which changes in Polylepis forest cover may be cyclical. This use of numerous satellite images (five, in this case) has only recently become practical with the advent of new legislation passed in 2008 that made the entire Landsat archive freely available online (Wulder, Masek, Cohen, Loveland, & Woodcock, 2012). In this way, the methods used in this case study are also a test case of new approaches to forest cover monitoring, especially in regions like the tropical Andean highland where there are few long-term monitoring sites. A full accounting of these methods is included in chapter 3.

Perceptions of environmental change, as well as data on social, economic, and biophysical influences on change were collected from the residents of Colina via semi-structured interviews and ethnographic-style observations. Interviews were conducted in Spanish by me, with the aid of a research assistant from Colina whom I hired to translate from Quechua to Spanish. These interviews followed an interview guide (see Appendix C), with variations as new themes arose. Observation data was collected throughout my time in Colina, and this includes notes on the appearance of the Polylepis forest, observations of livestock, and informal conversations with Colinanos during car rides and around the community plaza. Each round of qualitative data collection informed future efforts in an iterative fashion. For instance, after one
interviewee mentioned charcoal production I began to discuss this issue in all subsequent
interviews, and take note of signs of production in the forest. All of this data was analyzed using
NVivo qualitative data analysis software to identify the emergent themes. A more thorough
accounting of this process is included in chapter 4.

Together these methods provide quantitative data on *Polylepis* forest cover change in
Colina from 1991-2011 informed by qualitative data on perceptions of change, as well as land
use practices, economic circumstances, and other biophysical processes. This places observed
change in the context of the greater landscape, and provides a means of indentifying social and
biophysical processes that are potentially involved with *Polylepis* forest loss.

1.6 Toward a Holistic Ecology

This case study includes three distinct parts, all of which are integral to the holistic
landscape approach. Chapter 2 is a discourse analysis focusing on the rise in prominence of
certain interpretations of *Polylepis* forest distribution and conservation, and how the dominance
of this narrative has lead to a misreading of the landscape. This serves two purposes. First, it
presents a thorough discussion of the scholarship on *Polylepis* forests to provide a greater context
for this case study. The analysis in chapter 2 also situates the work of this case study as a specific
response to this dominant narrative of *Polylepis* forest.

The third chapter details the results of a *Polylepis* forest cover change analysis in the
community of Colina from 1991-2011. This chapter provides valuable data on actual change in
forest cover, which is lacking from much of the literature on these systems. Observations of
change found in this chapter provide a reference for the work of identifying potential factors in
Polylepis forest loss. The results of this analysis are then placed in the context of the larger debate on forest cover change in the region.

Chapter 4 details the findings of qualitative research with the community members of Colina. This component of the case study provides valuable insights into how social processes inform land use, and how changes in the biophysical environment affect land use and livelihoods. This type of data is generally missing from studies of Polylepis forests, which I argue has contributed to misidentifying drivers of change in these systems.

The final chapter of this study synthesizes the data from chapters 3 and 4 to present a response to the dominant discourse identified in chapter 2. This synthesis also makes the case for the holistic framework used in this case study as a better means of analyzing land cover change and identifying conservation strategies that have the potential to be more socially just and ecologically effective.
Chapter 2

Landscape, Subject, and Intervention: Discourse Analysis of Polylepis Forest in Bolivia

2.1 Introduction

Discourse, or the way issues are discussed and problems framed, is an important area of research in Political Ecology, Science and Technology Studies, and related fields (Forsyth, 2003; Goldman, et al., 2011; Hajer, 1995; Robbins, 2011). This involves more than just analyzing what is said, but also the institutional and political context in which statements come to be considered as true (Forsyth, 2003; Hajer, 1995). Polylepis forest research is a contested area of natural science yet some of this scholarship has effectively mobilized its findings to support a discourse of forest degradation that has influenced conservation policy in Bolivia and specifically in Tunari National Park (TNP) where this case study research was conducted. This scientific discourse of Polylepis has three chief accomplishments, all of which will be challenged in the following analysis, as well as in the empirical work found in subsequent chapters.

The first accomplishment is the discursive construction of an Andean landscape that is naturally forested and without people – or at least without people engaged in peasant livelihoods. This constructed landscape contributes to the production of a subject, the campesino\(^1\), incapable of conserving Polylepis forests. This is the second accomplishment of the discourse. These discursive accomplishments then produce space for specific conservation interventions. At stake in this Polylepis discourse are the livelihoods and well-being of the campesino communities that live in and around the forests as well as the future of these unique forest systems.

\(^{1}\) Campesino is the Spanish term for peasant that is commonly used in Bolivia. I use the term campesino in this text to refer to individuals living in specific communities in rural Bolivia. I use the term peasant in the generic sense to refer to individuals living in rural communities engaged to some extent in subsistence livelihoods.
As will be argued here, and in the following chapters, this dominant discourse presents the Andean highland landscape and its peasant communities in problematic ways. Likewise, the types of conservation interventions it solicits are unlikely to address observed decreases in *Polylepis* forest cover, much less do so in a socially responsible manner. To accomplish this I use the tools of Science and Technology Studies (STS) to deconstruct and analyze this environmental discourse. STS is an evolving interdisciplinary field that explores the complex interconnections between politics, culture, and scientific knowledge. In so doing, this scholarship often presents science and society as co-produced (Goldman et al., 2011). This focus on the production of scientific knowledge, and the process through which scientific explanations become accepted ‘truths,’ (Forsyth, 2003; Goldman et al., 2011), will provide a sharp lens for analyzing the development of *Polylepis* conservation discourse.

This remainder of this analysis will take place in four parts. First, I will discuss the production of scientific knowledge on *Polylepis* forest systems and the debates about their place in tropical Andean biogeography. I will then explore the ways in which some of this knowledge was mobilized to produce a discourse of the Andean highland landscape. The third section of this analysis focuses specifically on the ways that this discourse frames the campesino subject. The final section of analysis demonstrates the ways that this discourse then produces specific spaces of conservation intervention. Each step along the way, I will challenge this discourse by presenting confounding scientific evidence and suggesting ways in which this discourse will lead to social suffering and ineffective forest conservation.
2.2 Production of Scientific Knowledge

The dominant discourse of *Polylepis* forest change that is the focus of analysis in this chapter is best understood in the context of the larger debate on the origins of tropical Andean biogeography. In the Andean tropics the alpine zone is divided into a humid region found in the north, referred to as *páramo* (figure 2.1), and arid and semi-arid regions found in the outer tropics and the Andean plateau that is referred to as the *puna* (figure 2.2).

Páramo communities dominate the Andean alpine from northern Venezuela to central Peru at elevations ranging from about 3000-4500m above sea level (asl). Páramo communities are also found in the alpine zone of Costa Rica. The páramo is one of the most species rich grassland systems in the world, with populations including an estimated 112 families, 479 genera, and an estimated 3000-4000 species (Ramsay & Oxley, 1996). Páramo is often divided into three sub-groups: the shrub dominated *subpáramo*, the *grass páramo* dominated by tussock grasses, and the sparse and less diverse *superpáramo* that exists above the upper maximum treeline – usually around 4200m asl.

The term *puna* is generally used in the literature to refer to the biogeography of the inter-Andean plateau, an area that stretches from central Peru through a large portion of Bolivia and
into northern Argentina and Chile (Baied & Wheeler, 1993). These communities are less diverse than the páramo, often appearing as sparse bunch grasslands interspersed with small shrubs. The puna is also defined by low annual precipitation, ranging from 700 mm per year in the more humid east to regions in the south and west that receive as little as 100 mm of precipitation per year (Kessler 2002). The puna can be divided into three geographic regions based on climate and soil conditions: the moist puna to the northeast, the dry puna found in the north-central section of the plateau, and the salt puna in the southwest, so named for its saline soils and large prehistoric salt deposits (Baied & Wheeler, 1993). In the case of both the Páramo and the Puna, paleoecological research dates the origins of these systems to the late Pliocene or early Pleistocene, roughly 2 million years before the present (yrs. B.P.) (Lauer, 1981; Salgado-Labouriau, 1986; van der Hammen, 1974).

The forest line in the central and northern Andes is generally found between 3000-3500m asl (Fjeldså & Kessler, 1996; Horn & Kappelle, 2009). Forest line is defined in various ways by ecologists, and for consistency I follow Cairnes et al. (2007) in defining the forest line as the altitudinal limit to continuous, closed canopy forest cover. Within the Puna and Páramo above
the forest line are found isolated and often small patches of forest composed almost exclusively of one or a few tree species of the genus *Polylepis*. These forests are found anywhere from 500 – 2000 meters above the forest line (Kessler, 2002). The ‘treeline’ is commonly defined as the patchy ecotone above the forest line and below the altitudinal limit to arboreal vegetation (Cairns et al., 2007), which then classifies these *Polylepis* forests as the treeline system in the central and northern Andes.

This definition of tree line is difficult in this regional context, however, because of the large extent of the altitudinal gradient, and because *Polylepis* systems generally form contiguous and well defined forest patches that are more similar to forest line systems (Körner, 2003). For nearly a century botanists and other natural scientists have speculated and debated the possible causes of this unusual geography.

Until the middle of the twentieth century the distribution of *Polylepis* forest was believed to be the result of climatic and edaphic conditions (Kessler, 2002).² This hypothesis on *Polylepis* distribution is an amalgam of what Körner refers to as the “shelter hypothesis” and the “fossil hypothesis” (Körner, 2003). The shelter hypothesis argues that *Polylepis* forests are distributed as they are because microsite conditions to which the genus has specifically adapted. The fossil hypothesis is a subtle variation on the shelter hypothesis that argues that *Polylepis* evolved a fit to climatic conditions that are no longer extant, and that its current distribution reflects those populations that were able to persist in climatic refugia (*ibid*). These hypotheses are still actively supported by some researchers – mostly paleoecologists and paleoclimatologists – and climate has been suggested as the primary driver of *Polylepis* cover change in several recent publications

² The majority of this early scholarship was produced by German scientists and published in German language journals. Due to language barriers, a review of this literature is unfortunately beyond the scope of this thesis.
(Gosling, Hanselman, Knox, Valencia, & Bush, 2009; Williams, Gosling, Brooks, Coe, & Xu, 2011; Williams, Gosling, Coe, Brooks, & Gulliver, 2011). Andean paleoecology is an important area of scholarship, and I will discuss it in more detail shortly.

In 1958 Heinz Ellenberg published (also in German) a paper arguing that the tropical Andean highland was once largely forested, and that the current distribution of forest was the result of hundreds or thousands of years of human activity, what Körner calls the ‘remnant hypothesis’ (Ellenberg, 1979; Kessler, 2002; Körner, 2003). Ellenberg’s work, and subsequent work based on his hypothesis, is best understood as a scientific response to the prevailing climate based theories that had become axiomatic in the first half of the twentieth century. In his 1977 Tansley lecture to the British Ecological Society (Ellenberg, 1979) Ellenberg marshals several pieces of evidence to support his hypothesis of a forested Andean highland. First, and principally, Ellenberg offers the observation that in the tropical Andean alpine region, native forest (i.e. not Eucalyptus or Pine) is found to grow in many different edaphic and microclimatic conditions. Furthermore, he notes that *Polylepis* has been observed colonizing abandoned agricultural terraces in Peru without human introduction. All this, he argues, overwhelmingly suggests that the current forest line and the patchy distribution of highland forest are not limited by climate or microsite conditions. Ellenberg then supports this with evidence from early climatic modeling that generated land cover maps that associate “climax vegetation types” with climatic regions (Ellenberg, 1979, p. 407). He suggests that the difference between these ideals and current land cover is due largely to human agriculture, livestock herding, and the use of fire that is commonly associated with both. Fire, Ellenberg notes, is most certainly a human invention in the Andes (as opposed to Africa) where there is little evidence of lightning caused
ignition. He then supports this evidence with descriptive examples of land use and land cover in the region that are contrary to his climatic ideal.

Ellenberg’s argument is nearly identical to those of more recent proponents of the remnant hypothesis such as Laegaard (1992) and Kessler (1995). Though he offers no statistical data, Kessler (1995) also reports that test plots where fire and grazing were removed are quickly colonized by *Polylepis* seedlings (though it is not possible to vet this remark without knowing more details). Fjeldså (1992) arrives at similar conclusions to Ellenberg, though he uses the habitat patterns of Andean birds to support his claims. He notes that there are many bird species in the region that sometimes use *Polylepis* habitat but relatively few *Polylepis* specialists. Fjeldså argues that this indicates that these forests systems where recently much more common than at the present. Similarly, Vuilleumier (1984) argues that the lack of significant genetic variation in the *Polylepis* specialist the Giant Conebill suggests that the fragmentation of the forest (and the species) is relatively recent. It should be noted that Vuilleumier also presents several other hypotheses for the lack of genetic variation that do not include recent fragmentation of *Polylepis* habitat.

Ellenberg and his later supporters offer a compelling counterpoint to the shelter/fossil hypotheses. Of course, from the perspective of current science, Ellenberg’s notion of climate-determined “climax vegetation” a la Fredrick Clement is problematic (see: Botkin, 1990; Drury & Nisbet, 1971; Peet, 1992). Kessler (2002) also reports that Ellenberg’s hypothesis was severely criticized until the late 1980’s. Much of this work is also in German, but Simpson (1979) offers a critique in English on several points. First, he notes that Ellenberg uncritically correlates the existence of patches of forest at high elevations with the notion that these forest could grow in many areas, citing a study by Smith (1978) that found *Polylepis sericea* unable to establish in the
open Páramo of Venezuela. Simpson suggests that the significant geographic isolation of different Polylepis species suggests that these forests have been significantly fragmented for much longer than Ellenberg suggests, and he takes Ellenberg to task for incorrectly comparing the climate of the Mediterranean with that of the Andes. Critique aside, however, the evidence offered in support of the remnant hypothesis suggests that the current distribution of Polylepis forest in the Andes is not wholly determined by climate and edaphic conditions, or at the very least, that these are not the only factor inhibiting lateral expansion (Cierjacks, Wesche, & Hensen, 2007). What coverage may have been like in the past is another matter. Yet paleoecological evidence is conspicuously absent from arguments in favor of the remnant hypothesis.

There have been significant advances in paleoecological research in the Andes in the last seven to ten years, but even in the 1970’s and 1980’s there were extant studies that did not support the remnant hypothesis. In 1974 van der Hammen published an extensive accounting of climatic and vegetative change in South America during the Pleistocene and early Holocene (van der Hammen, 1974). Van der Hammen finds, drawing on pollen records and sediment analysis data from multiple sites, that the forest line in the Andean tropics has fluctuated significantly in conjunction with climatic and glacial shifts for approximately the last two million years. This evidence suggests that the forest line has at times been at least 1500m lower than its current location, but not significantly higher. Van der Hammen also finds that the grass-dominated systems currently found in the Páramo have been significant constituents of the region for much longer than the age of human habitation (approximately 12,000-15,000 yr B.P. (Baied & Wheeler, 1993)). In regard to Polylepis distribution, this study finds that these forests were only

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3 This paper has received 603 citations (GoogleScholar, 5/2/2013) to date, and was the first major scholarship of its kind in the Andes (Simpson, 1979).
a significant portion of ground cover during a relatively humid period approximately 30,000 yr B.P., and that the genus (as well as all other trees) became virtually extinct with the onset of dry conditions roughly 21,000 yr B.P. Significantly, van der Hammen reported a similar contraction of *Polylepis* cover during a similar wet-to-dry climatic shift in the Holocene (van der Hammen, 1989). This suggests that humidity, or other linked processes (e.g. fire), is a potentially limiting factor for *Polylepis* forest.

Lauer (1981) reports similar findings in a study of glacial fluctuation in the Páramo, arguing that the extent of *Polylepis* coverage has changed with climate, but that there is no evidence that suggests that it once formed a significant forest belt. A similar study by Hansen et al. (1984) set in the Peruvian Andes northeast of Lima reports significant fluctuations in *Polylepis* cover from approximately 43,000-12,000 years ago, which the authors attribute to the same climatic and glacial shifts noted by van der Hammen. Since the late 1990’s these findings have been replicated numerous times in other locations in Ecuador, Peru, and Bolivia (Bush et al., 2005; Chepstow-Lusty et al., 1998; Chepstow-Lusty et al., 2005; Gosling et al., 2009; Williams, Gosling, Brooks, et al., 2011; Williams, Gosling, Coe, et al., 2011), leading to a seeming consensus among paleoecologists that the remnant hypothesis of *Polylepis* distribution is inaccurate (at least in terms of past coverage).

One of the problems with this paleoecological data, of course, is that it is impossible to definitively link observed changes in *Polylepis* cover with specific drivers, even though the correlation between climate and coverage is very strong. Many of the scholars cited here qualify their findings appropriately. Kessler also argues that palynology (the study of fossil pollen) provides a poor proxy for *Polylepis* coverage because the pollen is morphologically indistinguishable from *Acaena*, and because there are too few samples – frequently from sites ill-
suited to *Polylepis* (Kessler, 2002). However, even in a best-case scenario where all the pollen found in sediment cores is from *Polylepis* rather than *Acaena*, the fossil evidence still suggests that there was likely never significant forest coverage in the Andean highland. Furthermore, recent findings from Bolivia at sites suitable for *Polylepis* forest reinforce past findings (Williams, Gosling, Brooks, et al., 2011; Williams, Gosling, Coe, et al., 2011). Kessler, or any of the other current proponents of the remnant hypothesis have yet to respond to this recent work in the academic literature.

Based on this evidence, the debate on *Polylepis* distribution among researchers is best described as controversial. The next section will discuss the rise in prominence of the remnant hypothesis in the last fifteen to twenty years, as well as how the science behind this position was mobilized for specific conservation actions. As Kessler states in his 2002 paper:

“The clarification of the “*Polylepis* problem” is not merely of academic interest. The potential of large areas of the high Andes to support natural forest presents an immense challenge for ecosystem conservation and restoration… The large-scale destruction of forests has had a profound impact on ecosystem functioning and services, affecting biota and human inhabitants alike… Addressing this problem has major knock-on implications for many efforts related to the problems of poverty throughout the Andes today.” (p. 97)

### 2.3 Mobilizing Knowledge: Production of an Andean Landscape

The German botanist Michael Kessler (quoting Miehe and Miehe, 1994) frames the puzzle of *Polylepis* distribution as the “*Polylepis* problem” (Kessler, 2002), and this framing is of central importance to the rise of the remnant hypothesis as the dominant *Polylepis* discourse. (The very use of the word ‘problem’ itself problematic, and I will return to it shortly). Kessler, along with Danish ornithologist Jan Fjeldså, have for the last twenty years been the most consistent proponents of Ellenberg’s remnant hypothesis discussed above. As previously
discussed, this hypothesis is not uncontested, but over the last twenty years it has become what Forsyth (2003) refers to as an “environmental orthodoxy,” or an axiomatic explanation of observed conditions. Before directly considering the ascendance of the “remnant hypothesis” I first return to the “Polylepis problem” and the bounding of the Andean landscape.

The notion of a “Polylepis problem” is immediately suspect because it connotes a deviation from some \textit{a priori} norm. This is especially true when discussing ecological conditions in light of non-equilibrium concepts in ecology. Non-equilibrium theory in ecology understands landscapes to be in flux between many different states, all of which can be considered a ‘steady-state’ if framed at the appropriate temporal scale (Turner, 2010; Turner, et al., 2001; Zimmerer, 1994). The norm in this discourse is an Andean highland that is significantly forested, which Kessler explicitly posits (Kessler, 2002). The empirical basis for this claim comes from a study Kessler conducted between 1989 and 1991 in which he mapped over 200 \textit{Polylepis} forest stands in Bolivia and recorded site conditions to identify limits to distribution (Kessler, 1995). His findings indicate that \textit{Polylepis} are sited in many different growing conditions. Kessler then uses this finding to argue that \textit{Polylepis} is a generalist, not a specialist genus and refute a competing claim that \textit{Polylepis} distribution is controlled by adaptive fit to specific microsite conditions (the “shelter hypothesis,” see: Körner, 2003). He also, and this is crucial to the development of this discourse, identifies all the areas in the Bolivian highland with conditions suitable to \textit{Polylepis} forest – amounting to approximately 20\% of the total land area. This area, of which roughly 11\% was forested at the time, is presented as the potential \textit{Polylepis} distribution (Kessler, 1995).

This may seem like a neutral claim (‘potential’ is not necessarily a value-laden word), but Kessler goes on to suggest that the discrepancy between the present and potential distribution of \textit{Polylepis} is the result of human activity. Consider this quote: “These rough estimates allow an
assessment of how profoundly human activities have influenced the Andean ecosystem,” (Kessler, 1995, p. 289). With this causal connection, Kessler begins the process of what STS scholars call *boundary formation*, where distinctions are made between what is and is not a part of the Andean highland landscape (Forsyth, 2003). In this case, by framing Polylepis distribution in Bolivia as a deviation from an ideal and attributing this to anthropogenic activity, Kessler presents a landscape in which Polylepis forest and humans do not co-exist. Or more accurately, Polylepis forest and campesinos. The Andean highland then becomes a landscape that contains Polylepis forests, but not necessarily people.

The language used by Kessler in this 1995 paper (originally presented at a 1993 conference titled Biodiversity and Conservation of Tropical Montane Forests) is far from extreme. He even admits that all of the potential habitat may not have been forested since the last glacial maximum (15000-21000 yr B.P.), but he none-the-less attributes this to human activity. By 1996, however, a publication by Fjeldså and Kessler – which is perhaps the most widely cited publication on Polylepis in the last three decades (145 citations in Google Scholar as of 4/2/2013) – demonstrates well the evolution of these ideas toward a more formal environmental discourse. In this book, based largely on Kessler’s research in the early 1990’s, the argument is not that a significant area of the Bolivian highland *could* be forested with Polylepis, but that Polylepis forests are the “natural” vegetation cover of the region (Fjeldså & Kessler, 1996, p. 17). Here, as in the earlier work, human (campesino) activity is identified as the chief driver of destruction of the ‘natural’ vegetation. In this representation the boundaries are distinctly drawn onto the Andean landscape: Polylepis forests are natural and campesino communities are not.

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4 The concept of boundary formation used here is distinct from other boundary concepts in STS, and should be understood as part of problem framing. “Boundary objects,” and “boundary organizations” are distinct concepts in STS that are used to query linkages between different groups – particularly scientific, policy, and activist groups – around a specific issue. For excellent discussions of these other ideas, see: Goldman, 2011, and Forsyth, 2003.
Following Braun (2002), the invocation of ‘naturalness’ accomplishes two things for this discourse. First, it posits the ‘natural’ as external to that which is human or social. This further cements the boundary that separates humans from a landscape that includes *Polylepis* forest. Secondly, the ‘natural’ is understood to be universal, even eternal. This allows the discourse of *Polylepis* to suggest that the territory identified originally as potential habitat is actually land that *ought* to be forested.

This idea of naturalness has been critiqued by many scholars, from Denevan’s dismantling of the pristine myth (Denevan, 1992) to Cronon’s analysis of the social construction of “wilderness” (Cronon, 1996). Following Denevan, it is fundamentally problematic to construct an image of the Andean highland as naturally free of humans when human populations have been extant in the region for at least 12,000 years, with large settlements and intensive land use since at least 1200 yr BP (Baied & Wheeler, 1993; Williams, Gosling, Coe, et al., 2011; Young, 1998). And following Cronon, the notion that all potential habitats for *Polylepis* forest ought to be forested is much more a reflection of human values than of ecology. In fact the supposition that *Polylepis* forest is the ‘natural’ vegetation cover of currently unforested regions invokes social and ecological homeostasis that has been widely critiqued as untenable (Botkin, 1990; Turner et al., 2001; Zimmerer, 1994). It is also a considerable leap to suggest that regions with the necessary conditions to host *Polylepis* forest would be forested today if not for human disturbance. Empirical research to date is insufficient to indicate how *Polylepis* would expand if human use changed (Hedberg, unpublished manuscript). Furthermore, palynological study of the region suggests that past landscapes have likely never been forested to the extent that this evolving discourse posits. Palynological evidence from sediment cores at several sites in Bolivia indicate that *Polylepis* was more prevalent prior to 14,500 yr B.P. but never at levels that were
commensurate with closed canopy forest (Baied & Wheeler, 1993; Chepsto-Lusty et al., 2005; Gosling, et al., 2009; Williams, Gosling, Brooks, Coe, & Xu, 2011; Williams, Gosling, Coe, Brooks, & Gulliver, 2011). These studies also find that significant decrease in Polylepis forest cover tends to coincide with major climate shifts. This is not to suggest that humans had nothing to do with land cover change, but rather that the situation is much more complex than this discourse implies.

Given these discrepancies it is somewhat surprising that this discourse on Polylepis was established as orthodoxy. Yet Andean scholar Daniel Gade observed that by the late 1990’s most land cover studies in the central and northern Andes began from the assumption that the highland was previously forested, and that humans are one of the primary drivers of change (Gade, 1999). And Fjeldså and Kessler’s position is found in subsequent publications (ex: (Coblentz & Keating, 2008; Hensen, 2002; Renison, et al., 2011). Following an STS framework, one reason for the establishment of this discourse may be related to the epistemological underpinnings of science. As demonstrated above, conclusive empirical evidence (in quality or quantity) to support any hypothesis on the distribution of Polylepis is not yet (and may never be) available. Following Campbell (2011), this lack of evidence (and consensus) allows scientists like Fjeldså and Kessler to both claim empirical support for their hypothesis and aver that there is no scientific evidence to definitively refute their position. Furthermore, Campbell argues that this kind of uncertainty creates an environment in which there is little to be gained from engaging in debates over competing explanations. This latter point is readily found in some recent publications that do not wholly subscribe to the “remnant hypothesis.” Renison et al. (2006), for instance, present both the “remnant hypothesis” and competing climatic explanations, but go no further than the neutral position that the actual causes of Polylepis distribution are unclear. While
this is the appropriate scientific claim, it does little to combat the certainty of the dominant
discourse. It is worth noting that Renison and two co-authors from the 2006 paper published
again in 2011 where they state: “human impact has greatly reduced the surface area occupied by
high-mountain forest in Central Argentina and other tropical and subtropical mountain forests of
South America, which would otherwise be dominated by trees of the Polylepis genus.” (Renison
et al., 2011, p. 390)

Another strength of this discourse is that it is simple. It takes a complex social-ecological
issue and packages it into a cause-and-effect relationship that is much more tractable (and
satisfying) than uncertainty (Forsyth, 2003). And the image of a forested ‘nature’ in which
humans are the external degrading force is also a familiar trope. Following Braun (2002) and
Cronon (1996), this discursive framing of the Andean landscape likely fits into images of
‘nature’ that many already accept as true. I do not mean to suggest negligence on the part of
society, science, or specific scientists, but rather to offer an explanation as to why the remnant
hypothesis has risen in prominence. A similar argument might apply to the image of the
campesino produced by this discourse – an image that is equally important to the overall
Polylepis discourse. In the next section I explore in detail the ways in which this discourse
frames the campesino as incompatible with and incapable of conserving Polylepis forests.

2.4 The Discourse of the Campesino Subject

Humans have been an active part of the Andean highland for at least the last 12,000 years
(Baied & Wheeler, 1993). While the first humans in the region were likely hunter-gather
communities, the practice of some form of what today is classified as peasant agropastoralism
has likely been widespread in the landscape for at least 2000 years (Williams, Gosling, Coe, et
al., 2011). Of particular importance to the Polylepis discourse, the introduction of cattle and sheep to the region occurred with the Spanish conquest in the early-mid sixteenth century, and these species were quickly and widely adopted by the native inhabitants (Gade, 1992). It is difficult to deny that humans have played a significant role in shaping the Andean highland landscape during this period. But that is not the argument that I wish to make. My intention in this analysis is to question how peasant livelihoods came to be understood as ‘unnatural’ and ill-adapted to the landscape, and the human communities as incapable of forest conservation.

Part of this subject framing hinges on the notion of ‘naturalness’ discussed in the previous section. From a holistic ontological perspective, it is difficult to understand how humans and human livelihoods can be understood as unnatural when they have been present and evolving in the region for several millennia. As in the case of the discursive framing of the Andean landscape, an STS lens understands this framing as a process of boundary formation. The Polylepis discourse draws on certain empirical evidence to demonstrate that campesino livelihood strategies are linked to declines in forest cover, which allows for the bounding of campesino communities as external to the forest ecosystem. This relationship, in conjunction with the supposition that the Andean highland was significantly forested prior to the arrival of humans, effectively frames the ‘natural’ landscape as that which existed prior to humans, implicitly casting campesino livelihood strategies as ‘unnatural.’

This is, in fact, the exact strategy used by Fjeldså and Kessler, and others in framing campesino livelihoods (Fjeldså & Kessler, 1996; Hensen, 2002; Ibisch, 2002). In all of these instances, fire and (excessive) grazing of cattle and sheep are identified as the primary drivers of Polylepis forest loss. To support this argument, the various authors appeal to several observations. It is true that campesino livelihoods in the Andean highland frequently use fire to
rejuvenate pasture, as well as graze cattle and sheep in and around Polylepis forests. Paleoecological records also indicate that a rise in the prevalence of fire in the region approximately 14,000 yr B.P. coincided in many cases with a decline in Polylepis cover (Williams, Gosling, Brooks, et al., 2011). And recent research suggests that grazing cattle (there have been no studies that focus on sheep) at very high stocking rates adversely affects the Polylepis regeneration (Cierjacks, Rühr, Wesche, & Hensen, 2008; Pollice et al., 2012; Torres, et al., 2008; Zimmermann et al., 2009). However damning this may seem, identifying fire and grazing as the dominant drivers of Polylepis forest cover loss is still problematic.

The increase in fire found in the paleoecological record coincided with both the first human settlement in the region and climatic shifts toward warmer and significantly drier conditions. This confluence of events makes it nearly impossible to pinpoint specific cause-and-effect relationships for forest loss. In fact, the climatic evidence is significant enough to lead some paleoecologists to suggest that climate change may be much more important than current discourse on Polylepis distribution posits (Gosling et al., 2009; Williams, Gosling, Brooks, et al., 2011). Furthermore, a recent study by Renison et al. (2006) actually suggests that the relationship between Polylepis and fire may not be as simple as previously thought, and argues that the removal of fire from these ecosystems may not be a wise conservation strategy. In regard to livestock grazing, the same research that links heavy grazing with Polylepis degradation also finds that light to moderate levels of grazing actually improve seedling recruitment (Cierjacks, Rühr, et al., 2008; Pollice et al., 2012; Torres et al., 2008; Zimmermann et al., 2009). Despite the uncertainty about the relationships between fire, grazing, and Polylepis forest, the scholars writing in support of this discourse offer cause-and-effect relationships as uncontested facts, often without explicit empirical evidence to support their claims.
This selective representation accomplishes what STS scholars refer to as the \textit{black-boxing} of the relationships between \textit{Polylepis} forest, livestock grazing, and fire. Black-boxing occurs when a process, term, or object’s “internal nature is taken to be objectively established, immutable, or beyond the possibility for human action to reshape.” (Forsyth, 2003, p. 86) By black-boxing fire and grazing, the interactions between these processes and the Andean highland landscape become universal, and easily fit into reductive cause-and-effect frameworks. Campesino livelihoods then become necessarily ill-adapted to the landscape, and thus incompatible with the conservation of \textit{Polylepis} forests. This argument is then strengthened by representing the campesino as ecologically ignorant and economically incapable of conservation.

Much of the literature on \textit{Polylepis} conservation acknowledges the need to involve local communities (ex: Fjeldså & Kessler, 1996; Ibisch, 2002). However, this is often within the context of rhetoric that depicts campesino communities as ecologically ignorant. Consider the following quote:

“[T]he reasons for burning are sometimes quite unclear. Some people tell that they burn forest to get a drier climate, others that the smoke causes rain! Many ecologists have described this burning as a tradition with no purpose, or as “sheer pyromania” (Seibert 1983). We find it most purposeful to place this behaviour in a broader social and cultural context where unsustainable management methods introduced by the Spaniards, cultural suppression of indigenous cultures and silly policies have left the campesino populations without alternatives (see 4.5A). So people put fire to the dry grass because they know that the area will soon look nice and green when the rains start, and without considering historical causes or negative long-term consequences. The burning of grassy slopes is at times so severe that the resulting smoke stops airtravel to La Paz airport.”(Fjeldså & Kessler, 1996, p. 38)

Beyond the pejorative and somewhat colonial tenor of this text, it presents the campesino as ecologically ignorant, and incapable of making environmentally sustainable decisions. It is almost a certainty that there are many reasons that campesinos set fire to grassland, but it is a fallacy to claim that there is no recognized ecological motivation. As one Colinano, Eddie, told
me (the only one, in fact, that was willing to even mention the benefits of periodic pasture burning), “if you burn the pasture more green grass will grow.” This statement seems quite similar to part of the passage quoted above, but it is indicative of a more acute awareness of the specific grassland ecology in the Andean highland. The bunchgrass communities that dominate much of the Puna and Páramo have been found to contain as much as 70% dead matter in their above-ground biomass, which is insufficient for grazing cattle (Hofstede et al., 1995). And given the fact that periodic fire has been an integral part of these grasslands for at least 12,000 years (Horn & Kappelle, 2009; Williams, Gosling, Brooks, et al., 2011), it is not entirely clear what the “negative long-term consequences” might be (other than the potential loss of forest).

Interviewees also frequently acknowledged the potential risk that grass fire posed to Polylepis forest, naming it as one of the reasons that the community prohibited pasture burning. Numerous interviewees also demonstrated an awareness of the hydrological benefits of Polylepis forests, of which Fjeldså and Kessler suggest the campesinos are also unaware. Several respondents described how the forest “soaks up” the rain during the wet season and then slowly releases the water throughout the year, thus improving soil moisture and water availability in the community.

In this case study community, at least, the local residents have an acute ecological understanding of many aspects of their landscape – a knowledge that has been demonstrated in many cases in the field of political ecology. Yet this is not how campesinos are represented in some of the most important Polylepis publications.

In addition to representing campesinos as ecologically ignorant, this discourse also frames them as economically irrational and incapable of managing the land for optimal production. This economic framing is accomplished partially through an appeal to ecosystem services. Identifying certain ecological processes as ‘ecosystem services’ assigns (economic)

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5 See Robbins, 2011 for numerous examples, as well as the literature review in the first chapter of this text.
value to certain aspects of a landscape and implicitly devalues others (Vatn, 2000). In a sense, identifying specific ecosystem services (in this particular case it is hydrological regulation and soil erosion) is akin to the process of boundary formation. For instance, the grassy understory of *Polylepis* forests provide an important source of grazing fodder during certain times of the year. Yet by not identifying this as an ‘ecosystem service’ Fjeldså and Kessler essentially disassociate any benefits from these forests with livestock grazing. There is also a sense in which ‘ecosystem services’ renders the landscape in economic terms, thus translating ecological complexity into market value (Robertson, 2006). This subtle marketizing of the Andean landscape implicitly places the value of *Polylepis* forests in a territory where campesinos are often only marginal participants.

Thus framed, Fjeldså and Kessler argue that campesinos often make “short-sighted” decisions to “overexploit” resources (Fjeldså & Kessler, 1996, pp. 45-46). To their credit, they do note that in many cases campesino communities in Bolivia have few economic alternatives, but in many ways conceding this structural disparity only strengthens their argument. The campesino has no agency in this framing; they have no choice but to degrade the forest; it is an inevitability. Any admission of agency is correlated with economic irrationality: campesinos actively chose short-term profit over long-term ecological sustainability *because* they do not understand the long term consequences of their actions (Fjeldså & Kessler, 1996, pp. 45-46). Conversely, Jameson and Ramsay (2007) found that peasant farmers at their study site in Peru were aware of the adverse impact of grazing and wood harvesting on *Polylepis* forest, but continued to do so because they had no choice.

Fjeldså and Kessler, as well as other scholars, also frame the cultural commitment to cattle and sheep as economically irrational. Hensen (2002), for instance, points to the cultural
status that many campesino communities ascribe to cattle ownership and large herd size, and suggests (somewhat implicitly) that this is an economically irrational cultural tenet because of the long-term ecological damage that large cattle herds produce. Not only does this argument imply that the campesinos (a problematic generalization in itself) are culturally incapable of conserving Polylepis forest, it also limits the consideration of forest benefits to the long-term. This is a process that STS scholars refer to as problem closure (Forsyth, 2003; Hajer, 1995). In other words, these texts define the problem of Polylepis forest loss as a loss of long-term sustainability, thereby rendering short-term resource crises secondary in the analysis of the drivers of forest loss. This selective act of determining what counts as a problem allows this discourse of Polylepis to further solidify the image of the campesino as economically irrational and incapable of conserving forest cover.

Through multiple avenues this discourse frames campesino communities as ill-adapted to, and incapable of conserving Polylepis forests. It takes very little time in these communities to poke holes in this environmental narrative, but it has been effective none-the-less. Following Bassett and Zuéli (Bassett & Zuéli, 2003), this success may be due to the fact that the image of peasant mismanagement aligns with dominant global environmental narratives that are already established. It may also hinge on the positionality of the voices behind the discourse. In the case of Fjeldså and Kessler, the speakers are European scientists whose voices often win out in discussions of environmental change (Bassett & Zuéli, 2003; Forsyth, 2003). In the next section I examine the ways that the discourse of the landscape and the subject combine to create spaces for specific interventions to conserve Polylepis forest cover.
2.5 Spaces of Intervention

In this section analysis I pivot slightly from the more obvious ‘discourse of intervention’ to what I call the *spaces of intervention*. I do this for two reasons. First, the conservation interventions that emerge from this discourse are in many ways logical extensions of the discourse of landscape and subject rather than unique discursive framings. Secondly, and more importantly for the principle arguments of this thesis, these interventions have a specific spatial character (Roth, 2008). The spatial focus of these interventions carry specific implications for the human communities and the *Polylepis* forest ecosystems in the Andean highland. Additionally, a focus on the spaces of conservation intervention provides an important contrast to the holistic landscape approach that structures the analysis of this case study and will be a recurring reference in the evolving discussions in the coming chapters.

As demonstrated in the previous sections, the discourse of *Polylepis* draws well-defined boundaries between *Polylepis* forests and human communities, and frames the threat to the forest as human disturbance (see figure 2.3). This framing scales the problem of *Polylepis* forest loss to the site of the forest, which in turn spatially locates interventions to conserve the forest. This is what Rangan and Kull (Rangan & Kull, 2009) refer to as the “translational moment” when observations made at one scale are linked to processes to produce
environmental ‘truths.’ (p. 36). In other words, the process by which scale becomes discourse. This is an important conceptual underpinning to the production of spaces of intervention, and warrants further explanation.

The Polylepis discourse renders the forest, human communities, and (by omission) many other aspects of the landscape as distinct entities. Furthermore, it frames the major threats to the forest as actions made by campesino communities at the site of the forest. The conservation problem then becomes spatially specific, and any interventions to protect Polylepis forests necessarily focus on the site of the forest as well. Returning to figure 2.3, interventions resulting from this framing will focus on disrupting the flow of human impacts on the forest. This is exactly the type of intervention proposed by Fjeldså and Kessler – the primary advocates of the Polylepis discourse.

The crux of their intervention is a rational modernization of the Andean highland into use zones, with designated areas for intensified grazing, agriculture, and ‘undisturbed’ forest (Fjeldså & Kessler, 1996). While it is not explicitly stated, the spatial nature of this intervention clearly implies that Polylepis forest loss is due human activities and that the problem can be effectively addressed by simply removing these activities from the forest and locating them elsewhere. One of the significant problems with this strategy is that a landscape does not exist in discrete zones, nor is it used in that way by the people that make their livelihood from the land (Robbins, 2001). Furthermore, it is ecologically dubious at best to assume that altering disturbance regimes and other landscape processes at one scale will yield the desired conservation outcome without carefully analyzing the interconnections between different processes and communities throughout the landscape system (Perry, 1995). And as Roth (2008) and Zimmerer (2000) have argued, this focus on single, idealized space for conservation often overwrites the spatial
complexity of resource use in humanized landscapes, which can lead to poor social and ecological outcomes. As I will demonstrate in subsequent chapters, this discursive space of intervention is ecologically mismatched to the goals of Polylepis conservation in the Andean highland of Bolivia.

In keeping with this discursive space of intervention, the current laws governing conservation in Tunari National Park, where this case study is sited, strictly prohibits grazing or timber extraction in the forest, as well as the production of charcoal, the use of fire in pastures, or the clearing of land for agriculture (Boillat, 2007; TNP, 2013). The most recent and relevant of the laws governing Tunari National Park is Ley 1262, which was written in 1991 – concurrent to Michael Kessler’s original research on Polylepis forest cover in Bolivia (Kessler, 1995; Ley 1262, 1991). The extent to which Kessler and other European scientists were involved in the policy process is not a matter of public record, so a direct attribution cannot be made. It is worth noting, however, that Fjeldså and Kessler’s 1996 master work is glowingly endorsed by the national director of biodiversity conservation for the Bolivian Ministry of Sustainable Development and Environment. So while it is not possible to assert that the early discourse framing discussed in this chapter begat Ley 1262, it seems possible – likely even – that the early work of Fjeldså and Kessler and current park regulations took shape in institutions that shared ideas. Regardless of the authorship, however, the Bolivian park service (SERNAP)6 is certainly a part of a Polylepis “discourse coalition” (Hajer, 1995) that unites the Bolivian government and various scientists around a specific narrative of environmental change. And this coalition has, almost without exception, focused its attention on spatially specific interventions, often with negative consequences for campesino communities.

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6 SERNAP is the acronym for Servicio Nacional de Áreas Protegidas, the Bolivian equivalent of the US National Park Service.
The enforcement of park regulations in Tunari National Park, for instance, demonstrates well the potential social impact of spatially mismatched conservation intervention. In the section of the park where these laws are strictly enforced the local campesino communities have had to drastically reduce their herd size and lost much of their agricultural land to forest (Boillat, 2007). This has led many families to migrate to Cochabamba and elsewhere for work. Some have even engaged in the illegal sale of land to real estate developers to compensate for lost land use (ibid). Even in Colina, where park regulations have not been fully enforced due to lack of resources, residents migrate and struggle to earn a living, at least partly (see chapter 4) due to changing land uses that are focused on the space of the forest.

2.6 Truth and Lies

In this chapter I have presented an in-depth analysis of the dominant discourse on Polylepis forest drawing largely on the tools of STS. In so doing I demonstrated that this discourse constructs a landscape in which Polylepis forests and (campesino) humans cannot co-exist. This discourse then produces specific spaces of intervention that are unlikely to be ecologically effective, or socially just.

The real trouble with this discourse, though, is that it is mostly true. Grazing and fire are, in some cases, damaging to Polylepis forests (Cierjacks, Salgado, Wesche, & Hensen, 2008; Torres et al., 2008). Paleoecological records indicate that Polylepis distribution has decreased since humans first migrated to the central and northern Andes, and human land use likely played a role in that decline (Williams, Gosling, Brooks, et al., 2011). And as the empirics of this case study will indicate in the next chapter, there is at least one campesino community in Bolivia that

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7 In the enforcement zone of the park, there are also significant forest plantations comprised of the species Eucalyptus globulus and Pinus radiata, both of which are exotics. It would be inappropriate to suggest that these ramifications are the result of Polylepis forest conservation per se, but the law does not differentiate between forest composition, and the same regulations apply to all forested areas in Tunari National Park. I would argue, therefore that this is still the result of a spatially mismatched intervention.
is experiencing *Polylepis* forest decline in conjunction with the livelihood practices implicated in the discourse.

So what do you do when many of the dismantled pieces of an environmental narrative are (at least in some respects) true? Following Forsyth (2008), and by proxy, Piers Blaikie, my goal moving forward with this analysis is to pick up these pieces and reassemble them in a manner that is both more ecologically effective and better for campesino communities. Where this discourse fails most profoundly is in its spatial mismatch. As this case study demonstrates, the spatial focus on the site of the forest fails to capture the complexity of interacting processes at play in the landscape (Sayre, 2005). What is needed is a holistic landscape framework that can effectively incorporate the myriad ‘social’ and ‘ecological’ processes at work in the landscape. With this framework I hope to find new spaces of intervention that might yield better outcomes for all the communities in the landscape.
Chapter 3

Polylepis Forest Cover Change in the Community of Colina: 1991-2011

3.1 Introduction

An important component of the holistic landscape framework used for this case study is assessing biophysical changes that are occurring (if any) in the community of Colina. Following Zimmerer and Young (1998), it is also necessary to examine the rate, extent, and kind of change, which is often more ecologically revealing than the mere presence of change. It is also necessary to analyze the spatial properties of change in the landscape. This spatial analysis provides a means of directly challenging the scalar problems of the dominant discourse detailed in the previous chapter.

The following chapter presents a Polylepis forest cover change analysis for the period from 1991 to 2011. This analysis utilizes Landsat 5TM imagery of the study area, and land cover data collected in the field during July of 2012. Multiple methods of forest cover mapping are used to compare Polylepis forest distribution at five year intervals to provide a detailed progression of forest change in Colina from the year the area was incorporated into Tunari National Park to the present. 2011 is considered for the purposes of this study to be ‘the present.’ This assumption was made to allow for the use of Landsat 5tm imagery, which do not have the scan line errors found in Landsat 7ETM+ imagery. Due to technical difficulty, Landsat 5 was powered down in late 2011. The launch of Landsat 8 in early 2013 (USGS) will hopefully allow this research to continue into the future.

Despite the long-term decline of Polylepis forests posited by dominant narratives discussed in the previous chapter, there have been very few land cover change analyses that
focus on *Polylepis* systems. There are likely several reasons for this deficiency. First, due to the remote location and lack of resources, there are very few long-term monitoring sites in the Andean highland (Keating, 2007). This deficiency may also be due to a lack of available data. Repeat photography and comparison of aerial photos are two of the principal methods (other than satellite remote sensing) for land cover change analysis. These methods unfortunately require source materials that are not always easy to locate (if they exist at all), or present significant bureaucratic challenges to attain them. As an example of the latter, I was not even able to obtain a map of Tunari National Park from the SERNAP while in the field. Currently there are just a handful of studies that use these methods to examine *Polylepis* systems (see: (Byers, 2000; Jameson & Ramsay, 2007; Tohan, 2000).

Satellite remote sensing analysis offers great potential for the study of *Polylepis* cover change, especially since 2008 when the entire Landsat archive became freely available (Wulder, Masek, Cohen, Loveland, & Woodcock, 2012). However, in an extensive academic database search I found only two published studies – Braun (1997) and Tohan (2000) – that used remote sensing to examine the distribution of *Polylepis*, and even in these cases only Tohan used it to track land cover change. Fjeldså and Kessler (1996) argue that *Polylepis* forests are difficult to locate via satellite imagery or aerial photography, and this assumption may have hindered study. I would amend that statement to say that it is difficult to *ex situ* identify *Polylepis* forests using remote sensing. It is true that the fragmented distribution and frequently small patch size of these forests present a challenge for medium resolution satellite imagery like the Landsat series of sensors. But pre-analysis ground truthing can more than make up for this. Additionally, with the increasing availability of free high spatial resolution imagery from sources like Google Earth,
even time in the field may not be necessary. Witmer (2008), for instance, used Google Earth to successfully compile an entire classification data set in his study of post-civil war Bosnia.

Satellite remote sensing has been used with great success in the Andes to study land cover change. Indeed, studies such as Postigo et al. (2008) and Kintz et al. (2006) in Peru, and Brandt and Townsend (2006) in Bolivia are excellent examples of this work, and they each inform this case study. None of these studies, however, specifically focuses on *Polylepis* forest. Given this lack of *Polylepis* forest cover change analysis, the work in this chapter not only provides an essential component to this case study, but it also makes a methodological contribution to the study of these unique forest systems.

### 3.2 Data Selection and Preprocessing

Landsat 5TM images of the study area were obtained from the USGS EROS data center. One image was selected for 1991, 1996, 2001, 2006, and 2011, providing five image sample years at five year time steps. Each image was captured between early June and early August. This time of year was selected for two reasons. First, this period corresponds with the winter dry season in this part of Bolivia. This timing maximizes the spectral distinction between the evergreen foliage of *Polylepis* and senescing grassland vegetation. Secondly, this season corresponds with the time of year that *in situ* data collection was conducted in an effort to maintain validity of ground truth data and in-field observations. Selecting images captured during the dry season yielded five images with zero cloud cover over the study area, obviating the need to mask images for cloud shadow.

Data preprocessing was minimal for this study due to advances in product processing at USGS. All Landsat images requested from USGS now receive Level 1 Terrain Corrected (L1T)
geometric preprocessing. L1T images are accurately registered to UTM coordinate space, and corrected for terrain distortions using a digital elevation model (DEM). This latter point is particularly important in topographically extreme environments like the Andes. Using L1T images relieves end-users (like myself) from the need to geometrically preprocess image data (Hansen & Loveland, 2012).

Atmospheric preprocessing for this study, which is much more complex (and troublesome) than geometric correction, was also executed by USGS through participation in a small program called the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). LEDAPS utilizes the model-based atmospheric correction modules developed for the Moderate Resolution Imaging Spectrometer (MODIS) to generate accurate and radiometricly consistent surface reflectance images from Landsat 5TM and Landsat 7ETM+ (Masek et al., 2006). Utilizing LEDAPS processed images saves significant time in image analysis, and it allows for accurate relative (i.e. post-classification) comparisons between image dates (Huang et al., 2009). LEDAPS imagery also prevents the need to attempt radiometric normalizations between image years, which can be time consuming and highly problematic, especially in highly dynamic regions (Canty & Nielsen, 2008).

Though there was no need to mask the images for cloud cover, there was one region in the images that required masking due to topographic shadow. The southwestern aspect of the slopes on which the study area is located combined with the early-mid morning image capture, created dark shadow that covers a portion of the area containing Polylepis forest. Each image had slight variations in the size and extent of shadow as a result of slight variations in time and date of image capture. To account for this variation I constructed a universal shadow mask that was applied to all images prior to processing (see appendix A).
3.3 Data Processing and Analysis

Two methods were used for processing and mapping *Polylepis* forest cover change during the study period: supervised classification, and Mixture-Tuned Match Filtering (MTMF). Both of these methods proved effective at mapping forest cover, but the type of data generated with each method was quite different, with implications for the conclusions that can be drawn from each. These two methods were also able to triangulate with each other, providing internal validity to this analysis.

3.3.1 Supervised Classification

Ground truth data was collected in the field in late July of 2012 to use for supervised classification of Landsat 5TM images. Four primary land cover types were identified in the field and ground truth points were gathered for each category. These four categories are as follows: ‘agriculture,’ ‘grassland,’ ‘*Polylepis* forest,’ and ‘mixed forest.’ Mixed forest was qualitatively determined in the field to be areas that contained between 40% and 65% *Polylepis* cover, with the rest of the cover comprised of grassland.\(^1\) It should be noted here that this study region was not the area I intended to conduct field research. Prior to entering the field in 2012 I conducted *ex situ* analysis of a 2011 Landsat 5TM image in order to address the question of spectral distinction, and identify important land cover categories, as well as regions to target for ground truthing. Unfortunately, I encountered significant logistical and political barriers in accessing this region, and the study site I was able to access was relatively unknown to me. That being said, the *in situ* land cover categories that are used in this study were sufficient to allow for valid remote sensing analysis. There were some problems in spectral differentiation between several of the

\(^1\) Since no standardized measure was used to determine the percentage of tree cover at the ‘mixed’ versus ‘*Polylepis*’ points, there is some difficulty in accurately differentiating this category and confidently assessing accuracy for the ‘mixed’ category.
non-forest categories, which will be discussed below. But given that the primary purpose of this analysis is change in Polylepis forest cover change, these issues do not directly affect findings.

One hundred forty-four ground truth points were gathered in the field (see table 3.1). The ‘agriculture,’ ‘grassland,’ and ‘mixed forest’ categories were then augmented with additional points derived from a 2012 high spatial resolution QuickBird image obtained through Google Earth (Witmer, 2008). This was done by determining the coordinate locations of the specific cover types, and then locating the same coordinate location in the 2011 Landsat image to extract the spectral information. Following Kennedy et al. (2010), the region of interest for this study was transformed using a Tasseled Cap transformation to reduce noise and highlight features in the data that are associated with green vegetation. The 2011 tasseled cap image (see appendix A) was then used to generate training classes for the classification algorithm using ground truth data.

Using this training data, classification was conducted on the 2011 tasseled cap image using the default thresholds for Maximum Likelihood, Minimum Distance, Mahalanobis Distance, Spectral Angle Mapper, and Neural Network algorithms. The initial classification was conducted on an unmasked image to utilize regions in the 2011 image that were not in shadow in other earlier images.

An accuracy assessment test set was then generated from IKONOS high spectral resolution imagery (obtained from ESRI) of the same area. A sample of 75 points was selected

<table>
<thead>
<tr>
<th>Ground Truth Points by Category</th>
<th>Field Collected</th>
<th>Google Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>Grassland</td>
<td>28</td>
<td>40</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>Polylepis</td>
<td>90</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 3.1
for accuracy assessment. Given the standard goal of 85% accuracy in land cover classification, this sample should produce a result with an 8.24% error range (Jensen, 2004). The test set was used in ENVI to generate a confusion matrix for each classification. From this initial set of algorithms, the Mahalanobis Distance method performed the best, with an overall accuracy of 74.193% and a kappa score of 0.6463. The Maximum Likelihood classifier performed nearly as well, with accuracy of 72% and a kappa of .6160; however the resulting image was much noisier than the Mahalanobis algorithm. The Mahalanobis Distance method was selected for this study, and only this method was used for future iterations.

The main problem with the initial pass at classification was the ‘mixed forest’ category, which had only a 33% producer accuracy, with the main confusion arising with the ‘agriculture’ class. This was anticipated, and numerous iterations of the classifier were run with different threshold levels set for each class in an effort to improve performance, but virtually no change in performance was observed with changes in thresholding. It was thus determined that the mixed forest class should be collapsed into the ‘Polylepis forest’ and ‘agriculture’ categories, and a new set of training classes was produced. With the new, reduced set of training classes, the classification produced an over-all accuracy of 85.333% with a kappa score of 0.7764. Accuracy of 85% is considered the threshold of acceptability for land cover classification (Jensen, 2004).

All of the remaining error in the classification was the result of confusion between the ‘grassland’ and ‘agriculture’ classes, and given that the focus of this study is on changes in Polylepis forest, these two classes were then collapsed into one class of open cover (see figure 3.1 and Appendix A). The resulting two-class map will make it impossible to determine the exact from-to aspect of forest change. However, since the typical agricultural plot in and around the forest is smaller than the spatial extent of one Landsat 5TM pixel (30mx30m) it is likely that this
would have been difficult regardless. This spatial mismatch is also one of the likely reasons that distinguishing between ‘agriculture’ and ‘grassland’ was difficult. Fortunately, knowledge gained from qualitative work indicates that agricultural plots in and around the forest are long established, and that new plots are rarely (if ever) created by clearing forest. Some change from sample year to sample year may be due to periodic rotation of fallow fields, but this can be accounted for to some extent by spatial correlation. Given this additional data, most of the loss in forest cover can be assumed to be transitioning into grassland. However, to account for uncertainty, I refer to all non-forested area as ‘open cover.’

The classification training set was then used to classify the earlier images using the Mahalanobis Distance classifier with the same statistical thresholds used for the 2011 image. The ENVI thematic change workflow was then used to generate change statistics and maps of changed areas between the following image pairs: 1991-1996, 1996-2001, 2001-2006, 2006-2011, and 1991-2011. The thematic change workflow is conducts a pixel-to-pixel analysis for two images, recording the from-to change for each pixel, and mapping each type of change in the same coordinate space. Following Coppin et al. (1996), and Lu et al. (2004), high level of accuracy of the classification and geometric correction produces highly accurate change detection.
3.3.2 Mixture-Tuned Match Filtering

While the supervised classification method provided accurate results, it failed to effectively differentiate between different densities of forest cover. This makes it impossible to distinguish between subtle changes in forest structure, which is a common problem with this type of change detection method (Lambin & Strahlers, 1994; Masek, Lindsay, & Goward, 2000). It is also possible that some of the initial problems encountered in differentiating between ‘agriculture,’ ‘grassland,’ and ‘mixed forest’ indicate that some of these pixels that are classified as ‘open cover’ are actually thinly forested areas going unnoticed. To address these deficiencies I utilized an alternative mapping method known as Mixture-Tuned Match Filtering (MTMF).

MTMF is a variation of linear spectral unmixing that analyzes each pixel in an image to determine the percentage of each pixel that is comprised of an identified cover type (Williams & Hunt, 2004). This method is very similar to that used by Brandt and Townsend (2006) to successfully map forest cover in southern Bolivia. MTMF has the added advantage of not requiring that all major land cover types in an image be known. This is particularly useful when working with multi-spectral imagery like Landsat that has much less data dimensionality than the hyperspectral imagery for which these methods were developed. In this way the difficulties in spectrally differentiating between agriculture and grassland become less problematic. By utilizing MTMF, I was able to breakdown the category of ‘Polylepis forest’ into multiple categories of cover based on the percentage of cover, which is assumed to be a proxy for canopy density. This provides for much more detailed forest change analysis.

Spectral endmembers for MTMF (and spectral mixing analysis more generally) can be identified in one of two ways: in the field, or from within the image (Jensen, 2004). Both of these methods have advantages. Endmembers identified from ground truth data offer the assurance of
in situ data collection. However, the accuracy of MTMF results rely on the identification of the most spectrally pure endmembers, which may not correspond with ground truth points. Using tools like the pixel purity index (PPI) and the n-D visualize identify the most spectrally pure endmembers in a given image, but some source of external data is needed to accurately associate endmembers with specific cover types. Following Brandt and Townsend (2006), I utilized an iterative method for identifying endmembers through the use of PPI, the n-D visualizer, ground truth data, and spectral profiles form the original images.

The first step in this process is a Minimum Noise Fraction transform (MNF), which reduces noise in the spectral data and highlights the most distinct and dimensional bands for analysis (Williams & Hunt, 2004). This is more necessary when using hyperspectral data, which contain as many as 224 spectral bands and generate much more noise (Jensen, 2004). Next, PPI was used to identify the most spectrally pure pixels in the image. PPI does this by casting vectors, with each pixel in the image receiving a score that corresponds to the number of times that it was found at the end of the vector (Jensen, 2004). For this study the 70,000 iterations of PPI were run to fully exhaust all possible endmembers. Pixels were then selected based on three criteria. First, an endmember pixel had to have a PPI score of at least 4,000. Secondly, the pixel had to be within one pixel space of a ground truth point identified as Polylepis. Lastly, the spectral profile of the pixel in the original image had to be consistent with green photosynthetic vegetation, which would only be Polylepis in these instances. This yielded six pixels form the 2011 image that were then examined in the n-D visualizer to assure that they formed a tight cluster in an n-dimensional scatter plot. Six pixels were chosen in this case to account to the extreme topographic variation in the study area. These endmembers were then exported as an endmember collection file for use in MTMF.
The MTMF mapping algorithm was then used to determine the percentage of *Polylepis* cover in each pixel in the image. The resulting image has two bands – the match score, which identifies the percentage of cover in each pixel, and the infeasibility score, which indicates the likelihood that each pixel is a false match. A good MTMF result yields few pixels with high match scores and high infeasibility scores. The 2011 MTMF image produced very few false positives, indicating an excellent result (see Figure 3.2).

Due to subtle differences in brightness between the image dates, the same endmember set could not be used for earlier images. To identify endmembers for MTMF in earlier images, I adapted the process used to identify endmembers in the 2011 image. In this case, since ground truth data was not available for earlier images, endmembers were selected for each year based on the following criteria: 1) pixels that had a PPI score greater than 4,000; 2) pixels that were found within the region classified as ‘*Polylepis* forest’ in the corresponding supervised classification; and 3) pixels that had a spectral profile consistent with green photosynthetic vegetation in the original image. This procedure yielded five or six endmembers for each sample year. These pixels were then viewed in the *n*-D visualizer to ensure that they formed a tight cluster in spectral space, and subsequently exported as for use in MTMF. Based on match and infeasibility scores for each of the years, this process produced excellent results.
The MTMF images were then classified using a simple decision tree classifier. The 2011 image was first classified into three classes for accuracy assessment: ‘open cover’ for values less than 0.15, ‘mixed forest’ for pixels with values between 0.15-0.55, and ‘forest’ for pixels with values greater than 0.55. The values chosen here do not exactly match the values qualitatively used in the field to distinguish between ‘forest’ and ‘mixed forest,’ but this was done intentionally to account for the variability of qualitative assessment. This classification was then tested for accuracy, receiving an overall accuracy of 83.1% with a kappa score of 0.7346. Particularly telling in this analysis is that the producer accuracy of the ‘mixed forest’ category increased from 33% to 66.67% over the supervised classification, and many of the misclassified pixels only deviated from the accurate class by a few hundredths of a point. It is likely that accuracy could be improved after numerous iterations of fine tuning the value ranges for the classification, but this is not necessary for the purposes of this study, especially since the values for each class was determined qualitatively. It is clear from these results that this method of MTMF classification accurately locates Polylepis cover in the study area, and is effective at differentiating between different densities of tree cover.

A new decision tree was then constructed that divided Polylepis cover into three categories of density. These new classes were as follows: ‘dense forest’ for pixels with values greater than 0.7, ‘open canopy forest’ for pixel values greater than 0.55 but less than or equal to 0.7, ‘sparse/nascent forest’ for values greater than 0.15 and less than or equal to 0.55, and ‘open cover’ for all pixels.
with values less than or equal to 0.15. This decision tree was then used to classify the MTMF images for all five sample years (see figure 3.3). The subsequent land cover maps were then analyzed using the ENVI thematic workflow to generate change statistics and maps for the same image pairs used for supervised classification.

3.4 Findings

Both the supervised classification and MTMF classification maps indicate a slow decrease in *Polylepis* cover of between 0.3-0.4 ha/yr, which is an average of about 0.4% decrease per year in both cases. Comparison of MTMF images finds a decrease of 0.4 ha/yr, with loss of total *Polylepis* cover reported during every sample year with the exception of the most recent interval from 2000-2011 in which total area increased by 0.72 ha, or 0.81%. Supervised classification analysis found an average change of .31 ha/yr, but the change from sample year to sample year is more erratic. In this set of images, there is a 3.3% decrease in forest from 1991 to 1996 followed by a 5.8% increase in forested area from 1996 to 2001. Then from 2001 to 2011 *Polylepis* forest decreases in total area by just over 11%, with the most significant decrease occurring form 2006-2011 (see table 3.2 for a full break down of change statistics).

The area considered ‘forested’ differs between the two methods, with MTMF classifying more *Polylepis* cover for any given sample year. There was some variation in this however. For the years 1991, 1996, and 2011, MTMF images contained approximately 18% more *Polylepis* forest cover, but only about 6% more forest cover in 2001 and 2006. This is to be expected, however, because the MTMF algorithm is classifying very thinly forested areas that are likely considered ‘open cover’ by the Mahalanobis Distance algorithm. The discrepancy in forest change from 1996-2001 can also be explained this way. The MTMF statistics for 1996-2001
Table 3.2

<table>
<thead>
<tr>
<th>Year</th>
<th>MTMF</th>
<th>Total</th>
<th>Mahalanobis</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1991</td>
<td></td>
</tr>
<tr>
<td>Dense Forest</td>
<td>32.58</td>
<td>36%</td>
<td>Polylepis Forest</td>
<td>73.62</td>
</tr>
<tr>
<td>Open Canopy</td>
<td>12.87</td>
<td>14%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sparse/Nascent</td>
<td>44.37</td>
<td>49%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1996</td>
<td></td>
</tr>
<tr>
<td>Dense Forest</td>
<td>19.26</td>
<td>22%</td>
<td>Polylepis Forest</td>
<td>71.82</td>
</tr>
<tr>
<td>Open Canopy</td>
<td>13.41</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sparse/Nascent</td>
<td>54.81</td>
<td>63%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2001</td>
<td></td>
</tr>
<tr>
<td>Dense Forest</td>
<td>21.33</td>
<td>26%</td>
<td>Polylepis Forest</td>
<td>75.96</td>
</tr>
<tr>
<td>Open Canopy</td>
<td>13.41</td>
<td>16%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sparse/Nascent</td>
<td>48.06</td>
<td>58%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2006</td>
<td></td>
</tr>
<tr>
<td>Dense Forest</td>
<td>11.88</td>
<td>15%</td>
<td>Polylepis Forest</td>
<td>74.43</td>
</tr>
<tr>
<td>Open Canopy</td>
<td>12.33</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sparse/Nascent</td>
<td>56.88</td>
<td>70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2011</td>
<td></td>
</tr>
<tr>
<td>Dense Forest</td>
<td>13.41</td>
<td>16%</td>
<td>Polylepis Forest</td>
<td>67.5</td>
</tr>
<tr>
<td>Open Canopy</td>
<td>12.96</td>
<td>16%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sparse/Nascent</td>
<td>55.44</td>
<td>68%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

indicate an increase in ‘dense forest’ and a decrease in ‘sparse/nascent forest.’ It is likely, then, that the supervised classification, which more consistently classifies denser forest cover, interpreted this change as an increase in forest cover, whereas the more sensitive MTMF detected the decrease in ‘sparse/nascent forest’ and more accurately reported a decrease in total area. Despite this discrepancy, both methods report the same amount of total Polylepis loss at roughly 8-9% from 1991-2011.
There is one thin strip of *Polylepis* forest in the study area that supervised classification failed to detect, and MTMF tends to classify as ‘sparse/nascent forest’ (see figure 3.4). This is likely due to the fact that this strip of *Polylepis* cover is less than 30m across in many places, so that even relatively dense thickets of trees register as ‘sparse/nascent’ at the pixel level. This calls into question some of the change in forest cover found in this analysis. This is not to say that the change signal is false, but rather that some change labeled as a transition between levels of density, or from ‘open cover’ to ‘sparse/nascent’ may in fact be other kinds of change in *Polylepis* cover that Landsat pixels are just too coarse to capture. This spatial mismatch is a common problem to satellite remote sensing analysis (ex: Fisher, Mustard, & Vadeboncoeur, 2006), and while it does indicate that some subtle change is being missed, it does not invalidate the findings.

A closer examination of the kinds of change occurring in the *Polylepis* forest – both in the supervised and MTMF classification – indicate that forest thinning rather than clearing (natural and anthropogenic) is likely occurring (see Appendix B). The area of forest lost to ‘open
cover’ found in the analysis of supervised classification images decreases as a percentage of total forest area from 1991-2011, with the lowest rate occurring between 2001 and 2006. However, the area returning to Polylepis cover decreases significantly after 2001, thus increasing the net forest loss over that time. This suggests that observed forest loss is due to insufficient regeneration rather than forest clearing (though forest clearing is likely also a factor). It is possible, given the shortcomings of the supervised classification method, that there is more forest regeneration occurring that this data indicates. This is one of the primary reasons that the MTMF method was also utilized, and these findings also suggest thinning of the forest, but not necessarily a lack of regeneration.

The data generated from comparison of MTMF images indicates that the category of ‘sparse/nascent forest’ increased in percentage of cover from 49% in 1991 to 68% in 2011 – an increase of nearly 40%. Over the same time period ‘dense forest’ decreased as a percentage of total Polylepis cover from 36% in 1991 to 16% in 2011 for a total decrease of 55%. The percentage of ‘open canopy forest’ stayed relatively consistent throughout the study period at approximately 15% of total cover. At each sample ‘sparse/nascent forest’ expanded into an area of previously unforested territory that was greater than the area of denser Polylepis cover that transitioned to ‘sparse/nascent.’ However, the expansion of this class into previously unforested territory was always counteracted by a total area of ‘sparse/nascent forest’ lost to ‘open cover’ that was greater than or equal to gains. There was also a high degree of turnover in areas of change both to and from the ‘sparse/nascent forest’ class (see table 3.3). As table 3.3 indicates, in any given sample year, at least half of the area that transitions from sparse Polylepis to ‘open cover’ had had experienced the opposite change (from ‘open cover’ to ‘sparse/nascent forest’) in the previous sample year. Likewise, a significant, but smaller, percentage of new Polylepis cover
in each sample year had converted to ‘open cover’ in the previous sample. With this high rate of turnover, and the imbalance of expansion and contraction indicates that the net increase in the ‘sparse/nascent’ cover class from 1991-2011 is due entirely to thinning of previously denser *Polylepis* cover.

It is possible that this observed thinning is due to over extraction rather than low rates of regeneration, but differentiating between these two drivers of change requires plot-level analysis that is beyond the scope of this study. However, the fact that a significant area of ‘open cover’ shows evidence of the emergence of *Polylepis* from sample year to sample year suggests that regeneration is not necessarily an issue (at least not in certain parts of the forest). The predominant change in the two denser classes of *Polylepis* cover is toward thinner categories rather than to ‘open cover.’ This indicates that forest clearing is not the principle driver of change in these regions, but as noted above, this does not mean that timber extraction is not part of the problem.

Further compounding the question of regeneration is the fact that a small percentage of the ‘sparse/nascent forest’ and ‘open canopy forest’ classes do transition to denser categories of *Polylepis* cover during each sample interval. In fact, a comparison of thinning and maturing trends in forest cover yields a murky signal. Samples taken at 1996 and 2006 indicate that

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**Table 3.3** This table indicates the percentage and absolute area of total change in the ‘sparse/nascent’ cover class that experienced the opposite change in the previous sample year.

<table>
<thead>
<tr>
<th></th>
<th>from Sparse/Nascent to Open Cover</th>
<th>from Open Cover to Sparse/Nascent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>ha</td>
</tr>
<tr>
<td>1996-2001</td>
<td>78.57</td>
<td>14.71</td>
</tr>
<tr>
<td>2001-2006</td>
<td>47.20</td>
<td>7.52</td>
</tr>
<tr>
<td>2006-2011</td>
<td>50.50</td>
<td>6.64</td>
</tr>
</tbody>
</table>

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2 The issue of timber extraction will be discussed further in the next chapter.
roughly 25% of total *Polylepis* thinned from the previous sample year compared with only 8% and 9% in 2001 and 2011, respectively. In contrast, samples in 2001 and 2011 find 18% a 16%, respectively, of the total forest area was maturing to denser categories with only 13% thinning. It is important in light of these observations, however, to not correlate maturation with regeneration. It is entirely possible that existing forest that MTMF identifies as more dense from one sample date to the next could equally be the result of growth in existing trees and not the presence of new individuals. The same could be said for some of the expansion of ‘sparse/nascent forest’ into unforested territory. Plot level study is necessary to illuminate these landscape level findings and identify specific drivers of forest cover change.

Nonetheless, there are some tentative conclusions that can be made based on these findings. First, areas that are more densely forested are more likely to transition toward a less dense state of *Polylepis* cover when they do change. Secondly, while the amount of sparse *Polylepis* cover expanding into previously unforested areas is significant, it is always negated or surpassed by areas of sparse forest transitioning to unforested cover. Thus the overall trend, though erratic, over the study period is toward smaller area of *Polylepis* cover that is less dense than in the past. These findings indicate that the rate of regeneration in the forest is less than the rate of extraction and die-off.

The spatial clustering of the three *Polylepis* cover categories provides a coherent forest structure across the sample years. The ‘dense forest’ category is predominantly found in the core interior of the forest region and on the steep northern slope that stretches into the shadowed area of the image. ‘Open canopy forest’ is found predominantly in areas directly adjacent to dense forest. The ‘sparse/nascent forest’ category forms the exterior of the forested areas, as well as a significant cluster in the southeastern quadrant of the study area. This area is the southeast is also
where the majority of the forest agriculture plots are located and the sparseness in many cases may be the result of numerous small agricultural plots within a pixel space rather than widely scattered trees. There is a consistent and diffuse clustering of ‘sparse/nascent forest’ in the southwestern quadrant as well – the same region that was poorly classified in the supervised classification images. This area is also highly dynamic over the study period, which will be discussed in more detail shortly. There is also a persistent stretch of ‘sparse/nascent’ *Polylepis* cover that connects two blocks of denser forest throughout the study period.

The spatial distribution of change is somewhat incoherent, but there are some trends that emerge from visual spatial analysis. In the supervised classifications, the majority of change occurs along the forest edge, with some clustering in the southeastern quadrant that is likely the result of fallow field clearing in forest agriculture plots (this region also saw a significant amount of the turnover noted in figure 3.7). The MTMF images also indicate consistent change around the forest edge. In both cases, the change is comprised of both forest loss and expansion, though the area lost generally exceeds gains. The majority of this change occurs in the ‘sparse/nascent forest’ class, which is consistent with trends noted above. Changes along the forest edge also indicate a consistent decrease in *Polylepis* forest along the northern edge of the study region that extends into the shadowed portion of the image. It is possible that this is the result of up-slope migration and not forest loss, but the shadows present in the Landsat 5TM imagery make this distinction impossible. There is a physical barrier to up-slope migration in the form of a vertical rock face, which casts some doubt on the extent of forest migration. The consistency of these changes indicates a slow shrinking of *Polylepis* cover over time rather than a fragmentation of existing forest into smaller patches.
The stretch of ‘sparse/nascent forest’ that connects two regions of denser forest (see figure 3.5) changes significantly from sample year to sample year, but it does not appear to be progressing toward disappearance. There are several homes and some agricultural plots in this area, and it is possible that the periodic change in this section of forest is due to the clearing of longer-term fallow fields. There is no evidence during the study period that this section of forest is becoming denser, and it would take relatively little change to break this connection and fragment the forest cover into two distinct patches.

The MTMF analysis indicates that the denser classes of Polylepis cover clustered in the forest interior are becoming less extensive, and somewhat fragmented. However, this change does not give a clear signal. While the over-all trend from 1991-2011 is a decrease in forest density, there is an increase in ‘dense forest’ from 1996-2001 and 2006-2011. This incoherence makes it difficult to determine a definitive trend in Polylepis distribution in the larger central area of forest. In the northernmost section of forest, however, there is a consistent sample-to-sample decrease in denser categories of Polylepis forest. This suggests that the drivers of change in Polylepis cover, whether they are anthropogenic or otherwise, have variable impact based on location and microsite conditions.

The region in the southwestern quadrant of the study area that initially proved difficult to classify presents an interesting counter trend to the overall trajectory of Polylepis thinning and
decline. In this region (see figure 3.6) the total area of *Polylepis* cover increases over the study period from 2.25 ha in 1991 to 5.13 ha in 2011. This increase is very fragmented, and given the other issues mentioned above, it is difficult to determine if this area is trending toward closed canopy forest. It is worth noting that this region was identified by multiple interviewees as a region of new forest. From a landscape perspective, this region of forest expansion could offset the loss of *Polylepis* cover in other areas, but is not possible at this time to determine if this is likely. One obstacle to expansion in this area is its proximity to human settlement. This area contains several houses, as well as agricultural plots, and the community school and municipal buildings are nearby as well. Given these barriers it is difficult to imagine significant *Polylepis* expansion in this sub-region. Further monitoring of this and other changes, as well as more detailed spatial analysis with tools such as FRAGSTATS are necessary to better understand trends in forest cover change.

### 3.5 Discussion

The change trends found in this analysis could easily be used to support the dominant discourse discussed in the previous chapter. In fact, this slow decrease in size accompanied by thinning is exactly the type of change identified by Fjeldså and Kessler (1996). However, placing this change in the context of other discussions in the academic literature raises numerous other possibilities that complicate simplistic readings of these observations. Also important in this contextualization is placing observed change in a broader, interconnected landscape (which the discourse effectively dismantles). In addition to fire and grazing, climate change and economic processes should also be considered as contributing to observed changes in *Polylepis* cover. And importantly, synergies between these processes must be thoroughly explored (Turner, 2010).
Despite the fact that (anthropogenic) fire is identified as one of the main drivers of Polylepis forest loss, there have been very few studies that quantify the effects of fire in these systems. Cierjacks and Salgado et al. (2008) find fire to be particularly devastating to a Polylepis incana forest in Ecuador, though they note that the trees actively regenerate after the fire event. Conversely, Cierjacks, Wesche, and Hensen (2007) find in different location in Ecuador that fire rarely damages adult trees or penetrates the interior of the forest. Furthermore, Kessler (2000) observes that mature Polylepis trees are well adapted to fire do to their thick and multi-layered park, and that generally only seedlings perish in ground fires. And Renison et al. (2006) reports that mature trees frequently resprout after fire events. Rather than suggest that these studies invalidate each other, I argue that they indicate that there is significant variation in Polylepis response to fire depending on the character of the event and the site conditions.

Particularly important in the context this case study is an understanding of the relationship between fire and grazing. Kerby et al. (2007) for instance, used dynamic vegetation modeling to demonstrate that grazing can significantly reduce fuel load and control the extent of fire. This is similar to Savage and Swetnam (1990), who found that sheep grazing in the southwestern United States coincided with significant decreases in fire frequency, likely due to decreases in ground fuels. In fact, Bachelet et al. (2000) found (using similar methods to Kerby et al.) that grazing sufficiently limited the effects of fire in South Dakota to actually protect existing forest stands and promote seedling recruitment. There is a significant need for studies that explore these dynamics in the Andes (Zimmermann, Renison, Leyer, & Hensen, 2009), but in the mean time it is clear that a simplistic connection between grass fire and Polylepis decline is highly problematic. This is especially true for this case study because interviewees universally stated that they no longer burn their pastures, and have not done so for at least fifteen years.
Approaching this issue from a landscape perspective, it is important to consider how changing fire regimes in the adjacent grasslands might cause shifts in other processes in the landscape – namely grazing. Research indicates that the grassland communities in the central Andes are not able to support cattle and sheep without regular burning (Hofstede, Castillo, & Osorio, 1995). It is entirely possible, then, that removing fire (or at least greatly diminishing it) from pasture land will lead to a displacement of grazing to other areas of the landscape like the *Polylepis* forest.

As mentioned in chapter 2, recent research indicates that the negative impact of grazing on *Polylepis* forest is only found at high stocking rates, especially under continuous grazing. Under these conditions studies find that regeneration is significantly limited due to trampling, soil erosion, and possibly the consumption of young seedlings (Cierjacks, Rühr, Wesche, & Hensen, 2008; Pollice, Marcora, & Renison, 2012; Torres, Renison, Hensen, Suarez, & Enrico, 2008; Zimmermann et al., 2009). Following the dominant discourse, grazing of cattle and sheep seem a likely driver of forest thinning and loss. As with fire, however, this simple cause and effect relationship needs more critical exploration.

Interview respondents in Colina indicate that they do graze their livestock within the forest, but generally do so only during the latter part of the rainy season when other grazing areas are exhausted, or on hot, rainless days when the animals need to take refuge in the shade. Interviewees also state that the stocking rates in the community have declined significantly over the last twenty years due to the deterioration of pasture and depopulation. This grazing scenario is in keeping with the findings of recent research that links moderate and intermittent grazing with increased *Polylepis* regeneration (Cierjacks, Rühr, et al., 2008; Pollice et al., 2012; Torres et al., 2008; Zimmermann et al., 2009). Unfortunately, I was unable to obtain accurate head counts of livestock in Colina, both because some interviewees were not willing to share that
information, and because I was not able to interview every household.\(^3\) It is possible, then, that the stocking rates were too high in the past and continue to be unsustainable, even after significant decrease. It is also possible that grazing rotations have changed in response to changing resource availability. This will be discussed in further detail in the next chapter. Turner and Hiernaux (2002), and Butt (2010) both document significant spatial and temporal shifts in grazing in response to resource availability. This seems especially pertinent to this case, given that fire regimes in the adjacent grasslands have recently changed with likely implications for forage production. Longer-term plot level studies are needed to assess this hypothesis. At this stage, however, it is possible to suggest that the grazing is involved in observed change in \textit{Polylepis} cover, potentially related to changes in resource availability and biophysical changes in other parts of the landscape. In particular, this thesis suggests that changes in forage availability in adjacent open pasture land has led to unsustainable grazing pressure in the \textit{Polylepis} forest, which research suggests will severely limit regeneration (Cierjacks, Rühr, et al., 2008; Pollice et al., 2012; Torres et al., 2008; Zimmermann et al., 2009). Grazing practices in Colina will be discussed in more detail in the next chapter.

Grazing should also be understood as an economic activity, and economic developments and processes at other scales need to be considered as active and integrated landscape processes. Research in other peasant communities in the Bolivian highland indicate that livestock are an important means of wealth storage and emergency cash reserve (Hensen, 2002; Ibisch, 2002). Interview respondents in Colina said that livestock inputs are essential to their agricultural practice, and are an integral component of their diversified livelihood strategy. Interviewees also

\(^3\) The syndicate does not keep aggregate records of herd size, or were unwilling to share them. In an interview with the current director of the syndicate, he told me that he did not know exactly how many animals there were in Colina, or how many families kept livestock.
indicated that they had little choice but to keep livestock in order to make a living. This economic situation is important to consider in the context of the role of grazing in *Polylepis* forest loss. If pasturage is in fact decreasing, Colinanos may not have the option of decreasing herd size or transitioning to other income sources (other than migration, which many do). This interaction between economic and biophysical processes is very much like the synergy between climate change and ecological disturbances discussed by Turner (2010).

Zimmerer (1993) offers key insights into the impact of rural out migration and engagement in off-farm labor. In his study of soil conservation practices in the Cochabamba highlands, Zimmerer found that the loss of labor to migration precipitated significant shifts away from labor intensive soil conservation practices. Similar processes may also be underway with the herding practices in Colina. Due to labor shortage, grazing rotations may be relying more heavily on the forest understory, which is closer to homes, thus requiring less travel. Interviewees stated that grazing in communal pasture often required relocating to small huts at higher elevation due to the distance from home. This type of practice would be difficult to maintain without adequate labor to concurrently maintain agricultural fields during the rainy season. One older interview participant, Guillermo, told me that he no longer keeps any animals because he has no one to help him tend them. Further fieldwork following Turner and Hiernaux (2002) and Butt (2010) is necessary to explore this hypothesis.

Fire, grazing and economics must also all be considered in combination with changing regional climate. Paleoecological research finds that climatic shifts in the mid Holocene to relatively warmer and drier conditions coincided with significant decreases in *Polylepis* forest cover (Gosling, Hanselman, Knox, Valencia, & Bush, 2009; Williams, Gosling, Brooks, Coe, & Xu, 2011). This correlation is significant enough to lead Gosling et al. (2009) to argue that
current climate trends in the central Andes may be the most pressing driver of long-term shifts in
Polylepis forest cover. I attempted to obtain and analyze climate records for the immediate
region of Colina, but like many things in Bolivia, this data was difficult to obtain, and the records
that I found were incomplete. However, Vuille et al. (2003) find that current climate trends in
the arid and semiarid regions of Bolivia and Peru are trending toward drier and warmer
conditions. And modeling studies suggest that this trend will continue through the 21st Century
(Urrutia & Vuille, 2009; Vuille et al., 2008). These same findings are also reported by
interviewees in Colina, particularly that precipitation has become less abundant and less
predictable. Dynamic vegetation modeling conducted by Bond et al. (2003) found that in more
arid environments in South Africa (≤ 650 mm/yr), climate was often the limiting factor to forest
expansion, regardless of fire regime. Bachelet et al. (2000) found through similar methods that
grazing and fire interact with warmer and drier climate to favor the replacement of forest with
grassland and shrubland. It should be noted, however, that the latter study also found that heavy
grazing actually promoted forest maintenance under certain conditions. These studies suggest
that changing climate in the region may be exacerbating the effects of grazing on Polylepis forest
in Colina, as well as independently driving forest loss.

In light of this discussion, there are two distinct possibilities that must be considered as
contributory to observed forest change. First, it is possible that changing climate is largely
responsible for this change by rendering current land use practices unsustainable. The second,
and more likely possibility is that changing climate is interacting with (and inducing shifts in)
fire and grazing regimes and economic processes to produce polyvalent drivers of forest change.

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4 Further exploration of climate and Polylepis forest cover change is one of the directions of future research for this project.
3.6 Conclusion

By utilizing both supervised classification and MTMF methods of forest cover mapping I have successfully conducted a nuanced change analysis of *Polylepis* forest in Colina form 1991-2011. The over-all change trends in forest cover indicate a slow and steady decline in forest cover combined with sporadic thinning. These observations are consistent with the changes identified by the dominant discourse in *Polylepis* forest change, and grazing and fire are (or were) part of this landscape. However, by discussing these trends in the context of other processes in a holistic landscape framework, I have endeavored to recast these observed changes in a more complete light. I find it likely that grazing is implicated in observed changes in *Polylepis* cover in Colina, but not in the simplistic manner that discourse posits. I agree with Fjeldså and Kessler that grazing must be considered as one of the many processes in the landscape that affect *Polylepis*. It is likely, however, that grazing pressure in Colina is a response to various other changes in the landscape, namely fire, climate, and economy.

A holistic landscape framework requires more than just considering *Polylepis* forest change in dialogue with other physical processes in the landscape. Human and social processes also affect, and are affected by, these same biophysical processes, and they must be formally studied and synthesized with the type of analysis conducted in this chapter. In the next chapter I explore the findings from qualitative research in the community of Colina to provide further context for the forest cover change detailed in this chapter.
Chapter 4

Placing *Polylepis* Cover Change in Context: Exploring Linkages Between Livelihoods, Management, Perception, and Change in Colina

4.1 Introduction

Even after placing observed forest cover change in the context of other, related academic conversations it is difficult to link identify factors influencing this change without additional information. As noted in the previous chapter, plot-level ecological data is needed to better understand ecological interactions. Also necessary in this equation is data on the human components of the landscape – especially the campesino perspective, which is effectively silenced in the discourse discussed in chapter 2. In the following chapter I focus on the latter of these two data sources. The findings in this chapter draw on ethnographic style qualitative data collected in the field in July of 2012. There are limits to this data, which will be discussed in detail, but it nonetheless provides valuable insight and helps place *Polylepis* forest cover change in a broader context of interacting processes.

In this chapter I will discuss several themes that emerged from semi-structured interviews and observations in Colina that offer a more complete picture of *Polylepis* cover change than is possible with remote sensing analysis alone. These themes fall into three categories: livelihoods, environmental management, and perceptions of environmental change. Livelihoods and environmental management are particularly germane to this case study because they specifically linked to *Polylepis* forest cover loss by the dominant discourse discussed in the second chapter. Perceptions of environmental change provide a means of triangulation for the remote sensing analysis in the previous chapter, and they also allow this case study to explore other types of
change that may be affecting *Polylepis* forest cover in Colina. As I will demonstrate in this chapter, there are two other environmental changes reported by the community members – changes that are not detected by the methods used in the last chapter, and that are likely important components of observed *Polylepis* forest cover change in this community.

By combining ethnographic data with remote sensing analysis I am able to more effectively observe the whole landscape, and better understand the entanglement of social and biophysical change (Jiang, 2003; Robbins, 2001, 2003). In so doing, this case study makes an important contribution to *Polylepis* forest research, as well as to a growing body of human-environment research that seeks to understand the relationship between land cover change and social processes (Lambin et al., 2001; Moran & Ostrom, 2005).

4.2 Methods

I employed semi-structured interviews and ethnographic style observations to collect qualitative data for this case study in the community of Colina in July of 2012. Semi-structured interviews were conducted with an interview guide (see Appendix C) and focused on two specific areas: environmental perception and land use practices. Asking questions about environmental perception allowed me to focus on what was important to the community members about different parts of the landscape, and how these parts relate to each other. This area of inquiry also allowed me to ask questions about personal understanding and experience of environmental change. The portion of the interview focusing on land use practices provided informative data on livestock management, and other livelihood practices, as well as environmental management and adaptations to perceived landscape change.
Observational data provides a point of triangulation for interview data. Also, following Robbins (2010), observation allows me to probe the relationship between discourse (i.e. community explanations of livelihood practice) and actual land use and provides important insights into the relationship between culture and landscape. Collecting observational data was particularly important in regard to charcoal production, which will be discussed in more detail below.

4.2.1 Semi-Structured Interviews

I interviewed 24 people while in Colina – 15 men and 9 women. Interviewees covered a large range of ages from 21-70. Interviews participants were selected to maximize diversity in the sample. From a certain point of view, this amounted to a convenience sample due to a seemingly high frequency of absentee residents. However, I was purposive in my sampling, pushing my assistant to help me identify more women and young Colinanos. I also decided to stop interviewing males over the age of 50 to avoid a sampling bias. I did not interview anyone under the age of 18 in compliance with my IRB. Two of the interviews were conducted with leaders of the local syndicate. Each interview lasted an average of 20 minutes. My goal upon entering the field was to conduct a smaller number of interviews that were roughly an hour in length. Unfortunately, I arrived in Colina directly prior to the potato planting season, and no one I spoke with was willing to speak for much longer than 30 minutes. I tried in several cases to return for second interviews but was denied permission.

Two of these interviews (one male and one female) failed. Both of these interviews were some of the first that I conducted. Neither of these individuals seemed comfortable speaking in Spanish, and at that point my Quechua translator did not clearly understand how to help in those
situations. Also, in the case of the failed female interview, it was very clear that she did not want to talk to me. Two interviews were conducted in groups of two; Adan and Sandra, a husband and wife, and Edita and Ana, two women in their early 30’s. The interview with my assistant’s mother devolved into a bad situation when her son-in-law attempted to take over the interview, and I decided to end the interview. These issues leave a total of 14 men and 7 women over 19 interviews.

Interviews were conducted in Spanish by me. Colina, like most of the campesino communities in TNP, is a Quechua indigenous community which required me to use a translator for about half of the interviews. In these cases, usually with older Colinanos, my research assistant translated (sometimes poorly) from Quechua to Spanish. Using a translator presented some challenges, as did speaking with Colinanos in a language that was not native to either of us. Nonetheless, these interviews provided a wealth of information.

All the interviews were recorded and transcribed using NVivo qualitative analysis software and then coded to identify relevant themes. I utilized a progressive coding process adapted from the constructivist grounded theory of Charmaz (2000). The first phase of analysis used open coding to identify important themes, with subsequent analysis grouping this data into the final themes identified in the introduction.

4.2.2 Observations

I collected a total of approximately 80 hours of ethnographic observations during the course of my fieldwork in Colina. This included many different activities and types of data. I spent a considerable amount of time hauling things in the bed of my pickup truck, from people to PVC irrigation piping to flowers. This took place both within the community and back and forth
from the municipality of Tiquipaya in the Cochabamba valley. This gave me the opportunity to have informal conversations with many different people, including the teachers that worked in the local school, and to see first-hand the types of goods that were commonly brought to the city for sale. Also included in observational data are the many other informal conversations I had with community members at the central plaza and with my assistant during the many hours we spent together. I also observed the livestock management of numerous families, and spent many hours walking through the Polylepis forest, taking photographs and observing the condition of the forest. This data provides a point of triangulation for interview data, and it has also allowed me to fill in the gaps in some of my interviews by providing a more detailed context of life in Colina.

4.3 Obstacles to Data Collection

There are always challenges associated with data collection, and often these issues become more complex when dealing with inter-personal relations. In this case, I encountered several obstacles to data collection that warrant further discussion. These issues limit the effectiveness of my qualitative data in some respects, but in other ways these challenges provided interesting perspective for interpreting results.

When collecting qualitative data it is important to continuously reflect upon your relationship to participants vis-à-vis power dynamics, particularly as they are mediated by race, class and gender (Naples, 2003). I faced a difficult challenge in Colina in this respect that stemmed from my introduction by SERNAP. On the one hand my alliance with the national Park Service was a strategic necessity because I would not have been able to gain access to the community or receive permission to conduct research in Colina without the guarantee of the park
rangers that regularly visit the community. However, relations between Colinanos and SERNAP are not without tension as the authority of the Park Service is hotly contested in the expansion zone of TNP and many campesino communities in the region view the creation of the park as an unjustified land-grab (Boillat, Rist, Serrano, Ponce, & Delgadillo, 2008; Boillat, 2007). My association with SERNAP made it difficult to discuss illicit activities like charcoal production during interviews, and numerous people refused to trust me even though I promised to protect their identities. In one case, an individual that had given me his name and set up an interview for the following morning told me that he no longer trusted me, nor wished to help me, and required me to black his name out of my notebook so that he could not be identified. However, my position also provided an interesting perspective for statements made about SERNAP activities and authority, and I have come to understand many of these statements as acts of political claims making by Colinanos.

This idea of positionality also factored into cultural barriers that were difficult to cross. This was particularly true in my efforts to interview women. Serrano et al. (2006) found that there were significant cultural barriers that prevented white foreign men from interviewing women in the Quechua communities in TNP, particularly when their husbands were not present. I found this to be the case in Colina, as well. In many cases women interviewees seemed uncomfortable with me, and my assistant was often less willing to assist in these interviews (a fact that led to several heated discussions). In several cases other men in Colina seemed frustrated by my attempts to speak with women, and repeated efforts to organize focus groups with the assistance of community leaders were of no avail. Given these many challenges, I

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1 All interviewees are identified through pseudonyms, as is the community itself, and no individuals in Colina were identified to SERNAP, nor was the practice of any illicit activities.
consider it a great achievement that I was able to successfully interview seven women for this case study.

Language was also a significant challenge for qualitative data collection in Colina. While many of the Colinanos, particularly those under the age of 40, are bi-lingual the fact that Spanish was a second language made conveying the meaning of my interview questions a challenge, and some resulting in some interviews in which certain questions were just not discussed. In these cases, and in all the interviews with community members less comfortable in Spanish, the translation work of my assistant was a necessity. Unfortunately, my assistant, Eddie, was not always a dependable translator. In some cases, he would translate a lengthy response into just a few words, or decide not to translate when interviewees clearly did not understand my questions. At times he would even argue with me about the questions I asked, insisting that we already asked too many people particular questions. His translation proficiency also seemed to hinge on how bored he was at the time, becoming much worse toward the end of my time in Colina.

Finally, time was perhaps the greatest challenge to data collection in Colina. As mentioned in the last chapter, I had intended to conduct research in another area of TNP that I was not able to access, and I was only able to gain permission to conduct research in Colina at the very end of my time in Bolivia. This meant that I had less time to gain the trust of the community and less time to arrange interviews. The community also determined that I should only be allowed to work in Colina for ten days, and I was required to sign a contract to that effect. In this position, I had little room to bargain with Colinanos, and I could not afford to risk expulsion from the community. The logistical obstacles to access also mean that my fieldwork was conducted at the very end of July, directly before the potato planting season. At this time most of the Colinanos were working at a furious pace to finish an irrigation project, and to
prepare for the onset of the rainy season. In this environment, many Colinanos were reluctant to spend more than 20-30 minutes speaking with me, and as mentioned above, several refused to speak with me after our initial interview.

All of these issues complicated data qualitative data collection in Colina, but they are by no means unique to this case. And in spite of this confluence of circumstances, I was still able to collect sufficient data to accomplish this case study.

4.4 Livelihoods

Scholars have documented the uneven development in Bolivia that has generally left much of the rural highland population behind (Bebbington, 1998; Zimmerer, 1993). The election of Evo Morales in 2005 brought with it much hope of improving circumstances for highland campesinos, but relatively little progress has been made, and it is too soon to tell if the tides are shifting (Kohl, 2010; Weisbrot, Ray, & Johnston, 2010). In the face of changing markets in which they struggle to compete, many campesinos have few options but to continue with agropastoral livelihoods and supplement income with temporary to permanent migration (Bebbington, 1998; Preston, 1998; Zimmerer, 1993). This is not to suggest that campesinos are without agency (ibid) – quite the opposite. The people of Colina are continuously adapting to changing ecological and economic circumstances, but in the face of severely limited resources they have necessarily narrow framework within which act.

The characterization of subsistence agriculture combined with migration presented by Zimmerer, Bebbington, and Preston is very much the case in Colina. Every person that I spoke with produced the majority of their own food, and sold what surplus they had to purchase other essentials. Many Colinanos also have relatives that live and work in other parts of Bolivia and
South America, or seek work in the city themselves. Nearly every respondent said that livestock were an important component of their livelihood, but that it would be difficult to substitute the loss of any source of income, whether it be from livestock or crop cultivation. Several people also told me that agricultural production depended on keeping livestock for manure inputs, and for the use of cattle for plowing fields.

Several interviewees did not keep livestock, though they had in the past, but their reasons varied. Adan and his Sandra, both in their early 30’s, did not currently have any livestock because they did not have enough land to support them. Adan and Sandra were able to fill in this gap in their livelihood by cultivating flowers for sale in the city. Sandra told me that flowers are actually more profitable than livestock, and produce stems for sale each week. Even so, Adan assured me that he intended to purchase livestock again in the future. Fernando, 70, owns a small mixed herd of llama, alpaca, sheep, and cattle (ten animals total) but did not keep them in Colina. He chose to leave his animals with his children that lived in a neighboring community because the pasture was apparently better there. Fernando admitted that the animals do travel back and forth between locations, but that they were kept outside of Colina for much of the time. Boillat (2007) reported found that this practice was not uncommon in other communities in TNP. Guillermo, 57, told me that he no longer keeps animals because he cannot maintain a herd without additional labor. His wife and parents are deceased, and all of his children have migrated away from Colina and return infrequently. This lack of labor prevented Guillermo from diversifying his livelihood, so he chose to focus on agriculture rather than herding livestock. Similarly, Carla (age 70) stated that she had a much larger herd when her children were still living in Colina. All nine of her children had permanently migrated from the community.
These latter reports of labor scarcity are similar to the findings of Preston (1998), who reports that off-farm migration lead to changes in livelihood strategies among those that remain. This type of engagement in off farm work is becoming increasingly common in Colina. Jaime, 35 and the current leader of the syndicate, told me: “In reality, the land isn’t sufficient, so the majority of people go to the city to work, you know? Because sometimes the land isn’t enough.” Eladio, 33, told me that many of the people that have left to find work have not returned, and in his mind, this has led to noticeable declines in the productivity of the community land. I was not able to get specific responses to what kinds of practices have changed, but this is certainly congruous with the work of Zimmerer (1993), who found that off-farm migration lead to changes in soil management strategies that lead to increased erosion.

I was curious while in the field why more people did not grow flowers like Adan and Sandra in response to changing economic circumstances, especially since it seemed so profitable. It appears, however, that Adan and Sandra are a bit of an exception in Colina. Pablo, another of the syndicate leaders, told me that growing flowers is a great business, but that most of the land in Colina is not suitable for flower cultivation. He expressed that this limitation to crop diversification was a real problem for the community. This sentiment was expressed by several others that told me that they would gladly grow flowers if they could, but their land would not produce them. I was unable to ascertain what the specific limitations to flower production are in Colina, and extensive data base queries returned no results in the academic literature on this type of peasant flower production for regional markets. However, based on evidence from interviews and observations, as well as an article on commercial export flower production in the Cochabamba valley, I suspect that the limiting factors in Colina are a combination of water and shelter. Haydu et al. (1992) report that extensive irrigation works are necessary for flower
cultivation in the Cochabamba valley, as are greenhouses to protect the plants from periodic freezing temperatures and high winds. Numerous families in Colina have greenhouses, but they are used for cultivating produce – mostly lettuce, tomatoes, and peppers. Irrigation water was not universally available at the time of data collection (Adan and Sandra do have a piped water spigot), but a project was underway to deliver spring water throughout the community (see below for a description). Adan and Sandra’s land is set apart from that of many other Colinanos I spoke with in that it is at a relatively lower elevation, and it is surrounded by an Aliso (another native Andean tree) woodland. Several interviewees told me that one of the benefits of the Polylepis forest was that served as a wind shield for the community. From this evidence, I suspect that the sheltered characteristics of Adan and Sandra’s land, which is rare in Colina, contribute significantly to their ability to cultivate flowers, and likewise, to the inability of many others.

One of the few options in times of shortfall in Colina seems to be the production of charcoal for sale in the city. This was a difficult topic to discuss with people, though a few were willing to discuss it openly. I suspect that much of the issue in this case stemmed from my position as allied with SERNAP. Charcoal production was outlawed in TNP with the institution of Ley 1262 in 1991, and while Colina lies in the expansion zone of TNP where park laws have not yet been fully enforced, a community forest management plan enacted 4 years ago banned the production of charcoal as well. This ban was instituted and enforced by the syndicate, but opinions differ as to whether or not it was mandated by TNP (this will be discussed more in the next section). Regardless of the origin of this ban, however, charcoal production is illegal and many Colinanos were reluctant to directly discuss its production with me.
I had not intended to discuss charcoal production with the people of Colina, but I began asking questions after one interviewee, Vulmaro, 43, pointed out a small fire scar on a nearby hill and told me that it was the result of charcoal production. Vulmaro told me that people tend to make charcoal when crops fail, but that in good years very little is produced. This is similar to McSweeney (2004), who found that rural farmers in Honduras would resort to the sale of forest products like charcoal as a type of “natural insurance” when other income sources fail.

After Vulmaro, only one other person, Esma, 23, openly admitted to making charcoal, but she assured me that she made very little. Every other person that I interviewed stated that there were some Colinanos that made charcoal, but not many, and the producers were always identified as an ambiguous other. Even when confronted with the charcoal in their possession, Colinanos projected the production onto someone else. In one case a Colinano asked for my assistance in hauling approximately 100 pounds of charcoal to the market in Tiquipaya. When I asked where the charcoal had come from he assured me that it was made by his neighbor, Fernando. However, I had interviewed Fernando that day (in the presence of the Colinano in question) and he had assured me that he never made charcoal, as had the person who asked for my help in hauling it to town.

The most common reason given for not making charcoal was that it is illegal. One woman insisted that she did not even know how to make it. Another, Alondra – age 47 – said that she would make charcoal but that she did not have the time. Alondra lives alone, and similar to Carla and Guillermo, she may be faced with labor shortages that limit her livelihood decisions. In many other cases, however, I suspect that people do make charcoal, but do not speak of it openly (at least not with me) to protect themselves from legal trouble. This is based not only the already mentioned interactions, but also on the discovery of the remnants of fire pits concealed in
the *Polylepis* forest, which my assistant confirmed were the product of charcoal production (see figure 4.1). Pablo, one of the community leaders that I spoke with, told me that Colinanos used to be able to make charcoal to by food and other basic needs, such as school fees. This ban on charcoal production has removed an important source of income for the people of Colina without providing any suitable alternative. In such situations, it is not surprising that Colinanos continue to produce charcoal in a more clandestine manner (see Robbins, McSweeney, Chhangani, and Rice (2009) for a more thorough discussion of illicit resource extraction). Charcoal and the circumstances of its production will become more significant in later discussion of environmental change.

### 4.5 Environmental Management

As would be expected in a community that derives much of its livelihood from the land, Colinanos very actively manage their landscape. Jaime, the syndicate leader, told me that all the land in Colina was used for specific purposes. The highest elevation area was used for grazing, the central portion where the primary pueblo is located is for cultivating certain crops like potatoes and beans, and the lower portion of the community is used for cultivating a wider variety of crops that require slightly warmer conditions, such as maize and other grains. This segmentation of the landscape is informative, but it is far from a rigid framework. The upper region is also an important area of agricultural production, especially for potato and other root
crops, but I also saw fields of oats at considerable elevation. And livestock are grazed throughout the entire gradient of community land to distribute manure and make use of all available forage. This variation is in keeping with the Zimmerer (2003), who found considerable variation in cultivation along altitudinal gradients in Bolivia and Peru.

Grazing livestock follows a general annual rotation through all of the community land, but there is considerable variation within this framework, as well (see figure 4.2). During the dry season, which falls roughly from May to August, animals are moved through the lower portion of the community (region 1). At this time they are grazed on field waste and fed cultivated fodder such as oats or barley. During dry season each family keeps their own herds tethered to their family lots. With the onset of the rains in August or September the Colinanos begin to move their animals to pasture land in the upper portion of the community (region 2). This area includes the Polylepis forest (region 3), but interviews suggest that the forest is only utilized for grazing at specific times. The upper pasture land is communal, and Colinanos range widely with their herds during this time. At this time of year, community members often stay with their animals and live in small huts and satellite homes in the upper reaches of the community. As noted earlier, this practice requires sufficient household labor to devote family members to herding and others to tending crops. As the forage in the open pasture becomes depleted, herds are moved into the

Fig. 4.2 Annual rotation of grazing in Colina
Polylepis forest to graze on grass in the forest understory. Evidence from interviews suggests that there is considerable variation in the timing of this transition, which will be discussed in detail below. Numerous interview respondents also mentioned the importance of shade within the forest as a refuge from the hot sun during rainless days, which suggests that this region is also used intermittently throughout the rainy season. Seasonal rotation similar to that of Colina has been observed in other communities in TNP (Boillat, 2007) as well as in other regions of the Bolivian highland (Preston, 1998) and East Africa (Butt, 2010). In these cases, as in Colina, this rotation allows herders to take advantage of spatial fluctuations in forage and to maximize the use of available resources.

In the academic literature this style of livestock management is often referred to as ‘opportunistic management,’ or ‘opportunistic grazing’ (Baker & Hoffman, 2006; Bassett & Koné, 2006; Scoones, 1995). This concept is generally applied to communal grazing in Africa that covers much larger territories than in Colina, but Scoones (1995) finds that resident herds like those in this case study follow similar strategies, albeit at a more localized scale. Research in Africa suggests that there is considerable variation between individual herders, and that these differences are often related to access to non-communal grazing resources, other capital assets, and labor (Baker & Hoffman, 2006; Bassett & Koné, 2006; Turner, 1999). While the environmental context is quite different in Colina from that of Sahelian and Southern Africa, there is considerable similarly between these studies and the findings from this research.

Within this general structure of herd movement, the most variation in expressed grazing strategy was in the use of the Polylepis forest. Several interviewees did not differentiate between forested and open areas when discussing rainy season grazing practice, referring to the entire
region as ‘arriba.’ When asked, these respondents stated that this included the forested region, and that they also grazed their animals there during that season.

Braulio, 21 and the brother of Jaime, told me that they utilized the forest for pasture only when other sources of forage are exhausted. He specifically mentioned November as a time when forest grazing is important. This suggests that the *Polylepis* forest may be an important source of emergency forage for livestock throughout the year, not just during latter part of the rainy season. Braulio’s comments are congruent with the findings of Boillat (2007) in other parts of TNP where communities specifically use the *Polylepis* forest for grazing during the interim between the depletion of cultivated fodder and pasture green-up. Pablo also indicated that the *Polylepis* forest was a source of emergency fodder, saying: “we respect the forest, you know? But there isn’t much fodder… and we have to go to where there’s forest.” Several other Colinanos told me that the forest provides a consistent source of green forage, even when other areas are exhausted. These responses suggest that reliance on grasses in the *Polylepis* forest is highly variable from year to year, depending on the productivity of open pasture and the yield of fodder crops.

Three interview respondents, Alondra (47), Moya (32), and Teo (60) said that they graze their livestock in the forest throughout the year. Teo said he did this because the forage was better in the forest, which he attributed to the rich soil produced by leaf litter. Although Alondra and Moya did not offer reasons for this grazing strategy, it is likely due in part to differing personal resources, which seem to affect how different families manage their animals.

Alondra is an older woman who lives by herself, and her year-round use of the forest may be a result of limited time to both grow fodder and travel great distances with her animals. Recall
that Alondra also said that she did not make charcoal because she did not have the time. She also cut our interview short and literally ran away to tend to her cattle. Carla, who is seventy and reported keeping smaller herds since her children left the Colina, said that she primarily grazes in the *Polylepis* forest during the months of July and August – when most other people I spoke with graze their animals around the home and feed them hay. This choice could be due to the fact that she lives directly adjacent to the forest, or because she is not able to produce enough fodder to feed her animals during the dry season. This latter possibility could be the result of lack of labor, lack of land, or both. Baker and Hoffman (2006), and Turner (1999), both found that herding strategies on communal land varied widely in relation to labor availability and personal resources. A similar finding was presented by Preston (1998) in Tarija, Southern Bolivia. Adan, for instance, told me that he did not keep animals because he lacked sufficient land to support them. This is similar to the findings of Bassett and Koné (2006), who found that herd size and strategy was greatly influenced by access to land resources. Adan, as mentioned above, substitutes this loss of livelihood with flower cultivation, which many Colinanos are not able to pursue. Other residents of Colina facing similar land shortages may have no choice but to more frequently utilize the forest for grazing. Also interesting in this discussion of resources is the herd management of Fernando, who was able to keep his animals in another community to take advantage of better pasture. No other Colinanos mentioned this during interviews, but it is possible that others that have family connections in neighboring communities also make similar herding decisions.

Agricultural land is apportioned to families in the community and is traditionally subdivided and passed on from father to son. According to Jaime, each family respects the boundaries of their land, and there is no recourse for obtaining more land if a family needs to
expand. This situation creates land shortages for some families. Diego, 30, for instance, was not able to obtain land from his father and was thus forced to relocate to another, larger community – an event over which he is still quite bitter.

There are many agricultural plots within the *Polylepis* forest, almost all of which are located in the eastern extent of the forest where the terrain is less steep (see figure 4.3). These plots are valuable and highly productive assets for those Colinanos that own them, though they do not seem to be apportioned evenly among community members. I was not able to determine how these plots are apportioned during the course of my fieldwork. Those interviewees that do own plots within the *Polylepis* forest accredited the high productivity to the leaf litter and improved soil moisture. Research on *Polylepis* agroforestry has found that this leaf litter can improve crop yield by as much as six-fold (Fjeldså & Kessler, 1996). These fields are rotated through fallow periods, but most interviewees indicated that fallows rarely last longer than two or three years. During this time, *Polylepis* will re-colonize fallows, but these seedlings are removed when cultivation returns. Interview respondents said that the *Polylepis* trees around these plots are carefully tended, however, to assure that a steady supply of organic input.

According to most respondents I spoke with about the subject, these forest plots are long established, and new plots are never cleared from the forest. This suggests that agricultural clearing for agricultural production is not a primary factor in observed forest loss. However, one respondent, Vulmaro, told me that families do sometimes clear forest when they need land. This
practice, he said, is permitted by the community on a rotating basis based on need, and that clearing is restricted to areas where trees are at least 40-50 years old. This response is difficult to interpret because it is unique and seemingly contrary to the experience of Diego who wished that he had been allowed to clear forest to obtain land. This response is worth noting, however, because it could reflect prior practices (Vulmaro is 43), or current practices that most were not willing to discuss. Vulmaro is also the only Colinano that as willing to openly discuss charcoal production at any length. The results of remote sensing analysis do not suggest that forest clearing is a significant issue in Colina. Given that the typical agricultural plot within the Polylepis forest is smaller than a Landsat pixel, is it possible that some of the observed thinning of the forest is due to the creation of new agroforestry plots, but this distinction is not possible.

The community of Colina has also instituted a set of regulations governing the use of their Polylepis forest. This plan was instituted by around 2009, and it prohibits the felling of living trees, the use of fire for clearing land (a practice that was likely prohibited at an earlier date), and the making of charcoal. According to Jaime, this plan was agreed upon by the community, and those caught in violation are fined by the syndicate. There are a few people who violate these regulations, Jaime said, but for the most part, people respect them. This opinion was reiterated by nearly everyone with whom I spoke.

The genesis of this forest conservation plan is somewhat unclear based on my interviews. Most respondents I discussed this with told me, like Jaime, that these were community regulations and that TNP had nothing to do with them. Some, like Eladio, were quite critical of Park efforts to assert authority in Colina, insisting that they were able to protect the environment on their own. Jaime even went as far as to suggest that TNP officials never did more than come and chat every once-in-a-while. The forest management plan, Jaime said, was a community
response to pollution and climate change, and because they realized that the *Polylepis* forest was decreasing and needed protection. Pablo, however, who is also a community leader, had a somewhat different opinion. Speaking specifically of the ban on charcoal production, he said: “it’s because we’re in the Park. That’s the reason that it’s banned, you know?” Pablo did not deny that the community enacted the regulations, but he placed the origin of at least some of the specifics on TNP. Interestingly, he claimed complete ownership for the community ban on pasture burning, stating that that was necessary to protect the *Polylepis* as well as many other native species that live in the grassland. This suggests that Pablo may be externalizing the source of regulations that he perceives as negatively affecting livelihoods and internalizing those that he believes are beneficial.

While it was difficult to get straight answers from people on *Polylepis* conservation, I suspect that it is likely a combination of Park effort and community cooperation. Boillat (2007) reports a paradigm shift in park management toward community co-management, and I interpret interview responses on the subject to indicate that at least some aspects of the *Polylepis* conservation plan are a response to this initiative. Following Agrawal (2005), the tendency of many in the community to claim ownership of *Polylepis* conservation may be an indication of environmental subject formation.

I suggest, however, that there are also political motivations behind these ownership claims. TNP has been the site of significant unrest since the mid 1990’s when many of the campesino communities began to actively protest that they deemed as an unjust government land-grab (Boillat et al., 2008; Boillat, 2007). This conflict is manifest in the many negative responses to park authority given to me by Colinanos. Also suggestive of continuing conflict is that fact that several interviewees did not wish to discuss park regulations with me. In this
respect, I find that my affiliation with SERNAP provided some insight to these responses. I interpret the simultaneous ownership of conservation and rejection of park authority as an act of political claims making. By communicating their ability to successfully and independently conserve *Polylepis* forest to me, Colinanos were, in essence, communicating to TNP officials that it was their land, and they had authority over it.

This protest is also reflected in several components of community forest management that are counter to park regulation. Fuel wood collection is supposed to be restricted to dead wood, but according to Teo, this includes the traditional practice of harvesting ‘dry’ lower limbs from mature trees (see also: Simpson, 1979). And harvesting living trees is permitted for construction. Grazing is also permitted within the *Polylepis* forest, which park regulations prohibit. Jaime told me several times to “not exaggerate” (to TNP officials) the damage to *Polylepis* from grazing, which he and many others argue is minimal to non-existent. This statement from Jaime puts the tension between TNP and Colina in perspective: “If we are going to have only kewiña forest and nothing else, where are we going to live?”

**4.6 Perceptions of Environmental Change**

Many, if not all, of the Colinanos I interviewed expressed the opinion that numerous changes have been occurring in the landscape over the last 20 years. These include changes in the *Polylepis* forest, but also changes in pasture land and climate – particularly precipitation. Better understanding these perceptions of environmental change allows another nexus for qualitative data to interrogate observed changes in *Polylepis* forest cover.

Perceptions of change in *Polylepis* forest among Colinanos seemed to vary the most in comparison to other aspects of environmental change. Several people reported that the forest had
not changed at all during the last 20 years. All of these respondents were men, and only one, Pablo, was under the age of 60. The remainder of interviewees that expressed an opinion on the subject are equally divided between those that think there is more *Polylepis* forest \((n=5)\) and those that think there is less \((n=6)\). Most of the Colinanos that considered the forest to have expanded attribute the increase to the success of their active conservation. Jaime and his brother Braulio both cited a specific area of regeneration – the same area in the southwest quadrant discussed in the last chapter – as evidence of forest expansion. Given the connection between political claims making and conservation discussed above, this connection between conservation and forest expansion is not surprising.

Opinions as to why *Polylepis* forest cover has decreased vary among interviewees. Carla (70) and Lando (53) both suggest that the decrease in forest cover may be related to decreases in rainfall. Diego and Vulmaro both attribute the decrease in *Polylepis* cover to increased population. However, these responses should be qualified. As mentioned earlier, Diego was forced to leave Colina due to lack of land, and he remains bitter, even ten years after the event. He was one of the few respondents that told me there are more people and more livestock in Colina now than in the past, and his opinions may be colored by his past experience. Vulmaro said that forest had been lost to clearing for agricultural production. He was the only respondent that spoke of such a practice, with numerous interviews stating the opposite. Vulmaro also noted that while there is less total forest now than 20 years ago, *Polylepis* forests are currently expanding. Edita (32) and Eladio (333) had similar responses to this latter remark, commenting that the forest had decreased in some areas but was expanding in others. Eladio specifically faulted the lack of planting for areas of decrease. Teo (60) also indicated that there had been
areas of expansion and contraction in *Polylepis* cover, but that these gains and losses have basically balanced out.

None of my interview participants linked grazing in the forest with perceived decreases in *Polylepis* forest cover. This is contrary to the findings of Jameson and Ramsay (2007) in Peru, where local farmers acknowledged that herding in the *Polylepis* forest contributed to thinning canopy among other damages to the trees. The reports from Colina do not contradict recent research on the relationship between cattle grazing and *Polylepis* forest systems, however. This body of research finds that livestock will graze on the small seedlings but that grazing at moderate rates still increases seedling recruitment (Cierjacks, Rühr, Wesche, & Hensen, 2008; Pollice, Marcora, & Renison, 2012; Torres, Renison, Hensen, Suarez, & Enrico, 2008; Zimmermann, Renison, Leyer, & Hensen, 2009). Additionally, these studies find no evidence that Livestock browse on, or otherwise damage, mature trees. These findings echo the reports of Colinanos that their livestock would occasionally eat the leaves of small tender branches, but that this did not harm individual *Polylepis* trees. One interviewee, Hernan (59), also told me that the younger *Polylepis* trees resprout after being severely eaten back by cattle and sheep. This finding has not been reported in the literature on *Polylepis*-grazing interactions, but one recent study has found that *Polylepis australis* in Argentina frequently resprouts after fire events (Renison, Hensen, Suarez, & Cingolani, 2006). These findings lend credence to the Colinano position on the affects of grazing on *Polylepis* forests, however, it should be reiterated that much of this research also finds that heavy and persistent grazing pressure severely limits *Polylepis* regeneration (Cierjacks et al., 2008; Pollice et al., 2012; Torres et al., 2008; Zimmermann et al., 2009).
These variations in perception of *Polylepis* forest change are somewhat problematic in light of the findings presented in chapter 3. However, I suggest that these variations are the product of spatial differentiation of experience with the *Polylepis* forest. Lando, for instance, indicated a specific area directly adjacent to his home as land that had converted from *Polylepis* to open cover. And this is, in fact, an area of decrease identified in remote sensing analysis. This same stretch of forest is very proximate to the home of Carla, who also reported that *Polylepis* forest has decreased. Jaime and Braulio both indicated a specific area as evidence of forest expansion, and as mentioned earlier, this area, which is relatively close to their homes, has been the site of forest expansion over the last 20 years. This same area of forest is near to Moya’s home, and she too indicated that *Polylepis* has expanded. In each of these cases, individual experiences with specific areas of Polylepis forest are congruent with observed forest change. It is only from a landscape level analysis of *Polylepis* cover that the over-all decrease can be observed. And this perspective is difficult to attain without the use of remote sensing technology.

Unlike discussions of forest cover change, Colinanos were much more united in their perceptions of pasture change. In all but two interviews in which we discussed it, respondents stated that pastures have become less productive over the last 20 years. Of these Colinanos, nearly everyone attributed this to decreased rainfall. Diego, fittingly, attributed it to over population, but this is perhaps best understood as a bias on his part. Jaime and Braulio suggested that over grazing may be part of the problem, but they were the only ones (other than Diego) to suggest this. Colinanos link decreasing precipitation with a decrease in the production of quality forage in their communal pastures. Numerous respondents attributed this decrease in pasture

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2 I asked every interviewee if pasture, *Polylepis* forest, and climate had changed over the past 20 years. Not all respondents gave coherent answers, however, either because they did not understand the question, or because they did not wish to discuss it.
productivity to a concurrent decrease in herd size throughout the community. Interestingly, no Colinanos correlated decreased pasture productivity with the change in fire regime over the last ten to fifteen years. This is in spite of the fact that several Colinanos indicated that the burning of pasture was associated with the production of grazing forage. This apparent disconnect may be due to the fact that they did not wish to give me (as an ally of SERNAP) an indication that they thought fire was beneficial in some way. It could also be the case that decreasing precipitation is more important to pasture production in Colina than fire.

Decreased production in pasture land lends new insight to the discussion of grazing inside the *Polylepis* forest. It is possible that reported reliance on forest grazing is a direct response to decreased availability of pasture forage. This is in keeping with the opportunistic grazing research that finds significant spatial variation in grazing in relation to drought and forage availability (Butt, 2010; Scoones, 1995). In light of these changes in pasture, it is also interesting to note that numerous Colinanos said that they preferred grazing in areas with at least some *Polylepis* because the grass was greener. It is worth noting that Boillat (2007) found similar general grazing rotations in other communities in TNP, but that at the time of his research (approximately six to eight years ago) much less forest grazing was reported.

Nearly all Colinanos I spoke with said that rainfall has diminished in the past 20 years. Of all the environmental changes, this seemed to be the most pressing to the community. Numerous interviewees indicated that the onset of rains had moved to later in the year and that during the rainy season there are now more days without precipitation. McDowell and Hess (2012) found a similar consensus among Bolivian campesino farmers living in similar conditions in the La Paz department to the north of Colina, as did Postigo (2013) in a campesino community in the highland of central Peru. The variation in precipitation form year to year varies
significantly in the Bolivian Andes, and Colinanos reported that there are always years with less rainfall and lower crop yield. However, the consensus seems to be that the dry years have become more frequent, which is congruent with regional climate data (Vuille, Bradley, Werner, & Keimig, 2003).

While many interviewees attributed decreased precipitation with decreased pasture, the larger issue is loss of crop yield. The lack of reliable rainfall has become significant enough that the community has begun laying PVC irrigation to distribute water from a mountain spring on their land to all the farmsteads down slope (see figure 4.4). Similar modifications to local water resources in response to perceived climate change have also been reported in the highlands of Central Peru (Postigo, 2013).

This reporting of consistent shortfalls in precipitation, with likely decreases in crop yield place the earlier discussion of charcoal production in the context of decreased livelihood security (McSweeney, 2004). In the case of Colina, however, increased frequency of crop shortfall may be producing unsustainable pressure on forest resources, and thus contributing to forest loss. Given that charcoal production is now illegal, it seems more likely that wood extracted for production will be done on smaller scales to avoid detection, which could manifest as thinning forest at the scale of Landsat. It is unfortunate that I was not able to more openly discuss charcoal production with the people of Colina.
It is also important to consider this drying trend in light of past *Polylepis* responses to climate change discussed in chapter 2. Given that *Polylepis* forests have significantly contracted concurrently with climatic drying in the past, the observed decrease in Colina could be another manifestation of climatic forcing. Since accurate climate data at the local and regional level is difficult to obtain in this part of Bolivia, this qualitative data may be the first and best indication of climatic trends that have significant consequences for *Polylepis* forest cover.

### 4.7 Conclusion

These findings from the qualitative component of this case study provide valuable insight on the social aspects of the Colina landscape. They also shed light on other biophysical changes occurring in the landscape that are not detectable through the forest cover change analysis presented in the previous chapter. By studying these qualitative findings alongside the remote sensing analysis, a more complete picture of landscape change is generated. Changes in *Polylepis* forest cover must now be understood as related to changes in grassland and climate. Likewise, these myriad changes must also be understood as related to change in disturbance regimes, such as fire, grazing, and drought. Lastly, a holistic understanding necessitates that all of this be understood in the context of local and regional economy that is entwined with the landscape of Colina. This is the task of the next and final chapter.
Chapter 5

Reassembling the Landscape in Colina: From Parts to Wholes

5.1 Making Sense of Mixed Methods Data

The third and fourth chapters both present viable approaches to forest cover change research, and there are successful examples in the academic literature on environmental change that follow the basic concept of one or the other. I argue, as have others (Forsyth, 1998; Zimmerer & Bassett, 2003), that crucial information is lost when these multiple streams of data, or ways of knowing, are not synthesized. As Forsyth (1998) so aptly states: “[a]voiding integrating natural and social science risks reiterating dangerous ‘dominating discourses’ of degradation that do not help developing societies nor address practical environmental problems.” (p. 114) It is exactly this type of ‘dominating discourse,’ as discussed in chapter 2, that this case study seeks to challenge. To that end, the final chapter of this thesis seeks to weave together the threads of data that emerge from the empirics of this case study to suggest a different story of Polylepis forest change. This story is not one of resiliency, nor of balance, but rather one that is complex, even messy, and more complete than either quantitative or qualitative methods could hope to achieve. This is also a story that is unique to Colina, and while there are lessons that can be learned from this case study on how to approach Polylepis forest change analysis, the specific findings of this research are likely not generalizable to other regions. With replication of this type of research in other areas of the tropical Andes, however, some general findings may emerge.

In the next section of this chapter I reframe observed changes in Polylepis forest in Colina as one of interacting processes, rather than unidirectional action on the forest system. This
framing allows the different elements of the landscape and multi-scalar processes to be read together in a more holistic fashion. This presents environmental change in Colina as a dialogue in which there are many participants. I then discuss why this type of synthesis is important for *Polylepis* forest research (and environmental change research more generally), and conclude with several priorities for future research in these forest systems.

### 5.2 Colina as a Social-Ecological System

The changes in Colina’s *Polylepis* forest over the past 20 years are similar to those predicted by the dominant discourse discussed in the second chapter. In keeping with this discourse, fire and grazing would be identified as the drivers of observed decreases. In Colina this causal connection is made somewhat more tenuous given that pasture burning (as well as the use of fire to prepare agricultural fields) has been banned. This fact would likely increase the strength of the implication that grazing within the forest is the dominant driver of *Polylepis* cover loss. As the discussion in chapter 3 suggests, however, this simplified line of reasoning faces considerable challenges when placed in the context of greater discussions on the potential drivers of *Polylepis* forest cover change. This is especially true given the complex relationship that *Polylepis* forests seem to have with livestock, and the equally complex interactions between grazing and other disturbances such as drought and fire. Furthermore, as discussed in chapter 4, livelihoods in Colina are thoroughly entwined with forest use and are subject to change in relation to economic processes and biophysical change. With this knowledge, it seems unlikely that observed decrease and thinning of the *Polylepis* forest in Colina is the product of a simple cause-and-effect relationship.
Rather than thinking of the *Polylepis* forest in Colina as a discrete system that is acted upon by external forces (as the dominant discourse suggests), I find it more useful to consider this forest a Social-Ecological System (SES) (Ostrom, 2007). SES research has evolved over the past fifteen years, drawing on systems ecology and systems theory to assess and sustainably manage complex human-environment systems (Berkes, Folke, & Colding, 1998; Gunderson & Holling, 2002; Ostrom, 2007, 2009). Following Ostrom (2007, 2009), an SES is often framed as a resource system, such as a grazing area, with the associated resources, resource users, and governance structures interacting in complex ways that mutually affect each other. Through querying these interactions across multiple scales, SES research seeks to understand the specific issues that make a system either sustainable or unsustainable. Much of this research is focused on institutions and resource governance, but I find the SES concept useful in this holistic landscape framework because it places relevant component systems in dialogue and fosters the exploration of linkages across scales. The principal component systems of the SES identified in this case study are *Polylepis* forest, open pasture, livestock, agriculture, and the Colinanos (see figure 5.1). There are certainly

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**Polylepis Forest as Social-Ecological System**

![Diagram](image)

Fig. 5.1 A concept model of the *Polylepis* forest in Colina as a SES, with bi-directional feedbacks linking the subsystems.
more components to this SES than are identified here, but these are major components and a first step toward a better understanding of the complex functioning of this system.

The *Polylepis* forest maintains soil moisture, shade that protects understory vegetation and animals from the tropical sun, and contributes vital soil nutrients from leaf litter. The grass understory is an important source of forage for livestock when other sources of pasture and feed crops are exhausted, and the livestock (at moderate stocking rates) benefit the *Polylepis* by removing excess ground cover which improves seedling recruitment (Cierjacks, Rühr, Wesche, & Hensen, 2008; Pollice, Marcora, & Renison, 2012; Torres, Renison, Hensen, Suarez, & Enrico, 2008; Zimmermann, Renison, Leyer, & Hensen, 2009). Leaf litter and manure from livestock are utilized for fertilizer in potato and bean fields within the forest. This then leads the human community to carefully maintain the *Polylepis* trees adjacent to farm fields and creates extensive forest edge that is an active site of regeneration for the genus (Cierjacks, Wesche, & Hensen, 2007). The open pasture and *Polylepis* forest are each mutually benefit from the productivity of the other by allowing grazing pressure to be distributed between the two systems to control over-grazing in either location. The open pastures then contribute to the continuation of the forest as a resource for grazing and agricultural production. And the human community is actively managing this SES as they derive their livelihood from the landscape. I do not mean to suggest with this framing that the system evolved this way, or that it is in homeostasis. The data presented in chapters 3 and 4 clearly indicate a landscape undergoing significant biophysical and social change. What this new framing accomplishes is to highlight the extent to which the *Polylepis* forest in Colina is entangled in a complex web of interactions. This SES framing also highlights many of the processes and interactions that can lead to either a sustainable or unsustainable SES in Colina.
It is important to note that this SES is not a closed system. Any and all of the components in figure 5.1 are subject to disturbance and stress from external processes. Following Perry (1995), disturbances in any one of the component members of the guild can produce cascading effects through the other members of the system, as well as to additional communities (and SESs) that are not part of the assemblage. This idea of connectivity and cascading effects draws directly on the concept of nested hierarchical structure in landscapes (Naveh & Lieberman, 1994; Pickett, Kolasa, Armesto, & Collins, 1989). The hierarchical landscape model is derived from General Systems Theory, and considers different communities within a landscape (e.g. Polylepis forest, grassland, etc.) to be at once whole systems and components of a more complex system (Naveh, 2000; Naveh & Lieberman, 1994). Ostrom (2007) makes a similar argument for SESs by suggesting that they are “decomposable,” or that the component systems function independently in many respects. Following this idea of connectivity, Pickett et al. (1989) argue that external inputs to a system will often manifest differently at different hierarchical levels. In other words, what registers as a disturbance at one level – open pasture, for instance – may cause less noticeable stress in another component system.¹ This framing of the Colina landscape makes the difficulty in identifying single drivers of Polylepis forest change readily apparent. This holistic systems approach also exposes possibilities for understanding observed Polylepis forest cover change.

5.3 A New Hypothesis for Polylepis Forest Change in Colina

In light of discussions in the third and forth chapters, climate change appears to be a likely factor in the changes in the SES outlined above. According to Colinanos, decreased precipitation is forcing a change in the grass communities in open pasture and decreasing crop

¹ Following Pickett et al. (1989) a disturbance is an external force that causes a change in structure, and stress is an external force that disrupts functioning but does not lead to a change in structure.
yields in agricultural plots. Though it was not mentioned in interviews, I suspect that reported changes in open pasture are likely compounded by recent changes in fire regime (Hofstede, Castillo, & Osorio, 1995; Ramsay & Oxley, 1996). This then manifests as a stress in the livestock system by decreasing the availability of forage and fodder. Stress in the livestock system induces a shift in grazing rotations toward increased reliance on the Polylepis understory. Under these circumstances, it is possible that grazing pressure on the forest has surpassed rates at which the Polylepis trees are able to regenerate (Cierjacks et al., 2008; Pollice et al., 2012; Torres et al., 2008; Zimmermann et al., 2009). Over the course of twenty years, decreased regeneration could likely manifest as forest thinning. Decreased crop yield must also be considered in this equation. Following the discussion in chapter 4, it is possible that decreased yield has lead to increased reliance on forest products like charcoal, which could also lead to thinning. The Polylepis trees themselves may also be responding independently to climate change. Given previous changes in Polylepis forests that have coincided with climatic drying, it is entirely possible that the same shift is currently underway (Gosling, Hanselman, Knox, Valencia, & Bush, 2009).

It might seem reasonable, given this framing of the Colina landscape, to suggest that the Colinanos end, or at least greatly curtail, their reliance on livestock. As the findings of the previous chapter make abundantly clear, however, there are no other options available to the people of Colina that would allow them to remain in the community.

With economics factored into this change equation, this new hypothesis for observed Polylepis change might be succinctly summarized thusly: changing climate, in combination with a change in fire regime, has led to a deterioration of open pasture resources and a decrease in crop yield in Colina. These changes have interacted with a stagnant to deteriorating economic
situation to contribute to a shift in reliance on *Polylepis* forest resources for grazing (and possibly for products like charcoal). This increased pressure on forest resources, in combination with climatic effects on the *Polylepis* system, have contributed to an observed decrease and thinning of *Polylepis* cover from 1991-2011. Additional study (in both the natural and social sciences) is necessary to verify this hypothesis for *Polylepis* cover change in Colina, but it is a plausible and compelling conclusion based on the findings of this case study.

5.4 Toward a Holistic Ecology in Colina

At this point, given the findings, it is not entirely unreasonable to question the value of this case study in relation to other work on *Polylepis* forest conservation. After all, the dominant discourse discussed in the second chapter identified extensive grazing as one of the principal drivers of *Polylepis* cover loss, and based on an analysis of the evidence in the Colina case, grazing pressure is also hypothesized to be linked to observed forest loss. Recall, however, from chapter 2 that the major problem with that discourse was not so much that it was *wrong* but that it was miss-scaled to the complexities of *Polylepis* forest cover loss. From a uni-scalar perspective, grazing can indeed be seen as the external driver of forest cover loss in Colina, as could extraction for charcoal production. But as this case study illustrates, *Polylepis* forest cover change is a multi-scalar, polyvalent issue that cannot be boiled down to a single driver. This issue must be understood within the context of the whole landscape, and solutions (if any exist) must take this complexity into account.

Consider the existing regulations in TNP that ban grazing, agriculture, fire, and timber harvesting from forested areas. From a uni-scalar perspective, this seems like the appropriate course of action in the Colina case. From the perspective of the cooperative guild, however, it is clear that grazing is integral to the system, and potentially beneficial to *Polylepis* regeneration.
And given that cattle and sheep have been grazed in these landscapes (and in *Polylepis* forests) for approximately 500 years, and with native camelids prior to that, the wholesale removal of grazing from *Polylepis* systems may have ecological ramifications that are as yet poorly understood. In other words, removing grazing may be a very bad conservation decision. Furthermore, given the likely role of climate change in observed decreases, and the unknown interactions between climatic and grazing disturbances (Dale et al., 2001; Turner, 2010), it is unclear if removing grazing would lead to forest expansion, even in the best case.

As this case study also demonstrates, strict bans on grazing are economically unthinkable in Colina. Removing their ability to keep livestock would create a void in their livelihoods that is currently irreplaceable for most Colinanos. The loss of livestock would also likely lead to decreased agricultural productivity due to the loss of manure for fertilizer. Under current conditions, many Colinanos would have no choice but to rely more heavily on forest products in the short-term, and ultimately to leave the community to find work elsewhere. The former response would be counterproductive to forest recovery, and the latter is socially unthinkable. It is telling that Diego, who was forced to leave Colina due to lack of land, is convinced that depopulation is the ultimate goal of TNP. Even if this is not a political reality, his opinion suggests that many Colinanos are faced with very stark choices.

It is possible that with significant financial aid some decrease in livestock herding would be possible in Colina, but this would likely require a long-term commitment of resources from TNP, which is already underfunded (Boillat, 2007). Even conversion to a more intensive, rationalized, system of production favored by Fjeldså and Kessler (1996) would likely be unfeasible in Colina. Given the decrease in pasture productivity, and the dependence on livestock and leaf litter for agricultural inputs, it is unlikely that intensive use zones like those outlined by
Fjeldså and Kessler would be sustainable in Colina without significant and sustained chemical inputs, and the repeated planting of exotic pasture grasses. This would also require sustained financial assistance to Colina, and it is unclear whether such a system would ever produce enough yield to become self-sustaining.

These conclusions would not be possible without a holistic research framework that incorporates multiple sources of data. Furthermore, the findings of this case study are the result of a multi-scalar approach that incorporates the myriad social and biophysical processes that contribute to landscape change. Following Zimmerer and Bassett (2003), it is only by synthesizing all (or as much as possible) of this information that the unique circumstances of a case like Colina can be sufficiently analyzed. And following Forsyth (2008) this work creates space for new narratives to emerge that might be more beneficial to the Colinanos, the *Polylepis* forest, and the greater landscape in which they exists.

5.5 Moving Forward

This case study has demonstrated the benefit of incorporating qualitative data with remote sensing change detection analysis for the study of *Polylepis* forests in the tropical Andean highland. In so doing, this study contributes to an expanding set of case studies in other systems (Jameson & Ramsay, 2007; Jiang, 2003; Postigo, Young, & Crews, 2008; Robbins, 2003). Of particular relevance to this case study is that of Jameson and Ramsay (2007) who employed similar methods for the study of a *Polylepis* forest in Peru. The findings of the Colina case study, as well as that of Jameson and Ramsay highlight the need for replication of this approach to studying *Polylepis* forest systems in other locations across the full range of their habitat. It is telling that the findings of the Colina case are significantly different from those of Jameson and Ramsay in the Cordillera de Vilcanota, Peru, as well as those of Byers (2000) and Tohan (2000)
in Huascarán National Park, also in Peru. All three of these studies found no significant change in size or shape of *Polylepis* forest patches, with Byers (2000) and Tohan (2000) both reporting some forest expansion. The fact that this thesis and these three forest cover change analyses found different results suggests that there is considerable variation across the range of *Polylepis* forests, and only through significant repetition can any potential trends be determined. And as the results of this case study suggest, these studies must also analyze the social dynamics and changes in other areas of the landscape in order to fully comprehend the complexities of *Polylepis* forest change.

This case study also brings to light the need for more long term monitoring of structural changes in the grassland systems that dominate the Andean highland, as other areas may be experiencing the same types of structural shifts found in Colina. Concerted effort should also be directed toward the study of climate change in the tropical Andean highland to better understand how these macro-scale shifts are related to changes in vegetation cover. In Colina, plot-level ecological study is necessary, both in the open pasture and the *Polylepis* forest, to test the hypotheses generated from this case study. Further qualitative research is also necessary in Colina, ideally over a longer period of time. This will allow researchers to build trust in the community and better understand the complexities of their lives and livelihoods. And this should be part of an effort – either with TNP or other Non-Governmental Organizations – to improve the lives of Colinarinos, and conserve the landscape.

Hopefully this future work can build upon the first steps made in this case study, and lead to better knowledge of the ecology of *Polylepis* forests and the landscapes in which they exist.
Appendix A

Catalogue of Remote Sensing Images

1. Landsat images with bands 4, 3, and 1 displayed in a color composite

These Landsat Images were obtained from the USGS EROS Data Center. Each image was processed to surface reflectance by the Landsat Ecosystem Disturbance Adaptive Processing program, also run by the USGS and EROS.
2. Tasseled Cap Transform Images

The tasseled cap transform reduces the six spectral bands of Landsat 5TM imagery to a three band image that highlights green vegetation and bare soil. The three bands in these images are Brightness (red), Greenness (green), and Wetness (blue). Because this transform is based on band ratios, it normalizes differences in brightness and allows direct comparisons from sample year to sample year.
2001 Tasseled Cap Transform

2006 Tasseled Cap Transform

2011 Tasseled Cap Transform
3. Mahalanobis Distance Classification

These land cover maps were made using the Mahalanobis Distance Algorithm on a tasseled cap transform of Landsat 5TM images. These maps originally contained cover classes for agriculture and mixed forest, but these were collapsed into existing categories to improve the accuracy of the classification.
2001 Mahalanobis Distance Map

2006 Mahalanobis Distance Map

2011 Mahalanobis Distance Map
These images were produce through a spectral mapping algorithm called Mixture-Tuned Match Filtering (MTMF). The resulting image contains two bands: the match score band, and the infeasibility band. Displayed here are the match score maps. The black pixels contain no Polylepis cover moving through a gradient of cover density to pure-white pixels that contain 100% Polylepis cover.
2001 Mixture-Tuned Match Filter Image

2006 Mixture-Tuned Match Filter Image

2011 Mixture-Tuned Match Filter Images
These maps were created through a supervised classification of MTMF images. A decision tree classifier was used to categorize different densities of *Polylepis* cover into discrete categories of land cover for comparison between sample years.
Appendix B

*Polylepis* Cover and Change Statistics

1. Mahalanobis Distance Classification Statistics

<table>
<thead>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
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<td>Polylepis Forest Cover in Colina</td>
<td>ha</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>75.78</td>
<td></td>
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<td>1996</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>76.50</td>
<td></td>
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</tr>
<tr>
<td>2011</td>
<td>69.57</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Polylepis Forest Cover**

- 1991: 75.78
- 1996: 73.98
- 2001: 77.94
- 2006: 76.50
- 2011: 69.57

![Bar Chart: Polylepis Forest Cover](chart.png)

**Polylepis Cover Change by Kind**

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<th>Sample Year</th>
<th>Expansion</th>
<th>Contraction</th>
<th>Net Change</th>
<th>Expansion</th>
<th>Contraction</th>
<th>Net Change</th>
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<td>+13.68</td>
<td>+18.49</td>
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<td>-8.20</td>
<td>-0.54</td>
<td>-0.69</td>
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<td>2006-2011</td>
<td>+4.32</td>
<td>+5.64</td>
<td>-10.08</td>
<td>-13.16</td>
<td>-5.76</td>
<td>-7.52</td>
</tr>
</tbody>
</table>

![Bar Chart: Polylepis Cover Change by Kind](chart2.png)

**Sample Year**

- 1991-1996: 11.25 ha, -1.44 ha, 4.32 ha
- 1996-2001: 13.68 ha, 2.88 ha, +4.32 ha
- 2001-2006: 5.85 ha, 0.54 ha, -0.54 ha
- 2006-2011: 6.39 ha, -0.54 ha, -5.76 ha
2. MTMF Classification Statistics

### Polylepis Cover by Category

<table>
<thead>
<tr>
<th></th>
<th>Sparse/Nascent Forest</th>
<th>Open Canopy Forest</th>
<th>Dense Forest</th>
</tr>
</thead>
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<tr>
<td></td>
<td>ha</td>
<td>%</td>
<td>ha</td>
</tr>
<tr>
<td>1991</td>
<td>44.37</td>
<td>49.4</td>
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<tr>
<td>2011</td>
<td>55.44</td>
<td>67.77</td>
<td>12.96</td>
</tr>
</tbody>
</table>

### Graphical Representation

![Polylepis Cover by Category Graph](image-url)
3. MTMF From-To Change Statistics

*The figures in this table represent the amount, in hectares, of each MTMF cover category (the initial state) that changed to each of the three other categories (the final state) during each sample interval.*

<table>
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<td><strong>Initial State</strong></td>
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<tr>
<td>Open Cover</td>
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<td>6.390</td>
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<td></td>
<td></td>
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<td>4.050</td>
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<td>4.410</td>
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<td><strong>Initial State</strong></td>
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<tr>
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<td>13.140</td>
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<td>0.000</td>
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<td><strong>Final State</strong></td>
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<tr>
<td>Open Cover</td>
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<td>Sparse/Nascent Forest</td>
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<td>2.430</td>
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Appendix C

Interview Guide, English Version

All interviewees were asked the questions in the following interview guide. There was also some variation in each interview depending on individual responses and follow-up questioning, but that is not possible to capture here.

1. How valuable and important are your pastures, and why?
2. How valuable and important is the *kewiña* forest, and why?
3. What is an ideal pasture like?
4. How important are livestock for you, your family, and your community? Why?
5. What other things do you do to earn a living?
6. How do you decide where, when, and for how long to graze your animals?
7. Do you ever graze your animals in the *kewiñas*? Do you manage them differently when they are inside the forest?
8. Does the *kewiña* forest change when you pasture your animals in or around the forest? How so, and why?
9. Have your pastures changed in the last 15-20 years? How so, and why?
10. Has the size or composition of your herds changed in the last 15-20 years? Why?
11. Have there been changes in the *kewiña* forest in the last 15-20 years? How so, and why?
12. What is your opinion of the environmental regulations in Tunari National Park?

*After learning in early interviews that Colina had its own *Polylepis* forest management plan, and that charcoal production was occurring, I added the following questions to all subsequent interviews:*

1. What is your opinion of your community forest regulations for conserving the *kewiñas*?
2. When did this plan start, and why?
3. What other kinds of things do you use *kewiñas* for?
4. Do you ever make charcoal? Why or why not?
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