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Research Priorities for the Conservation and Sustainable Governance of Andean Forest Landscapes

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The long-term survival of Andean forest landscapes (AFL) and of their capacity to contribute to sustainable development in a context of global change requires integrated adaptation and mitigation responses informed by a thorough understanding of the dynamic and complex interactions between their ecological and social components. This article proposes a research agenda that can help guide AFL research efforts for the next 15 years. The agenda was developed between July 2015 and June 2016 through a series of workshops in Ecuador, Peru, and Switzerland and involved 48 researchers and development experts working on AFL from different disciplinary perspectives. Based on our review of current research and identification of pressing challenges for the conservation and sustainable governance of AFL, we propose a conceptual framework that draws on sustainability sciences and social–ecological systems research, and we identify a set of high-priority research goals and objectives organized into 3 broad categories: systems knowledge, target knowledge, and transformation knowledge. This paper is intended to be a reference for a broad array of actors engaged in policy, research, and implementation in the Andean region. We hope it will trigger collaborative research initiatives for the continued conservation and sustainable governance of AFL.

Keywords: *Andes; social–ecological systems; global change; sustainable development; transdisciplinary research; Sustainable Development Goals; Agenda 2030.*

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Introduction

The Andean mountain range extends for about 7000 km from Venezuela to Argentina and contains exceptional biodiversity. A triple pattern of decrease in temperature with increasing elevation, decrease in precipitation from the equator to lower southern latitudes, and variation in the geological history of Andean uplift results in extremely high biological diversity and explains the unique rapid succession of ecosystems and life forms found in the region (Parsons 1982; Lauer 1993; Josse et al 2009). High levels of species diversity and endemism in the region result not only from environmental heterogeneity, but also from complex evolutionary processes (Killeen et

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al 2007). In consequence, the Andes support the highest species richness of vascular plants, birds, and amphibians of Earth's biodiversity hotspots, and the region ranks second in reptile diversity (Myers et al 2000; Meyer et al 2015).

In this paper, Andean forests are defined as montane forests located between 500 m above sea level and the tree line, including tropical and subtropical forests of the central and northern Andes, as well as the temperate and Mediterranean forests found in the southern Andes (Cuesta et al 2009; Table 1 provides a glossary of terms used in this paper). The region's high biological diversity is mirrored by historical and current patterns of human occupation that have generated complex mosaics of social and ecological systems. As a result of the interaction between these systems, Andean forest landscapes (AFL) are heterogeneous areas that present remnants of Andean forest ecosystems interspersed with land-cover categories of anthropogenic origin (Mathez-Stiefel et al 2017).

The unique biophysical and socioeconomic features of AFL qualify them as global priorities for conservation and sustainable management efforts and make target 15.4 of the United Nations (UN) Sustainable Development Goals (SDGs) specifically relevant to them: "By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development" (United Nations General Assembly 2015: 25). About 60 million people depend directly or indirectly on the ecosystem services provided by AFL (eg provision of timber, food, medicine, and fuelwood; local climate and water regulation; global climate regulation through carbon fixation and storage; and protection against natural disasters) (Cincotta et al 2000). Andean metropolises such as Bogota, La Paz, Quito, and Santiago de Chile have grown exponentially during the last decades and depend on the integrity of their surrounding ecosystems, particularly forests (Parsons 1982). As such, AFL are crucial to achieving many of the SDGs for the Andean region, including poverty reduction, increased food security, improved human wellbeing, effective climate action, and conservation of terrestrial ecosystems.

Features characteristic of mountain areas create specific challenges for sustainable management and governance. Steep environmental gradients, complex patterns of rainfall influenced by topography, and high potential for soil erosion and landslides are elements of the risk context to which Andean communities have been responding for centuries (Stadel 2008). Currently, AFL may be more affected by climate change than their surrounding lowlands. Indeed, there is evidence that temperature and precipitation patterns are likely to rapidly shift in the Andean region in the 21st century (Urrutia and Vuille 2009; Vuille et al 2015), with observed effects on Andean forests (Feeley et al 2011; Herzog et al 2011). Climate change is already affecting Andean production systems, requiring careful planning by local populations regarding use of their resource base in order to sustain key ecosystem services (Buytaert et al 2011; Postigo 2014).

AFL are currently changing at accelerated rates (Báez et al 2015; Duque et al 2015). They are exposed to and sensitive to a combination of impacts linked to (1) variations in key bioclimatic conditions for the functioning and persistence of biotic communities and (2) disturbances caused by changing land-use regimes (Bellard et al 2014). These anthropogenic disturbances are mainly linked to agricultural expansion, intensive and extensive cattle ranching, mining activities, and timber extraction (Sarmiento and Frolich 2002; Vargas 2008; Bebbington and Bury 2009; Bueno and Llambí 2015). The 5 tropical Andean countries (Bolivia, Colombia, Ecuador, Peru, and Venezuela) have lost at least 50,000 km^2 of their initial montane forest cover (Mulligan 2010), largely due to forest clearing and the resulting degradation (Young 2009; Garavito et al 2012). These changes not only affect the ecological integrity of Andean forests, they also reduce the flow of benefits that local and extralocal human populations receive from these ecosystems.

The long-term survival of AFL and of their capacity to contribute to sustainable development in a context of global change requires integrated adaptation and mitigation responses from stakeholders working at different levels (Locatelli et al 2015). These responses should be informed by a thorough understanding of the ecological and social components of AFL, their complex interactions, and their dynamics. To this end, we present here a research agenda that can help, for the next 15 years, to guide research that informs efforts to achieve the SDGs in the Andean region. Based on a review of the current state of research and the identification of pressing challenges for the conservation and sustainable governance of AFL, we propose a conceptual framework and a set of high-priority research goals and objectives. This paper is intended to be a reference for a broad array of actors engaged in policy, research, and implementation in the Andean region. We hope it will trigger collaborative research initiatives for the continued conservation and sustainable governance of AFL.

Methodology

This research agenda was developed between July 2015 and June 2016 through a series of workshops that took place in Ecuador, Peru, and Switzerland and involved 48 researchers and development experts working on AFL. The process is detailed in Table 2, and a list of participants is provided in Table S1 (*Supplemental material*, http://dx.doi.org/10.1659/MRD-JOURNAL-D-16-00093.S1).

The first step was to develop a research approach and conceptual framework that could gather under a single umbrella the diverse disciplinary and interdisciplinary

TABLE 1 Definitions of key terms. (Table continued on next page.)

Term	Definition	Reference(s)
Adaptation to climate change	The process of adjustment to actual or expected climate change and its effects.	Mach et al (2014)
Andean forests	Montane forest ecosystems between 500 m above sea level and the tree line in the Andean mountain range. These include the tropical and subtropical forests of the central and northern Andes as well as the temperate and Mediterranean forests in the southern Andes.	Cuesta et al (2009)
Andean forest landscapes	Mosaics of Andean forest remnants interspersed with anthropogenic land covers. These mosaics result from interactions among environmental, socioeconomic, and political dynamics at different scales.	Mathez-Stiefel et al (2017)
Ecosystem services	The benefits provided by ecosystems. These include provisioning services, such as food, water, timber, fiber, and genetic resources; regulating services, such as the regulation of climate, floods, disease, and water quality, as well as waste treatment; cultural services, such as recreation, aesthetic enjoyment, and spiritual fulfillment; and supporting services, such as soil formation, pollination, and nutrient cycling.	Millennium Ecosystem Assessment (2005)
Ecotone	Transition zone between adjacent ecosystems.	McArthur and Sanderson (1999)
Environmental governance	A series of regulatory processes, mechanisms, and organizations through which state actors, businesses, civil society organizations, and communities influence environmental actions and responses.	Lemos and Agrawal (2006)
Environmental justice	A phenomenon with 3 dimensions: (1) equitable distribution of environmental risks and benefits among the places and people involved, (2) recognition of the diversity of participants and experiences in affected communities, and (3) the participation of all social groups in the political process of environmental policymaking and decision-making.	Schlosberg (2004)
Forest dynamics	Changes in forest structure (tree density, size, strata) and composition (species identities) through time.	Connell and Slatyer (1977)
Global environmental change	The anthropogenic impacts (social, demographic, economic, and other) on terrestrial ecosystems, oceans, and the atmosphere, and the interactions and feedbacks between the Earth system and human systems.	Steffen et al (2006)
Interdisciplinary research	Research that applies concepts and methods of different disciplines to the study of complex systems and problems.	Hirsch Hadorn et al (2006)
Landscape restoration	A planned process to restore ecological integrity and enhance human wellbeing in a deforested or degraded landscape.	Stanturf et al (2015)
Livelihood	Assets (natural, physical, human, financial, and social), activities, and the access to these (mediated by institutions and social relations) that together determine the livelihood gained by an individual or household.	Ellis (2000)
Mitigation of climate change	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.	Mach et al (2014)
Resilience	The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.	Mach et al (2014)
Social–ecological systems	Complex and adaptive linked systems of humans (and their social organizations) and the biophysical environment, and their interactions at different spatial, temporal, and organizational scales.	Berkes and Folke (1998) Liu et al (2007)
Stakeholder participation	A process in which individuals, groups, and organizations choose to take an active role in making decisions that affect them.	Reed (2008)

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TABLE 1 Continued. (First part of Table 1 on previous page.)

Term	Definition	Reference(s)
Sustainability science	Science that seeks to be responsive to the needs and values of society while preserving the life-support systems of Earth.	Jerneck et al (2011)
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.	WCED (1987)
Traditional ecological knowledge	A cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationships of living beings (including humans) with one another and with their environment.	Berkes et al (2000)
Transdisciplinary research	Research that helps provide the knowledge needed for societal problem-solving regarding complex societal concerns. This includes debate and cooperation within the scientific community and between researchers and the larger society.	Hirsch Hadorn et al (2006) Wiesmann et al (2008)
Tree line	Line that connects the highest patches of forest on a slope; transition between high-elevation grasslands and the underlying cloud forest.	Körner (1998)

research needed to understand the complexity and dynamics of AFL and to shape strategies for its sustainable management. The resulting framework was elaborated based on scholarly work in sustainability sciences and social–ecological systems.

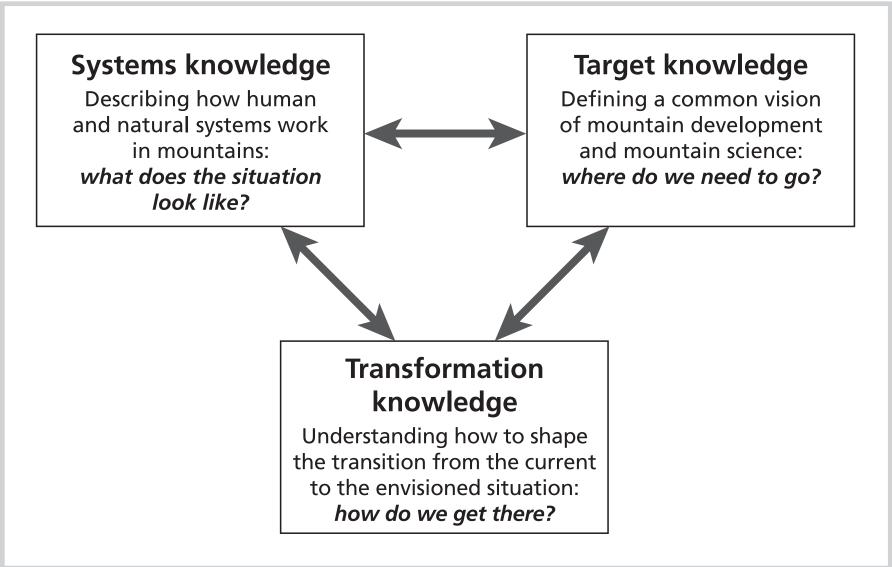
The second step was to gather insights from experts in academia and the nonprofit sector on current AFL knowledge gaps, challenges, and research priorities. This was done during 3 workshops conducted in Quito, Ecuador (29–31 July 2015), Lima, Peru (14 October 2015), and Bern, Switzerland (10 February 2016). The participants represented a wide array of disciplinary expertise (agronomy, botany, ethnobiology, forestry, geography, hydrology, plant ecology, political ecology, and sociology) and experience in diverse geographic contexts of the Andean region (Argentina, Bolivia,

TABLE 2 Methods used to develop the research agenda.[a)]

Step	Objective	Methods	Results
1	**Develop a conceptual and analytical framework**	Review of existing frameworks from sustainability sciences and social–ecological systems research	Draft conceptual framework Analytical framework (Figure 2)
2	**Identify and prioritize research challenges**	Expert workshop 1 (Quito): Group and plenary discussions on (a) impacts of climate change on biodiversity and ecosystem functions, and (b) options and challenges for the restoration of Andean forests	Preliminary list of research priorities
		Expert workshop 2 (Lima): Group and plenary discussions on (a) the draft conceptual framework, (b) current challenges for the conservation and sustainable governance of AFL, and (c) research needs to respond to these challenges	Revised conceptual framework List of current challenges List of research priorities
		Expert workshop 3 (Bern): Based on results from workshop 2, group and plenary discussions on (a) the draft conceptual framework and (b) research priorities	Final conceptual framework (Figure 1) Revised list of research priorities
3	**Synthesize findings and review the literature**	Integration of results from steps 1 and 2 into main research goals and objectives, supported by examples of existing work from the literature	List of research goals and objectives in systems knowledge, target knowledge, and transformation knowledge
		Consultation with experts for the revision of the final research agenda	Final research agenda (summarized in Table 3)

[a)] Participants in this process are listed in *Supplemental material*, Table S1; (http://dx.doi.org/10.1659/MRD-JOURNAL-D-16-00093.S1).

FIGURE 1 Knowledge for sustainable development in mountains. The arrows indicate that the forms of knowledge are not absolute types, as they feed into each other. (Source: reproduced from Mathez-Stiefel, Wymann von Dach, et al 2016)



Colombia, Ecuador, Peru, Venezuela). The goal of these 3 events was to identify and prioritize research challenges and gaps that are relevant for the sustainable management of AFL. The conceptual framework developed in the first step was used to frame and orient the discussions.

In the Quito workshop, participants discussed research needs in 2 main areas: (1) the most relevant impacts of climate change on biodiversity and ecosystem function, and (2) opportunities and challenges for the effective restoration of Andean forests. In Lima, interdisciplinary working groups were asked to (1) discuss and revise the proposed conceptual framework, (2) list and prioritize the main challenges for the conservation and sustainable management of AFL, in a context of climate change, and (3) identify research objectives that would make it possible to address the main research gaps for each of the prioritized challenges. The results from the Lima workshop were discussed and further elaborated at the Bern workshop using a similar approach.

The third step consisted of synthesizing and integrating the results of the 3 workshops into research goals and objectives, according to the form of transdisciplinary knowledge to which they correspond, as described by Hirsch Hadorn et al (2006) and adapted to the mountain context by Mathez-Stiefel, Wymann von Dach, et al (2016) (Figure 1). Three categories of knowledge were considered:

1. *Systems knowledge*: understanding and describing how social–ecological systems work;
2. *Target knowledge*: defining with local stakeholders a common vision for sustainable governance;
3. *Transformation knowledge*: encapsulating the knowledge needed to shape the transition from current to envisioned practices.

The experts who participated in the workshops were invited to provide additional feedback on this synthesis based on the current state of research. Based on this feedback, the final research agenda was produced. This agenda is presented below.

A research agenda for AFL

Conceptual framework

The production of new scientific knowledge in the search for solutions to the complex sustainability challenges faced by AFL requires innovative approaches that bridge disciplinary boundaries in the attempt to unravel the complexity and dynamics of AFL. It also requires the coproduction of knowledge by researchers, policymakers, and practitioners (Cornell et al 2013), as well as a nuanced understanding of the institutional arrangements and roles of stakeholders engaged in the mobilization of knowledge, from the collection of primary data to the analysis and application of complex information in policymaking (Grainger and Obersteiner 2011). Sustainability sciences can provide a conceptual framework that enables collaboration between the social and natural sciences, thus establishing a dialogue between the resulting integrative science and societal stakeholders involved in AFL governance through inter- and transdisciplinary research (Wiesmann et al 2008).

Sustainability sciences can be used to design a generic research platform based on a matrix with 3 dimensions: (1) *core themes* or stages (scientific understanding,

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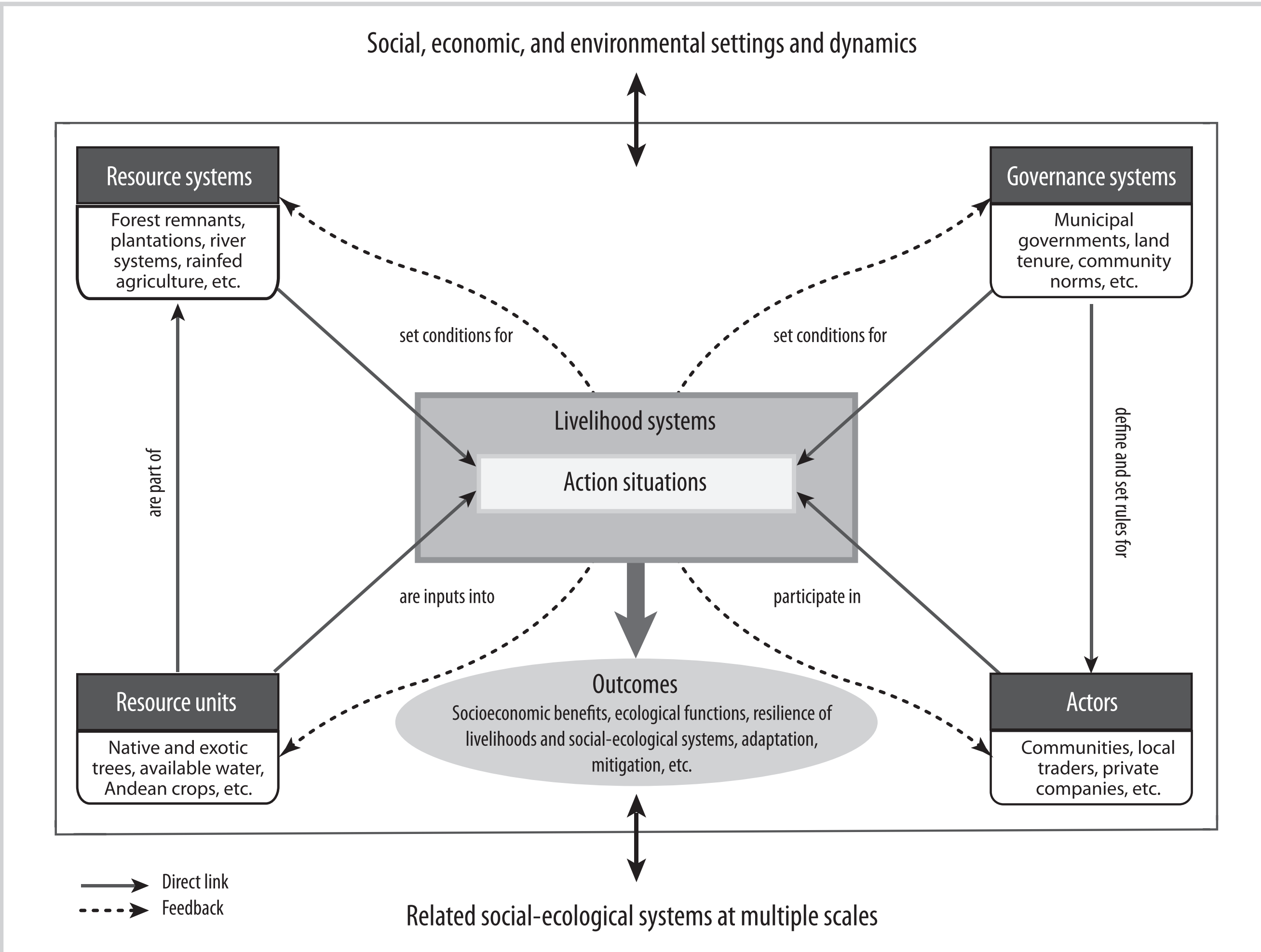
FIGURE 2 Conceptualization of AFL as a social–ecological system. (Source: adapted from McGinnis and Ostrom 2014)



sustainability goals, sustainability pathways); (2) *cross-cutting approaches* (problem-solving or critical research); and (3) any combination of *sustainability challenges* (eg climate change, deforestation, land degradation, and water scarcity) (Jerneck et al 2011). The core themes also correspond to the 3 knowledge categories that structure this research agenda: systems, target, and transformation knowledge (Hirsch Hadorn et al 2006; Figure 1). Sustainability sciences aim to meet society's needs while conserving Earth's life-support systems (Jerneck et al 2011). Such an approach implies that AFL should be conceptualized as social–ecological systems, with properties arising from exchanges between subsystems and between the system as a whole and its environment (Halliday and Glaser 2011).

An adaptation of the social–ecological framework developed by McGinnis and Ostrom (2014) is proposed to structure sustainability-oriented research in AFL. This framework makes it possible to explore the complex links between people and resources at the system and individual levels, as well as the outcomes of decisions about resource use (Figure 2). While ecological research focuses on the processes and status of ecosystems and their interactions, social-science research focuses on the processes and institutional arrangements used to manage natural resources. Features of interest to both types of researchers are the different "action situations" (ways in which multiple actors transform resources; see McGinnis and Ostrom 2014) that arise in different livelihood systems. The interactions between participants in an action situation help to determine an array of social, economic, and environmental outcomes, including the resilience of the whole resource regime. These outcomes are valued differently by different actors, who "seek to achieve goals for themselves and for the communities [with] which they identify, but do so within the context of ubiquitous social dilemmas and biophysical constraints, as well as cognitive limitations and cultural predispositions" (McGinnis and Ostrom 2014: 2).

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The framework provides a way to study the feedbacks that occur from these interactions and outcomes, as well as the possible effects of exogenous influences (from related ecological systems or socioeconomic and political settings) acting on the system. For example, the effects of economic globalization, or the rules imposed by actors from outside the AFL (such as national governments) may have important impacts on AFL, their subsystems, or the interactions between them (Lambin et al 2003; Boillat et al 2017). The social–ecological systems of AFL should also be analyzed at different scales, depending on where decisions regarding the resources are made or where elements of the system interact (Scholes et al 2013).

Based on this framework, the following sections present the goals and objectives proposed for future research in AFL, citing recent studies where relevant to specific research themes. These research priorities are summarized in Table 3, along with the specific SDG targets to which they can contribute directly or indirectly.

Priorities in systems knowledge

1 *Understand the impacts of global socio-environmental change on the composition, structure, and functions of AFL:* Our knowledge of the dynamics of the resource systems related to AFL—in particular, the biological diversity, ecophysiology, species interactions, and drivers of change in Andean forest ecosystems—needs to be improved. Entire groups of organisms (eg birds and mammals) and ecological interactions under pressure due to global environmental change remain virtually unexplored in the Andes (Báez et al 2016). Despite recent progress, knowledge remains fragmented and needs to be better synthesized. A systematic review of the impacts of socio-environmental change on Andean forest ecosystem processes is needed, including an analysis of patterns, both at well-studied sites and in poorly investigated forest ecosystems. For example, elevational migration of Andean plant species associated with rising temperatures has been documented in some areas (Feeley et al 2011; Duque et al 2015); however, its consequences for forest dynamics and ecosystem functioning (Báez et al 2015) and plant interactions are poorly understood (Alexander et al 2015).

Critical research areas include ecotones (eg the upper forest limit or tree line), interspecific interactions (eg competition, facilitation, pollination, and plant–microbial interactions), ecosystem recovery after human alterations or changes in disturbance types and cycles (eg drought, replacement of forests by African pastures, and fires), and responses to changes in biogeochemical processes (eg nitrogen and phosphorus cycling). Particular emphasis should be given to the study of resource systems that require additional attention due to their uniqueness, restricted distribution, or conservation status, including dry forests (Linares-Palomino et al 2011; Banda et al 2016). A key methodological consideration relates to elevational and latitudinal gradients of precipitation, fog presence, and horizontal precipitation (Killeen et al 2007; Urrutia and Vuille 2009; Huasco et al 2014). At smaller spatial scales, environmental moisture also varies greatly, from humid to xeric conditions (Killeen et al 2007; Kessler et al 2011). For example, recent research at the upper forest line has shown that shrubs can facilitate the establishment of forest trees both in natural areas above the tree line and in disturbed areas such as agricultural fields, highlighting the potential of nurse-plant interactions for promoting ecological restoration in degraded areas (Bueno and Llambí 2015).

In this category, the following research objectives should be prioritized:

1.1. Understand general patterns of tree diversity along elevational and latitudinal gradients, forest structure, forest dynamics, carbon stocks, and rates of carbon fixation, in key sites along the tropical and subtropical Andes (Homeier et al 2010; Asner et al 2014; Huasco et al 2014; Werner and Homeier 2015). This includes the mapping of the historical and current extent of Andean forest ecosystems and the distributions of key species (Josse et al 2009; Tovar et al 2013).

1.2. Understand how biotic interactions such as facilitation, pollination, and grazing affect biological diversity, structure, and ecosystem functioning in Andean forests along environmental (Malhi et al 2010; Llambí et al 2013) and land-use (eg grazing intensity) (Becker et al 2007; Malizia et al 2013) gradients.

1.3. Understand how abiotic factors such as water and nutrient availability, incident radiation, and their interactions with topography and geomorphology affect eco-physiological, community, and ecosystem responses in Andean forests at local and landscape scales (Bader et al 2007; Schwarzkopf et al 2011; Homeier et al 2012; Cárate-Tandalla et al 2015; Homeier et al 2017).

1.4. Improve our knowledge of historical forest responses to climate fluctuations through paleoecological, paleopalynological, and dendroclimatological studies (Bush et al 2007; Gosling et al 2009).

1.5. Understand changes in the diversity of mountain forest species and carbon-cycle dynamics after disturbance events due to human activities and land-use gradients (Werner et al 2005; Báez et al 2010), ongoing global environmental change (Homeier et al 2012), and new disturbance regimes such as fire and drought (Nadkarni and Solano 2002). This should include the examination of barriers and processes driving the successional dynamics of Andean forest regeneration after disturbance (eg Aide et al 2010; Homeier et al 2013; Bueno and Llambí 2015).

1.6. Characterize the relationship between the structure and functioning of Andean forest ecosystems and their contribution to hydrological (Ataroff and Rada 2000; Bruijnzeel et al 2010; Balthazar et al 2015) and

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TABLE 3 Research priorities and the corresponding SDG targets. (Table continued on next page.)

Research priority		SDG targets[a)]
Systems knowledge		
1.	**Impacts of global socio-environmental change on AFL**	
1.1	Patterns of tree diversity, forest structure and dynamics, and carbon stocks	6.6, 15.1, 15.2, 15.4, 15.5
1.2	Effects of biotic interactions on the biodiversity, structure, and functioning of forests	6.6, 15.1, 15.2, 15.4, 15.5, 15.8
1.3	Effects of abiotic factors on responses of forest ecosystems to global change	6.6, 15.1, 15.2, 15.4, 15.5
1.4	Historical responses of forest ecosystems to climate fluctuations	6.6, 15.1, 15.2, 15.4, 15.5
1.5	Successional dynamics of forest regeneration after natural and anthropogenic disturbances	6.6, 15.1, 15.2, 15.3, 15.4, 15.5
1.6	Contribution of structure and functioning of forests to ecosystem services	6.6, 15.1, 15.2, 15.4, 15.5
2.	**Interactions between complex social and environmental dynamics**	
2.1	Implications of socioeconomic changes for patterns of resource access and use	1.4, 2.3, 2.5, 6.6, 12.2, 15.1, 15.2, 15.4, 15.5, 15.6
2.2	Drivers of different trajectories of tree cover change	6.6, 15.1, 15.2, 15.4, 15.5
2.3	Past and present landscape dynamics: land-cover and land-use change, use regimes, and population growth	6.6, 15.1, 15.2, 15.3, 15.4, 15.5
2.4	Influence of climate variables on the vulnerability of livelihoods and ecosystem services	1.5, 2.4, 6.5, 13.1, 15.1
2.5	Governance processes that frame the patterns of use and management of forests and other resources	2.3, 2.5, 6.5, 6.6, 12.2, 15.1, 15.2, 15.4, 15.5, 15.6, 15.7
2.6	Non-timber forest product availability in different social–ecological contexts	1.4, 15.1, 15.2, 15.4, 15.5
3.	**Impacts of governance and management practices on livelihoods and ecosystem services**	
3.1	Contributions of landscape management to the strengthening of local livelihoods	1.2, 2.1, 2.3, 2.A, 6.5, 8.3, 8.9, 12.2
3.2	Factors that ensure that local livelihoods benefit from sustainable landscape management	1.2, 1.4, 2.3, 6.B, 8.3, 8.9
3.3	Synergies and trade-offs among competing management goals and their impacts on ecosystem services	2.5, 6.5, 6.6, 12.2, 15.1, 15.2, 15.4, 15.5
3.4	Effects of alternative management regimes on people's resilience to climate change and natural disasters	1.5, 2.4, 12.2, 13.1
Target knowledge		
4.	**Sustainability goals for AFL management**	
4.1	Perceptions, cultural values, identities, and knowledge of different actor categories	1.4, 2.5, 6.B, 10.2, 15.6
4.2	Environmental justice and equity in the definition of sustainability goals	1.4, 1.B, 2.5, 5.5, 6.B, 10.2, 15.6, 15.9
4.3	Inclusive methods and research frameworks to generate actionable knowledge	1.5, 2.5, 5.5, 6.B, 10.2, 15.6
4.4	Multistakeholder definition of restoration concepts and options	6.6, 10.2, 15.1, 15.2, 15.3, 15.4, 15.5, 15.9

TABLE 3 Continued. (First part of Table 3 on previous page.)

Research priority		SDG targets[a)]
Transformation knowledge		
5.	**Robust and place-based governance models**	
5.1	Elements of the promotion of locally adapted, inclusive, and equitable governance models	1.4, 2.5, 5.5, 5.A, 6.5, 6.6, 6.B, 10.2, 12.2, 15.1, 15.2, 15.4, 15.5, 15.6, 15.7, 15.9
5.2	Inclusive design of compensation schemes for the goods and services provided by forest ecosystems	1.4, 2.5, 6.5, 6.6, 6.B, 10.2, 12.2, 13.2, 15.1, 15.2, 15.4, 15.5, 15.6
5.3	Incentives for maintenance of ecosystem services and the economic development of landscapes	1.2, 2.5, 6.5, 6.6, 8.3, 8.9, 12.2, 13.2, 15.1, 15.2, 15.4, 15.5
5.4	Local knowledge and legal instruments to support institutional change for increased sustainability	1.4, 2.5, 6.6, 12.2, 13.2, 15.1, 15.2, 15.4, 15.5, 15.6, 15.7, 15.9
5.5	Barriers to the participation of marginalized actors in bodies of environmental governance	1.4, 2.5, 5.5, 5.A, 6.B, 10.2, 15.6
6.	**Sustainable governance across scales**	
6.1	Up- and out-scaling approaches for successful management practices from local to national and regional levels	1.B, 6.5, 6.6, 12.2, 13.2, 15.1, 15.2, 15.3, 15.4, 15.5, 15.9
6.2	Social learning processes that integrate the knowledge of different actors at multiple scales	2.5, 6.5, 6.6, 6.b, 10.2, 12.2, 13.2, 15.1, 15.2, 15.4, 15.5, 15.6, 15.9
6.3	Mechanisms for implementing national and regional policies in diverse local contexts	1.B, 2.5, 6.5, 6.6, 8.3, 8.9, 12.2, 13.2, 15.1, 15.2, 15.4, 15.5, 15.6, 15.7, 15.9
6.4	Diffusion of synthesis information on AFL to inform decision-making	6.5, 6.6, 12.2, 13.2, 15.1, 15.2, 15.3, 15.4, 15.5, 15.9
7.	**Landscape restoration practices**	
7.1	Critical review of existing restoration initiatives: potentials, bottlenecks, and enabling conditions	1.5, 6.6, 15.1, 15.2, 15.3, 15.4, 15.5
7.2	Comparison of forest self-regeneration with active restoration approaches	6.6, 15.1, 15.2, 15.3, 15.4, 15.5
7.3	Impacts of different restoration practices on livelihoods and ecosystem services	1.2, 6.5, 6.6, 15.1, 15.2, 15.3, 15.4, 15.5
7.4	Definition of common criteria for the assessment of restoration practices	6.6, 10.2, 15.1, 15.2, 15.3, 15.4, 15.5
7.5	Validation of locally adapted restoration technologies	6.6, 15.1, 15.2, 15.3, 15.4, 15.5
7.6	Tools for the restoration of connectivity between Andean forest remnant patches and the Amazon Basin	6.5, 6.6, 15.1, 15.2, 15.3, 15.4, 15.5

[a)] The full list of SDGs and targets can be found in the 2030 Agenda (United Nations 2015).

other key ecosystem services, such as pollination and protection against natural hazards (eg through increased soil stability on steep slopes).

2 *Characterize linkages and interactions between complex social and environmental dynamics in AFL:* AFL composition and dynamism are being altered as a result of a combination of global, regional, and local changes in climatic and socioeconomic drivers (Young 2009). As a result, a key dimension of this research goal relates to the importance of historic, current, and likely future drivers of change as they promote social and ecological changes.

Robust information is needed related to spatial and temporal patterns of land-use and land-cover change. This requires monitoring of forests and forest use, historical analyses, and development of predictive capabilities (Ponce-Reyes et al 2013; Ortega-Andrade et al 2015). Special attention should be paid to the socioeconomic and political context, as economic, demographic, political, technological, and market-related

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dynamics are not yet systematically understood. For example, disentangling the relative effects of social, institutional, and economic drivers of deforestation and forest degradation is important to develop sound policies at local to national scales. The effects of land tenure and other factors that influence patterns of access to and use of land resources have been studied for lowland tropical forests (eg Holland et al 2017), but less is known about AFL. While research on AFL actors has progressed somewhat, research on specific governance features—such as formal property rights; tenure structures; informal use rights and related social network structures; public, private, and common-pool resource management organizations and their interactions; and structures of and rationales for incentives and sanctions—remains fragmented.

In this category, the following research objectives should be prioritized:

2.1. Understand the implications of processes of socioeconomic change—including urbanization, migration of human populations to urban areas, and integration in the market economy—on patterns of access to and use of resources (Clark et al 2012; Aide et al 2013; Chazdon et al 2016). Special attention should be paid to the impacts of large-scale exploitation of subsoil resources (Kuecker 2007; Bebbington and Bury 2009).
2.2. Characterize the main proximate causes, underlying drivers, and differentiated trajectories of tree cover change, including forest conversion, natural regeneration, and restoration, from farm to landscape scales (Munroe et al 2013; Peralvo and Cuesta 2014; Lerner et al 2015). In particular, tree-line dynamics under different land-use regimes should be studied as a way to monitor and evaluate changes in habitat fragmentation and connectivity and system response to global environmental change (Young and León 2007; Rehm and Feeley 2013; Tapia-Armijos et al 2015).
2.3. Improve the understanding of past and present landscape dynamics (Lutz et al 2013), considering land-use and land-cover change, natural resource use regimes (eg timber extraction), population growth, and the implications of the potential for novel ecosystems to expand (Hobbs et al 2006).
2.4. Study the influence of climate variables on the vulnerability of livelihoods, production chains, and ecosystem services (Young and Lipton 2006; Balthazar et al 2015).
2.5. Analyze the governance processes (eg land tenure types and formal and informal norms) and household dynamics that frame the use and management of forests and other natural resources (Andersson 2003; Rival 2003; Hofstede et al 2010).
2.6. Characterize the differences in availability of non-timber forest products in different social–ecological contexts along environmental and biophysical gradients (Báez et al 2010; Sundqvist et al 2013; Asner et al 2014).

3 *Analyze the impact of AFL governance and management practices on livelihoods and ecosystem services:* It is important to focus on action situations and assess the sustainability of their outcomes—for example, their effect on the provision of critical ecosystem services such as water regulation. The relationships among ecosystem services, livelihoods, and the effectiveness of forestry and agroforestry practices are poorly understood (Chaudhary et al 2016). More knowledge is needed about how specific governance dynamics and management practices are related to justice (social, intragenerational, and intergenerational) or actor-specific livelihood outcomes. It is also necessary to understand how forest management practices (eg rotation systems and selective logging) and forest cover change (eg forest conversion to cropland and pastures, and reforestation with exotic or local species) affect biodiversity, carbon sequestration, hydrologic functions, and other key ecosystem services. For example, in the Ecuadorian AFL, areas where assisted restoration has been implemented contain more animal-dispersed species and species useful to humans in both the canopy and understory than naturally regenerating areas (Wilson and Rhemtulla 2016). Human intervention in and management of succession may thus prove vital to the conservation and restoration of ecosystem services.

In this category, the following research objectives should be prioritized:

3.1. Analyze how landscape management strengthens local livelihoods (eg through the provision of diversified goods such as fodder, fuelwood, food, or medicinal plants) (Postigo et al 2008).
3.2. Determine what factors (eg tenure regimes, community bylaws, use of traditional knowledge, value chains and their governance, and ecotourism development) ensure that local livelihoods benefit from sustainable management (Parraguez Vergara and Barton 2013).
3.3. Assess synergies and trade-offs among competing management goals and the impacts of associated practices on biodiversity and key ecosystem services, including timber and non-timber forest products (Raboin and Posner 2012), water regulation (Celleri and Feyen 2009), soil fertility (Harden et al 2013), and carbon sequestration (Gibbon et al 2010).
3.4. Analyze the effects of alternative management regimes—for example, the management of agrobiodiversity (Zimmerer 2010) and the use of vegetation for water regulation or prevention of

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landslides (Robledo et al 2004)—on local communities' resilience to climate change and natural disasters.

Priorities in target knowledge

4 *Define sustainability goals for the management of AFL:* To identify pathways to greater sustainability, there is first a need to develop, in conjunction with place- and non-place-based stakeholders, a joint vision that can guide policy, practices, and planning strategies in a rapidly changing context. Two types of research are needed to support this process. First, actor-specific perceptions, knowledge, values, and identities need to be made explicit. (These vary among, for example, farmers, forest managers, and providers and receivers of ecosystem services; both individuals and collective entities can be considered actors.) These are crucial attributes that guide the definition of concepts and concrete sustainability indicators as well as the framing of specific action situations (Pohl et al 2017). Second, common normative grounds need to be found and enhanced through dialogue and social learning on sustainability (Gómez 2015), which should result from the transdisciplinary and multiscale integration of knowledge from researchers, local land users, and policymakers. This could be done through face-to-face or virtual knowledge platforms and/or workshops and other consultations. Given the profound implications of greenhouse gas emissions from the global North for AFL and the people living in them, there is an element of environmental justice involved (Adger 2001).

In this category, the following research objectives should be prioritized:

4.1. Elucidate the perceptions (Valdivia et al 2010; Boillat and Berkes 2013; Postigo 2014), cultural values (Brandt et al 2012; dos Reis et al 2014), identities (Rhoades 2006), and knowledge (Boillat et al 2013; Brandt et al 2013) of different actor categories. This includes the linkages among diverse stakeholders' valuations of Andean forests and preferred land- and resource-use regimes, investment decisions, and livelihood systems (Báez et al 2010; Wilson and Rhemtulla 2016).

4.2. Include environmental justice and equity concerns in the definition of sustainability goals (Martinez-Alier et al 2014), with special reference to the perspectives of indigenous and local communities, women, and other marginalized groups (Paulson 2003; Escobedo et al 2015; Mathez-Stiefel, Ayquipa-Valenzuela, et al 2016).

4.3. Develop inclusive methods and frameworks to generate locally relevant and actionable knowledge about AFL, their ecosystems, and customary resource management institutions (Mathez-Stiefel, Ayquipa-Valenzuela, et al 2016). This should include the generation of future scenarios and pathways based on different actors' needs and priorities, including conservation, development, mitigation, and adaptation, in contexts where it is expected that climate change will pose further challenges for Andean livelihoods (Postigo et al 2008; Valdivia et al 2010; Postigo 2014).

4.4. Jointly with local stakeholders, define the concept of and options for restoration, including definitions of forest and land degradation and identification of restoration goals (eg defining the reference ecosystems for restoration initiatives). It is important that this process be done in a participatory and inclusive way, in particular, in the Latin American context, where states are currently taking an important role in leading restoration initiatives, as shown by Murcia et al (2016) in the case of Colombia.

Priorities in transformation knowledge

5 *Promote robust place-based governance models to support sustainability goals in AFL:* Sustainable management requires governance models that include a broad set of practices and the involvement of stakeholders at multiple scales with different, sometimes conflicting, territorial interests, often rooted in asymmetrical power relations. A place-based governance that builds on local identities to promote the inclusion of marginalized social groups is necessary to attain outcomes that are both equitable and effective in achieving sustainability goals (Thomas and Twyman 2005). Knowledge of key attributes of the resource and governance systems is needed to assess inclusion and to promote effective governance, especially in relation to sustainability outcomes (Cash et al 2006). In the Andean countries, inclusive and robust place-based governance faces the challenge of integrating different scales of land-use planning, past environmental and social injustices, prioritization of national strategic projects, and informal local institutions that mediate land and resource use.

In this category, the following research objectives should be prioritized:

5.1. Identify the elements required to promote inclusive place-based governance models, adapted to the local context, that consider the power asymmetries among actors, the natural context, and the maintenance of local livelihoods (Young and Lipton 2006; Hill 2013).

5.2. Compare institutional arrangements that engage the public sector, local communities, and market actors in the design of compensation schemes for goods and services (Ebeling and Yasué 2009).

5.3. Propose adequate combinations of input-related incentives (eg training, land tenure security, access to credit, and land-use planning) and output-related incentives (eg payments for environmental services and access to value chains) that support maintenance

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of ecosystem services and economic development (Quintero et al 2009; Thiele et al 2011).

5.4. Identify local knowledge and legal instruments that can support institutional change and collective action for sustainable governance (Valdivia et al 2010; Shanee et al 2015; Buytaert et al 2016).

5.5. Assess the barriers to the participation of different actors, in particular women and other marginalized groups, in bodies of environmental governance (eg protected area management committees and municipal and regional environmental commissions) (Salas Laines 2011; Mathez-Stiefel, Ayquipa-Valenzuela, et al 2016).

6 *Promote the sustainable governance of AFL at different scales:* Scaling-up local experiences (eg management practices and governance arrangements) to landscape, national, or regional levels is often a stated goal for interventions that promote the sustainable governance of natural resources (Cash et al 2006). Yet, what works well in one place may not necessarily function in another, due to social or ecological differences, which are especially pronounced in mountain areas. It is also necessary to take into account the specificities of local contexts when assessing socioeconomic and political factors that shape national policies, and this may not lead to simple universal mandates or procedures, either. One approach would be to evaluate the effects of local bottlenecks that hinder the implementation of national policies (eg competing economic priorities and socio-environmental conflicts).

Overall, there is a need to explicitly consider the institutional arrangements, power relations, and other processes that promote or hinder the intended effects of these interventions at both local and national/regional levels of policymaking and implementation (Rist et al 2007). Special attention should be paid to successful socioeconomic innovations that have been tested in local contexts and have the potential to be scaled up or replicated elsewhere. In the Ecuadorian Andes, for instance, agro-industrial floriculture has proven resilient to changes in global trade patterns and climate, and it has provided opportunities for employment, reducing outmigration (Knapp 2017). Another recent initiative in Ecuador has focused on alternative market channels with direct exchanges between local producers and buyers in weekly markets, to increase food sovereignty and strengthen social networks (Padilla and García 2016).

In this category, the following research objectives should be prioritized:

6.1. Develop and test ways to up- and out-scale local solutions (eg management innovations and traditional practices) to the national or regional level.

6.2. Develop and apply approaches that integrate knowledge produced by different actors at multiple scales (eg integration of traditional and new technologies in a way that is appropriate for local contexts) through social learning processes (Rist et al 2007). This can be done through the use of multistakeholder learning tools (Rist et al 2009) and the promotion of science–policy interfaces (López-Rodríguez 2016).

6.3. Improve the mechanisms through which national and regional policies are implemented in diverse local contexts (Moss and Newing 2010), focusing on different institutional management schemes (eg community based, private, and public) (Swift et al 2004; Shanee et al 2015). Particular attention should be paid to the integration of forest users' and local communities' interests into regional and national processes of land-use planning (Norris 2014; Zimmerer and Bell 2015).

6.4. Facilitate the diffusion of synthesis information about the importance of AFL, their sustainability challenges, and their links with livelihoods and ecosystem services to inform decision-making in national and regional agendas, particularly those dealing with climate change adaptation and mitigation, and large national projects that draw on AFL resources (Andersson 2003; Rival 2003; Llambí et al 2005).

7 *Promote restoration in AFL:* Landscape restoration is a fundamental strategy to recover and maintain the ecological functions of forests and landscapes (eg species composition and diversity, water regulation and provision, and carbon storage) under future environmental conditions. Restoration has recently been given higher priority in the land-use and forestry agendas of Latin American countries, which committed at the 20th Conference of Parties in Lima in 2014 to Initiative 20×20, an effort to restore more than 20 million hectares of degraded land by 2020. Promoting effective restoration as part of a broader set of strategies for sustainable land management requires detailed systems knowledge about Andean forest ecosystem dynamics, the functioning of anthropogenic systems, and the socio-institutional aspects of restoration. It also requires transformation knowledge, which should be produced with local and external stakeholders to validate the systems knowledge and to define restoration goals, as described in research objective 4.4. above.

In this category, the following research objectives should be prioritized:

7.1. Identify the main potentials, bottlenecks, and enabling institutional conditions for restoration by critically reviewing, through a multistakeholder participatory process, existing initiatives in the region. This should include consideration of how restored forests can contribute to mitigation and

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adaptation, as well as their resilience under future climate scenarios.

7.2. Compare active restoration approaches with the self-regeneration capacity of degraded forest (secondary succession pathways) after different forms and durations of use (Chazdon et al 2016; Wilson and Rhemtulla 2016).

7.3. Compare the impacts of different restoration practices (eg natural regeneration, reforestation with exotic or local species, restoration of remnant forest, and planting of trees on farms) on key ecosystem services and livelihoods (Hofstede et al 2002; Farley 2007; Wilson and Rhemtulla 2016), and draw conclusions for action from local to landscape scales.

7.4. Through stakeholder participation, define a common set of criteria to assess the success of efforts to restore forest biodiversity and functions (eg species composition and ecosystem services) by comparing restored areas with natural forest, and identify suitable indicator taxa (Fehse et al 2002; Báez et al 2010; Orsi et al 2011; Spracklen and Righelato 2016; Wilson and Rhemtulla 2016).

7.5. Identify and validate with stakeholders locally developed and adapted technical approaches (eg related to tree seedling production, planting techniques, and introduction of nurse plants) for the restoration of altered ecosystems, considering the wide range of social and environmental conditions in the AFL (Aide et al 2010; Gómez-Ruiz et al 2013; Anthelme et al 2014; Bueno and Llambí 2015).

7.6. Develop concepts and tools to identify areas where ecosystem restoration has the potential to maintain and enhance connections between Andean forest remnant patches (Anthelme et al 2014; Wilson and Rhemtulla 2016) and with the Amazon Basin, or to provide the maximum benefits to human populations (Orsi et al 2011), or where it can be compensated through payment-for-environmental-services schemes.

The way forward

A combination of contributions from different research fields to *systems*, *target*, and *transformation* knowledge is urgently needed to support decision-making and guide future interventions in AFL, in order to contribute to sustainable development in the Andes. Improving our understanding of AFL social–ecological *systems* requires both specialized disciplinary studies to address specific knowledge gaps (eg focusing on AFL subsystems) and interdisciplinary approaches to further disentangle the dynamic interactions among social, economic, ecologic, and political factors, as well as the links between actor interactions and related outcomes. The production of *target* knowledge for increased sustainability in AFL requires a transdisciplinary dialogue among actors from academia, civil society, and governments at different levels about sustainability goals and the trade-offs between multiple outcomes. Learning from the knowledge, technological skills, and experiences of local people and practitioners will be crucial for the generation of *transformation* knowledge (Zinngrebe 2016). Finally, it will be essential to focus on both knowledge production and concrete interventions, in a practice of reflexive governance that challenges the normative base of both (Voss and Bauknecht 2006).

The scientific knowledge produced by the proposed research agenda may contribute to a large number of SDGs and targets, as shown in Table 3, with special relevance for Goal 15 (protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss), but also for Goals 1 (end poverty), 2 (achieve food security and promote sustainable agriculture), 5 (achieve gender equality), 6 (achieve availability and sustainable management of water), 8 (promote inclusive and sustainable economic growth), 10 (reduce inequality), 12 (ensure sustainable consumption and production patterns), and 13 (take action to combat climate change and its impacts) (United Nations General Assembly 2015). To contribute to achieving the SDGs in the Andean region, we recommend that research in AFL focus on the action situations, where the links between resource systems and governance systems are concretized, as well as on their outcomes in terms of synergies and trade-offs among ecosystem services and livelihood benefits for Andean populations.

Our review and discussions showed that there is relatively little experience with such integrated research in the Andes, and that the necessary institutions may not yet exist. Meeting the proposed goals will require commitment to their achievement as well as enhancements to educational, research, and management capabilities. Also necessary is the strengthening of platforms for collaboration and knowledge exchange among researchers and practitioners in the region (eg the Andean Forest Network), which would facilitate the synthesis of long-term monitoring information on the regional variability of Andean forest ecosystems (Peralvo and Bustamante 2015) and help coordinate comparative integrated studies.

Strategies must also be developed to improve communication and dissemination of knowledge about the value of AFL and their critical role in biodiversity conservation, livelihood benefits, and other ecosystem services, and their projected responses to global processes of change. This knowledge should inform landholders, policymakers, and other stakeholders on mechanisms for achieving multiple objectives in AFL and reconciling the imperatives of environmental conservation and

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socioeconomic development. More specifically, the knowledge produced by this research may facilitate the inclusion of managed or restored AFL in climate change mitigation and other national programs (eg the Reducing Emissions from Deforestation and Forest Degradation program and National Adaptation Plans).

This research agenda is not exhaustive and does not identify all the gaps in research on the complexity of AFL. It is a living document that should be iteratively adapted as the context and needs of AFL stakeholders evolve. We believe that the conceptual framework and many of the research priorities presented here may also apply to other mountain areas of the developing world, in light of their many commonalities with the Andean region, including the most important drivers of changes in forest landscapes. However, the process of developing a regionally adapted research agenda should not be bypassed, because sustainability goals will inevitably vary over time, across space, and among actors, and a sustainability research agenda will thus only be legitimate if it is the product of a local, evidence-informed dialogue.

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Supplemental material

TABLE S1 Experts who helped develop the AFL research agenda.

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