

IMPACTS OF ANTHROPOGENIC ACTIVITY ON THE VEGETATION OF *POLYLEPIS* WOODLANDS IN THE REGION OF COCHABAMBA, BOLIVIA

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Resumen. Influencia del hombre sobre la vegetación de los bosques de *Polylepis* en la región de Cochabamba/Bolivia. Los bosques de *Polylepis*, endémicos de los Andes, pertenecen a los ecosistemas boscosos más amenazados de Sudamérica. En Bolivia, el área que todavía persiste, abarca solamente el 10% de su área potencial. La distribución actual de estos bosques se caracteriza por la existencia de pequeñas manchas aisladas. El análisis de la estructura de la vegetación, de la composición florística, y de los factores de los hábitats más importantes muestran que, en la actualidad, el sotobosque de los remanentes de *Polylepis* en la región de Cochabamba está compuesto de especies propias de pastos, barbechos y formaciones arbustivas. La destrucción del bosque es el resultado del fuego que durante varios siglos fue utilizado para ampliar campos agrícolas. Esta práctica se mantiene en la actualidad. Casi todas las formaciones boscosas están sometidas al pastoreo, en algunas zonas moderado y en otras intenso. En ambos casos, afecta claramente tanto a la estructura y a la combinación florística como a la renovación. La influencia del hombre sobre la vegetación queda ilustrada por el ejemplo de un bosque de *Polylepis besseri* ssp. *subtusalbida*, situado en las alrededores de Cochabamba, a 3500–3800 m s.n.m. Esta área boscosa ha sido tradicionalmente usada como sistema agroforestal. Se explican las consecuencias del pastoreo, uso del fuego, tala y recogida de leña sobre la vegetación, así como del microclima y la estructura del suelo. Además, se dan recomendaciones para el uso agrícola sostenible y la conservación del bosque, y se discuten los problemas que surgen de su realización.

Abstract. The *Polylepis* forests in the Andean highlands are one of South America's most endangered forest ecosystems. In Bolivia, the remaining area is about 10% of the potential area, and the present distribution of these woodlands is characterized by the presence of small, isolated stands. An analysis of vegetation structure, floristic composition, and main habitat factors shows that at the present time the undergrowth of *Polylepis* remnants in the region of Cochabamba is composed of species typically found in open shrub- and grasslands, pastures, and fallows. Large-scale forest destruction resulted from the use of fire over many centuries to gain agricultural land. This method is still being employed. Nearly all stands are used moderately or intensively as pasture land, substantially affecting their structure, species combination, and rejuvenation. The anthropogenic influence on the vegetation coverage is illustrated by a stand of *Polylepis besseri* ssp. *subtusalbida*, located in the surroundings of Cochabamba, 3500–3800 m a.s.l. This variously wooded area is traditionally used as an agroforestry system. The consequences of crop production, grazing, firewood utilization, and felling on vegetation, microclimate, and soil structure are explained. Recommendations for sustainable land use and forest conservation are given, and problems of its realization are discussed. Accepted 07 November 2001.

Key words: Agroforestry, Andes, Bolivia, forest conservation, forest destruction, grazing, human influence, *Polylepis*, sustainable land use.

INTRODUCTION

The genus *Polylepis* (Rosaceae) is endemic to the South American Andes and has aroused the interest of ecologists and plant geographers since its description by Ruiz & Pavon (1794). The 20 species and 8 subspecies (Kessler 1995a) are distributed from Venezuela to Argentina (Baumann 1988). Some of these "highest climbing trees of the world" (Troll 1959) grow in the uppermost region of the tropical montane forest, but several other species thrive in isolated

stands high above the current timberline to 5200 m a.s.l. (*Polylepis tarapacana* on Sajama volcano, Bolivia). Due to this particular area, the natural distribution of the high Andean *Polylepis* forests has been debated for decades. Koepcke (1961), Walter & Medina (1969), Simpson (1986), and Rauh (1988) considered these stands as microclimatically favored. In sharp contrast to this, and as early as the 1950s, Ellenberg (1958) suggested that the Andean parts of Peru had probably been covered naturally by forest or scrub communities up to 4500 m a.s.l., and that the present vegetation is "the result of the progressive fo-

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rest destruction by grazing and disorganized utilization of wood since centuries." Today it is generally recognized that the present-day distribution of *Polylepis* forests is attributable to human impact (Ellenberg 1958, Lægaard 1992, Fjeldså 1992, Hensen 1995, Kessler 1995a, Fjeldså & Kessler 1996, Lauer *et al.* 2001). According to Kessler (1995a), the remaining woodlands represent less than 10% of the potential forest area in the high Andes. This percentage decreases even more if we disregard the dispersed *Polylepis* bushlands in the arid parts of the puna zone. The main reason for this immense forest destruction has been the burning for arable land.

This paper presents a brief outline of the history of the anthropogenic impact in the region of Cochabamba valley and summarizes the results of an ecological study of the vegetation structure of the remaining *Polylepis* woodlands (Hensen 1993, 1995). In addition, the ecological consequences of former and current land use practices on floristic composition is illustrated by a stand of *Polylepis besseri* ssp. *subtusalbida*, located in the Province of Cochabamba, 3500-3800 m a.s.l. The effects of agricultural utilization on a formerly considerably denser forest stand can be studied here up to the present day because extensive developments did not begin until the agrarian reform of 1952. Taking this example, the consequences of grazing, felling, fire, and firewood utilization on vegetation, microclimate, and soil structure of *Polylepis* woodlands are explained and recommendations for sustainable land use and forest conservation are given.

HISTORY OF THE ANTHROPOGENIC IMPACT IN THE REGION OF COCHABAMBA VALLEY

The history of the Cochabamba valley region and the high Andean areas surrounding it can be traced back to the Old Stone Age through archaeological skeleton and tool discoveries (Ibarra 1971). According to AGRUCO/CIDRE (1986), pieces of pottery of the "Tumulos culture" (1000 B.C.—200 A.D.) indicate an already well-developed agriculture with the corresponding vegetation modifications. Several present-day designations of regions in the eastern cordillera originate from the Aymara language and confirm the settlement already in preincaic time (Bollinger & Döring 1977). According to Diez de San Miguel (1567; cited by Kessler & Driesch 1993), extensive areas of the Andean highlands were used for the breeding of llamas and alpacas, indicating habitat degradation on

a large scale. The Inca agriculture that reached Cochabamba in the 15th century is known to have been very compatible with the environment (Romero 1992). The main objective of their agriculture was to keep soil fertility stable for a long time. Therefore steep slopes were terraced and the pastures of camelids (llamas, alpacas, vicuñas) limited to artificially watered grazing areas. However, according to Ruthsatz (1983), the former density of colonization is thought to have been as high as in the present day, meaning that the ecological balance in the highlands was certainly already disturbed during Inca domination.

Mansilla (1984) attempted a reconstruction of the former high Andean vegetation cover evaluating travel descriptions by Spanish colonialists (e.g., Ciega De Leon, Polo de Ondogardo, Acosta, Cobo and others, all 16th to 17th century). All of them agree about the mild climate of the altiplano with its clear rivers and lakes, diverse fauna, and various vegetation formations. Gonzales (1955, in Koepcke 1961) mentions, for the high Andes of Peru, that the majority of today's desertlike regions were covered by xero- and mesophytic forest vegetation during the Spanish conquests. However, far-reaching effects on the vegetation cover, including extensive forest destruction, did not occur until the arrival of European land-use practices (Kessler & Driesch 1993). The exploitation of mineral resources was a major aim of the Spanish colonialists, to which the entire economical and social structure had to be subjected (Pampuch & Echalar 1987). The foundation of all larger Bolivian cities occurred simultaneously with the introduction of useful European plants and livestock. Founded in 1574, Cochabamba became an important center for the supply of food, wood, leather, and wool for the mining areas, and inhabitants hoped for a rapid increase in production by modernizing the Incaic land-use practices. Slopes were cultivated with draught animals and a better irrigation system was sought by arranging furrows parallel to inclination. Sheep increasingly replaced camelids in their importance as wool suppliers and large grazing areas were cleared with fire. In addition, deforestation accelerated due to the enormous demand for timber and firewood in the mining areas and newly founded cities.

In the 17th century first reports mentioned the disappearance of forests, degradation of climate, and decrease in agricultural profits (Mansilla 1984). In the 19th century the natural vegetation cover of the Bolivian high Andes is said to have almost disappeared, accelerated additionally by the construction of rail-

ways and road networks. The Bolivian revolution and agrarian reform of 1952 released additional very strong pressure on natural resources because cultivable areas were now passed to the heirs by equal share of inheritance (Bode 1998). Due to population increase and the continual loss of fertility of arable and grazing areas, more and more unfavorable mountain ranges are being taken under the plough. Today, soil erosion is thought to be the greatest ecological problem in Bolivia (Ellenberg 1981); already 40% of the entire country is regarded as destroyed (Rist & San Martin 1991).

FLORISTIC COMPOSITION OF PRESENT-DAY *POLYLEPIS* WOODLANDS

Within the spacious surroundings of the Cochabamba valley basin system, *Polylepis* forests and woodlands are found between 2900 and 4100 m a.s.l. (Fig. 1). They consist of the species/subspecies *Polylepis sericea*, *P. racemosa* ssp. *lanata*, *P. besseri* ssp. *subtusalbida*, *P. tomentella* ssp. *incanoides*, and *P. tomentella* ssp.

nana (nomenclature follows Kessler 1995b). The size of these remnants varies between 0.5 and > 50 ha; their distribution shows a clear correlation with elevation and mean annual precipitation (Fig. 2). Because very few stands are characterized by a closed crown cover I here prefer to use the term woodland.

Between March 1990 and June 1991, 207 relevés were carried out in 23 different *Polylepis* woodlands (Fig. 1), following the method of Braun-Blanquet (1964). The survey table (Table 1) shows a clear division into two groups, the "partially altered" and the "strongly altered" *Polylepis* stands (according to Seibert & Menhofer 1991). This division is the result of the differing intensity of anthropogenic influence as deduced from species composition. The "partially altered" *Polylepis* stands, which serve above all for the supply of firewood and as forest pasture, could be divided into four plant communities: Humid *Vallea stipularis*-*Polylepis racemosa* ssp. *lanata* woodlands, semi-dry to dry *Woodsia montevidensis*-*Polylepis besseri* ssp. *subtusalbida* woodlands, dry *Polylepis tomentella* ssp. *incanoides* woodlands, and very dry

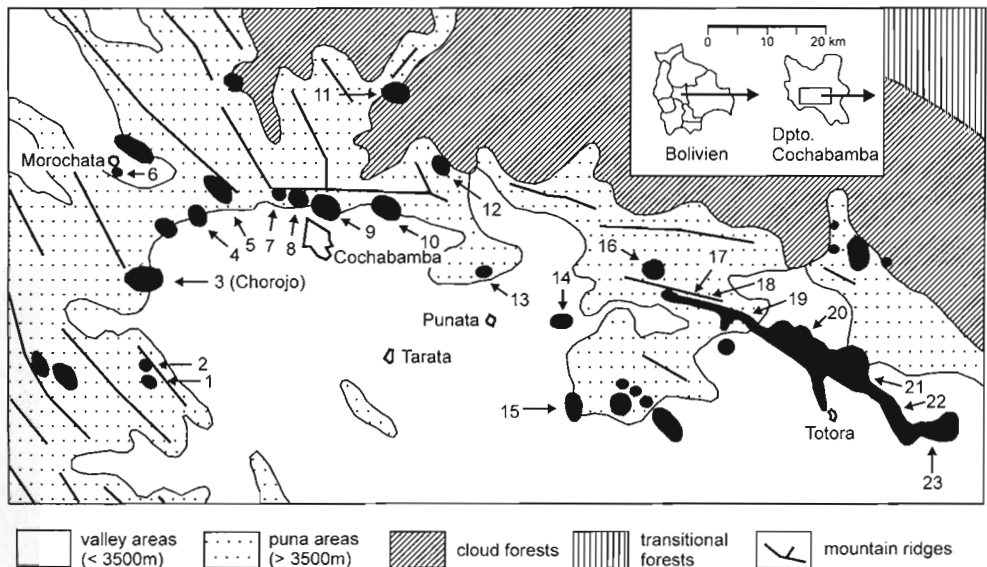


FIG. 1. Position of *Polylepis* stands in the surroundings of Cochabamba. They are indicated by the following numeration: 1 Lampaya, 2 Llanke, 3 Chorojo, Rodeo, Chacapaya, 4 Palca Pampa, 5 San Miguel, 6 Morochata, 7 Lap'ia, 8 Titiri, Puca Puca, 9 Parque Tunari, 10 Sapanani, Pacha Wasa, 11 Mayca Mayu, 12 Candelaria, 13 Chaki Khocha, Tuti, 14 Kewiñal, 15 Alalay, 16 Infernillos, 17 Zapata Rancho, 18 Mojón, 19 Cocapata, 20 Lach'uj Mayu, 21 Rodeo Chico, 22 Yana Wara, 23 Llutu Pampa. The remaining areas indicate additional woods which were not studied.

plant community	partially altered												strongly altered																	
	I			II			III			IV			V			VI			VII			VIII								
number of relevés	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
<i>Bouletia tenella</i>																														
<i>Cenactium mucronatum</i>																														
<i>Solanum acutale</i>																														
<i>Calceolaria engleriana</i>																														
<i>Vulpia magalana</i>																														
<i>Poa annua</i>																														
<i>Bryum</i> sp.																														
dry and "strongly altered" communities																														
<i>Sevia chamaedry</i>																														
<i>Hypericum brevistylum</i>																														
<i>Liabum ovatum</i>																														
<i>Briza monandra</i>																														
<i>Gomphrena bicolor</i>																														
<i>Lepachinia meyerii</i>																														
<i>Tagetes pusilla</i>																														
<i>Facelis lasiocarpa</i>																														
<i>Sevia tarijensis</i>																														
<i>Ophioglossum scariosum</i>																														
<i>Gilia lacinata</i>																														
<i>Gnaphalium cheiranthifolium</i>																														
<i>Barbisia fiebrigii</i>																														
<i>Castilleja pumila</i>																														
<i>Oreomyrrhis andicola</i>																														
<i>Hypochoeris meyeniana</i>																														
<i>Plantago orbignyana</i> ssp. <i>pseudomollis</i>																														
<i>Plantago lanceolata</i>																														
<i>Cyperus andinus</i>																														
semi-dry to very dry stands																														
<i>Chelidanthus pruinata</i>																														
<i>Briza stricta</i>																														
<i>Bidens pseudocosmos</i>																														
<i>Escallonia retinosa</i>																														
<i>Sevia samaijatenensis</i>																														
<i>Hieracium stachyoidesum</i>																														
<i>Alonsoa linearis</i> var. <i>linearis</i>																														
<i>Conyza floribunda</i>																														
<i>Lepachinia graveolens</i>																														

plant community	partially altered										strongly altered																	
	I		II			III					IV		V		strongly altered													
number of relevés	1	2	3	4	1	2	a	b	c	d	e	a	b	c	a	b	c	d	5	3	6	8	10	9	8	10	8	
<i>Oxalis</i> IH 2078	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Tagetes maxima</i>	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Barnadesia polyacantha</i>	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Vallea stipularis</i> -group	2	3	IV	2	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Vallea stipularis</i>	2	2	V	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Polystichum cochleatum</i>	1	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Elaphoglossum</i> sp.	2	.	III	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Thuidium</i> sp.	2	.	III	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Valeriana</i> cf. <i>effusa</i>	2	.	III	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Hydrocole bonplandii</i> var. <i>hirtipes</i>	2	.	II	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Brachyotum microdon</i>	.	3	II	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Differential species of II (semi-dry to dry stands)																												
<i>Lathyrus megellanicus</i>	.	.	II	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Berberis</i> IH 1073	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Senecio</i> IH 1335	.	.	.	3	V	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Ribes</i> IH 1063	.	.	.	4	III	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Solanum</i> Sect. Tub. IH 1338	.	.	.	4	IV	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Boulevia tropaeolifolia</i>	.	.	.	4	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Berberis</i> IH 1021	.	.	.	1	V	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Hieracium mandonii</i>	.	.	.	1	II	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Jornalla ruralis</i>
<i>Centasium</i> IH 1045
<i>Baccharis alpina</i>
<i>Baccharis nitida</i>
<i>Arenaria</i> sp. IH 2316
<i>Thalictrum venturii</i>
<i>Clematis sericea</i>
<i>Ophrysopus charta</i>
<i>Calceolaria lobata</i>
<i>Solanum cochabambense</i>
<i>Asplenium castaneum</i>
<i>Campyloneuron angustifolium</i>
<i>Nassella pubiflora</i>
<i>Festuca sublimis</i>
<i>Urtica chamaedryoides</i>
<i>Erodium moschatum</i>
<i>Genium</i> cf. <i>bolivianum</i>
<i>Solanum</i> cf. <i>atricorneolum</i>

plant community	partially altered												strongly altered									
	I				II				III				IV				V					
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	5	6	7	8	9	10
<i>Gamochaeta sphacelata</i>																						
<i>Bromus pitensis</i>																						
<i>Sarcosemma lysimachioides</i>																						
<i>Bulbovylis</i> sp.																						
<i>Achyrocline ramosissima</i>																						
<i>Barbula</i> sp.																						
<i>Hedeoma mandonii</i>																						
<i>Spergularia</i> sp.																						
<i>Barbula elongata</i>																						
<i>Gomphrena</i> sp. IH 2322																						
<i>Cenactium nutans</i>																						
<i>Sterea snuebelii</i>																						
<i>Pipochaetium tuberculatum</i>																						
<i>Baccharis leptophylla</i>																						
<i>Plazia daphnoides</i>																						
Differential species of III (dry stands)																						
<i>Mutisia vicia</i>																						
<i>Berberis</i> sp. IH 2425																						
<i>Schinus myrtifolius</i>																						
<i>Eupatorium bunifolium</i>																						
<i>Adesmia</i> sp. IH 2421																						
<i>Viguiera pazensis</i>																						
<i>Dichondra argentea</i>																						
<i>Baccharis</i> sp.																						
<i>Eupatorium</i> sp. IH 2468																						
Differential species of IV (very dry stands)																						
<i>Aristida adscensionis</i>																						
<i>Dodonaea viscosa</i>																						
<i>Borreria densiflora</i> var. <i>perennis</i>																						
<i>Polygala cisanthina</i>																						
<i>Muhlenbergia rigida</i>																						
<i>Berberis boliviana</i>																						
<i>Eragrostis</i> sp.																						
<i>Lycurus phaeoides</i>																						
<i>Paronychia hieronymi</i>																						
<i>Verbena micropbylla</i>																						
<i>Juncus</i> sp. IH 1957																						

III
III
II
II
II
II
II
II
II
II
II
II
II
II
II
II

Elyonurus nitens
Lepochinia bella
Manninia eriocharpa
Dalea tarapacana
Salvia sp. IH 2008
Sisyrinchium pachyrrhizum
Margyriacarpus setosus
Calamagrostis brennariata
Selaginella sp.
Pellaea ternifolia
Bulbosylis capillaris
Evolvulus sericeus
Notocitrium marginatum

Differential species of V ("strongly altered" communities)

<i>Calamagrostis heterophylla</i>	1	V	I	II	II	II	I
<i>Azorella biloba</i>	2	III	V	r	IV	r	II
<i>Gilia gracilis</i>	3	II	II	II	II	II	I
<i>Agrostis solitensis</i>	2	I	I	II	V	II	II
<i>Stipa inconspicua</i>	2	I	I	II	III	V	I
<i>Calamagrostis vicinarum</i>	2	II	I	II	II	II	II
<i>Paronychia muschleri</i>	1	I	II	I	I	I	V
<i>Tarasa tenella</i>	1	I	III	I	I	II	I
<i>Eryngium nudicaule</i>	1	IV	III	IV	III	II	I
<i>Lupinus</i> sp.	1	IV	III	III	I	I	I
<i>Muhlenbergia peruviana</i>	1	II	III	III	II	II	II
<i>Belloa subspicata</i>	1	II	II	II	II	II	II

warm and low altitude situations (< 3800 m a.l.s.)

<i>Liatrum asperifolium</i>	1	V	I	II	II	II	I
<i>Calceolaria parviflora</i> ssp. <i>parviflora</i>	1	II	II	II	II	II	I
<i>Hypoxis decumbens</i>	3	V	II	II	II	II	I
<i>Commelina elliptica</i>	1	II	II	II	II	II	I

old and permanent fallowland (> 3800 m a.l.s.)

<i>Sisyrinchium brevipes</i>	1	II	II	II	II	II	I
<i>Gentiana sedifolia</i>	1	IV	III	IV	III	III	I
<i>Lucilia pickeringii</i>	1	II	II	II	II	III	I
<i>Gumoucheta subfalcata</i>	1	II	II	II	II	II	III
<i>Juncus imbricatus</i>	1	II	II	II	II	II	II
<i>Paspalum pygmaeum</i>	1	+	+	+	+	+	II
<i>Lepidium bipinnatifidum</i>	1	II	II	II	II	II	I

young fallowland (> 3800 m a.l.s.)

<i>Plantago myosuurus</i> ssp. <i>humilior</i>	1	II	II	II	II	II	IV
<i>Erodium cicutarium</i>	1	II	II	II	II	II	V

plant community	partially altered												strongly altered							
	I		II		III		IV		V		VI		VII		VIII					
number of relevés	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
<i>Coryza artemisiifolia</i>																				
<i>Medicago polymorpha</i>																				
<i>Aphanes parvula</i>																				
<i>Verbena hispida</i>																				
<i>Apium leptophyllum</i>																				
<i>Gnaphalium spicatum</i>																				
<i>Eleocharis cf. albidibracteata</i>																				
<i>Perezia multiflora</i>																				
<i>Peperomia peruviana</i>																				
<i>Hieronymus alchemilloides</i>																				
<i>Cordia mexicana</i>																				
<i>Cardonema ramosissimum</i>																				
<i>Ranunculus praemorsus</i>																				
<i>Stuckertella capitata</i>																				
<i>Veronica persica</i>																				

Polylepis tomentella ssp. *nana* bushlands. I refrain from a phytosociological classification because no adequate and comparable database exists for the region of Cochabamba. This is in accordance with Seibert & Menhofer (1991) and Kessler & Hensen (2001), who warn against a rash syntaxonomical classification in phytosociologically poorly studied regions.

The phytosociological data on *Polylepis* woodlands in the province of Cochabamba already published by Hensen (1995) can be summarized as follows (Table 1): Highly constant species in all communities are *Gymoxys glabriuscula*, a tall Asteraceae often found on verges or at fields edges, and *Satureja boliviana*, a Lamiaceae characteristic of fallows and uncultivated terrace steps (own observation; cf. Richter & Lauer 1987 for the valley of Charazani). Other accessory species occurring on all types of soil are *Ageratina azangaroensis* (Asteraceae), the puna tussock grasses *Stipa ichu*, *Calamagrostis antoniana*, and *Festuca dolichophylla*, and the worldwide-distributed bryophyte *Polytrichum juniperinum*.

The humid *Polylepis racemosa* woodlands occur between 3200 and 3400 m a.s.l. in different regions of the East Andean incline. In the areas investigated, the sky is mostly overcast and fog formation often occurs. Mean annual temperatures are 12–14 °C, mean precipitation 1000–1500 mm (Hensen 1995, Kessler 1995a). Columns 1–4 (Table 1) comprise different types of woods. In the most humid community characterized by *Lycopodium thyoides* (I/1) several tree species were found: *Polylepis racemosa*, *Prumnopitys exigua* (Podocarpaceae), *Weinmannia fagaroides* (Cunoniaceae), *Oreopanax* sp. (Araliaceae), and *Clethra* sp. (Clethraceae). Their trunks are covered by bryophytes and lichens, their branches by thallo- and cormoepiphytes (Piperaceae, Bromeliaceae, Onagraceae, Pteridophyta). The scrub layer is composed of species that are also common in the surrounding open vegetation: *Baccharis genistelloides*, *Ageratina sternbergiana*, or *Satureja boliviana*. The understory of the community with *Lycopodium clavatum* (I/2) is formed mainly by ericaceous shrubs (*Gaultheria glomerata*, *Pernettya prostrata*) known to be very frequent in regularly burned páramo-vegetation (Lægaard 1992). Additionally, community I/3 is characterized by a fire-adapted plant, *Hesperomeles lanuginosa* (Rosaceae; Lægaard 1992). The transition to the *Polylepis besseri* woodlands with more balanced water conditions is formed by community I/4, differentiated by *Tagetes maxima*.

The semi-dry to dry *Polylepis besseri* ssp. *subtusalbida* communities (Table 1; II) are situated within the slopes facing the dry valley of Cochabamba. Their climate is characterized by mean annual temperatures of 8–14 °C and precipitations of 600–900 mm. Floristically, there are no clear-cut limits between the differentiated subunits (II/1–4). The semi-dry woodlands 1–3 show transitions to the humid *Polylepis* woodlands (I), the driest community II/4 is connected to the dry woodlands of *Polylepis tomentella* (III–IV) by several species. Anthropogenic impacts also lead to correspondences with the group of “strongly altered” *Polylepis* stands (V). The group with *Woodisia montevidensis*, *Bromus lanatus*, *Schinus andinus*, and *Calceolaria sparsiflora* encompasses the characteristic species. The semi-dry woodlands III/1–3 are differentiated by several lianas and ferns (*Cajophora canarinoides*, *Galium mandonii*, *Mutisia matthewsii*, *Salpichroa tristis* var. *lehmannii*, *Asplenium fragile*, *Adiantum poiretii*); the drier unit (II/4) found on open and often eroded slopes poor in nutrients is separated by *Conyza deserticola* and *Gamochaeta simplicaulis* (Asteraceae).

Polylepis tomentella woodlands (III and IV) are distinguished by several species (cf. Fernández 1997). The shrubs *Baccharis dracunculifolia*, *B. tricuneata* (Asteraceae), and *Minthostachys andina* (Lamiaceae) are highly constant in both communities, as well as the tussock grasses *Stipa ichu* and *Festuca dolichophylla* and the hemicyptophytes *Briza stricta* and *Hypochoeris elata*. The community with *Polylepis tomentella* ssp. *incanoides* (III) includes five woodland stands between Epizana and Pojo (3050 to 3150 m, Fig. 1). Meteorological data exist for Montepunco (3500 m; mean annual precipitation 686 mm) and for Totorá (2900 m a.s.l., mean annual precipitation 590 mm, mean annual temperature 16 °C). Shrubs such as *Agalinis reflexidens* (Scrophulariaceae), *Eupatorium bunifolium* or *Viguiera pazensis* (Asteraceae) dominate; the herbaceous layer is of minor importance. The dominant tree species of community IV, *Polylepis tomentella* ssp. *nana*, is probably locally endemic; a single but extensive (50 ha) stand is located between Araní and Vacas at 3300 m a.s.l. (Fig. 1, Kewiñal). Precipitation rate is assumed to be approximately 500 mm/year (Hensen 1995). The plots investigated are clearly differentiated by the occurrence of *Baccharis obtusifolia* (Asteraceae), *Senna aymara* (Fabaceae), *Lepechinia bella* (Lamiaceae), and *Dodonaea viscosa* (Sapindaceae), a common pioneer species of eroded soils. Equally constant are *Cheilanthes pruinosa* (Sinopteri-

daceae), *Lycurus phleoides* (Poaceae), and *Evolvulus sericeus* (Convolvaceae; according to Baar 1990 an indicator species of extremely dry and infertile pastures).

IMPACT OF TRADITIONAL AGROFORESTRY ON STRUCTURE AND FLORISTIC COMPOSITION OF *POLYLEPIS* STANDS

The “strongly altered” *Polylepis* stands (V) are successional stages of communities attributed to a former utilization as farmland. These relevés were taken within the woodlands of Chorojo, an Andean village situated at an altitude of 3500 to 4800 m, with a mean of precipitation of about 900 mm and a mean temperature of 10–11 °C (Fig. 1, 3). Differential species of these successional stages comprise the group with *Calamagrostis heterophylla*, a short Poaceae that according to Gutte & Gutte (1976) is often found in the area of short-grass puna. With *Azorella biloba*, *Paronychia muschleri*, *Agrostis toluensis*, and *Gilia gracilis*, other turf-forming species are included. Many of the accompanying species such as *Luzula racemosa*, *Ophioglossum scariosum*, *Polytrichum juniperinum*, *Lachemilla aphanoides* var. *tripartita*, *Castilleja pumila*, and *Cotula mexicana* are documented by Baar (1990) for the high-Andean pasture lands of the Bolivian province Ayopaya. Additionally, several rosette-forming species and genera such as *Geranium sessiliflorum*, *Hypochoeris*, *Belloa*, *Werneria*, *Perezia*, and *Paronychia* are identical with species collected by Gutte & Gutte (1976) in the tussock- and short-grass puna in Peru. The three communities distinguished in Table 1 (VI/1–3) reflect different types of utilization (Table 1; for further details see Hensen 1995). The presence of several foreign floral elements such as *Erodium cicutarium*, *Veronica persica*, *Poa annua*, *Sonchus oleraceus*, *Capsella bursa-pastoris*, *Taraxacum officinale*, and *Medicago polymorpha* is striking. These agrestals were imported with European crop plants and found suitable habitat conditions following the clearing of vegetation cover and nitrogen accumulation.

Due to historical peculiarities, the village of Chorojo is characterized by a unique forest history. Before 1952 the forest was used exclusively by the family of the landowner, who extracted firewood for personal needs and sold tanniferous bark to a leather factory. The oldest villagers of Chorojo still remember a forest described as dense, dark, and in some parts impenetrable (Hensen 1993, AGRUCO/PROBONA 1999). After the agrarian reform, the farmers allowed

the burning of the vegetation cover (that in many areas of the high Andes led to the complete destruction of the forests) only in a few exceptions and on a very small scale, presumably because of the ongoing influence of the former landowner (Hensen 1993). Today, the variously wooded area is traditionally used as an agroforestry system as defined by OTS and CATTIE (1986; Bellot & Hensen 1991): (1) Single trees remain on ploughed land. (2) Several *Polylepis* hedgerows are kept for wind protection. (3) The vegetation, including the trees, is utilized by the people in local medicine, as timber and fire wood, and as a nutrition supply (Hensen 1992a, 1992b). (4) Young leaves and saplings are valued as animal fodder. (5) Dense woodland areas protect herdsman and pasture animals against strong solar radiation by providing shadow. However, the extensive field and pasture use means that the majority of the *Polylepis* stands in Chorojo are today extensively cleared (cf. Liberman 1990). As explained above, the greatest part of the present woodland area is covered by "strongly altered" plant communities which must be evaluated as negative succession stages if one starts from the initial

state. "Partially altered" *Polylepis* woodlands, today regarded as the vegetation most resembling the potential natural vegetation (Hensen 1995), are found only in a few places. According to the calculations of AGRUCO/PROBONA (1999), the whole woodland will have disappeared in 19 years.

As a great advantage of cultivation within the woodland, the farmers named the shortening of fallow time, which can be traced back, on the one hand, to the higher organic substance content, on the other, to the more favorable water balance of the woodland soils. Navia (1991) noted the rotation on the fields within the woodland to be potatoes – oca/papalisa – barley/wheat – barley/oat – fallow (1 year; Fig. 4). Outside the woodland cultivation is possible for only three years, followed by a continuous fallow of 3 to 18 years (Fig. 4). However, today the stands of trees are completely senescent. Above all, younger farmers interviewed by Hensen (1993) see in the woodland fields potential areas of arable land in which tree rejuvenation is not desired. According to their understanding, trees left on the fields reduce their profit because crop failure results, particularly in the area

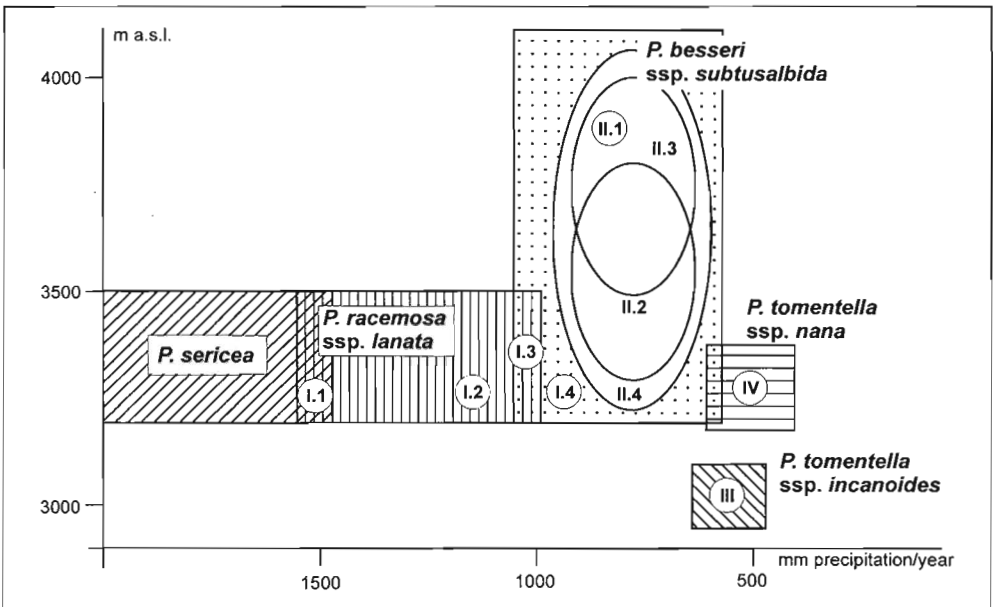


FIG. 2. Presumed distribution of *Polylepis* species/subspecies along altitudinal levels in the region of Cochabamba within a precipitation gradient. The numbered parts approximately indicate the distribution area of the differentiated plant communities.

around the trunk bases. Indeed, cornfield studies by Navia (1991) proved a three- to fivefold increase in yield with increasing distance from the trunk. However the profit on potatoes was affected only insignificantly by the presence of trees.

The sowing of Andean tuberous vegetables such as potatoes, oca, or papalisa takes place at the end of August, a time of high soil dryness. Therefore the fields are already prepared at the end of the rainy season, when the soil can still be worked easily. However through this management the topsoil lacks protection from the strong winds during wintertime. Thus forest soil conditions differ considerably according to relief and land use history. As shown by Hensen (1993), silicate-rich sandstones with a shallow layer of soil (lithosoles, ranker) or deep brunisoles dominate in the most closed parts of the woodlands. In open and steep stands, surface water flow often results in "headed" profiles. At the base of the slope these erosion processes lead to soil profiles characterized by indications of embankments. Their low deposit density allows them to quickly dry out and remain in constant movement, as shown by surface erosion

grooves (Hensen 1993). However, the largest part of the woodland is located on slopes with an inclination of between 10 and 30° (Fig. 3). Here, soils are more or less degraded; very often bare rock juts out visibly. The conservation of only individual trees but not of the whole woodland ecosystem can therefore at most only delay soil degradation.

The high crop yields of Chorojo village lead to a high density of stock. Sheep, goats, llamas, alpacas, cows, pigs, and donkeys serve not only as means of transport and as food supply, but also as an important security, representing easily available capital in times of illness, crop failure, or festivities. Additionally, herd size is regarded as an important status symbol within and among the villages. According to Ellenberg (1981) and Augstburger (1990), heavy overgrazing is the most important factor in erosion. Augstburger estimates the overgrazing for the high Andes of Bolivia to be approximately 70%, which means that instead of an ecologically acceptable stocking density of one sheep, on average 1.7 sheep graze per hectare. The main consequence of woodland pasture is the lack of tree rejuvenation (Hensen 1991, Kessler

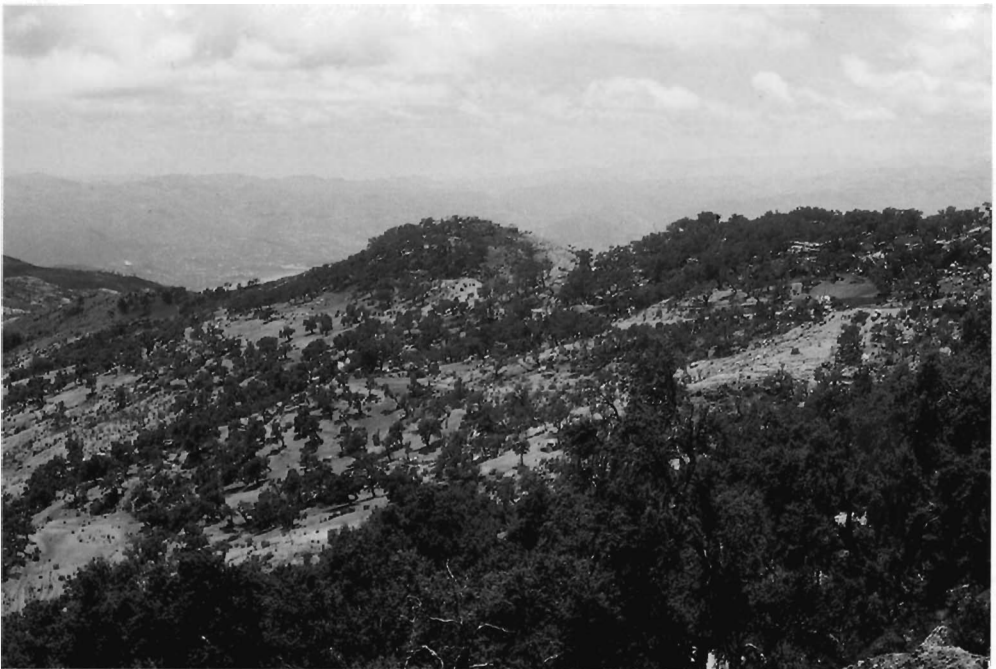


FIG. 3. The *Polylepis besseri* ssp. *subtrusalbida* woodland of the village of Chorojo.

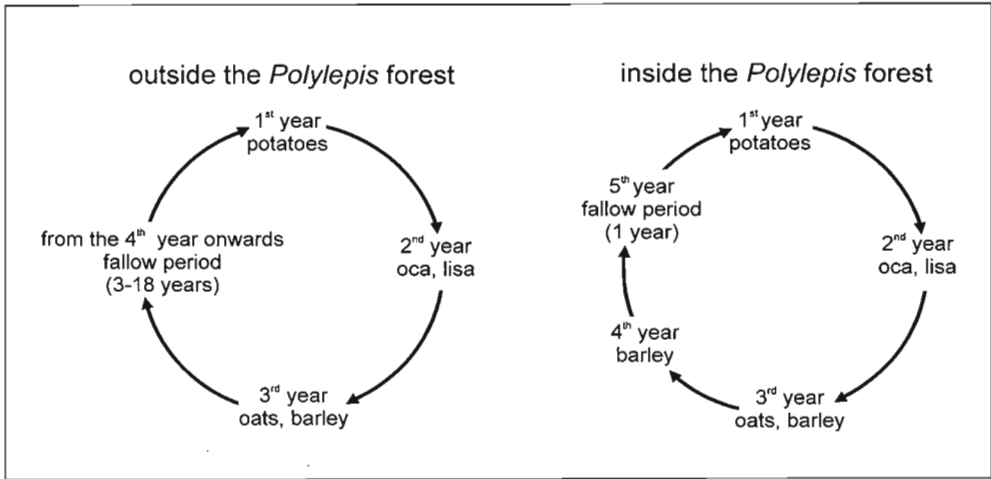


FIG. 4. Crop rotation systems outside and inside *Polylepis* woodlands in the village of Chorojo (Province Cochabamba).

1995a). Although at the end of the rainy season > 100 seedlings/m² of *Polylepis* can be found (Hensen 1994), young plants of > 5 cm are almost entirely lacking. To the herdsman, the woodland clearance is welcome because better feeding possibilities exist on open grassland areas.

THE *POLYLEPIS* STANDS OF COCHABAMBA – A DIAGNOSIS OF THEIR CURRENT STATE

Comparing the vegetation of the *Polylepis* woodlands in the surroundings of Cochabamba (Table 1) with information on the distribution of individual plants in the literature (e.g., Herzog 1910, 1923; Weberbauer 1911; Gutte & Gutte 1976; Baar 1990; Beck & Garcia 1991; Seibert & Menhofer 1991; Ibisch 1993; Pestalozzi 1998), it is remarkable that the undergrowth of *Polylepis* remnants in the region of Cochabamba is composed of species that are typically found in open shrub- and grasslands, pastures, and uncultivated fields. Shade species adapted to climatic conditions inside woodland with reduced radiation and balanced conditions of temperature, soil water, and air humidity occur very rarely. Particularly the understory of open and very open woodland stands resembles the vegetation formations of its surroundings.

In the literature, comments on the reduction of *Polylepis* forests through the influence of man can be frequently found (e.g., Koepcke 1961, Hueck 1961, 1962, Fernandez 1970, Beck & Ellenberg 1977, Ruthsatz 1977, 1983, Simpson 1979, Jordan 1983, Fjeldså 1987, 1992, Frimer & Møller Nielsen 1989, Baar 1990, Beck & Garcia 1991, Lægaard 1992, Arbolandino 1992, Ibisch 1993, Kessler 1995a, Fjeldså & Kessler 1996, Bode 1998, Lauer *et al.* 2001). Large-scale forest destruction resulted from the use of fire across many centuries to gain agricultural land. This method is still being employed and leads as a rule to the destruction of the forest. As a result of this age-long anthropogenic impact, almost all investigated areas are nowadays mosaics of grass- and woodland, where closed areas alternate with open (Fig. 3). Further forest utilization includes extraction of timber and firewood, charcoal making, and grazing. Nearly all stands are used as pastureland in a moderate to extreme way, substantially affecting their structure, species composition, and rejuvenation.

Land use in the form of an agroforestry system is unique to the study area but unable to preserve the woodland. The local arrangements in the village Chorojo serve exclusively to protect individual trees, so that I would disagree with Liberman (1990), who judges the land use to be "sensible and conserving the natural resources." According to the farmers of Choro-

jo, the positive effects on soil fertility attributed to agroforestry (OTS & CATIE 1986, Otarola 1987, Reynel & Morales 1987, Reynel & Leon 1990, DFPA 1990, Carlson & Añazco 1990) are counteracted by negative factors (competition for nutrients, light and water, impeded cultivation, reduced cultivatable area). Particularly the younger farmers are not interested in rejuvenation of the trees. They evaluate the woodland exclusively within the perspective of agricultural development. This situation is above all due to the current scarcity of arable land as a result of population increase and the continuing decrease in soil fertility through erosion, grazing, and inadequate fertilization. Also a loss of "traditions" (for example the increasing displacement of joint cultivation forms such as *ayanoqas*) certainly plays an essential role here. According to the farmers, trees remaining on arable land seem to affect crop yield only indirectly through the reduced number of fallow years. As shown by Navia (1991), yields might be reduced on fields with trees – at least in dry and even climatically normal years. Therefore the critical evaluation of the establishment of agroforestry systems by Kessler & Breman (1991; for semiarid Africa) seems justified.

Scattered fields exist also in other *Polylepis* woodlands, at least within the semi-dry to dry stands of *Polylepis besseri* ssp. *subtusalbida*. However, the fields are generally completely cleared of trees and the clearing continually enlarged in the following years. Woodlands used in a similar manner to those in Chorojo do not exist. The reason is that in other regions with comparable environmental conditions the *Polylepis* forests that persisted after the Bolivian heyday of mining and railway construction have been burned down already, and the humus-rich, very fertile forest soils have been subjected to agricultural use or are already eroded.

WHAT SHOULD BE DONE TO CONSERVE THE LAST *POLYLEPIS* STANDS?

The Andean farmer sees himself confronted with a high number of problems affecting his survival. The area of cultivatable land continually decreases due to equal share of inheritance and increase in population density. More and more inclined slopes not suitable for cultivation (and/or subsequent pastoral farming) are ploughed over. As a result, soil fertility decreases rapidly through wind and water erosion. The inclusion of trees into agricultural activities is rare since trees do not bring any recognizable short-term

advantages for the farmer. Thus most forest areas of the high Andean mountains have already fallen victim to the flames (Kessler 1995a).

The highest goal for such an overpopulated region as the Andean high mountains cannot be a nature conservation policy aimed only at conserving. Nature reserves are certainly indispensable in order to preserve biologically valuable ecosystems as refuges, but do not include the inhabitants. Some *Polylepis* woodlands should be put under protection as a whole in order to conserve these very special ecosystems. The government should grant compensation to the local communities, which at the same time could perform a control function. Additionally, diversified ecological educational work which includes all age groups and sections of society seems absolutely necessary.

Nature conservation programs with the task of preserving or even regenerating the living conditions of the Bolivian population must intervene in the structuring of landscape. Concepts should be developed leading to an ecologically sensible and distinct juxtaposition of crop production, grazing, and woodland areas, particularly in the extremely sensitive tropical mountain ecosystems (Fig. 5). Use of agricultural areas should be intensified in order to decrease the pressure on the last woodland reserves on a long-term basis. Since it is almost impossible for the majority of the Bolivian farmers to treat their fields with inorganic fertilizer, improvement of fallowlands should be increased through, e.g., green manuring or compost economy. The burning down of stands should be locally regulated, if not suppressed completely, and the agricultural utilization of steep inclinations prohibited. Small village communities must be made aware that the destruction of the vegetation cover results in irreparable alterations to the water balance that significantly affect their own living conditions. A similar action plan is proposed by Fjeldså & Kessler (1996).

Traditional land-use systems could be further developed through the integration of ecologically compatible cultivation systems (for example, agroforestry and rotation systems, terracing of inclinations or distribution of environmentally suitable farm implements). However, there is little experience with agroforestry systems in semiarid regions. In Cochabamba, a series of experiments within the local forest program (described by Schlaifer 1990) showed that the farmers rapidly lost interest in agroforestry because of the slow growth of most native tree species; many young trees withered in the dry season or became