Increasing the Socio-Ecological Resilience of Agro-Ecosystems and Livelihoods in Mountain Drylands from a Biocultural Perspective – a Case Study from the Bolivian Andes

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For Lukas

Photograph by R. Brandt

"Si no hay árboles, no hay vida."

(Without trees there is no life.)

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Inhabitant of the
Community of Tres Cruces, Cochabamba, Bolivia

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SUMMARY

SUMMARY

Mountain drylands face alarming desertification risks. This particularly affects the agro-ecosystems of these regions and the rural livelihoods, which depend on them. Restoring and diversifying the natural woodlands are therefore of major concern to enhance the socio-ecological resilience of mountain drylands. Mountain socio-ecological systems are commonly rich in biological and cultural diversity due to their high geodiversity. The observation that cultural and biological diversity are inextricably linked within socio-ecological systems has given rise to the concept of biocultural diversity. This concept suggests that the mutual interactions between biological and cultural diversity stimulate further diversification in nature and culture. The analysis of diversity from a biocultural perspective can thus provide valuable insights for environmental conservation and restoration initiatives. Applied to the case of agro-ecosystems, to adopt a biocultural perspective on restoration means to recognize and use the potential of both native plant diversity of natural woodlands and the corresponding diversity of cultural expressions, such as local plant-related knowledge. This can be put into practice, for instance, through the growing of trees and shrubs along with crops and livestock (agroforestry).

For my doctoral thesis, I have analyzed the case of a peasant community situated at an altitude of 2,760–3,830 m.a.s.l. in the municipality of Tapacarí in the department Cochabamba, Bolivia. This semi-arid mountain area is affected by soil degradation and deforestation and thus, the risk of desertification. The goal of the study, presented in CHAPTER 1, is to provide useful knowledge for diversifying agro-ecosystems by implementing agroforestry systems in a way that takes into consideration the beneficial components of the local biological (native woody species) and cultural (local plant-related knowledge) diversity. In detail, my thesis aims to fill the knowledge gaps that exist particularly regarding the ecological requirements, cultivation techniques and socio-ecological values of native trees and shrubs. The thesis focuses on the following main questions: (1) Which environmental and social factors control woody species' valuation? Which species present the highest context-specific socio-ecological values? (2) How relevant is the consideration of intracultural variation of knowledge and valuation in the selection and use of agroforestry plants? (3) Which are the responses of selected agroforestry species to dryland-specific environmental stress, and what are their implications for making agroforestry more attractive to land users?

In CHAPTER 2, I illustrate the development of an analytical framework for identifying the most promising agroforestry species by analyzing the site-specific socio-ecological factors affecting the distribution and value of woody plants. The analytical framework was tested by using vegetation surveys, soil studies, and interviews concerning plant uses. Socio-ecological values and the availability ("ecological apparency") of plants were calculated. Detrended correspondence and principal component analyses were applied to reveal the socio-ecological context of significant factors for plant distribution and uses. The findings showed that although shrubs were more ecologically apparent than trees, the latter were perceived to be more valuable as the usefulness of species increased with plant height and timber provision. Phytosociological factors played a minor but still significant role in perceived usefulness. In this socio-ecological context, *Schinus molle* and *Prosopis laevigata* var. *andicola* (< 3,200 m.a.s.l.), *Polylepis subtusalbida* (> 3,200 m.a.s.l.), and *Baccharis dracunculifolia* were evaluated as the most promising species for agroforestry use.

CHAPTER 3 presents the analysis of the intracultural variation of the knowledge and cultural importance of local woody plants in relation to respondents' sex, age, and migratory activities. Data were collected through semi-structured and free-listing interviews. Ethnobotanical indices were used for calculating plants' cultural importance. Their intracultural variation was detected by using linear and generalized linear (mixed) models. The outcomes revealed that knowledge and valuation of plants increased with rising age but that they were lower for migrants; sex, by contrast, played a minor role. The findings suggested that the age effects result from declining plant use of valuable native species due to their decreasing availability, substitution by exotic marketable trees, the use of other materials (e.g. plastic) instead of wood, and the loss of traditional plant use-types that is related to decreasing dedication to traditional farming.

CHAPTER 4 demonstrates the effects of temperature and scarification on the seed germination of *Prosopis laevigata* var. *andicola* and *Schinus molle*, and their seedling survival and juvenile growth under diverse soil and water conditions. Results showed that temperatures above 30°C accelerated the germination of *S. molle*'s seeds but increased their fungi infestation. The germination capacity of *P. laevigata* var. *andicola* was significantly improved by applying acid and mechanical scarification. Medium to high moisture levels in sand provided the most favorable growth conditions for both species. *S. molle* was particularly sensitive to dry clay loam and *P. laevigata* var. *andicola* more vulnerable to water-saturated clay loam. Mulching thus enhanced the survival and growth of *S. molle* juveniles, but increased *P. laevigata*'s growth in sand and dry soils only. These findings may facilitate improving the propagation of these two species under drought conditions.

In conclusion, presented in CHAPTER 5, I argue that understanding the human-plant-relationships and their future trends is crucial for supporting local initiatives of restoration in accordance with the participants' needs and interests. These are assumed to be largely driven by complex and dynamic socio-ecological factors, of which rural out-migration, woodland destruction and biodiversity loss, and the globalized markets may play important roles. The interdisciplinary analytical framework developed and successfully employed in this research is therefore considered a valuable tool for the context-specific selection of agroforestry plants that are promising in diversifying both agro-ecosystems and farming production and thus, for supporting their resilience. Moreover, the study demonstrates the efficiency of easily applicable treatments, such as mulching, to improve plant growth exposed to drought conditions, and the importance of ecological studies on the species' habitat requirements and ecological interactions. However, the limitations in cultivating native woody species and in identifying "the right ones" should also be taken into account. Agroforestry science and practice should therefore focus also on restoring the reproductive potentials of the still existing native woody vegetation. Considering this, the incorporation of traditional ecological knowledge into ecological research is crucial for increasing both ecological and social resilience of agro-ecosystems.

ZUSAMMENFASSUNG

Gebirgige Trockengebiete sind von einer zunehmenden Desertifizierung bedroht. Dies betrifft insbesondere die Agrarökosysteme dieser Regionen und die davon abhängige ländliche Bevölkerung. Die Wiederherstellung und Diversifizierung der natürlichen Baum- und Strauchvegetation sind somit entscheidend, um die sozioökologische Resilienz der gebirgigen Trockengebiete zu erhöhen. Sozioökologische Systeme in Gebirgen sind aufgrund der hohen Geodiversität allgemein reich an biologischer und kultureller Vielfalt. Die Beobachtung einer engen Verzahnung von kultureller und biologischer Vielfalt innerhalb sozioökologischer Systeme brachte das Konzept der biokulturellen Diversität hervor. Dieses Konzept basiert auf der Annahme einer Stimulierung weiterer Diversifizierungsprozesse durch die gegenseitigen Wechselwirkungen von biologischer und kultureller Vielfalt. Eine biokulturelle Sichtweise kann somit wertvolle Impulse für den Schutz und die Renaturierung von Ökosystemen liefern. Im Falle von Agrarökosystemen beinhaltet dies die Beachtung und Verwendung der Potenziale der heimischen Pflanzenvielfalt und der kulturellen Vielfalt, wie beispielsweise der lokalen ethnobotanischen Kenntnisse. Dies kann durch die Kultivierung von Baum- und Straucharten in Agrar- und Weideflächen (Agroforstwirtschaft) in die Praxis umgesetzt werden.

Die Fallstudie meiner Dissertation wurde in einer andinen Bauerngemeinschaft in 2.760-3.830 m ü. NHN in der Provinz Tapacarí im Departement Cochabamba, Bolivien durchgeführt. Diese semi-aride Bergregion ist von Bodenerosion und Abholzung betroffen, was zu einer zunehmenden Desertifizierung führen kann. Die Studie verfolgt das Ziel einer Kenntniserweiterung zur Diversifizierung von Agrarökosystemen dieser Region (KAPITEL 1). Dies soll durch die Einführung von Agroforstsystemen erreicht werden, welche sowohl die Potenziale der lokalen biologischen (native Baum- und Straucharten) als auch der kulturellen Vielfalt (lokales ethnobotanisches Wissen) in Betracht zieht. Insbesondere sollen durch diese Studien Wissenslücken hinsichtlich der ökologischen Bedürfnisse, Kultivierungstechniken und der sozioökologischen Bewertung einheimischer Baum- und Straucharten der Untersuchungsregion geschlossen werden. Die folgenden Fragestellungen stehen im Mittelpunkt der Untersuchungen: (1) Welche sozialen und ökologischen Faktoren beeinflussen die Bewertung lokaler Baum- und Straucharten? Welche Arten erhalten die standortspezifisch höchste sozioökologische Wertigkeit? (2) Wie entscheidend ist die Berücksichtigung der intrakulturellen Variation des lokalen Wissens und der Wertigkeit der Arten für die Auswahl und Nutzung von Agroforstpflanzen? (3) Welche Reaktionen zeigen ausgewählte Agroforstpflanzen unter dem Einfluss von Trockenstress, und wie kann dieses Wissen genutzt werden, um die Agroforstwirtschaft attraktiver für deren Nutzer/innen zu machen?

In KAPITEL 2 wird die Entwicklung eines analytischen Rahmens zur Identifizierung vielversprechender agroforstlicher Arten illustriert. Hierbei fanden die standortspezifischen sozioökologischen Faktoren, welche für die Verbreitung und Bewertung von Baum- und Straucharten verantwortlich sind, besondere Berücksichtigung. Dieser analytische Rahmen wurde anschließend unter der Verwendung von Vegetations- und Bodenuntersuchungen sowie Interviews über die Pflanzennutzung getestet. Die sozioökologische Wertigkeit der Arten und deren Verfügbarkeit ("ecological apparency") wurden errechnet. Statistische Analysen (detrended correspondence and principal component analyses) evaluierten die für die Verbreitung und Nutzung von Pflanzen signifikanten sozioökologischen Faktoren. Die Ergebnisse zeigten, dass im Untersuchungsgebiet zwar Sträucher verfügbarer waren als Bäume, die letzteren aber dennoch als wertvoller wahrgenommen wurden, da die Nutzbarkeit der Arten mit ihrer Größe und ihrem Holzanteil stieg. Phytosoziologische Faktoren spielten bei der Bewertung der Nutzbarkeit eine geringere aber ebenfalls signifikante Rolle. In dem sozioökologischen Kontext des Untersuchungsgebietes wurden *Schinus molle* und *Prosopis laevigata* var. *andicola* (< 3.200 m ü. NHN), *Polylepis subtusalbida* (> 3.200 m ü. NHN) und *Baccharis dracunculifolia* als die vielversprechendsten Baum- und Straucharten für die Nutzung in Agroforstsystemen bewertet.

KAPITEL 3 veranschaulicht die Analyse der intrakulturellen Variation des lokalen Wissens und der kulturellen Wertigkeit von Baum- und Straucharten in Abhängigkeit vom Geschlecht, Alter und Migrationshintergrund der Befragten. Die Datenaufnahme erfolgte durch halbstrukturierte Interviews und Auflistungen. Ethnobotanische Indizes wurden zur Ermittlung der kulturellen Wertigkeit der Arten verwendet. Deren intrakulturelle Variation wurde durch statistische Modelle (linear and generalized linear [mixed] models) bestimmt. Die Ergebnisse zeigen, dass das Wissen und die Wertigkeit der Arten mit zunehmendem Alter der Befragten steigen, und diese für migrierende Personen geringer sind; das Geschlecht spielt eine vergleichsweise geringe Rolle. Die Ergebnisse weisen auf einen Zusammenhang zwischen den altersbedingten Effekten und der abnehmenden Verfügbarkeit nutzbarer einheimischer Arten hin. Zudem spielen der zunehmende Ersatz einheimischer durch exotische, kommerziell nutzbare Arten im Holzgebrauch sowie der häufiger werdende Gebrauch anderer Materialien (z.B. Plastik) eine Rolle. Der Verlust ethnobotanischen Wissens und der traditionellen Pflanzennutzung kann zudem mit der sinkenden Bedeutung der traditionellen Landwirtschaft in Verbindung gebracht werden.

KAPITEL 4 zeigt die Effekte von Temperatur und Skarifizierung auf die Samenkeimung von *Prosopis laevigata* var. *andicola* und *Schinus molle*, sowie die Überlebensrate und das Wachstum ihrer Sämlinge unter verschiedenen Boden- und Wasserbedingungen. Die Ergebnisse veranschaulichen, dass Temperaturen > 30°C die Keimung von *S. molle* beschleunigen, diese aber auch den Pilzbefall der Samen erhöhen. Die Keimungsfähigkeit von *P. laevigata* var. *andicola* wurde durch die Verwendung von mechanischer und Säureskarifizierung signifikant verbessert. Eine mittlere bis hohe Bodenfeuchtigkeit im Sand stellte sich als die günstigste Wachs-

tumsbedingung für beide Arten heraus. *S. molle* zeigte sich besonders sensibel in trockenem tonigen Lehm, während die Sämlinge von *P. laevigata* var. *andicola* anfälliger in wassergesättigtem tonigen Lehm waren. Die Anwendung von Mulch erhöhte die Überlebensrate und das Wachstum der *S. molle*-Sämlinge, während diese Methode das Wachstum von *P. laevigata* var. *andicola* nur in Sand und in trockenen Böden verbesserte. Diese Ergebnisse leisten einen Beitrag zur Optimierung der Kultivierungsmethoden beider untersuchter Arten unter dem Einfluss von Trockenstress.

In KAPITEL 5 möchte ich abschließend bemerken, dass ein Verständnis über das lokale ethnobotanische Wissen und die lokale Bewertung von Pflanzen sowie über deren Trends eine entscheidende Voraussetzung ist, um lokale Renaturierungsmaßnahmen in Einklang mit den Bedürfnissen und Interessen der Teilnehmenden zu unterstützen. Diese lokalen sozialen Faktoren werden wiederum durch komplexe und dynamische sozio-ökologische Rahmenfaktoren gelenkt. Es ist anzunehmen, dass hierbei die ländliche Abwanderung, die Zerstörung von Wäldern und Biodiversität sowie die globalisierten Märkte eine wichtige Rolle spielen. Der interdisziplinäre analytische Rahmen, der in dieser Forschungsarbeit entwickelt und erfolgreich angewandt wurde, kann somit als wertvolles Hilfsmittel bei der standortspezifischen und zukunftsweisenden Auswahl geeigneter Agroforstarten betrachtet werden. Das Ziel dieser Maßnahmen sollte die Diversifizierung von Agrarökosystemen und der landwirtschaftlichen Produktion sein, um deren Resilienz zu steigern. Außerdem zeigt die Studie die Leistungsfähigkeit leicht anwendbarer Methoden, wie beispielsweise das Mulchen, um das Pflanzenwachstum unter Trockenstress zu verbessern. Desweiteren wird durch die Forschungsarbeit auf die Bedeutsamkeit ökologischer Studien über einheimische Baum- und Straucharten, insbesondere über deren Standortansprüche und ökologische Wechselbeziehungen, hingewiesen. Allerdings sollten auch die Schwierigkeiten in der Kultivierung einheimischer Arten und in der Identifizierung "der richtigen Arten" in Betracht gezogen werden. Die agroforstliche Wissenschaft und Praxis sollten sich deshalb auch auf die Wiederherstellung der Fortpflanzungspotenziale der noch vorhandenen natürlichen Wald- und Strauchvegetation konzentrieren. Diesbezüglich ist die Integrierung traditionellen ökologischen Wissens in die ökologische Forschung entscheidend, um sowohl die ökologische als auch die soziale Resilienz von Agrarökosystemen zu steigern.

RESUMEN

Las tierras áridas y semi-áridas montañosas enfrentan alarmantes riesgos de de-

sertificación. Esto afecta particularmente los recursos de los agro-ecosistemas de esas regiones y por lo tanto, las poblaciones rurales que dependen de estos. Así, la restauración y diversificación de los bosques naturales son importantes para aumentar la resiliencia de los sistemas socio-ecológicos de estas regiones. Generalmente, los sistemas socio-ecológicos montañosos se caracterizan por una diversidad biológica y cultural muy alta debido a su geodiversidad. La observación de un enlace inseparable entre la diversidad cultural y biológica en los sistemas socio-ecológicos ha dado paso al concepto de la diversidad biocultural. Este concepto sugiere que las interacciones mutuas entre la diversidad biológica y cultural estimulan los procesos de diversificación de ambas. El análisis de la diversidad desde una perspectiva biocultural puede proporcionar así ideas valiosas a las iniciativas de restauración y conservación ambiental. En el caso de los agro-ecosistemas, adoptar una perspectiva biocultural en la restauración significa reconocer y usar el potencial tanto de la diversidad de las plantas nativas de los bosques naturales como de la correspondiente diversidad cultural, por ejemplo, el conocimiento local etnobotánico. Esto se puede poner en práctica, por ejemplo, a través de la agroforestería donde árboles y arbustos crecen junto a cultivos agrícolas y ganado.

En mi tesis doctoral, evalué el caso de una comunidad campesina situada a una altitud de 2.760-3.830 m.s.n.m. en el municipio Tapacarí del departamento de Cochabamba, Bolivia. Esta área semi-árida montañosa es afectada por la degradación del suelo y deforestación y así, el riesgo de desertificación. El estudio de la tesis tiene por objetivo, presentado en CAPÍTULO 1, proporcionar conocimientos útiles para la diversificación de los agro-ecosistemas por medio de sistemas agroforestales que consideren componentes beneficiosos de la diversidad biológica (especies nativas leñosas) y cultural (conocimiento local etnobotánico). Específicamente, mi tesis apunta a generar información principalmente en cuanto a los requerimientos de hábitat, técnicas de cultivo y valoración socio-ecológica de árboles y arbustos nativos. La tesis aborda las siguientes preguntas: (1) ¿Cuáles son los factores ecológicos y sociales que controlan la valoración de las especies leñosas? ¿Qué especies presentan los valores socio-ecológicos más altos en el contexto del área de estudio? (2) ¿Qué significancia tiene considerar la variación intracultural del conocimiento y valoración en la selección y uso de las plantas agroforestales? (3) ¿Cómo responden las especies agroforestales seleccionadas a factores medioambientales estresantes propios de tierras áridas, y que implicaciones conllevan estas respuestas para hacer la agro-

forestería más atractiva para sus usuarios?

En el CAPÍTULO 2 ilustro el desarrollo de un marco analítico para identificar las especies agroforestales más promisorias, analizando los factores socio-ecológicos del área de estudio que afectan la distribución y la valoración de las especies leñosas. El marco analítico se probó usando estudios de suelos y de la vegetación leñosa y entrevistas acerca de los usos de las plantas. Se calcularon los valores socio-ecológicos y la disponibilidad ("apariencia ecológica") de las especies. Luego se aplicaron análisis estadísticos (detrended correspondence analysis, principal component analysis) para revelar el contexto socio-ecológico de los factores significantes para la distribución de las especies y sus usos. Los resultados mostraron que aunque los arbustos fueron ecológicamente más aparentes que los árboles, los últimos se percibieron como más valiosos ya que la utilidad de las especies aumentó con la altura de las plantas y con la provisión de madera. Los factores fitosociológicos desempeñaron un rol menos importante, pero significativo respecto a la percepción de utilidad de las plantas. En el contexto socio-ecológico del área de estudio, *Schinus molle* y *Prosopis laevigata* var. *andicola* (< 3,200 m.s.n.m), *Polylepis subtusalbida* (> 3,200 m.s.n.m.) y *Baccharis dracunculifolia* se evaluaron como las especies más promisorias para su uso en agroforestería.

El CAPÍTULO 3 presenta el análisis de la variación intracultural del conocimiento y la importancia cultural de las plantas leñosas locales con relación al sexo, la edad y las actividades migratorias de los entrevistados. Los datos se obtuvieron a través de entrevistas semi-estructuradas y listados libres. Se usaron índices etnobotánicos para calcular la importancia cultural de las especies. Su variación intracultural se evaluó usando métodos estadísticos (linear and generalized linear [mixed] models). Los resultados revelaron que el conocimiento y la valoración de las plantas aumentaron con la edad de los entrevistados, pero fueron más bajos en migrantes; el sexo, por el contrario, desempeñó un papel menos importante. Las conclusiones sugieren que el efecto de la edad resulta de la disminución del uso de especies nativas valiosas debido a su baja disponibilidad, sustitución por árboles comerciales exóticos, el uso de otros materiales (p. ej. plástico) en vez de la madera y la pérdida de tipos tradicionales del uso de plantas relacionado con la decreciente práctica de la agricultura tradicional.

EL CAPÍTULO 4 muestra los efectos de temperatura y escarificación sobre la germinación de las semillas de *Prosopis laevigata* var. *andicola* y *Schinus molle*, y la supervivencia y el crecimiento de las plántulas bajo diversas condiciones de textura y humedad del suelo. Los resultados mostraron que temperaturas mayores a 30°C aceleraron la germinación de las semillas de *S. molle*, pero aumentaron su infestación por hongos. La capacidad de germinación de *P. laevigata* var. *andicola* mejoró considerablemente al aplicarse escarificación ácida y mecánica. Niveles medios a altos de humedad del suelo arenoso proporcionaron las condiciones de crecimiento más favorables para ambas especies. *S. molle* se mostró particularmente sensible al suelo seco arcilloso, mientras que *P. laevigata* var. *andicola* fue más vulnerable al suelo arcilloso saturado por humedad. Cubrir el suelo con hojarasca así realzó la supervivencia y el crecimiento de las plántulas de *S. molle*, pero aumentó el crecimiento de *P. laevigata* var. *andicola* solo en arena y en suelos secos. Estos resultados pueden facilitar la propagación de estas dos especies en condiciones áridas y semi-áridas.

En conclusiones, presentados en CAPÍTULO 5, argumento que entender los conocimientos y la valoración de las plantas, asi como las tendencias futuras de las mismas permiten apoyar las iniciativas locales de restauración ambiental de acuerdo con las necesidades y los intereses de los participantes. Se supone que estos factores sociales locales sean en gran parte conducidos por factores socio-ecológicos complejos y dinámicos, de los cuales la migración rural, la destrucción de los bosques y los mercados globalizados desempeñan papeles importantes. El marco analítico interdisciplinario que se desarrolló y empleó éxitosamente en esta investigación, constituye por lo tanto, un instrumento valioso para seleccionar plantas agroforestales que prometen una diversificación de agro-ecosistemas y de la producción agrícola, pastoral y forestal. Esto a su vez incrementa la resiliencia de estos sistemas. Además, el estudio demuestra la eficacia de tratamientos fácilmente aplicables, como el uso de hojarasca, para mejorar el crecimiento de plántulas expuestas a condiciones de baja humedad, y la importancia de estudios ecológicos sobre los requerimientos de hábitat de las especies y de sus interacciones ecológicas. Sin embargo, las limitaciones respecto al cultivo de especies leñosas nativas y en la identificación “de las correctas” también deberían ser consideradas. Por lo tanto, el enfoque científico y práctico de la agroforestería debería concentrarse también en restaurar los potenciales reproductivos de la vegetación leñosa nativa existente. En cualquier caso, la incorporación del conocimiento local en la investigación ecológica es muy importante para conseguir aumentar tanto la resiliencia ecológica como social de los agro-ecosistemas.

CHAPTER 1

GENERAL INTRODUCTION

VULNERABILITY OF SOCIO-ECOLOGICAL SYSTEMS IN MOUNTAIN DRYLAND AREAS

Mountain dryland areas face the alarming risk of increasing desertification (Millennium Ecosystem Assessment 2005; Reynolds et al. 2007), which is the "reduction or loss of the biological or economic productivity" of land in arid, semi-arid and dry sub-humid areas (United Nations 1994). Desertification is caused by the interplay of both environmental and social factors (Reynolds et al. 2007). In this process, vegetation removal and inadequate soil use are crucial factors determining the decline of the fertility (Millennium Ecosystem Assessment 2005) and water storage capacity of soils. This is particularly critical in drylands, where high solar radiation and long periods of drought already generate water stress, and where extreme weather events, such as intense sporadic rainfalls and strong winds, accelerate the erosion of soils (Sharma 1998). Landslides and soil erosion are especially found in mountain drylands due to the gravitational forces on slopes (Körner and Ohsawa 2005; Berrahmouni et al. 2011). Ecosystem recovery from disturbances, in turn, is commonly slow or irreversible on fragile sloping sites (Körner 2002). Mountain dryland ecosystems' stability and productivity are therefore highly vulnerable (Jodha 2005; Reynolds et al. 2007).

Peasant farming livelihoods of mountain drylands are particularly affected by desertification (Jodha 2005; Reynolds et al. 2007). Their high social vulnerability is not merely a question of exposure to increasing desertification, but also linked to their sensitivity, as they are dependent on fragile natural resources, and to their capacity to adapt to multiple stresses (Adger 2006). Regarding this, they are limited in their response options due to the low productivity of mountain agro-ecosystems, and the common remoteness from markets and urban centers, which limits the farmers' access to basic services (e.g. education, health care, and infrastructure) and their economic and political participation (Jodha 2005). Environmental and social vulnerability can reinforce each other: intense resource use for meeting livelihood needs determines resource degradation and environmental vulnerability, which in turn decrease agricultural production, and subsequently increase poverty (Scherr 2000; Jodha 2005). This process has been particularly promoted by the global market- and technology-driven shifts in economy and politics since the 1980s (Jodha 2005; Kay 2008). As a livelihood response to multiple socio-ecological stresses (Black et al. 2011), rural out-migration is an increasing phenomenon in mountain areas worldwide (Grau and Aide 2007).

THE ROLE OF BIODIVERSITY IN AGRO-ECOSYSTEMS

Despite low ranges of opportunities, peasant communities of mountain areas constantly generate local strategies to reduce their vulnerability. In this respect, a key question is how policy can facilitate such initiatives (Scherr 2000) without increasing the rural livelihoods' dependence on external support, which can intensify social vulnerability in the long term (Jodha 2005). To mitigate vulnerability, the stresses associated with human-induced environmental changes, such as the process of desertification of farming land, should be reduced, and the socio-ecological resilience of agro-ecosystems and livelihoods should be strengthened (Adger 2006). Originating from the field of ecological theory (Holling 1973), the term "resilience" denotes a system's ability to absorb disturbances without losing its functions, and its capacity for adaptation, self-organization and renewal (e.g. Carpenter et al. 2001; Folke et al. 2004; Folke 2006).

Preserving and restoring plant diversity is considered crucial for coping with desertification risks (Maestre et al. 2012). Plant diversity is suggested to be a main driver of ecosystem functioning in face of environmental changes ("insurance effect") due to its variety of functional traits (response diversity), that allow for high ecosystem's adaptive capacity to recover from disturbances (Loreau 2000; Elmqvist et al. 2003; Fischer et al. 2006). Plant diversity is therefore considered crucial for the long-term stability and resilience of ecosystems (Maestre et al. 2012), particularly in regard to the formation, nutrient cycling, moisture retention and stability of soils (Millennium Ecosystem Assessment 2005). Consequently, the protection of native plant diversity will feedback positively on social systems, such as farming households, by stabilizing these ecosystem services.

MOUNTAINS' INTERLINKED DIVERSITIES

Mountains are commonly characterized by high biological diversity (Barthlott et al. 1996; Mutke and Barthlott 2005). This is attributed to the variety of abiotic factors (geodiversity) in the orographically highly structured mountainous landscapes (Barthlott et al. 1996). Small-scale topographic variety along with elevational gradients and moderate disturbances through gravitational slope dynamics play significant roles in creating habitat complexity and thus, biological richness. In addition, the fragmentation of mountain landscapes induces biogeographic isolation and endemism (Körner 2002; Spehn and Körner 2005). High geodiversity, however, does not necessarily cause high biological diversity. In mountains, ecosystems' productivity, on the one hand, decreases along altitudinal gradients with increasing environmental stress (e.g. frost, drought). This can affect the potential richness in biodiversity facilitated by geodiversity (Mutke and Barthlott 2005). Biotic interactions are, on the other hand, also crucial, and it is assumed that facilitative effects rise with elevation and environmental stress, and overcome competitive effects (Callaway et al. 2002; Maestre et al. 2009).

Mountains' geodiversity and fragmentation are also assumed to drive high cultural diversity (Stepp et al. 2005). The anthropological unit "culture" broadly refers to the symbolic features (e.g. language, knowledge, values, beliefs and customs) shared by a human collectivity (cf. Kuper 1999). However, the drawing of discrete limits between cultural groups is controversial (Collard and Foley 2002). Languages are vehicles for the transmission of cultural features (Maffi 2007), and linguistic diversity is often taken as a proxy for cultural diversity (e.g. Sutherland 2003; Stepp et al. 2004, 2005), which is, according to UNESCO (2005), defined as the "manifold ways in which the cultures of groups and societies find expression". In the context of mountain areas, it is suggested that social groups have evolved manifold survival strategies and cultural features in adaptation to geodiversity, and mountain ranges may reduce intra- and intercultural exchange and thus, promote cultural heterogenization (Stepp et al. 2005). However, this is only true in constantly productive environments. With increasing ecological risks (e.g. drought, frost) cultural diversity tends to decrease, because the socio-cultural networks and habitats must be larger to ensure subsistence (Nettle 1998).

It is suggested that the mutual interactions between biological and cultural diversity can stimulate further diversification processes (Maffi and Woodley 2010). On the one hand, social groups living in different environments learn to use different biological resources. This produces cultural diversity in terms of knowledge and practices (Maffi 2007). On the other hand, different cultural groups (including, but not limited to traditional communities; Cocks 2006, 2010) have different worldviews and practices, and alter ecosystems by using them in diverse ways (Mathez-Stiefel et al. 2007). This may create ecological niches and promote biological diversification (Maffi 2007). The latter suggestion is based on the ecological theories that biodiversity is highest at moderate disturbance levels in terms of frequency and intensity ("intermediate disturbance hypothesis"; Connell 1978), and that biological diversification is related to the range of habitats and the degree of species specialization ("niche diversification hypothesis"; see e.g. Hutchinson 1961). The observation of this "inextricable link between cultural and biological diversity" (ISE 1988) within complex and adaptive socio-ecological systems has brought forth the concept of biocultural diversity, which incorporates "the diversity of life in all of its manifestations" (Maffi 2005).

INCREASING SOCIO-ECOLOGICAL RESILIENCE FROM A BIOCULTURAL PERSPECTIVE

It is undeniable that man's dominating attitude towards the environment, as expressed by land use transformations, biotic additions and losses, and alterations of biogeochemical cycles, have degraded global biodiversity at alarming rates (Vitousek et al. 1997; Chapin et al. 2000). Additionally, these drivers of global environmental change affect biodiversity through the alteration of biotic interactions (e.g. increased pathogen infection, weakened mutualisms, enhanced herbivory, exotic species invasions; Tylianakis et al. 2008). In contrast to conventional conservation approaches, a biocultural perspective proposes solutions to environmental problems by protecting sensitive ecosystems and species with humans, not from humans. With the underlying philosophical view of humans as part of and not separate from nature (Maffi 2007), this perspective recognizes the collective human responsibility (Terborgh 2004) and, related to issues of social justice and pragmatic concerns, the crucial role of ground-up action and local stewardship in biodiversity conservation efforts (Orlove and Brush 1996). Moreover, if biodiversity is to some extent culture-specific, then conserving the cultural capital, such as traditional ecological knowledge, which is also put at risk by current social global changes (e.g. globalization, migratory movements), is assumed to be relevant not only for species and ecosystem preservation (United Nations 1992; Maffi 2007), but also for maintaining the adaptive capacity and resilience of whole socio-ecological systems (Turner et al. 2003; Maffi and Woodley 2010; Pretty 2011). In terms of combating desertification and increasing the resilience of both agro-ecosystems and peasant livelihoods in mountain drylands, this means not only conserving and restoring native plant diversity, but also recognizing, using and preserving the related cultural elements, such as the local traditional ecological knowledge (Jodha 2005; Maffi 2007; Reynolds et al. 2007).

AGROFORESTRY AND ETHNOBOTANY IN BIOCULTURAL CONSERVATION AND RESTORATION

By growing trees along with crops and livestock, the ancient and multifunctional practice of agroforestry can create new habitats and corridors in mono-crop agro-ecosystems and increase their above- and belowground biodiversity (Sanchez 1995; McNeely and Schroth 2006; Jose 2012). Agroforestry contributes to maintaining or restoring the ecosystem functions and services of agro-ecosystems (e.g. improving soil fertility, water retention, microclimate, pest control; Young 1997; Altieri 1999; Jose 2009), and may increase their ecological resilience (Jose 2012). Agroforestry can also diversify the socio-economic production of farming systems (e.g. timber, fodder, food), and reduce production risks linked to environmental changes, such as climate variability, which, in turn, may enhance social resilience (Verchot et al. 2007). To achieve this, the beneficial complementarities and synergies in agro-ecosystems must be supported by specific spatial and temporal arrangements and compositions of crops, livestock and woody species (Altieri 1999). In agroforestry, special caution is recommended when using exotic plants, which are potentially invasive, while implementing native woody species, especially keystone species, is advocated (Fischer et al. 2006).

Dating back to Paine (1969) and modified by, for instance, Power et al. (1996), keystone species are defined as those, whose effects on maintaining ecosystem structures, functions and diversities are disproportionately large in relation to their abundance. Playing a keystone role is strictly context-related and not a fixed species-specific attribute. Thus, the strength of species' interaction changes with environmental dynamics (Mills et al. 1995; Power et al. 1996). This theory from ecology was taken as a model to create the concept of cultural keystone species (CKS), which designate species with high importance for the socio-cultural stability in a specific context (Cristancho and Vining 2004; Garibaldi and Turner 2004). Using this concept for targeting species that are both ecologically and culturally significant is assumed a meaningful inclusion of traditional ecological knowledge into so-called biocultural conservation and restoration aimed at preserving biodiversity and related cultural features in a holistic way (Garibaldi and Turner 2004; Garibaldi 2009). In agroforestry, for instance, this is assumed to support encouraging local initiatives (e.g. Sanchez 1995; Thapa et al. 1995; Walker et al. 1995; McDonald et al. 2003; Langenberger et al. 2009), and to understand the resource users' perceptions in management decisions that also affect them (Huntington 2000).

It is, however, a major challenge to combine holistic traditional ecological knowledge, also referred to as endogenous knowledge, with scientific knowledge separated in disciplines, and to overcome the ontological (conception of being) and epistemological (conception of knowing) barriers between the local and scientific actors. Interdisciplinary "ethno-sciences" (e.g. ethnobiology, ethnobotany) that are based on the collaboration between social sciences and humanities with natural sciences can bridge such inter-scientific dialogues (Rist and Dahdouh-Guebas 2006; Rist et al. 2011) and provide excellent forums to explore the relationships between humans and the environment (Garibaldi 2009). In relation to the scientific use of endogenous plant-related knowledge, ethnobotany provides numerous methodological tools, such as, for example, the CKS model (Garibaldi and Turner 2004), to translate qualitative information into quantifiable data (e.g. Hoffman and Gallaher 2007; Tardío and Pardo-de-Santayana 2008). This is useful to analyze knowledge acquisition, transmission, and the factors that determine its maintenance and loss (Huntington 2000; Maffi 2005, 2007), as well as the cultural meanings attached to plants (Cristancho and Vining 2004). Through the collaboration with ethno-biologists, which has rarely been undertaken so far, a more sensitive handling with local participants' time and resources, data ownership, and result sharing can be achieved in ecologists' conservation research (Saslis-Lagoudakis and Clarke 2013).

OBJECTIVES

My doctoral thesis aims at providing interdisciplinary scientific support for the successful inclusion of native woody species in agroforestry systems. This goal was achieved by combining ethnobotanical methods with ecological studies of the target species. The selected socio-ecological system was a semi-arid rural mountain area in the Bolivian Andes, which is vulnerable because of accelerated soil degradation (e.g. Zimmerer 1993; Saavedra 2005; Kessler and Stroosnijder 2006), deforestation and plant diversity loss (e.g. Fjeldså and Kessler 1996; Hensen 2002; Ibisch and Mérida 2004; Navarro et al. 2005; Gareca et al. 2010), climate change effects (Vuille et al. 2003; McDowell and Hess 2012), severe poverty and rural out-migration (O'Hare and Rivas 2007), and the erosion of traditional knowledge (AGRUCO et al. 2010). Diversifying the Bolivian Andean agro-ecosystems and rural farming systems to increase their socio-ecological resilience is therefore an urgent need. Implementing agroforestry from a biocultural perspective, which means to identify and apply beneficial components of both biological (native woody species) and related cultural (traditional ecological knowledge) diversity through inter-scientific dialogues, is supposed to contribute to these goals (Figure 1.1).

In the Bolivian Andes, however, native trees and shrubs are rarely cultivated today (Ibisch 2002). Thus, more research on socio-ecological plant values is required (Madge 1995) in order to select agroforestry species that provide favorable environmental services and socio-economic cost-benefit ratios (Gausset 2004), and which meet the plant-related needs and interests of the land users and aim for compatibility with their livelihoods (Reed 2007). This is assumed crucial for restoration efforts, such as agroforestry, to be meaningful and motivating for local users (e.g. Garibaldi and Turner 2004; Saunders et al. 2006). Furthermore, the knowledge about native species' effective propagation and cultivation is scarce (Weise and Schrader 2001). This highlights the relevance of identifying and closing the knowledge gaps in relation to their survival and juvenile growth under the harsh environmental conditions of mountain drylands (Renison et al. 2005; Villagra et al. 2010).

By taking the case of the indigenous peasant community Tres Cruces situated at an altitude of 2,760–3,830 m.a.s.l. in the municipality of Tapacarí in Cochabamba, Bolivia, this doctoral thesis addresses the following key questions on the selection and cultivation of native woody species with potential for use in agroforestry (see also Figure 1.1):

(1) Which environmental and social factors control woody species' valuation? Which species present the highest context-specific socio-ecological values? These questions were addressed by developing an interdisciplinary analytical framework to select promising agroforestry plants. This framework, which can also be applied in other socio-ecological contexts, was tested in the study area, see CHAPTER 2: "*Agroforestry species of the Bolivian Andes: an integrated assessment of ecological, economic and socio-cultural plant values*".

(2) How relevant is the consideration of intracultural variation of knowledge and valuation in the selection and use of agroforestry plants? This question was addressed in CHAPTER 3: "*Knowledge and valuation of Andean agroforestry species: the role of sex, age, and migration among members of a rural community in Bolivia*".

(3) Which are the responses of selected agroforestry species to dryland-specific environmental stress, and what are their implications for making agroforestry more attractive to land users? These issues were focused in CHAPTER 4: "*Species-specific responses to environmental stress on germination and juvenile growth of two Bolivian Andean agroforestry species*".

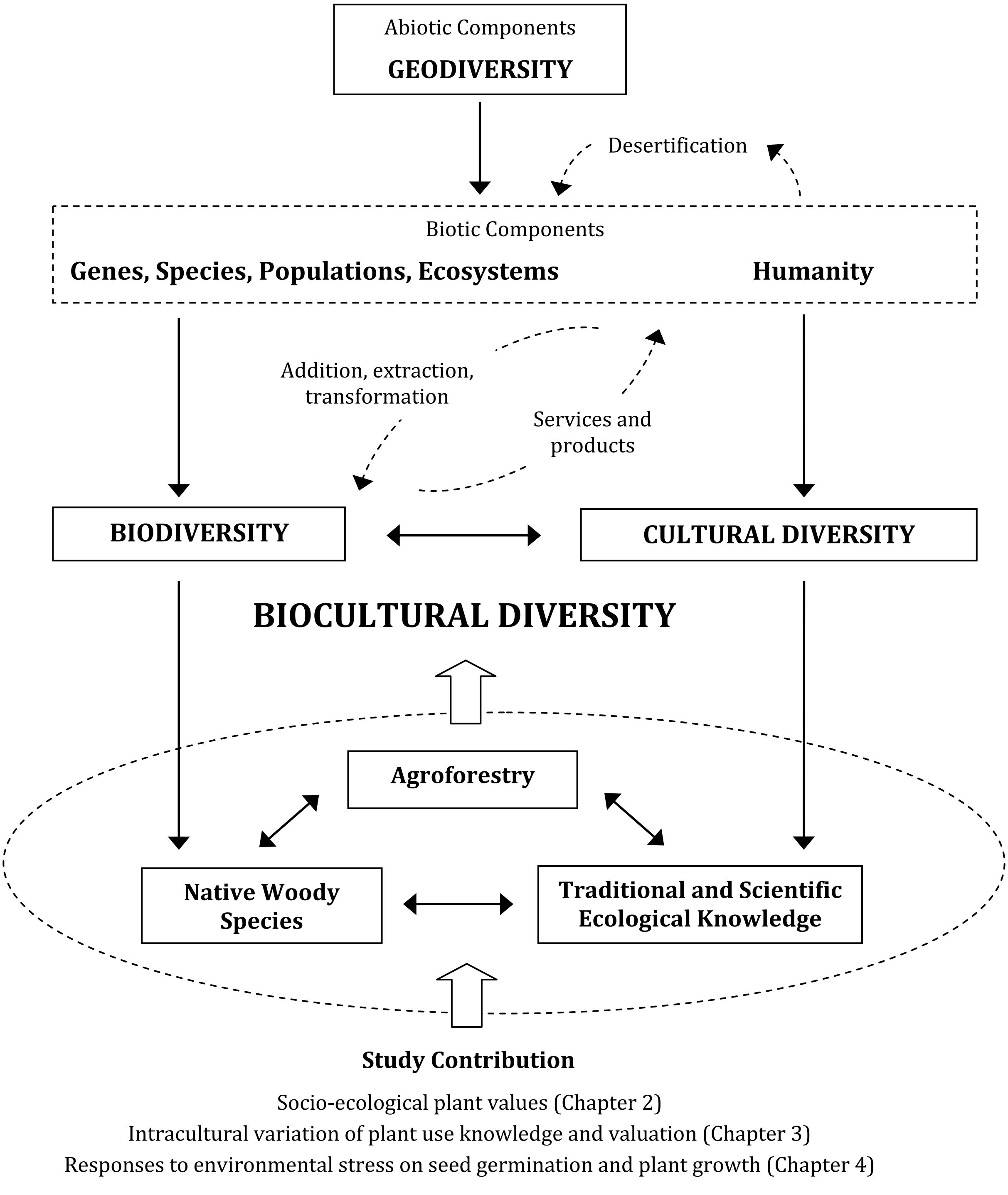

Figure 1.1 Interlinked geo-, bio- and cultural diversity, and study contributions to increase the biocultural diversity of socio-ecological systems (own elaboration)

AGROFORESTRY SPECIES OF THE BOLIVIAN ANDES: AN INTEGRATED ASSESSMENT OF ECOLOGICAL, ECONOMIC AND SOCIO-CULTURAL PLANT VALUES

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ABSTRACT

Agroforestry is a promising method for enhancing land-use sustainability in the Bolivian Andes. However, its benefits in terms of rural development are under-recognized due to gaps in understanding users' perceptions while taking into consideration both local and global environmental goals. Our study aimed to narrow these gaps by developing an analytical framework for analyzing the site-specific socio-ecological factors and interactions related to local woody species and assessing their ecological, economic, and socio-cultural plant values in order to identify the most promising agroforestry species. The framework was then tested in an indigenous community at 2,760-3,830 m.a.s.l., incorporating vegetation surveys, environmental studies, and interviews on plant functions. Ecological, economic, and socio-cultural values and the ecological apparency of plants were calculated, and detrended correspondence and principal component analyses helped to reveal the socio-ecological context of significant factors for plant distribution and uses. Results showed dominating seral woody species along an altitudinal gradient. Although shrubs were more ecologically apparent than trees, trees were perceived to be more valuable as the usefulness and cultural importance of species increased with plant height and timber availability. Phytosociological factors played a minor but still significant role in perceived usefulness. *Schinus molle* and *Prosopis laevigata* var. *andicola* (< 3200 m.a.s.l.), *Polylepis subtusalbida* (> 3200 m.a.s.l.), and *Baccharis dracunculifolia* (both altitudinal zones) were evaluated as most promising for agroforestry use. In conclusion, our analytical framework proved to be a valuable tool for context-specific agroforestry plant selection. Nonetheless, economic, technical, and socio-cultural limitations of cultivating native agroforestry species were revealed as well. Agroforestry science and practice should, therefore, focus on enhancing reproductive potentials of existing woody vegetation, as well as problem-oriented horizontal dialogues between indigenous, expert, and scientific actors.

KEYWORDS

Agroforestry; Bolivian Andes; Local knowledge; Native woody species; Quantitative ethnobotany; Socio-ecological plant values

KNOWLEDGE AND VALUATION OF ANDEAN AGROFORESTRY SPECIES: THE ROLE OF SEX, AGE, AND MIGRATION AMONG MEMBERS OF A RURAL COMMUNITY IN BOLIVIA

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(OPEN ACCESS - ONLINE AT: HTTP://WWW.ETHNOBIOMED.COM/CONTENT/9/1/83)

ABSTRACT (IN ENGLISH)

Background: Agroforestry is a sustainable land use method with a long tradition in the Bolivian Andes. A better understanding of people's knowledge and valuation of woody species can help to adjust actor-oriented agroforestry systems. In this case study, carried out in a peasant community of the Bolivian Andes, we aimed at calculating the cultural importance of selected agroforestry species, and at analysing the intracultural variation in the cultural importance and knowledge of plants according to peasants' sex, age, and migration.

Methods: Data collection was based on semi-structured interviews and freelisting exercises. Two ethnobotanical indices (Composite Salience, Cultural Importance) were used for calculating the cultural importance of plants. Intracultural variation in the cultural importance and knowledge of plants was detected by using linear and generalized linear (mixed) models.

Results and discussion: The culturally most important woody species were mainly trees and exotic species (e.g. *Schinus molle*, *Prosopis laevigata* var. *andicola*, *Eucalyptus globulus*). We found that knowledge and valuation of plants increased with age but that they were lower for migrants; sex, by contrast, played a minor role. The age effects possibly result from decreasing ecological apparency of valuable native species, and their substitution by exotic marketable trees, loss of traditional plant uses or the use of other materials (e.g. plastic) instead of wood. Decreasing dedication to traditional farming may have led to successive abandonment of traditional tool uses, and the overall transformation of woody plant use is possibly related to diminishing medicinal knowledge.

Conclusions: Age and migration affect how people value woody species and what they know about their uses. For this reason, we recommend paying particular attention to the potential of native species, which could open promising perspectives especially for the young migrating peasant generation and draw their interest in agroforestry. These native species should be ecologically sound and selected on their potential to provide subsistence and promising commercial uses. In addition to offering socio-economic and environmental services, agroforestry initiatives using native trees and shrubs can play a crucial role in recovering elements of the lost ancient landscape that still forms part of local people's collective identity.

ABSTRACT (IN SPANISH)

Introducción: Agroforestería es un método de uso de la tierra sostenible con una larga tradición en los Andes bolivianos. Un mejor entendimiento del conocimiento y valoración de las especies leñosas puede apoyar la mejora de los sistemas agroforestales orientados a actores locales. Este estudio de caso se realizó en una comunidad campesina de los Andes bolivianos con los objetivos de calcular la importancia cultural de especies agroforestales seleccionadas y analizar la variación intracultural del conocimiento sobre las mismas y de su valoración según sexo, edad y migración de los campesinos.

Métodos: La colecta de datos se basó en entrevistas semiestructuradas y listados libres. Se usaron dos índices etnobotánicos (Composite Salience, Cultural Importance) para calcular la importancia cultural de plantas. La variación intracultural de la importancia de las plantas y del conocimiento sobre las mismas se evaluó mediante modelos lineares y modelos lineares generalizados (mixtos).

Resultados y discusión: Las especies leñosas culturalmente más importantes fueron principalmente árboles y especies exóticas (p.ej. *Schinus molle*, *Prosopis laevigata* var. *andicola*, *Eucalyptus globulus*). El sexo desempeñó un menor rol al contrario a los efectos positivos de la edad y efectos negativos de la migración sobre la importancia cultural de las plantas y el conocimiento sobre las mismas. El efecto de la edad posiblemente resultó debido a la disminución de apariencia ecológica de especies nativas y su reemplazo por árboles exóticos, la pérdida de usos tradicionales o la utilización de otros materiales (p.ej. plástico) en vez de madera. La menor dedicación a la agricultura tradicional podía haber implicado un abandono sucesivo de herramientas tradicionales, y una transformación general del uso de las plantas leñosas posiblemente se relacione con la disminución del conocimiento medicinal.

Conclusiones: Debido a los efectos de edad y migración sobre la valoración de plantas leñosas y el conocimiento sobre los usos de las mismas, recomendamos que se debe prestar una atención particular al potencial de especies nativas para abrir perspectivas prometedoras a la generación campesina joven migrante y aumentar su interés en la agroforestería. Por eso, se deberían seleccionar especies ecológicamente compatibles según su potencial para proporcionar la subsistencia y posibles usos comerciales. Aparte, las iniciativas agroforestales usando árboles y arbustos nativos pueden jugar un rol importante en la recuperación del paisaje tradicional que todavía forma parte de la identidad colectiva de los campesinos locales.

KEYWORDS

Cultural importance; Intracultural variation; Plant use knowledge; Quantitative ethnobotany; Woody species

BACKGROUND

Measuring the cultural importance of plants is a key issue in quantitative ethnobotanical studies (Hoffman and Gallaher 2007, Thomas et al. 2009a) and a valuable tool for sustainable land use practices such as agroforestry (González-Insuasti et al. 2008; Brandt et al. 2012). Ethnobotany provides numerous methods for obtaining quantifiable data to identify cultural plant values within their given socioecological context (Albuquerque et al. 2008). For example, "freelisting" enables rapid data sampling based on the assumption that the respondents mention culturally important species more frequently and earlier than others (Quinlan 2005, 2010). Whether people perceive plants as culturally important or not depends on their "ecological apparency". This hypothesis, adapted to ethnobotanical studies by Phillips and Gentry (1993b), proposes that the most common and accessible species are those which are more used and valued (see also Thomas et al. 2009b). Additionally, the quality, intensity, and exclusivity of plant uses should be considered (Turner 1988). This is commonly explored with in-depth, semi-structured interviews that focus on exhaustive inventories of plant knowledge including its theoretical dimensions (passive knowledge) (Tardío and Pardo-de-Santayana 2008). In contrast, freelisting does not produce exhaustive inventories, and instead aims at obtaining information on practical uses (active knowledge) (Quinlan 2005; Quinlan and Quinlan 2007; Tardío and Pardo-de-Santayana 2008). Combining methods that collect and analyse data on active and passive knowledge provides a broader understanding of the cultural importance of plants and improves the reliability of the results compared to applying single methods. It also provides interesting insights on the processes of knowledge transmission (Reyes-García et al. 2006, 2007).

The cultural importance of plants is commonly estimated by considering the level of agreement among the interviewees about the knowledge underlying plant use (Tardío and Pardo-de-Santayana 2008; Reyes-García et al. 2006), which is termed "informant consensus", e.g. Phillips and Gentry (1993a). This approach, however, carries the risk of overlooking the social distribution of knowledge, which is most often not equally shared within a certain cultural group (Tardío and Pardo-de-Santayana 2008). Consequently, in the last decade there was growing interest in analysing the factors that cause intracultural variation (Quinlan and Quinlan 2007; Reyes-García et al. 2007). Mainly reported in previous studies are age and sex (Begossi et al. 2002; Voeks and Leony 2004). In addition, factors often related to acculturation such as migration (Nesheim et al. 2006; Volpato et al 2009; Medeiros et al. 2012), market integration (Godoy et al. 2005), and formal education (Voeks and Leony 2004) have also been reported to have complex effects on ethnobotanical knowledge. Analysing these factors and the dynamics behind intracultural variation is fundamental for understanding the processes of transmission, transformation, recovery, or loss of ethnobotanical knowledge (Lozada et al. 2006; Santos Silva et al. 2011; Mathez-Stiefel and Vandebroek 2012; Mathez-Stiefel et al. 2012).

A better understanding of the intracultural variation in plant knowledge and valuation may help to improve sustainable agroforestry systems (González-Insuasti et al. 2008, 2011) that aim at providing socio-economic benefits for subsistence and commercial use (e.g. production of fodder, fuel, fruits (Brandt et al. 2012; Moreno-Calles et al. 2012), and environmental services in agro-pastoral landscapes (e.g. soil and biodiversity conservation, carbon sequestration (Young 1997; Verchot et al. 2007; Jose 2012). In the Bolivian Andes, agroforestry has a long tradition, dating back to before the arrival of the Spanish in the 1530s. However, agroforestry systems using native woody species (e.g. *Alnus acuminata*, *Buddleja* spp., *Schinus molle*) are rarely actively implemented today compared to plantations of the more productive exotic genus *Eucalyptus* (Chepstow-Lusty and Winfield 2000), because peasants prefer investing in land use systems that are more profitable in the short term than alternative use systems that are more promising in the long term (Mercer 2004). To reverse this trend, drawing attention to the cultural importance attributed to plants was shown to be a key factor in motivating peasants to better manage the woody species growing on their farm land (González-Insuasti et al. 2008). Scientific insights into the intracultural variation in such valuation could help optimise agroforestry management (González-Insuasti et al. 2011). For instance, sex-specific plant valuation and knowledge should be considered in the Bolivian Andes, where both women and men play crucial but different and complementary roles in agropastoral production and livelihoods. Among women's labour domains are domestic work, child care, livestock rearing (Figure 3.1), seed conservation, and fuelwood collection, while men are more involved in soil management, construction of buildings (Figure 3.2), manufacturing of tools, and temporary off-farm labour (Serrano et al. 2006). Such gender roles define the social groups in which people participate and communicate, and thus experience, learn, and share knowledge (Garro 1986). This includes knowledge and cultural importance of plants and their uses (Turner 1988).

Figure 3.1 Livestock rearing. Photograph by S.-L. Mathez-Stiefel

Figure 3.2 Reparation of roof cover by using woody branches, straw and loam. Photograph by R. Brandt

Moreover, age-specific variability should be considered, because the cultural importance of plants and its underlying knowledge are dynamic values. They transform over time and thus may vary from one generation to the next due to abrupt or gradual changes in how people use or do not use plants in changing living conditions (Turner 1988; Müller-Schwarze 2006).

In the Bolivian highlands and lowlands, rural out-migration to urban centres strongly influences peasants' livelihoods. Young adults in particular migrate to seek better income and access to basic services such as healthcare, education, and infrastructure (Grau and Aide 2007). These processes can increase the generational differences in plant-related knowledge and valuation, and can also cause loss of traditional knowledge among the youth (Bussmann and Sharon 2006; Estomba et al. 2006).

Our study aimed at investigating the cultural importance and knowledge of woody species with potential for use in agroforestry in a rural community of the Bolivian Andes, by analysing their intracultural variation. Particularly, we wanted to test the hypotheses that (1) there are sex-specific differences in ethnobotanical knowledge and valuation, in accordance with existing gender roles, and there is a decrease in knowledge and valuation of plants (2) among the youth and (3) as a consequence of migration. To achieve this, we calculated the cultural importance of 14 selected woody plant species, which were assessed among the most valuable plants for use in agroforestry in the context of the studied community (Brandt et al. 2012), by using two different methods of data collection and analysis respectively, and assessed the intracultural variation in the cultural importance of plants by distinguishing between the community members' sex, age, and migratory activity. We also evaluated the effects of sex, age, and migration on knowledge of the uses of these 14 woody plants.

METHODS

Research area

The present study took place in the indigenous rural community Tres Cruces (17°28′–17°30′ S, 66°27′–66°29′ W, ~850 ha, 2,760–3,830 m.a.s.l.) situated in the sub-central Waka Playa of the province of Tapacarí, Cochabamba, Bolivia (Figures 3.3 and 3.4).

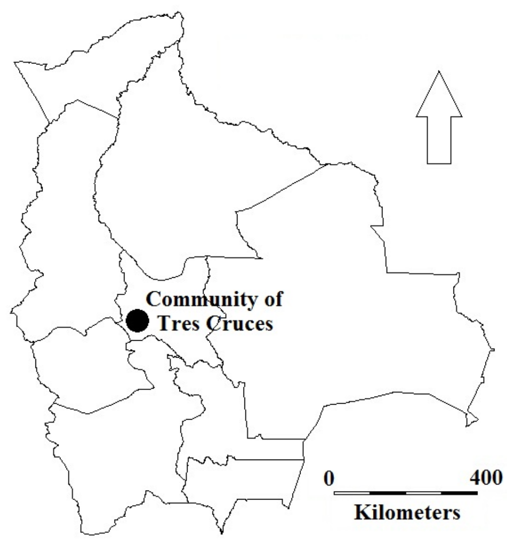

Figure 3.3 Research area. The research was conducted in the rural community of Tres Cruces (2,760–3,830 m.a.s.l.) in the province of Tapacarí, department of Cochabamba, Bolivia. Map elaborated with DIVA-GIS (2013)

This semi-arid region receives an average of 600 mm of annual precipitation, with > 80% of the rainfall occurring between November and March (Ramadas No. 401–17, 1971–2003, Bolivian National Meteorology and Hydrology Service, SENAMHI). Annual mean temperature is about 11°C (Honorable Alcaldía Municipal de Tapacarí, Ajuste del plan de desarrollo municipal Tapacarí 2003–2007).

From a biogeographical perspective, the study area extends over the Peruvian Puna Province, in transition to the Bolivian-Tucuman Province, and includes both altitudinal levels puna and prepuna (Navarro and Maldonado 2002). Natural vegetation of woody species, such as the frequently-growing *Baccharis dracunculifolia* and *Cestrum parqui*, consists of hedges and shrublands on field margins, waysides, stony terrace walls, fallow land, and in ravines (Brandt et al. 2012). Exotic trees and shrubs (e.g. *Eucalyptus* spp., *Pinus* spp., *Spartium junceum*) were heavily promoted during the course of a participatory rural development project (1999–2002).

The population of Tres Cruces consists of 50 indigenous Quechua-speaking families, some inhabitants being bilingual with Spanish. They depend on small-scale subsistence farming with 2 to 6 ha land per household. They cultivate tubers (e.g. *Solanum tuberosum*, *Ullucus tuberosum*), cereals (e.g. *Zea mays*, *Triticum sativum*, *Chenopodium quinoa*), vegetables and fruits, and rear livestock (ovine, caprine, bovine). Farming is complemented by temporary and permanent off-farm activities in the lowlands and urban centres.

Figure 3.4 Landscape of the research area. Photograph by S.-L. Mathez-Stiefel

Ethnobotanical data collection

The study was conducted within a development programme for the conservation and enhancement of biocultural diversity in the Bolivian, Peruvian, and Ecuadorian Andes (AGRUCO et al. 2010). Following a presentation of the research objectives, prior informed consent was obtained orally from the syndicate assembly of the community of Tres Cruces, the leaders of the sub-central Waka Playa, and from each person interviewed. Data were collected by the main author from January to December 2007 by applying two methods: freelisting (Quinlan 2005) on the importance of all local woody species, and semi-structured interviews (Tardío and Pardo-de-Santayana 2008) on the uses of 14 selected local woody species (including trees, shrubs, and subshrubs). Due to the research time constraints, we focused our data analysis only on the selected species. They were chosen for their promising potential use in agroforestry, based on their evaluations in an explorative study conducted in the same research area (Brandt et al. 2012; Table 3.1). The criteria for plant selection were high, integrated ecological, economic, and sociocultural plant values, high ecological apparency, and absence of negative plant attributes (e.g. toxicity for livestock).

Table 3.1 Characteristics of selected local woody species

#	Species	Vernacular name	Family	Life-form	Origin
1	*Baccharis dracunculifolia* DC.	T'ola	Asteraceae	Shrub	Native
2	*Berberis commutata* Eichler	Churisik'e	Berberidaceae	Shrub	Native
3	*Buddleja coriacea* Remy	Kishuara	Buddlejaceae	Tree	Native (cultivated)
4	*Clinopodium bolivianum* (Benth.) Kuntze	Chini muña, muña	Lamiaceae	Subshrub	Native
5	*Eucalyptus globulus* Labill.	Eucalipto, kalisto	Myrtaceae	Tree	Exotic
6	*Gynoxys psilophylla* Klatt	K'apa towi, loma towi, k'apa k'apa	Asteraceae	Tree	Native
7	*Kaunia saltensis* (Hieron.) R.M. King & H. Rob.	(Jaya) towi	Asteraceae	Shrub	Native
8	*Lepechinia graveolens* (Regel) Epling	Raqacho, raga raga	Lamiaceae	Shrub	Native
9	*Minthostachys ovata* (Briq.) Epling	K‘oa muña, muña	Lamiaceae	Subshrub	Native
10	*Polylepis subtusalbida* (Bitter) M. Kessler & Schmidt-Leb.	Kewiña, queñua	Rosaceae	Tree	Native
11	*Prosopis laevigata* var. *andicola* Burkart	Thaqo, algarrobo	Leguminosae	Tree	Native
12	*Sambucus peruviana* Kunth	Sauco	Caprifoliaceae	Tree	Exotic
13	*Schinus molle* L.	Molle	Anacardiaceae	Tree	Native
14	*Senna aymara* H.S. Irwin & Barneby	Motocho, motochila	Leguminosae	Shrub	Native

Selection based on species' high integrated plant values: ecological (EV), economic (RI), and sociocultural (ICI) plant values, and high ecological apparency (IV) (provided in Brandt et al. 2012)

Freelisting exercises and semi-structured interviews were conducted with twenty women and twenty men (approximately 25% of the total population). Participants were evenly spread over four age classes: (1) < 20 years, (2) 20–39 years, (3) 40–59 years, (4) ≥ 60 years, with five women and five men per age class. In accordance with Phillips and Gentry (1993b), participants were interviewed individually in order to avoid cross-influences between the responses. Languages used were Spanish or Quechua, in the latter case with support of an interpreter. Each interview started by identifying whether the participant was a permanent resident of the community, a temporary migrant having a residence both within and outside the community, or a permanent migrant having his/her main residence outside the community. The participants were then asked to freelist their favourite (n = 2-4) and other important local woody species (plant reports) and to explain the reasons for these preferences. The local (vernacular) plant names mentioned were related to their scientific names based on a previous study conducted in the same research area (Brandt et al. 2012), in which collected plant vouchers were identified by comparison with plant material from the herbarium of Cochabamba (BOLV) and in consultation with specialists. In addition, semi-structured interviews were conducted, during which the participants were asked whether and how they used the 14 selected plants for the following nine use-categories (use-reports), based on Brandt et al. (2012): (1) construction (house building), (2) environmental use (e.g. soil management), (3) field use (e.g. livestock fence, shelter), (4) fodder, (5) food (including beverages), (6) fuel, (7) medicine (including spiritual healing), (8) tools (e.g. plough, broom), and (9) other use (e.g. commercialisation, domestic uses such as kitchenware and furniture, social and spiritual uses including ornaments and rituals not performed as healing practices). This allowed a collection of exhaustive inventories of use-types per use-category for each species (e.g. participant x mentioned that *Minthostachys ovata*, k'oa muña is used in case of stomach ache and influenza; n = 2 use-types in use-category "medicine"). The interviews were recorded, then translated from Quechua to Spanish and transcribed.

Data analysis

The cultural importance of 14 selected woody species (Table 3.1) and the intracultural variation according to sex (female, male), age (< 20 years, 20–39 years, 40–59 years, ≥ 60 years) and migration ("no_ young": no migration < 40 years, "no_old": no migration ≥ 40 years, "temp": temporary migration, "perm": permanent migration; all temporary and permanent migrants interviewed were < 40 years) were calculated based on two different indices: Composite Salience (Composite S) (Quinlan 2005, 2010) was applied for data obtained by freelisting (active knowledge; Quinlan 2005; Quinlan and Quinlan 2007; Tardío and Pardo-de-Santayana 2008), and Cultural Importance (CI) for data gained from semi-structured interviews (passive knowledge; Tardío and Pardo-de-Santayana 2008). In order to calculate Composite S, first the salience of each selected plant for each participant was determined by dividing the plant's inverse rank in the participant's freelist by the total number of plants mentioned by this participant. Then, Composite S per plant was calculated by summing up the salience scores of each plant and dividing them by the number of participants (n = 40). Thus, the index theoretically ranges between 0 (not mentioned by any participant; not salient) and 1 (mentioned by all participants in first position; highly salient) (Quinlan 2005, 2010). It was further computed for each actor group per plant and factor (age, sex, and migration; as previously defined). In order to estimate CI, we first grouped all use-reports per plant and participant into the nine use-categories described above (mentioned: 1; not mentioned: 0), and reported the total number of use-types mentioned per use-category, plant, and participant. CI was then calculated for each species and for each actor group (age, sex, and migration; as previously defined) by summing up the proportions of informants that mentioned each use-category. Theoretically, CI may in this case range from 0 (no use-category mentioned by any participant; no cultural importance) to 9 (all use-categories mentioned by all participants; maximal cultural importance) (Tardío and Pardo-de-Santayana 2008).

Statistical analyses were performed in R software for statistical computing and graphics, version 2.14.0 (R Development Core Team 2012). First, we examined whether Composite S correlated to CI for the 14 selected species by using Spearman rank correlation tests. We applied one-way analyses of variance (ANOVA) using linear models to analyse the effects of the explanatory variables sex, age, and migration (as previously defined) on Composite S and CI (response variables). The two response variables were arcsine square-root transformed to achieve residual normal distribution. Subsequently, Tukey post-hoc tests were applied for pairwise comparisons of means. We also used two-sided binomial tests to compare the probabilities of use-categories being mentioned for each species. They allowed us to check whether previously detected significant intracultural variation in CI was a result of significant differences in the relative importance of one or more specific use-categories between the respective actor groups (Crawley 2007). Furthermore, analyses of covariance (ANCOVA) were applied using generalized linear models (GLM, R package "stats", function "glm"; R Development Core Team 2012) to evaluate whether the number of use-types mentioned per species varied depending on the participants' socio-economic characteristics (sex, age, migration). In these analyses, the interviewees' age was included as a continuous variable. Due to the low number of migrants, temporary and permanent migrants were grouped into one category (yes: migrant; no: resident). All possible two-way interactions among the explanatory variables were included in the maximal models. GLMs are adequate for count data as response variables with Poisson error distribution. If GLMs showed over-dispersion (mean > variance; assessed by calculating residual deviance/residual degrees of freedom) they were re-fitted as quasi-GLMs (Crawley 2007). Additionally, we analysed the fixed effects of sex, age, migration (as previously defined), and all possible two-way interactions among them on the number of use-types mentioned within use-categories (n = 9). To avoid pseudo-replication, we took into account crossed random effects of species and participants, using generalized linear mixed models (GLMM, R package "lme4", function "lmer"; Bates et al. 2011). GLMMs are suitable for count data as response variables with Poisson error distribution (Bolker et al. 2009). All maximal models were simplified in a stepwise-backward procedure based on likelihood ratio tests (chi-square, χ^2), or F-tests in case of quasi-GLMs; Crawley 2007). All non-significant terms ($p > 0.05$) were removed to obtain minimal adequate models for each response variable.

RESULTS

During the freelisting exercises, the participants mentioned a total of 33 woody plants (n = 207 plant-reports), 64% of which were naturally-growing native species, 15% cultivated native species (e.g. *Buddleja coriacea*, kishuara; not naturally growing in the study area but originating from Bolivia), and 21% cultivated exotic species. Trees (46%) were the most frequently-mentioned woody life-form. All of the 14 selected species considered promising for use in agroforestry (Table 3.1) were also mentioned by the participants during the freelisting exercises, except for *Berberis commutata* (churisik'e). Calculation of the selected species' CI values was based on a total of 1906 use-reports grouped into nine use-categories, the most cited of which were fodder (17.8% of use-reports), fuel (17.3%), and environmental uses (15.1%). Among the 14 selected species, *S. molle* (molle), *Prosopis laevigata* var. *andicola* (thaqo, algarrobo), *Eucalyptus globulus* (eucalipto, kalisto), and *B. dracunculifolia* (t'ola) were assessed as the culturally most important species exhibiting the highest Composite S and CI values (Figure 3.5). Between both indices, a highly significant and strong correlation ($R = 0.811$, $p < 0.001$) was found.

The evaluation of Composite S showed that *Lepechinia graveolens* (raqacho, raga raga) was more important for men than for women ($F_{(1,38)} = 5.424$, $p < 0.05$), and less important for participants under 20 than those aged 20 to 39 years ($F_{(3,36)} = 3.198$, $p < 0.05$). Further significant age-effects on the intracultural variation in Composite S were detected for *Polylepis* *subtusalbida* (kewiña, queñua) ($F_{(3,36)}$ = 3.238, $p < 0.05$) and *P. laevigata* var. *andicola* ($F_{(3,36)}$ = 4.717, $p < 0.01$). With regard to migration, significant intra-cultural variation was found for *E. globulus* ($F_{(3,36)}$ = 4.660, $p < 0.01$), *P. laevigata* var. *andicola* ($F_{(3,36)}$ = 3.723, $p < 0.05$), and *Sambucus peruviana* (sauco) ($F_{(3,36)}$ = 3.307, $p < 0.05$) (Table A3.2 Appendix).

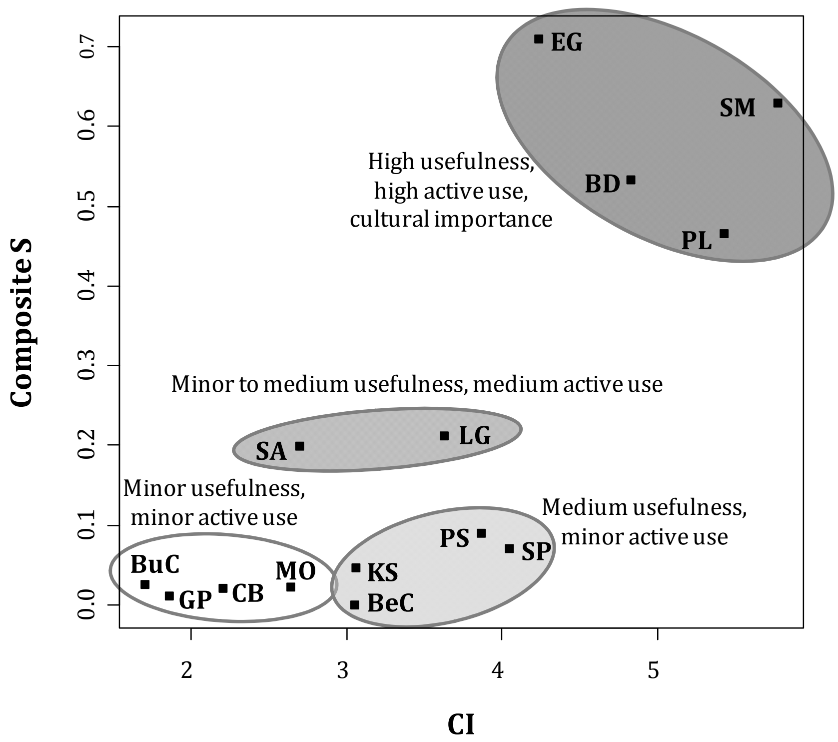

Figure 3.5 Cultural Importance and Composite Salience of woody species. Cultural Importance (CI) in relation to Composite Salience (Composite S) of 14 selected woody species: *Baccharis dracunculifolia* (BD), *Berberis commutata* (BeC), *Buddleja coriacea* (BuC), *Clinopodium bolivianum* (CB), *Eucalyptus globulus* (EG), *Gynoxys psilophylla* (GP), *Kaunia saltensis* (KS), *Lepechinia graveolens* (LG), *Minthostachys ovata* (MO), *Polylepis subtusalbida* (PS), *Prosopis laevigata* var. *andicola* (PL), *Sambucus peruviana* (SP), *Schinus molle* (SM), *Senna aymara* (SA)

Significant intracultural variation in CI was found for *P. laevigata* var. *andicola*, which could therefore suggest that it was culturally more important to women than men ($F_{(1,38)}$ = 6.209, $p < 0.05$). *B. commutata* ($F_{(3,36)}$ = 3.801, $p < 0.05$), *Gynoxys psilophylla* (k'apa towi, loma towi, k'apa k'apa) ($F_{(3,32)}$ = 5.001, $p < 0.01$) and *S. molle* ($F_{(3,36)}$ = 6.197, $p < 0.01$) were assumed to be culturally more important to elder than younger participants. Intracultural variation according to migration was found for *B. commutata* ($F_{(3,36)}$ = 6.065, $p < 0.01$), *G. psilophylla* ($F_{(3,32)}$ = 4.758, $p < 0.01$), *L. graveolens* ($F_{(3,36)}$ = 3.599, $p < 0.05$) and *S. molle* ($F_{(3,36)}$ = 6.587, $p < 0.01$), which were therefore suggested to be culturally more important to elder permanent residents than temporary migrants, and also to permanent migrants in the case of *G. psilophylla* (Table A3.3 Appendix).

A test of whether the significant intracultural variation in CI was based on specific use-categories showed that tool uses of *B. commutata* (< 20 lower than 40–59 years; $\chi^2_{(1)} = 7.273$, $p < 0.01$), fodder uses of *G. psilophylla* (20–39 lower than 40–59 years; $\chi^2_{(1)} = 8.128$, $p < 0.01$) and food uses of *S. molle* (< 20 lower than 40–59; $\chi^2_{(1)} = 4.267$, $p < 0.05$; < 20 lower than ≥60 years, $\chi^2_{(1)} = 10.208$, $p < 0.01$) were mentioned significantly more frequently by elder than by younger participants. Furthermore, elder permanent residents emphasised fodder ($\chi^2_{(1)} = 5.417$, $p < 0.05$) and tool uses ($\chi^2_{(1)} = 5.621$, $p < 0.05$) of *B. commutata* and environmental uses of *S. molle* ($\chi^2_{(1)} = 4.139$, $p < 0.05$) more than temporary migrants. In terms of total numbers of use-types known, we registered 2099 reports of 85 use-types across nine use-categories (n = 14 species). We found no significant effects of sex on the number of use-types known of the 14 selected plants. In contrast, knowledge of use-types increased significantly with age in case of *S. molle* ($\chi^2_{(1)} = 11.107$, $p < 0.001$), and was significantly lower for migrants than permanent residents for *B. commutata* ($F_{(1,38)} = 8.787$, $p < 0.01$), *G. psilophylla* ($\chi^2_{(1)} = 9.746$, $p < 0.01$), and *P. laevigata* var. *andicola* ($\chi^2_{(1)} = 4.596$, $p < 0.05$). Furthermore, female migrants knew significantly more use-types of *Senna aymara* (motocho, motochila) than male migrants ($\chi^2_{(1)} = 3.887$, $p < 0.05$) (Table 3.4).

Table 3.4 Effects of socio-economic variables on uses of woody species

Fixed effects	BD	BeC	BuC	CB	EG	GP	KS	LG	MO	PS	PL	SP	SM	SA
Intercept	1.614	1.322	0.588	0.876	1.594	0.847	1.119	1.335	1.055	1.405	2.001	1.476	1.527	1.122
age [a]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.009***	ns
sex(men)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.052
migr(yes)	ns	-0.716**	ns	ns	ns	-0.934**	ns	ns	ns	ns	-0.296*	ns	ns	0.200
age:sex(men)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
sex(men):migr (yes)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.913*
age:migr(yes)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
age:sex(men): migr (yes)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Parameter estimates for the effects of the socio-economic variables of age (continuous), sex, migration (migr), and all possible two-way-interactions on the number of use-types mentioned for 14 selected species (abbreviated names see caption of Figure 3.5). Results based on the minimal adequate generalized linear models (GLM) with count data as response variables. Significance of main effects determined by F-tests (for quasi-Poisson error distribution) and likelihood ratio tests (for Poisson error distribution). Terms: ns, not significant; levels of significance: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$

Regarding the effects of sex, age, and migration on the number of use-types mentioned within the different use-categories, knowledge increased significantly with age concerning medicine ($\chi^2_{(1)} = 9.347$, $p < 0.01$), tools ($\chi^2_{(1)} = 7.577$, $p < 0.01$), and other uses ($\chi^2_{(1)} = 5.881$, $p < 0.05$). In addition, it was significantly lower for migrants than permanent residents regarding construction ($\chi^2_{(1)} = 7.239$, $p < 0.01$), fodder ($\chi^2_{(1)} = 9.534$, $p < 0.01$) and other uses ($\chi^2_{(1)} = 7.335$, $p < 0.01$) (Table 3.5).

Table 3.5 Effects of socio-economic variables on uses within use-categories

Fixed effects	con	env	fie	fod	food	fuel	med	oth	tool
Intercept	-0.994	-0.714	-2.356	-0.355	-2.881	-0.765	-1.853	-2.651	-2.537
age [a]	ns	ns	ns	ns	ns	ns	0.013**	0.014*	0.011**
sex(men)	ns	ns	ns	ns	ns	ns	ns	ns	ns
migration(yes)	-0.391**	ns	ns	-0.377**	ns	ns	ns	-0.975**	ns
age:sex(men)	ns	ns	ns	ns	ns	ns	ns	ns	ns
sex(men):migr(yes)	ns	ns	ns	ns	ns	ns	ns	ns	ns
age:migr(yes)	ns	ns	ns	ns	ns	ns	ns	ns	ns
age:sex(men):migr(yes)	ns	ns	ns	ns	ns	ns	ns	ns	ns

Parameter estimates for the effects of the socio-economic variables of age (continuous), sex, migration (migr), and all possible two-way-interactions on the number of use-types mentioned for 14 selected species (see Table 3.1) within nine use-categories: construction (con), environmental use (env), field use (fie), fodder (fod), food, fuel, medicine (med), other use (oth), tool. Results based on the minimal adequate generalised linear mixed models (GLMM) with count data as response variables, and species and participants as crossed random effects. Significance of main effects determined by likelihood ratio tests. Terms: ns, not significant; levels of significance: *, $p < 0.05$; **, $p < 0.01$

DISCUSSION

Culturally important agroforestry species

Local people tended to give higher cultural importance to trees (e.g. *S. molle*) than shrubs (e.g. *L. graveolens*), as demonstrated by both ethnobotanical indices used (Composite S, CI) (Figure 3.5). This is supported by another study carried out in the same area (Brandt et al. 2012) that revealed that sociocultural plant values increased with plant height and timber availability. This may be explained by the scarcity of timber needed for fuelwood and construction in the region. However, some frequently-growing shrubs such as *B. dracunculifolia* were also intensively used as fuelwood, for livestock fences, and in restoration of soil fertility in fallow land (Figure 3.6), and were thus highly valued by local people.

This suggests that cultural importance and use-values of woody plants may not depend on their life-form only, but rather on their availability and accessibility (see also Phillips and Gentry 1993b; Thomas et al. 2008, 2009b; Brandt et al. 2012), especially in the case of frequently-used fuel plants (Thomas et al. 2011). Furthermore, plants' specific attributes (e.g. hard wood, tasty fruits) that exclusively meet important subsistence needs increase their cultural importance (Turner 1988). *S. molle*, *P. laevigata* var. *andicola*, *E. globulus*, and *B. dracunculifolia* were the culturally most important species in the study area (Figure 3.5) due to their high socio-economic and cultural values and high ecological apparency. However, in contrast to the native species mentioned, *E. globulus* was no promising agroforestry species (Brandt et al. 2012) due to its potential negative effects on cultivated crops (Mahboubi et al. 1997) and the environment (soil, water, biodiversity) (Gareca et al. 2007; Thomas et al. 2010). Apart from cultural importance, the plants' ecological values must therefore also be considered in the assessment of suitable woody species for agroforestry (Brandt et al. 2012).

Figure 3.6 Importance of *B. dracunculifolia* for the restoration of soil fertility in fallow land. Photograph by R. Brandt

Sex-specific valuation and knowledge of woody plants

Sex plays only a minor role in the intracultural variation of knowledge of the selected 14 woody plants in the study area, as no significant differences were found between women and men. The hypothesis about sex-specific differences in ethnobotanical knowledge and valuation in accordance with existing gender roles was not confirmed. This contradicts other studies (Begossi et al. 2002; Quinlan and Quinlan 2007; Camou-Guerrero et al. 2008) that showed sex-differentiated knowledge at the level of specific use-categories, which were explained by labour distribution between sexes, with men being experts in construction material and women knowing more about medicinal plants. However, the results are only partially comparable, because our research refers to selected woody species with potential for use in agroforestry while the studies mentioned also considered other life-forms (e.g. herbs) and plant uses (e.g. medicine). Furthermore, slightly significant sex-specific differences in cultural importance (Composite S) were shown in our study, but only for *L. graveolens*, which was more important for men than for women. This may be due to the shrub's importance as a "green fertiliser" for soil fertility restoration on agricultural plots during fallow periods. Observing these plots and ploughing fallow fields is a typical men's labour domain.

Additionally, men were more involved in soil conservation project activities (previously described), which may have increased their awareness of the environmental services provided by plants. In contrast, *P. laevigata* var. *andicola* was suggested to be culturally slightly more important for women than for men. This was surprising, because the species is commonly used for creating tools, which is typical men's labour (Serrano et al. 2006). However, it also provides other uses (e.g. food, fodder), which is possibly the reason for the result. Indeed, these are specific examples of intracultural variation in knowledge and valuation of plants that are mainly used as organic fertilisers and tools and thus, may not represent general patterns. However, seen as preliminary results and observations they may stimulate further exploration in future studies. The overall negligible effect of sex on the intracultural variation in plant knowledge and valuation of the selected woody species found in our study is consistent with Lozada et al. (2006) who explained this finding by their observation that both sexes may experience the selected plants similarly, despite their different social roles. Another explanation is that the highly developed horizontal knowledge transmission among neighbours and peers from the same generation reported in our study area (Mathez-Stiefel and Vandebroek 2012) might have resulted in men and women sharing knowledge of medicinal and other active plant uses. This is especially true in view of increasing temporary migratory activities and specific familial circumstances (e.g. diseases or death of family members), which tended to lead to less fixed and more complex and dynamic gender roles in the region (Serrano et al. 2006).

Generational differences in the valuation and knowledge of woody plants

Significant differences according to age were detected in the cultural importance of several woody species with potential agroforestry use. This confirms our hypothesis of a decrease in plant knowledge and valuation among the youth, regarding, for instance, *P. subtusalbida* and *B. commutata*. Both tree species are characteristic of the potential vegetation of endangered high-Andean *Polylepis* forests (Navarro et al. 2005), which are widely suppressed through human land and resource use (Ellenberg 1979; Kessler 2002). The *Polylepis* forests growing in the area, for instance, have been drastically reduced since the Agrarian Reform of 1957 through the extension of agricultural plots, grazing, and timber use (Mariscal and Rist 1999). The fact that the cultural importance of *P. subtusalbida* and *B. commutata* was lower for younger than for elder peasants may illustrate that decreasing abundance results in decreasing use (according to the "ecological apparency hypothesis", see Phillips and Gentry 1993b), and in decreasing valuation (Lawrence et al. 2005). Strikingly, the two ethnobotanical indices applied indicated a different relative cultural importance for both species. Composite S values, based on freelisting, were relatively low and indicated minor active use. In contrast, relatively high CI values resulted from the semi-structured interviews and increased with age, possibly indicating an important passive knowledge. Thus, low active use of these two species may not be equal to low usefulness, suggesting that the use knowledge of these plants was mainly passive and more likely a relic from the past. This may be attributed to decreasing availability and substitution by other species (e.g. *E. globulus*) for fuel and construction use, as also observed in other ethnobotanical studies (e.g. Lawrence et al. 2005). Besides, obsolete use-types (e.g. dye, coal), as reported by Brandt et al. (2012), can explain the decreasing cultural importance among the younger generation. We may consequently postulate that the ethnobotanical knowledge of the rare and seldom-used species *P. subtusalbida* and *B. commutata* is vulnerable to being lost. Even if knowledge is passive and no longer practiced, it may reflect the traditional sociocultural role of agroforestry species. In the interviews, the answers regarding *P. subtusalbida* and *B. commutata* showed abundant evidence for the paramount importance of such forests as a part of local people's collective memory and identity. The drastic reduction of native species, in turn, was interpreted by Boillat et al. (2013) as an effect of the increasingly disrespectful attitude towards the "natural expressions of Mother Earth". Furthermore, these results illustrate that different methods combined for data collection (freelisting, semi-structured interviews) and analysis (Composite S, CI) may allow for more precise estimates on whether people have a passive or active ethnobotanical knowledge (Figure 3.5), which in turn provides a broader understanding of cultural plant importance (Reyes-García et al. 2007). While a certain overlap between active (Composite S) and passive knowledge (CI) is inevitable, it is interesting to note a marked difference in the ranking positions of species in both indices, such as in the cases of *P. subtusalbida* and *B. commutata*. However, further studies on the use of such method combinations for the evaluation of passive and active plant use knowledge should be conducted in order to refine them and confirm their relevance. This could be done, for instance, also by combining interviews on plant use knowledge with observations and freelistings on actual plant use.

Native *S. molle* was not only less culturally important for the youth, but it was also the only species that was significantly less known by young participants compared to elders. Unlike the cases of *P. subtusalbida* and *B. commutata*, this cannot be explained by the species' decreasing ecological apparency. In fact, an upslope migration of *S. molle* (up to 3500 m.a.s.l.) has been locally observed, resulting from practices of natural regeneration management (Brandt et al. 2012), and possibly also supported by increasing temperatures due to climate change (Feeley et al. 2011). The lower knowledge of young peasants may rather reflect a decreasing application of traditional plant uses of *S. molle* (e.g. "chicha de molle" - alcoholic beverage, medicinal uses) than by elders. This is in line with the significant generational difference in medicinal knowledge shown by our study. A positive correlation of medicinal knowledge with age has frequently been observed (Begossi et al. 2002; Voeks and Leony 2004; Estomba et al. 2006; Quinlan and Quinlan 2007; Santos Silva et al. 2011). This difference may simply reflect the fact that learning about medicinal plant uses is a life-long process, and is important during adulthood (Phillips and Gentry 1993b; Mathez-Stiefel and Vandebroek 2012). Another explanation is that elder people are more likely to be ill and in closer contact with medicine (Voeks and Leony 2004). However, declining knowledge among the youth has also been interpreted as an indicator of medicinal knowledge loss (Estomba et al. 2006). As many young people migrate, they take less part in collaborative familial activities of medicinal plant use and experimentation and thus, may have fewer or no opportunities to acquire new knowledge or reactivate passive knowledge through instructions or by means of observation and imitation (Lozada et al. 2006). However, a previous study in the same area showed that there was no loss of knowledge of local natural remedies (including plants, animals, minerals) from one generation to the next, but rather a transformation of knowledge on specific medicinal uses (e.g. respiratory diseases), which could simply reflect differences in health needs among different generations (Mathez-Stiefel et al. 2012). In the present study, the decreasing medicinal knowledge of woody species observed among the young generation possibly indicates an overall transformation of woody plant use. Our results indeed show that timber uses are increasing in importance compared to the uses of other plant parts, especially for the application as fuelwood or livestock fences, which might be associated with the scarcity of timber in the region (Brandt et al. 2012).

Effects of age and migration on the valuation and knowledge of woody plants

A combined effect of age and migration on the cultural importance of woody plants was shown for several species (e.g. *B.*

commutata, *G. psilophylla*, *S. molle*); these species were of highest importance for elder permanent residents and less important for young migrants. However, we found no significant differences in cultural importance between young migrants and non-migrants, meaning that the observed differences were due to age rather than migration. Thus, this result did not confirm our hypothesis that migration led to a decrease in plant knowledge and valuation. A combined effect of age and migration was also found for the cultural importance of *P. laevigata* var. *andicola*; it was significantly less known by migrants and had lower Composite S for younger compared to elder people. As this species is mostly used for making agricultural tools, this in turn corresponded with increasing knowledge of tool uses with age. On the one hand, decreasing availability and declining quality (length, thickness, and hardness of branches) of plants for crafting tools were often reported by the participants. According to the ecological apparency hypothesis, this possibly led to less knowledge of tool uses among the youth. On the other hand, our results are in line with young peasants' decreasing commitment to traditional farming that is increasingly supplemented by off-farm activities for insuring and diversifying their income in the face of production risks (Gray 2009).

The exotic *E. globulus* was especially important for young permanent residents and temporary migrants. This is in accordance with the general trend of *Eucalyptus* plantations as key components of rural livelihood strategies in the Central Andes (Luzar 2007), because the species is not only used in subsistence farming, but can be commercialised due to its dominance in Andean timber markets (Chepstow-Lusty and Winfield 2000). Marketability was also shown in other ethnobotanical studies to be a crucial factor in successfully integrating trees into agroforestry systems (e.g. Langenberger et al. 2009). In our study area, *Eucalyptus* plantations can therefore be considered a local strategy to raise and diversify income and mitigate agro-pastoral production risks, even though this exotic species implies, for instance, potential allelopathic effects on cultivated crops (Mahboubi et al. 1997) and natural vegetation (Gareca et al. 2007; Thomas et al. 2010). *Eucalyptus* is therefore not recommended for use in agroforestry systems (Brandt et al. 2012). Permanent migrants in contrast may give less importance to this species as they have other income sources (e.g. off-farm labour, crops such as coca cultivated in the lowlands).

The knowledge of other use-categories (e.g. domestic plant uses) was significantly affected by migratory activities, which confirmed our hypothesis of a decrease in plant knowledge and valuation according to this factor. For example, migrants mostly substituted wooden kitchenware by easily purchasable material (e.g. plastic pots), and were less aware of using native trees (e.g. *P. subtusalbida*) in construction, opting instead to use the timber of exotic trees (*E. globulus*, *Pinus* spp.). As illustrated by these results, migration requires progressive adaptation to changing socio-economic, cultural, and environmental surroundings (Nesheim et al. 2006). This involves the assimilation and use of new plants and practices as well as adaptation or abandonment of traditional plants and uses (Volpato et al. 2009; Medeiros et al. 2012).

CONCLUSIONS

We believe that our investigation of the intracultural variation in the valuation and knowledge of plants contributes to a better understanding of the societal dynamics that underlie the attitudes and practices of indigenous Andean peasants towards woody plants. This in turn may help external actors support community-based agroforestry initiatives that are adapted to the dynamic socioecological context of the land users. The fact that the results do not reveal strong general patterns – but, rather, species-specific effects of sex, age, and migration – may reflect the level of precision of traditional knowledge and valuation at our study site: people seem to focus on specific species rather than on the woody vegetation in general. In this regard, the combination of two indices (Composite S and CI) may be of particular value in differentiating between active and passive ethnobotanical knowledge of woody plants and the type of transformation that these knowledge categories are undergoing.

In our study area, the valuation and knowledge of woody species and their uses showed a significant decline in younger and migrating peasants, but sex played a negligible role overall. Thus, when establishing community-based agroforestry systems, we recommend paying particular attention to the selection of species that meet the needs and interests of the young (temporarily) migrating peasant generation. In this regard, as the example of *Eucalyptus* illustrated, the importance of marketable species should be recognised, even though this specific exotic species is not recommended for use in agroforestry for ecological reasons. We thus suggest selecting ecologically sound species, which provide subsistence and potential commercial uses. Positive examples are, for instance, the native trees *S. molle* with its aromatic, antimicrobial, and insecticidal properties (Deveci et al. 2010; Zahed et al. 2011), and *P. laevigata* var. *andicola*, which provides highly nutritive pod flour (Barba de la Rosa et al. 2006). Furthermore, as the case of native *Polylepis* forest species (*P. subtusalbida*, *B. commutata*) showed, plants which are no longer actively used may still be of high sociocultural importance for collective identity. By privileging native trees and shrubs with important cultural value, we believe that agroforestry initiatives – in addition to offering socio-economic and environmental services – can play important roles in recovering elements of the lost ancient landscape that still forms part of local people's collective identity.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

RB designed the study, collected and analysed the data, and drafted the manuscript. SLMS, SR and IH helped with the study design and data interpretation. SL participated in the data analysis. All authors contributed to the revisions of the manuscript, and approved its final version. The photographs were taken by RB and SLMS.

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APPENDIX

Table A3.2 Composite Salience of woody species

Species	Composite Salience													
	Total			Sex		Age				Migration				
	# part	# cit	compS	female	male	< 20 [a]	20-39 [b]	40-59 [c]	≥ 60 [d]	no_young [a]	no_old [b]	temp [c]	perm [d]
BD	40	33	0.53	0.47 ± 0.31	0.60 ± 0.38	0.47 ± 0.41	0.49 ± 0.27	0.46 ± 0.40	0.72 ± 0.29	0.42 ± 0.30	0.59 ± 0.36	0.41 ± 0.34	0.63 ± 0.38
BeC	40	0	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BuC	40	4	0.03	0.00 ± 0.00	0.05 ± 0.13	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.17	0.03 ± 0.08	0.00 ± 0.00	0.05 ± 0.13	0.00 ± 0.00	0.00 ± 0.00
CB	40	1	0.02	0.04 ± 0.18	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.25	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.33
EG	40	38	0.71	0.79 ± 0.33	0.63 ± 0.34	0.81 ± 0.29	0.75 ± 0.38	0.69 ± 0.27	0.60 ± 0.40	0.94 ± 0.12*[d]	0.64 ± 0.34	0.90 ± 0.24*[d]	0.45 ± 0.38*[a,c]
GP	40	1	0.01	0.00 ± 0.00	0.02 ± 0.10	0.00 ± 0.00	0.00 ± 0.00	0.05 ± 0.14	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.10	0.00 ± 0.00	0.00 ± 0.00
KS	40	6	0.05	0.01 ± 0.04	0.08 ± 0.19	0.00 ± 0.00	0.01 ± 0.03	0.07 ± 0.17	0.11 ± 0.21	0.01 ± 0.03	0.09 ± 0.19	0.00 ± 0.00	0.00 ± 0.00
LG	40	18	0.21	0.10 ± 0.16*	0.33 ± 0.36*	0.01 ± 0.05*	0.33 ± 0.33*	0.18 ± 0.29	0.32 ± 0.36	0.09 ± 0.15	0.25 ± 0.32	0.15 ± 0.25	0.30 ± 0.42
MO	40	2	0.02	0.05 ± 0.15	0.00 ± 0.00	0.03 ± 0.11	0.06 ± 0.19	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.12	0.00 ± 0.00	0.00 ± 0.00	0.10 ± 0.24
PS	40	6	0.09	0.07 ± 0.21	0.11 ± 0.26	0.00 ± 0.00*[d]	0.00 ± 0.00*[d]	0.10 ± 0.23	0.25 ± 0.37*[a,b]	0.00 ± 0.00	0.18 ± 0.31	0.00 ± 0.00	0.00 ± 0.00
PL	40	28	0.47	0.38 ± 0.39	0.55 ± 0.34	0.19 ± 0.26*[c,d]	0.38 ± 0.32	0.73 ± 0.29*[a]	0.56 ± 0.40*[a]	0.26 ± 0.31*	0.65 ± 0.35*	0.32 ± 0.37	0.29 ± 0.26
SP	40	6	0.07	0.07 ± 0.19	0.08 ± 0.24	0.16 ± 0.35	0.08 ± 0.20	0.00 ± 0.00	0.05 ± 0.13	0.28 ± 0.40*	0.03 ± 0.09*	0.00 ± 0.00	0.02 ± 0.05
SM	40	33	0.63	0.64 ± 0.37	0.62 ± 0.37	0.55 ± 0.35	0.56 ± 0.38	0.78 ± 0.37	0.63 ± 0.37	0.69 ± 0.23	0.71 ± 0.37	0.63 ± 0.39	0.30 ± 0.37
SA	40	19	0.20	0.20 ± 0.25	0.20 ± 0.30	0.10 ± 0.23	0.12 ± 0.18	0.19 ± 0.26	0.38 ± 0.33	0.07 ± 0.13	0.29 ± 0.31	0.08 ± 0.09	0.20 ± 0.32

Composite Salience (compS; arcsine square-root transformed) of 14 selected local woody species (abbreviated names see caption of Figure 3.5) in dependence on the participants' socio-economic background (sex, age, migration). Sex: female (n = 20), male (n = 20). Age: < 20 years (n = 10), 20–39 years (n = 10), 40–59 years (n = 10), ≥ 60 years (n = 10). Migration: no_young (no migration < 40 years, n = 8), no_old (no migration ≥ 40 years, n = 20), temp (temporary migration, n = 6), perm (permanent migration, n = 6). Number of participants (# part). Number of citations (# cit). Data shown: mean values ± standard deviation. Significant differences between groups (a-d) determined by Tukey post-hoc tests. Level of significance: *, $p < 0.05$

Table A3.3 Cultural Importance of woody species

Species	Cultural Importance													
	Total				Sex		Age				Migration			
	# part	# cit	# cat	CI	female	male	< 20^{a}	20-39^{b}	40-59^{c}	≥ 60^{d}	no_young^{a}	no_old^{b}	temp^{c}	perm^{d}
BD	40	193	8	4.83	5.05 ± 1.15	4.60 ± 1.39	4.70 ± 1.57	4.70 ± 1.16	4.80 ± 1.23	5.10 ± 1.29	5.00 ± 1.31	4.95 ± 1.23	3.83 ± 1.60	5.17 ± 0.75
BeC	40	122	9	3.05	3.05 ± 1.70	3.05 ± 2.06	2.00 ± 1.63*	2.40 ± 1.35	4.30 ± 1.25*	3.50 ± 2.32	2.75 ± 1.16	3.90 ± 1.86***	1.00 ± 0.89***	2.67 ± 1.75
BuC	40	68	6	1.70	1.35 ± 1.69	2.05 ± 1.76	1.20 ± 1.40	1.30 ± 1.42	2.20 ± 2.15	2.10 ± 1.91	1.75 ± 1.75	2.15 ± 1.98	1.00 ± 1.10	0.83 ± 0.98
CB	40	88	5	2.20	2.25 ± 1.16	2.15 ± 0.99	1.80 ± 0.63	2.30 ± 0.95	2.30 ± 1.42	2.40 ± 1.17	2.00 ± 0.76	2.35 ± 1.27	1.83 ± 0.41	2.33 ± 1.21
EG	38	161	9	4.24	4.30 ± 1.03	4.17 ± 1.34	4.50 ± 1.58	4.40 ± 0.70	4.33 ± 1.00	3.67 ± 1.22	4.88 ± 0.64	4.00 ± 1.14	4.33 ± 1.03	4.00 ± 1.79
GP	36	67	6	1.86	1.81 ± 1.52	1.90 ± 1.21	1.33 ± 1.41*^{c}	1.20 ± 1.03*^{c}	3.25 ± 0.71*^{a,b}	1.89 ± 1.17	1.86 ± 1.35	2.53 ± 1.18*^{c,d}	0.83 ± 0.98*^{b}	1.00 ± 1.10*^{b}
KS	32	98	7	3.06	2.82 ± 1.33	3.33 ± 1.40	2.56 ± 1.24	2.86 ± 1.46	3.86 ± 1.07	3.11 ± 1.54	2.83 ± 1.33	3.44 ± 1.36	2.60 ± 1.34	2.60 ± 1.52
LG	40	145	8	3.63	3.85 ± 1.18	3.40 ± 1.23	3.10 ± 1.20	3.70 ± 1.06	3.80 ± 0.92	3.90 ± 1.60	3.63 ± 1.06	3.85 ± 1.27*	2.33 ± 0.82*	4.17 ± 0.75
MO	39	103	5	2.64	2.58 ± 0.96	2.70 ± 1.03	2.80 ± 0.79	2.00 ± 0.94	3.00 ± 1.05	2.78 ± 0.97	2.38 ± 0.74	2.89 ± 0.99	2.50 ± 1.05	2.33 ± 1.21
PS	39	151	9	3.87	3.45 ± 1.57	4.32 ± 1.42	2.90 ± 1.66	3.70 ± 1.64	4.60 ± 0.97	4.33 ± 1.41	3.63 ± 1.92	4.47 ± 1.17	3.17 ± 1.47	3.00 ± 1.67
PL	40	217	9	5.43	5.90 ± 1.29*	4.95 ± 1.15*	4.80 ± 1.03	5.60 ± 1.35	5.80 ± 1.40	5.50 ± 1.35	6.00 ± 1.51	5.65 ± 1.35	4.33 ± 0.82	5.00 ± 0.00
SP	40	162	9	4.05	3.90 ± 1.48	4.20 ± 1.44	3.40 ± 1.51	3.80 ± 1.48	4.20 ± 1.14	4.80 ± 1.48	3.88 ± 1.81	4.50 ± 1.32	2.67 ± 0.52	4.17 ± 1.33
SM	40	231	9	5.78	5.80 ± 1.70	5.75 ± 1.37	4.50 ± 1.58*^{c},**^{d}	5.40 ± 1.17	6.40 ± 1.07*^{a}	6.80 ± 1.23**^{a}	5.25 ± 1.16	6.60 ± 1.14**	4.00 ± 1.90**	5.50 ± 0.84
SA	37	100	9	2.70	3.06 ± 1.66	2.37 ± 1.64	2.57 ± 1.72	1.70 ± 0.48	3.20 ± 1.69	3.33 ± 2.06	2.00 ± 1.10	3.25 ± 1.83	2.00 ± 1.22	2.17 ± 1.47

Cultural Importance (CI; arcsine square-root transformed) of 14 selected local woody species (abbreviated names see caption of Figure 3.5) in dependence on the participants' socio-economic background (sex, age, migration). Sex: female (n = 20), male (n = 20). Age: < 20 years (n = 10), 20–39 years (n = 10), 40–59 years (n = 10), ≥ 60 years (n = 10). Migration: no_young (no migration < 40 years, n = 8), no_old (no migration ≥ 40 years, n = 20), temp (temporary migration, n = 6), perm (permanent migration, n = 6). Number of participants (# part). Number of citations (# cit). Number of use-categories (# cat). Data shown: mean values ± standard deviation. Significant differences between groups (a-d) determined by Tukey post-hoc tests. Levels of significance: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$

SPECIES-SPECIFIC RESPONSES TO ENVIRONMENTAL STRESS ON GERMINATION AND JUVENILE GROWTH OF TWO BOLIVIAN ANDEAN AGROFORESTRY SPECIES

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ABSTRACT

Integrating native trees in farmland can support soil, water and biodiversity conservation. This is particularly important in regions characterized by long periods of drought and soil erosion, such as the Bolivian Andes, where agroforestry with native woody species is rarely applied. Better knowledge on the effects of environmental stress on propagation and establishment of such native plants is needed to optimize their cultivation. In our study, we tested the effects of temperature and scarification on seed germination, and assessed seedling survival and juvenile growth of two potential agroforestry species (*Prosopis laevigata* var. *andicola*, *Schinus molle*) under diverse soil and water conditions. Temperatures above 30°C accelerated germination, but they increased fungi infestation in the case of *S. molle*. The application of acid and mechanical scarification significantly improved the germination capacity of *P. laevigata* var. *andicola*. Medium to high moisture levels in sand provided the most favorable conditions for plant growth. *S. molle* was more sensitive to dry and *P. laevigata* var. *andicola* more vulnerable to water-saturated clay loam. Mulching enhanced the survival and growth of *S. molle* juveniles, but increased *P. laevigata* var. *andicola*'s growth in sand and dry soils only. Our results may facilitate guidance on improving propagation of these two potential agroforestry species under environmental stress conditions. More generally, our study shows that easily applicable treatments, such as mulching, can significantly improve the cultivation of native species, provided that their habitat requirements and limiting factors are well known. This highlights the relevance of identifying and closing such knowledge gaps for native trees and shrubs in order to promote their potential for use in agroforestry.

KEYWORDS

Native woody species; *Prosopis laevigata* var. *andicola*; *Schinus molle*; Seedling survival; Soil texture; Water stress

SYNTHESIS

GENERAL DISCUSSION

The aim of this doctoral thesis has been to contribute interdisciplinary scientific knowledge to biocultural approaches which target to increase the socio-ecological resilience of agro-ecosystems and farming livelihoods vulnerable to desertification risks in mountain drylands. For this aim, the case of a rural peasant community in the semi-arid highlands of the Bolivian Andes has been analyzed in order to address important knowledge gaps concerning the selection and cultivation of native woody species with potential for use in agroforestry. The local users' valuation of native woody plant species was assessed using ethnobotanical methods from social science. Subsequently, the identified promising target species' ecological interactions and growth requirements were investigated in ecological studies. More specifically, the studies that compose this thesis have explored the socio-ecological values of woody species with potential for use in agroforestry (Chapter 2), the intracultural variation of plant-related knowledge and valuation among the inhabitants of the research area (Chapter 3), and the responses to environmental stress on seed germination and plant growth of two promising native agroforestry plants (Chapter 4).

CHAPTER 2 presented the factors underlying social plant valuation and the integrated socio-ecological values of local woody species with potential for use in agroforestry. The research revealed that the values given to plants by local inhabitants significantly increased with plant height and thus, with the provision of timber. In comparison, phytosociological factors like frequency and dominance played a less important but still significant role in plant valuation. The findings indicated that the quality, quantity, and exclusivity of a plant's uses are crucial in its valuation (cf. Turner 1988; Garibaldi and Turner 2004). In comparison, the ''ecological apparency hypothesis'' (e.g. Phillips and Gentry 1993b), which connects higher valuation to plants' visibility and availability, was shown to be less significant. Most of the locally abundant shrubs were only valued when they offered multiple high-quality uses (e.g. *Baccharis dracunculifolia*).

In contrast, trees, such as the exotic tree *Eucalyptus globulus,* scored highly in people's valuation due to its fast growth and provision of timber for subsistence and commercial uses. In local plant valuation, these positively perceived exclusive traits exceeded the negatively perceived traits, such as the exotic trees' high soil water consumption, which can determine the decreased productivity of adjacent agricultural crops. In the context of limited water availability due to the seasonally arid climate and increasingly shifting rainfall patterns, as reported by local peasants and also observed in other regions of the Central Andes (Mark et al. 2010), this can be considered particularly critical. It is commonly argued that *E. globulus* may unbalance the hydrological and nutrient cycles of soils (e.g. Kidanu et al. 2005). Furthermore, the species can affect agricultural productivity by inhibiting crop germination and growth through allelopathic effects (Mahboubi et al. 1997). The local preference for *E. globulus* is also most likely at odds with the goals of biodiversity conservation, as it is, along with its high competitive strength and allelopathic effects on understory vegetation, a potential invader (Richardson et al. 2004). However, whether a coexistence with understory plants and crops in agroforestry systems is possible or not, is dependent on various factors, of which *E. globulus'* height and density are crucial (Gareca et al. 2007). The potential impacts on soil moisture and fertility must also be taken as serious risks that can provoke accelerated desertification. The cultivation of *Eucalyptus* could therefore undermine the goal of increasing ecological resilience, with possible negative implications for both agriculture and forestry in the long term (Kidanu et al. 2005), which may also reinforce the social vulnerability of the farming systems in the long term.

The example of *E. globulus* demonstrates the potential incompatibility of social and ecological plant values, especially in case of useful but ecologically risky species (Nuñez and Simberloff 2005). Thus, the present research underlines the importance of assessing both social and ecological plant values in the selection of species used for agroforestry or any other conservation and restoration measure that aims to increase socio-ecological resilience. By applying these biocultural principles in the research area, using the interdisciplinary analytical framework developed in this study, the ecologically and culturally valuable species *Schinus molle* and *Prosopis laevigata* var. *andicola* (≤ 3,200 m.a.s.l.), *Polylepis subtusalbida* (≥ 3,200 m.a.s.l.), and *Baccharis dracunculifolia* were shown to provide multiple exclusive plant uses and important environmental services (e.g. *Polylepis* spp., air moisture absorption, organic matter production for increasing soil fertility; Fjeldså and Kessler 1996). They were thus evaluated as being the most promising woody species for local agroforestry use.

Investigating deeper the valuation of agroforestry species, **CHAPTER 3** addressed the intracultural variation of plant valuation and the knowledge about their uses. The results indicated that respondents' age and migratory activities significantly influenced their knowledge of plant uses, while the respondents' sex played a minor role. The documented social distribution of plant-related knowledge showed that in general, elders knew more about plant uses than the youth. These generational knowledge differences increased with migratory activities. On the one hand, the findings can be explained based on the fact that learning is a life-long process, and knowledge is accumulated with time (Voeks and Leony 2004). On the other hand, they may indicate an erosion of plant-related knowledge and valuation, which was also reported from other regions in Latin America (e.g. Ladio and Lozada 2004; Bussmann and Sharon 2006; Estomba et al. 2006). This has been related to local adaptation to global changes in societies, markets, and environments (Voeks and Leony 2004). Globalized production and consumption patterns have been linked, for instance, to decreased dependence on direct natural resource use and the accelerated loss of traditional production practices (Nesheim et al. 2006).

In the study area, the loss of traditional plant-related practices was, for instance, reflected by the replacement of wood by other materials (e.g. plastic) in domestic uses. The younger people's decreasing dedication to traditional farming, which also implied declining use of traditional wooden field tools, is a further example of increasingly lost traditional plant uses. It is often argued that high rates of rural out-migration, also encountered in the study area, accelerate the transformations of traditional social structures and cultures (Grau and Aide 2007). Hence, migration is assumed to increase also the loss in plant-related knowledge and valuation. This was, to a certain extent, confirmed by the results of the present research. In view of these findings and in relation to the overall goal of this doctoral thesis, the important question arises of what happens in the long run to the biocultural diversity and socio-ecological resilience of agro-ecosystems and livelihoods, when a growing number of young people migrate from rural areas?

At present, it is commonly assumed that migration leads to a decrease in agricultural production and consequently to lower disturbances of agro-ecosystems. This may benefit their natural recovery (Grau and Aide 2007) and, depending on the environmental factors and ecological interactions in agro-ecosystems, to their biological diversification. In the Bolivian Andes, migration is, however, a rural livelihood strategy that allows for multi-residency, which means that migrants often maintain their agricultural production in the areas of origin (Zoomers 2012). Clearly, as a result of migration, the direct contact with and the socioeconomic dependency on the natural resources of the area of origin, including native woody plants decrease. But more than having exclusively the positive effects of lowering disturbances related to land use, migration can likely undermine people's intellectual, emotional and spiritual connections with these resources (Voeks and Leony 2004). This in turn may affect biocultural diversity by way of decreasing the inhabitants' diversity-enhancing cultural capabilities and their motivation for taking active roles in agroforestry or, for that matter, in any other plant-related conservation or restoration effort (Garibaldi and Turner 2004).

The findings also presented that especially highly useful but decreasingly abundant native species, such as *P. subtusalbida* and *B. commutata,* are decreasingly valued by the youth and migrating people. Apart from the previously mentioned socio-cultural factors, this can also be related to the species' decreasing "ecological apparency" (Phillips and Gentry 1993b), reported by the inhabitants of the study area. Natural woodland degradations are an environmental change of global extent, as they threaten plant diversity in Bolivia (e.g. Fjeldså and Kessler 1996; Ibisch and Mérida 2004; Navarro et al. 2005) and worldwide in alarming rates (e.g. Chapin et al. 2000). As shown by the present research and in agreement with the "ecological apparancy hypothesis", plant diversity loss is assumed to affect plant-related knowledge and valuation.

The increasing loss of native woody species is also closely intertwined with their increasing replacement by exotic marketable trees, which was observed in the study area and all over the Central Andes (Luzar 2007). In the study area, exotic species, such as *Eucalyptus*, were shown to be crucial to meeting human needs for timber and fuel, as these could not be met by native species alone. Moreover, exotic species were shown to do this more efficiently than native trees did. This interplay of native and exotic woody plants has controversial effects on natural woodlands. On the one hand, this replacement could contribute to decreasing exploitation of native plants and thus, to successional woodland regeneration (Kidanu et al. 2005). In fact, this was also reported by the inhabitants of the study area for some *P. subtusalbida* woodland patches, which had naturally regenerated due to fewer disturbances since the extension of *E. globulus* plantations. On the other hand, exotic tree plantations compete with natural woodlands for space and natural resources. Additionally, the knowledge and valuation of native woody species is likely to decrease with their increasing replacement by exotic species, which in turn may also affect future diversity-enhancing capacities and initiatives. Furthermore, it is likely that exotic trees' dominance in timber markets slows down or even impedes the scientific research for improving the cultivation of native trees, which are often poorly understood (Weise and Schrader 2001).

In order to fill existing ecological knowledge gaps concerning promising native agroforestry species of the Bolivian Andes, the study presented in **CHAPTER 4** addressed species-specific responses to selected dryland environmental stressors by analysing seed germination and juvenile growth. The two species under scrutiny, *Schinus molle* and *Prosopis laevigata* var. *andicola*, were selected because, as shown in Chapter 2, they were assessed to be most useful and environmentally friendly. The most striking results were the sensitivity of *S. molle* seeds to fungi infestation and the improved germination capacity of *P. laevigata* var. *andicola* by acid and mechanical seed scarification. Furthermore, medium to high moisture levels in sand were shown to be most favorable for plant growth, while water-saturation in clay loam produced stress to *P. laevigata* var. *andicola*. In contrast, *S. molle* juveniles showed high sensitivity to dry clay loam. Mulching therefore enhanced the survival and growth of *S. molle* juveniles, while for *P. laevigata* var. *andicola*, it was efficient in sand and dry clay loam only. These results should facilitate guidance on improving propagation of these two promising agroforestry species under conditions of environmental stress. More generally, the study demonstrated the efficiency of easily applicable treatments, such as mulching, to improve the growth of native species, provided that their habitat requirements, limiting factors, and ecological interactions are well known.

IMPLICATIONS FOR POLICY AND PRACTICE

Preserving biocultural diversity, which means to conserve both biodiversity and the interlinked diversity-enhancing cultural elements, such as plant-related traditional knowledge, is likely to become even more important for strengthening the resilience of dryland ecosystems under the impact of global climate change. As also reported from the study area, climate change is expected to enhance water stress and extreme weather events and thus, the risk of desertification (Berrahmouni et al. 2011). In the Andes, temperature warming is predicted to rise with elevation (Bradley et al. 2004), which may, in addition to the mentioned effects, lead to increased glacier melting and serious impacts on water supply (Bradley et al. 2006). These scenarios underline the urgent need of setting priorities in policy and development plans to support Andean ecosystems and livelihoods in coping with increasing environmental stress. This can only be achieved through cross-sectoral policies that would integrate and bring together the stakeholders of different domains such as agriculture, forestry, biodiversity conservation, and water and land use, in decision-making processes at the local, regional and national level.

Human beings are drivers of both destruction and conservation in relation to biodiversity (Saunders et al. 2006). Social factors therefore determine the success or failure of any conservation or restoration activity, which "is about people as much as it is about species or ecosystems" (Mascia et al. 2003). Regarding this, the present doctoral thesis has demonstrated that understanding human-plant-interactions and their current trends is crucial in order to guide external practitioners in supporting local initiatives in accordance with the participants' changing needs and interests which are, to a large extent, driven by dynamic socio-ecological factors (e.g. rural out-migration, plant diversity loss, globalized markets). Cultural keystone species, as presented in this thesis, represent a fruitful angle of reflection on these aspects (Garibaldi and Turner 2004).

Identifying cultural keystone species is, however, challenging given the complexity and dynamics of human-plant-relationships (Garibaldi and Turner 2004). Similarly, determining ecological keystone species is difficult due to the complex and constantly changing ecological interactions. At this, using the interdisciplinary analytical framework developed in this research can support the selection processes of socio-ecologically important species for agroforestry or any other restoration measure. Focusing on such keystone species alone, however, involves the risk of overlooking other important species for conservation and restoration (Mills et al. 1995). Thus, in agroforestry, for instance, attention should also be paid to the management of a broad range of adapted species and plant communities that grow in agro-ecosystems (Backes 2001). In view of peasants' limited abilities for tree cultivation and increasing abandonment of agricultural land due to rural out-migration, simply allowing natural successional processes on fallow land could be a cost-effective alternative to cultivation (Bullock et al. 2011). Natural regeneration processes are, however, often slow due to unfavorable abiotic or biotic interactions (e.g. limited seed dispersal, herbivory) (Rey Benayas et al. 2008). Natural succession can be, nonetheless, stimulated and controlled by enhancing the reproductive potentials of the plants through management, such as weeding and mulching, or by dispersing seeds and seedlings (Wiersum 2004), or through the establishment of small-scale "woodland islets", which may drive the passive restoration of the surrounding areas (Rey Benayas et al. 2008). In these practices, ecological and cultural keystone species can serve as effective starting points (Garibaldi and Turner 2004). At this, using the interdisciplinary analytical framework developed in this study might be thus most supportive to select valuable species. The stimulation of reproductive potentials (e.g. dispersal of seedlings, watering) was shown to be practised in the study area in the case of *Schinus molle*, a plant appreciated for storing fodder in its crown and for providing shade. This illustrated once more the dependence of local conservation and restoration efforts on the values and significance given to the plants to be propagated, and on the cost-benefit calculations of the different actors involved in their management. Incorporating already existing local knowledge and practices into community-based conservation and restoration is therefore extremely important.

Regardless of whether the woody species used in agroforestry are cultivated or naturally grown, their beneficial synergies with crops and livestock must be strengthened through species- and location-specific arrangements (Altieri 1999). Care must be taken, for instance, concerning light and water competition between trees and agricultural crops (Hensen 2002). In case of ecologically risky species, such as *E. globulus*, special caution is required with respect to how, where and to which extent they are cultivated (Fjeldså 2002). The local regulation of livestock grazing is also of major concern to reduce damages in natural plant regeneration (Hensen 2002).

OUTLOOK ON FUTURE RESEARCH

The present doctoral thesis demonstrated that there is urgent need to undertake more research concerning the social factors that enable or limit biodiversity conservation and restoration efforts, such as agroforestry, in the Bolivian Andes and in mountain drylands in general. The current knowledge and value of plants and their future trends, as well as their underlying driving social and environmental factors need to be investigated in order to better understand the overall relationships between plants, their perceived values and human behavior related to their management. Closer cooperation between ecological and social science and between science and practice in conservation and restoration initiatives is therefore essential (Saunders et al. 2006). Biocultural concepts, which can provide useful theoretical and methodological insights, should have a central role in future research.

In agroforestry, in particular, improving ecological knowledge about promising native woody species, such as *S. molle* or *P. laevigata* var. *andicola*, is highly relevant. It is of special concern, for instance, to facilitate these species' reproductive potentials. The species' adaptive capacities and limitations in germination and growth, especially under harsh environmental conditions, such as they are in the Bolivian Andes, need therefore to be better understood. To this concern, the present doctoral thesis has made some valuable contributions.

Ecological knowledge gaps, however, remained and could not be addressed in the present research. Specifying the criteria for evaluating ecological plant values, for example, and analyzing them in the given context of the research area would be crucial, because in this study, ecological plant values were assessed mainly based on literature data of native Andean woody species, which are, however, scarce. Thus, more research should be directed at the better understanding of the native Andean woody species' ecological interactions in agroforestry systems. In this respect, it is, for instance, crucial to evaluate the woody species' synergistic (e.g. nitrogen fixation, improved microclimate) and antagonistic (e.g. allelopathy, water competition) effects on crop productivity and their mutual interactions with other integrated components, such as livestock (e.g. grazing effects, fodder plants) (cf. Altieri 1999). Furthermore, more knowledge must be gained about the woody agroforestry species' ecological interactions in naturally growing plant communities of agro-ecosystems, and their roles in successional processes. In this regard, it is crucial to analyze whether the species support biological diversification, the underlying driving forces of diversification, and how these can be supported by management.

In any case, incorporating traditional ecological knowledge into such ecological studies would complement them with more holistic insights from the plant users' practical experience. Moreover, this would result in a better application of ecological research findings, as they also take into account important sociocultural factors. Thus, more inter- and transdisciplinary methodologies must be developed to combine the collection and analysis of social and ecological data in applied socio-ecological research. In this regard, ethnobotany is "the missing link in ecology" (Saslis-Lagoudakis and Clarke 2013) and can play a crucial bridging role.

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I dedicate this thesis to Lukas, in loving memory.

APPENDIX

ADDITIONAL STUDY

Are the young less knowledgeable? Local knowledge of natural remedies and its transformations in the Andean highlands

Mathez-Stiefel SL, Brandt R, Lachmuth S, Rist S

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Abstract

A widespread concern among ethnobiologists is the rapid process of erosion of indigenous environmental knowledge observed worldwide. This paper examines the ongoing transformations of knowledge about natural remedies in the Quechua-speaking Andes. Freelisting exercises and interviews were conducted with 36 households at Bolivian and Peruvian study sites. (Generalized) linear mixed effects models were used to analyze the effects of age on knowledge about medicinal plants, animals, minerals, and their uses. Our study demonstrates that younger participants knew as much about natural remedies as their elders. However, proportional knowledge about some medicinal use categories of natural remedies varied with age. We conclude that knowledge about natural remedies is generally not being lost at the study sites. Nevertheless, it is undergoing transformations in terms of specific medicinal uses. A careful understanding of these complex transformation processes is needed to better orient initiatives for the conservation of biocultural diversity in the Andes and elsewhere.

Keywords

Ethnobiology; Indigenous environmental knowledge; Traditional medicine; Bolivia; Peru; Andes

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CONFERENCE AND WORKSHOP CONTRIBUTIONS

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JAN–SEP 1999	Internship at the nature conservation organisation „Sociedad Conservacionista Aragua“, Maracay, Venezuela
FEB–MAR 1996 MAR–APR 1997	Internship at the biological station „Ulu Gombak“, Kuala Lumpur, Malaysia of the Institute of Zoology, Johann-Wolfgang-Goethe-University, Frankfurt/M, Germany

Voluntary Activities and Memberships

APR 2009–PRESENT	Membership in the Society for Tropical Ecology (Gesellschaft für Tropenökologie e.V., gtö)
JUL 2002–AUG 2005	Voluntary work in the German Scout Association "St. Georg", Münster, Germany as a translator for Spanish-German in the intercultural exchange with the Bolivian Scout Association in Santa Cruz, Bolivia (Jul-Aug 2002) and in Münster, Germany (May-Jun 2003; Aug 2005)
JUN 1997–PRESENT	Membership in the Nature and Biodiversity Conservation Union Germany (Naturschutzbund e.V., NABU)
JAN 1997–AUG 2005	Voluntary work in the fair trade shop „la tienda e.V.“, Münster, Germany (2000-2001: board member)

Language Skills

MOTHER TONGUE	German
OTHER LANGUAGES	English, Spanish (very good knowledge) Latin, French, Portuguese (basic knowledge)

ERKLÄRUNG ÜBER DEN PERSÖNLICHEN ANTEIL AN DEN PUBLIKATIONEN

1. Study (Chapter 2)

Brandt R, Zimmermann H, Hensen I, Mariscal Castro J-C, Rist S (2012) Agroforestry species of the Bolivian Andes: an integrated assessment of ecological, economic and socio-cultural plant values. Agroforestry Systems 86(1): 1–16. doi: 10.1007/s10457-012-9503-y

FIELD WORK: **Regine Brandt** (100%)

LABORATORY WORK: **Regine Brandt** (80%); Catharina Landschulz and Michael Beckmann (together 20%)

ANALYSIS: **Regine Brandt** (70%); Heike Zimmermann (30%)

WRITING: **Regine Brandt** (80%); corrections by Stephan Rist (10%), Isabell Hensen, Heike Zimmermann, Juan C. Mariscal Castro (together 10%)

2. Study (Chapter 3)

Brandt R, Mathez-Stiefel S-L, Lachmuth S, Hensen I, Rist S (2013) Knowledge and valuation of Andean agroforestry species: the role of sex, age, and migration among members of a rural community in Bolivia. Journal of Ethnobiology and Ethnomedicine 9:83. doi: 10.1186/1746-4269-9-83. http://www.ethnobiomed.com/content/9/1/ 83

FIELD WORK: **Regine Brandt** (80%); Rolando Sánchez (20%)

ANALYSIS: **Regine Brandt** (70%); Susanne Lachmuth (30%)

WRITING: **Regine Brandt** (70%); corrections by Sarah-Lan Mathez-Stiefel and Stephan Rist (together 20%), Isabell Hensen and Susanne Lachmuth (together 10%)

3. Study (Chapter 4)

Brandt R, Lachmuth S, Landschulz C, Haß F, Hensen I (2014) Species-specific responses to environmental stress on germination and juvenile growth of two Bolivian Andean agroforestry species. New Forests 45(6): 777-795. doi: 10.1007/s11056-014-9436-6

FIELD WORK: **Regine Brandt** (40%); Catharina Landschulz and Friedemann Haß (together 60%)

LABORATORY WORK: **Regine Brandt** (40%); Catharina Landschulz and Friedemann Haß (together 60%)

ANALYSIS: **Regine Brandt** (70%); Susanne Lachmuth (30%)

WRITING: **Regine Brandt** (80%); corrections by Susanne Lachmuth, Isabell Hensen (together 20%)

EIGENSTÄNDIGKEITSERKLÄRUNG

Hiermit erkläre ich, dass diese Arbeit nicht bereits zu einem früheren Zeitpunkt der Naturwissenschaftlichen Fakultät I – Biowissenschaften der Martin-Luther-Universität Halle-Wittenberg oder einer anderen wissenschaftlichen Einrichtung zur Promotion vorgelegt wurde. Darüber hinaus erkläre ich, dass ich die vorliegende Arbeit eigenständig und ohne fremde Hilfe verfasst sowie keine anderen als die im Text angegebenen Quellen und Hilfsmittel verwendet habe. Textstellen, welche aus verwendeten Werken wörtlich oder inhaltlich übernommen wurden, wurden von mir als solche kenntlich gemacht. Im Übrigen erkläre ich, dass ich mich bisher noch nie um einen Doktorgrad beworben habe.

Halle (Saale), den 23. Juni 2014

Unterschrift: ________________________________

Regine Brandt