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Chapter 6
Silvopastoral Systems in Northern Argentine-Chilean Andean Patagonia: Ecosystem Services Provision in a Complex Territory

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Abstract Silvopastoral systems (SPS) are sustainable production systems, characterized by a great biodiversity and multifunctionality compared with other livestock production systems. Northern Argentine-Chilean Andean Patagonia is a complex socio-ecological system where the provision and perception of ecosystem services

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(ES) vary depending on multiple contexts. We aim to characterize multiple ES and the associated benefits from SPS under different contexts and key factors. We propose a conceptual model of the socio-ecosystem that considers socio-historical contexts, forest ecosystems, cultural contexts, relational values, and anthropogenic aspects. We provide a deep review of published information on these factors and how these are related to the provision and perception of ES. We also consider natural and anthropogenic drivers to assist government and institutions. Finally, we discuss the main knowledge gaps that need to be addressed to attain a sustainable management. There is a need for a multidisciplinary and regional approach that can serve as a new interpretive framework for managers and decision-makers. In particular, the inclusion of relational values with nature and the visibility of anthropocentric factors can be useful tools for local development.

Keywords Livestock · Native forest · Socio-ecosystem · Sustainable management

1 Introduction

Silvopastoral systems (SPS) are sustainable production systems, characterized by a great biodiversity and multifunctionality compared with other livestock production systems (e.g., conversion of native forests to forage). SPS intentionally integrate grasslands or pasture forage with livestock in a complex system where the interactions between components are actively managed to ensure sustainability (Salinas et al. 2017). The modern concept of sustainability implies ecological and economic viability, as well as social acceptability (Roseland 2000; Matthies et al. 2017). In this context, SPS aim to increase the provision of ecosystem services (ES) (e.g., forest, non-forest products, livestock), with the minimum impact on regulation and support services, and maintain the cultural services associated with forests.

The Andean zone of north Patagonia contains great ecological and socio-cultural diversity, encompassing the province of Río Negro in Argentina and the region of Aysén in Chile. This territory with common environmental and socio-cultural characteristics has led to the development of SPS as a similar production option. However, the actual use of SPS (predominantly pastoral) is still far from an integral management of the system. In most cases, management only considers the livestock component, while the medium- and long-term planning of pasture and forest resources has not been fully integrated.

In this region, livestock grazing in native forests is an historical practice. Prior to "criollos" settlement by the end of the nineteenth century, native communities based their productive activities on livestock, with a strong transhumance component to both sides of the Andes Mountains (Cardozo 2014; Rusch and Varela 2019). The first permanent settlers maintained an economic structure based on livestock, but they practiced forest clearing and fires to increase agricultural and livestock sectors in the region, as well as the use and commercialization of large amounts of native forest resources (Kitzberger and Veblen 1999; Sotomayor and Barros 2016; Rusch and Varela 2019). Besides the strong social and economic transformation in the territory, livestock production continues to be an important activity due to local traditions and rural home incomes (Bondel 2008; Guitart Fité 2008; Cardozo 2014). At different scales, livestock still remains as the main production being a main factor in the transformation of the natural landscape (Easdale 2007).

In order to attain sustainable development through the provision of multiple ES, it is necessary to consider the territorial complexity of the socio-ecosystem of SPS, where multiple factors interact at local and regional scale. For this, we propose a conceptual framework based on a socio-ecosystem to integrate the territorial complexity of Andean North Patagonia. This framework includes socio-historical contexts, forest ecosystems, and cultural contexts, and it considers relational values and anthropogenic aspects, two key factors that have not been integrated into previous socio-ecological analyses. First, we provide a review of the published information on these factors at the local scale including natural and anthropogenic disturbance drivers to assist governments and institutions. Then, we review the backgrounds related to the provision and perception of ES in SPS. Finally, we integrate current knowledge about ES within the proposed socio-ecosystem framework to discuss main knowledge gaps and needed management practices.

2 Silvopastoral Systems in Andean North Patagonia of Argentina and Chile

In the Andean forests of the Río Negro Province, Argentina, Cardozo (2014) identified and characterized two main typologies of livestock-based producers and different socio-productive strategies, grouped into "small" and "medium" categories. Both types carry out mixed livestock, mainly cattle with sheep and goats. The workforce is family-run, with temporary salaried employees. Small producers (up to 1000 ha) practice intensive continuous grazing (year-round) with winter food supplementation. The cattle herd is small (<10 breeding cows), and the average total stocking rate is 5.6 livestock units (LU)/ ha. A significant percentage of income is extra-property (>50%). Medium producers (up to 8000 ha) use a great diversity of environments and forest types, generally in an altitude gradient, which allows extensive grazing and seasonal management of livestock (winter-summer). The cattle herd is larger (>40 breeding cows) with mean total stocking rate of 1.2 LU/ha (Cardozo 2014). A large part of their income is from production (>50%), complementing the livestock activity with summer agrotourism (e.g., hiking, horseback riding, camping, shelter, rafting, fishing).

Medium-sized producers' farm is covered with native forests in more than 70% of the area (Cardozo 2014), traditionally used for both livestock activities and forest extraction (silvopastoral use). Livestock remains in the valleys and at middle slopes with a dominance of mixed forest of ciprés de la cordillera (*Austrocedrus chilensis*) and coihue (*Nothofagus dombeyi*) during autumn, winter, and spring (winter areas "invernadas"). In the summer, they move animals to highland forests (summer areas "veranada") dominated by lenga (*Nothofagus pumilio*) and ñire (*N. antarctica*) (Cardozo 2014; Arias Sepúlveda and Chillo 2017; Chillo et al. 2018; Amoroso et al. 2018). In this type of farms, it is common to find gaps in small areas to create grazing areas and corrals (pastures or "pampas"). In the forest, timber and firewood extraction is usually carried out to open the canopy to obtain wood products and increase of understory forage availability. In these open canopy areas, cattle spend more time and more intense use than in closed forest, creating heterogeneity in silvopastoral use in the same farm (Chillo et al. 2018, Amoroso et al. 2018).

In general, the complexity of this anthropogenic disturbance is associated with intensity gradients given by the heterogeneity in the landscape (exposure and slope, presence of streams, forest type) and management strategies (opening of pampas, presence of paddocks, and handling areas). Consequently, this results in a landscape's matrix of great spatial heterogeneity that includes areas with low-medium intense use and areas degraded by overexploitation (logging and overgrazing). This pattern has been recorded both in summer grazing areas of lenga forest (Quinteros et al. 2012, Quinteros 2018) and in mixed evergreen forests during winter grazing (Chillo et al. 2018, Amoroso et al. 2018) (Fig. 6.1).

In the north Patagonian forests of the Aysén Region (Chile), the heterogeneity of socio-productive environments and the geography determines the differentiation of producers, depending on farm size and availability of capital and technology. In this sentence, there are three types of exploitations: small producers (a peasant-type farm with an agricultural area of 12 basic irrigated hectares and the income mainly is from farming or forestry) and medium and large farmers with an agricultural area that provides significant commercial returns and benefits (PASO 2000). The

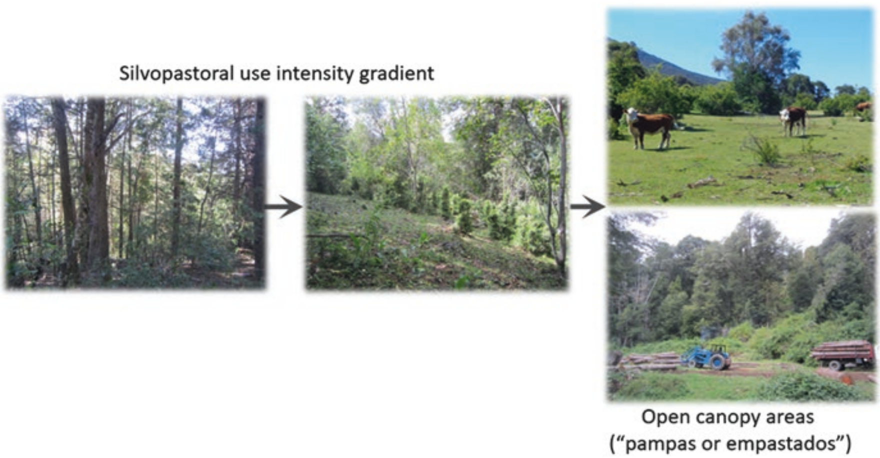

Fig. 6.1 Typical silvopastoral use gradient in winter areas of mixed ciprés-coihue forests at Río Negro Province, Argentina

productive activity in the Aysén region supports around 2285 cattle farms in 1,461,475 ha, mainly slaughtered in other regions. INE (2007) indicates that beef cattle reach 143,919 heads, mainly Coyhaique Province which accounts for 50% (FIA 2016). Of the total number of cattle, 60% is produced for small farmers in paddocks with meadows and forests.

In the region, there are two clearly defined cattle production systems, breeding and fattening, both of which are dominated by the Overo Colorado and Hereford bovine breeds. The bovine breeding system is developed by small and medium producers and is mainly sell directly on the farms or indirectly through local cattle fairs. This income is complemented by other farm activities such as the firewood, horticulture, and non-wood forest products. The fattening system is carried out mainly by large producers (more than 1000 breeding cows) (IICA et al. 2006). In the last 20 years, the average carrying capacity of the region has remained at around 0.15 EAU/ha (equivalent animal unit), which implies that the region can support a maximum of 189,735 EAU under current conditions.

The territory of the Aysén Region represents a recent history of colonization (Ortega and Brüning 2004), which has transformed large extensions of deciduous lenga and ñire forests into rangelands and scattered fragments of these native forests (Veblen et al. 1996, Sanchez et al. 2011). Thus, cattle ranching constitutes the basis of deep-rooted traditions in the local population since the beginning of colonization (Ortega and Brüning 2004). The use of the forest by livestock producers is associated with partial cutting for firewood (energy use), creating canopy openings that increase understory biomass for cattle grazing (Fig. 6.2). The occupation of the forest by cattle is not continuous and permanent, but it is accentuated in dry seasons with very hot summers or winters with very cold temperatures, where the use of the forest provides comfort to the cattle. Thus, the system of livestock uses lenga forests in summer and ñire forests in winter.

Fig. 6.2 Illustration of a typical silvopastoral system in ñire forest of the region of Aysén, Chile

3 Conceptual Framework of the Socio-ecosystem

According to Pascual et al. (2017), better life quality of local inhabitants would be achieved by linking nature material and intangible goods for people. Moreover, this idea should be expanded by considering different visions of nature from users or stakeholders. For example, native people values nature for human well-being (Rozzi 2012). In order to understand the ways of obtaining life quality in interaction with nature, it is first necessary to distinguish that different societies have different perceptions and knowledge (Pascual et al. 2017). In this context, we define “relational values” as the degrees of people responsibility in actions for perpetuation of ecological cycles. These different human-nature interactions are multidimensional and depend on multiple factors in a temporal trajectory such as social, economic, historical, and environmental.

The case of SPS in the Andean northern Patagonia in Chile and Argentina experienced through the history economic-social and environmental events that determined its current state. To achieve higher life quality, people have developed different management strategies according to their different perceptions of “quality.” Therefore, different conditioning contexts determine different ways of valuing and using native forests.

Here we present a conceptual framework for better understanding of the socio-ecosystem of SPS in Andean North Patagonia of Chile and Argentina (Fig. 6.3). In this heuristic model, multidimensional human-nature interactions are considered, including different contexts that arise from such complex socio-ecosystem. The existing forest systems and the socio-historical context are structuring elements in SPS interacting with the cultural context (Fig. 6.3). This creates different relational values of interaction with forests. This occurs because different social actors have different conceptions of environmental uses with contrasting possibilities to implement the vision in SPS.

The socio-historical context represents those external social and political factors that have directly affected the region over time, such as the creation of provincial/regional states, land colonization, and policies assigned to the use of land through different laws and public institutions. This set of decisions and policies has shaped the evolution of the SPS in Argentine and Chilean Patagonia over the last 300 years. For example, the new societies established at expenses of original people were a result of social and political decisions that determined a particular trajectory and interactions with nature.

The forest ecosystems represent the environmental context (ecosystem and biodiversity subsystem in Fig. 1.3, Chap. 1), characterized by the different forest types where the SPS are developed. The dominant plant community formation is the humid, deciduous, or evergreen temperate forest with different species composition according to altitude, latitude, and aspect. Together with a consistent variation in climate attributes, geomorphology characteristics, substrate, and topography, there is a variation in both vegetation and fauna species (Donoso 1993).

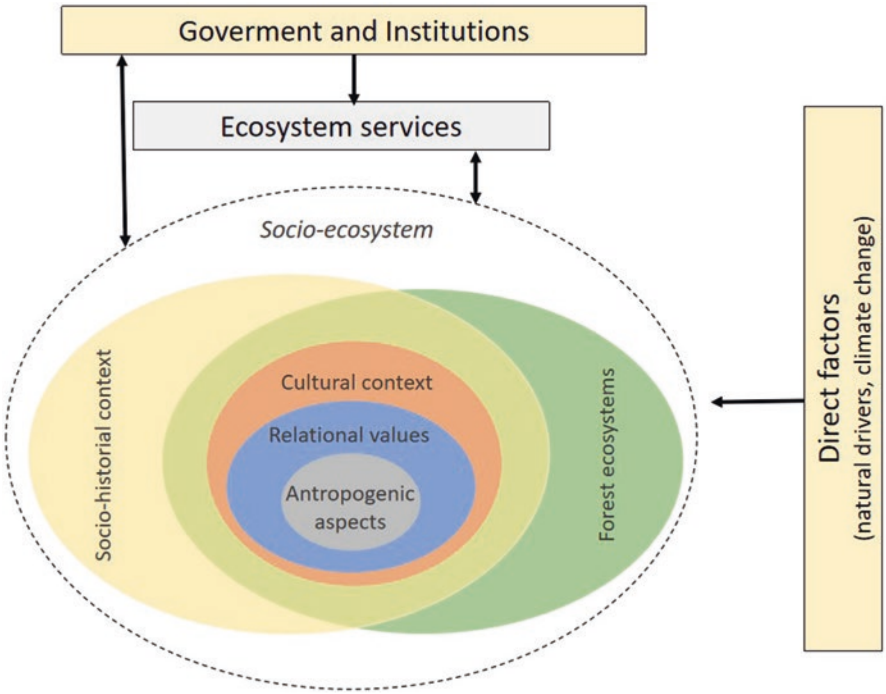

Fig. 6.3 Proposed conceptual framework of the socio-ecosystem (modified from Fig. 1.3) for the analysis of silvopastoral systems in Andean North Patagonia

In the north of the Argentine Patagonia, the western and altitudinal limit of the temperate forest is occupied by the lenga deciduous forest. This strip of forests protects a large part of the headwaters, being mainly monospecific, although mixed forests in humid environments are also common associated mainly with other species of the genus *Nothofagus* (*N. dombeyi*, *N. obliqua*, *N. alpina*) (González et al. 2006; Lara et al. 2014). These forests are dense, with large individuals (25–30 m tall) that gradually lose height with altitude until they blend with the coihue forest. Even in places where legna forest reach the highest productivity, these forests support a relatively low understory richness, except when it is associated with grasslands, peatlands, wetlands, and ñire forests. This evergreen species forms pure forests with tall and old individuals in humid extreme environments (3000–2500 mm/year) (Suarez and Kitzberger 2010) and gradually lose height and productivity when rainfall decrease (2000–1400 mm/year), where mixed forests with ciprés de la cordillera (*A. chilensis*) occurs. The mixed evergreen forests of coihue and ciprés are characterized by closed and dense canopies forming even-aged and stratified stands (Veblen et al. 1992a, b, Dezzotti 1996). The proportion of ciprés in these mixed forests is inversely proportional to soil moisture availability and altitude. As precipitation decreases to the east, ciprés forests dominates the mesic sites (900–1600 mm/year) forming pure and dense stands. In colder and wetter sites in the mountain, ciprés becomes a thicket associated with re-sprouting species such as ñire, *Lomatia hirsuta*, *Schinus patagonicus*, *Maytenus boaria*, and *Aristotelia chilensis*, among others (Donoso et al. 2006; Lara et al. 2014). At the driest distribution of ciprés (600–900 mm/year), open forests are developed characterized by isolated individuals or semi-closed to open stands in a steppe matrix, where the establishment of new individuals is sporadic (Villalba y Veblen 1997).

Ñire forests grow across the precipitation gradient and in a wide environmental diversity including valley bottoms, steep slopes with shallow soils, floodplain environments, and from the tree line to the forest-steppe ecotone (Veblen et al. 1996, Donoso et al. 2006). This species with broad ecological tolerance forms pure or mixed forests and occurs mainly as scrublands or open structures (Frangi et al. 2004). The characteristics of these forests is the high understory plant diversity and widely used for cattle raising.

In Chile, the Aysén Region occupies the eastern sectors of the Patagonian mountain range and comprises areas with valleys and higher rainfall where the dominant ecosystem is a temperate forest dominated by lenga and the evergreen Magellan's coihue (*N. betuloides*), tepa (*Laurelia phillipiana*), and mañíos (*Podocarpus* spp.) (Hepp 2019). According to Hepp (2014), in the Aysén Region, four large agro-climatic zones can be distinguished.

The coastal or insular zone is characterized by an extensive islands and archipelagos network located in the Patagonian channels and fjords and covered with evergreen forest mainly dominated by Magellan's coihue, mañíos, canelo (*Drimys winteri*), and other species. The predominant climate is temperate humid littoral with precipitations that exceed 3000 mm/year, reaching 7000 mm/year in some sectors. The islands have shallow and rich in organic matter soils on rocky material, not suitable for agricultural or forestry productive development. The humid agro-climatic zone is located in the continental western slope of the Andes mountain range. The predominant climate is the coastal humid temperate, characterized by average rainfall of 2640 mm/year. The predominant vegetation is the evergreen forest of Magellan's coihue, tepa, and *Podocarpus* spp., with other species in the understory such as canelo, notro (*Embothrium coccineum*), and myrtle (*Luma apiculata*).

The Intermediate zone, located on the eastern aspect of the Andes mountain range, is characterized by valleys that emerge towards the east of side of the region. This area has various climates, depending mainly on the altitude. At high altitudes, the boreal Andean climate predominates, while in the low areas, the intermediate humid temperate climate occurs with an average annual rainfall of 1150 mm/year. The predominant natural vegetation is the *Nothofagus* deciduous forest, especially lenga and ñire in certain more humid sectors and in transition towards steppe areas, respectively. This area was the most affected by large forest fires during the colonization period, particularly the beginnings of the twentieth century.

Finally, the steppe zone is associated with the steppe biome with tussock grasslands, in areas bordering Argentina. At high sites, the boreal Andean climate shares transitional characteristics towards colder conditions, with dominance of ñire forest.

However, the predominant climate is cold climate with an average annual precipitation 588 mm/year.

The regional cultural context is diverse and multicultural, determined from the ancestral existence of native peoples, the "criollos," and European immigration of the late nineteenth and early twentieth century, and the most recent immigration resulting in the current urban centers. The Andean North Patagonia has been inhabited by different communities of native peoples such as Mapuche, Tehuelche, or Mapuche-Tehuelche. The original territory of the Mapuche people occupied areas in southern Chile and Argentina, from the Pacific to the Atlantic oceans. These societies traveled long distances for the exchange of goods by synchronizing the cycles of nature in the complementary use of different environments (Ladio and Molares 2014, 2017). Currently, they live in subsistence conditions in marginal areas and correspond to the typology of small producers. In their subsistence systems, the role of the family and community action are key organizational aspects for the management of the SPS. For example, in the province of Río Negro, about 70% of livestock-forestry producers are considered small (small land size with low number of animals) and depend on family working force, with little contract labor (Cardozo 2014). In this context, the lack of young people working in family farms is recognized as the main problem for management and technological innovation (Cardozo 2014).

The main community organization for indigenous, artisan associations, and/or farmer's cooperatives to sale products (wool, timber, artefacts) in rural markets is essential to overcome the limiting conditions of development. In these communities, there are several ways of collaboration such as the exchange of goods (firewood for animals) and joint work in the construction of corrals and fences and animals marking. The community organization within the cultural context guarantees the governance within the SSP.

In Fig. 6.3, the relational model, based on Muradian and Pascual (2018), represents the set of society's preferences, principles, and virtues that explain the degree of responsibility towards nature. In case of the SPS of Andean North Patagonia from Chile and Argentina, we can distinguish the following: (1) domination, when degradation of nature is intentional; (2) exploitation, when nature is only considered an element of consumption and services; (3) custody, when it is protected for its intrinsic value; (4) management, when practices are carried out allowing the perpetuation of ecological cycles and cultural life systems simultaneously; (5) the ritualized exchange; and (6) devotion, when nature is established based on religiosity and mutual integration. In the Andean-Patagonian forests, these typologies can be described by their socio-environmental history. The characterization of the main actors interacting with forests from these points of view is essential for the understanding of the logic applied to management and the knowledge and values that are put into practice.

In the case of Mapuche-Tehuelche communities, the logic under which they use the landscape corresponds to a relational model linked to management, devotion, and ritualized exchange, where mutual care has prevailed between people and forest (Rozzi 2012; Castillo and Ladio 2017). But also other forms of interaction have been developed in the territory. The colonization of the Andean-Patagonian forests by Spanish and criollos began in the Chilean territory in the mid-nineteenth century. After more than 250 years of war between the Spanish and the Araucana nation, the advance on forest occurs by following a relational model of domination. With the consolidation of the Argentine state at the end of the nineteenth century, the occupation and use of the region were established under the relational model of exploitation of natural systems. A production model based on extensive cattle ranching on natural grasslands in the hands of few landowners occurred on lands usurped from native people. As a consequence, the notion of private property was established, followed by large-scale deforestations and fires that reduced the forest cover, mainly ciprés and coihue (Ladio and Molares 2014). This determined the displacement of small and medium farmers to the driest and less productive areas in the region. In both countries, since the twentieth century, the main drivers of use of the landscape correspond to logging of native and exotic forests, tourism, and livestock under an exploitation model based on market utilities.

Finally, with the creation of national parks (i.e., Lanin, Alerces, and Nahuel Huapi) in the middle of the twentieth century, a custody model was added to the Andean northern Patagonian based on SPS, which included logics of forest care directly linked to the valuation of ecosystem services and diversity. In the last 20 years, the parks have incorporated the figure of co-management with native communities, accounting for the valuation of the cultural context in the maintenance of biodiversity. Consequently, the different anthropogenic disturbances in SPS of north Andean-Patagonia arise from the link between the multiple contexts proposed for this socio-ecosystem.

Finally, the value and perception of different ES also vary depending on anthropogenic aspects. For example, local ecological knowledge (LEK) of farmers assist them to better manage nature, with greater governance and resilience (management of water, soil, biota, animal health) (Cardoso et al. 2015; Castillo and Ladio 2017). It is important the integration of LEK with scientific knowledge through mechanisms of social learning and interchange (Ladio 2017), as well as a link with state institutions of extension and technology transfer (Cardozo 2014). Also, it needs an adequate articulation between public and private institutions to obtain their welfare objectives (Ladio 2017; Castillo et al. 2020), as well as access to communication (telephones, internet, and roads), health, and education to rural inhabitants. Another important aspect is the access to a complementary use of landscapes for the collection of non-wood forest products (food and medicines) (Molares and Ladio 2012; Morales et al. 2017, 2018).

4 External Drivers of Change

Governments and institutions appear transversely within the socio-ecosystem model. In the SPS of north Andean-Patagonia, we identified mainly state institutions in their multiple levels of action. In Río Negro, there are two main laws regulating the forest use: Provincial Forestry Law No. 757 (1972) that establishes the regulatory framework for the defense, improvement, and use of forests and Provincial Law of Native Forests No. 4552 (2010) that establishes the complementary norms for the conservation and sustainable use of native forests under the National Law of Minimum Budgets No. 26331. Law 26,331 promotes the conservation of native forests through land planning, sustainable management, and land-use change regulations. Native forests have been classified according to three conservation categories: red (high forests conservation value for ancestral uses, gathering of non-timber forest products, scientific research, “respectful” tourism, conservation plans, ecological restoration), yellow (medium forests conservation value for sustainable productive activities and tourism under management and conservation plans), and green (low forest conservation value where land-use change is allowed).

At the national level, during the 2010–2014 period, more than 70% of the budget has been destined to SPS plans in yellow areas. Furthermore, articulation of public policies for silvopastoral development has been developed in a joint institutional agreement between the Ministry of Agriculture, Livestock, and Fisheries and the Ministry of Environment and Sustainable Development (SAyDS) and the National Agricultural Institute (INTA). This general agreement named “National Forest Management with Integrated Livestock (MBGI)” aims mainly to (i) contribute sustainable use of native forests as a tool of development and according to sustainability criteria and minimum standards established by Law No. 26,331 and (ii) strengthen the provinces by promoting capacity building for implementing MBGI plans and (ii) establish a monitoring system. To expand silvopastoral land-use systems and farmer adoption, a multiagency, interdisciplinary, and participatory strategy is required.

In Chile, there are mainly two state regulations related to incentives for the establishment and management of agroforestry systems. The System of Incentives for the Agro-environmental Sustainability of Degraded Soils (SIRSD-S) aims to recover the productive potential of degraded agricultural soils. The Institute of Agricultural Development (INDAP) and the Agricultural Livestock Service (SAG) are the institutions of the Ministry of Agriculture responsible of the administration of this financing instrument to different farmers according to their production size. In relation to agroforestry systems, the financing instrument incentives to establish trees cover under SPS use for soil conservation.

The objectives of Law N° 20,283 of Recovery of the Native Forest and Forest Development are the protection, recovery, and improvement of native forests, in order to ensure forest sustainability and environmental policy. It was promulgated in 2008 and contains regulatory and promotional aspects for the management and recovery of the Chilean native forest. The National Forestry Corporation (CONAF) is the institution responsible for its implementation. Unfortunately, Law N° 20,283 does not consider financing the implementation of SPS in native forest due to the lack of information on natural regeneration. However, there is the Native Forest Research Fund (FIBN) that finances competitive research projects to incorporate improvements to Law 20,283 including the topic forests and livestock.

Finally, there are several direct drivers that affect the operation and structure of SPS (Fig. 6.3). The study and description of the main forest disturbances in northern Patagonia (39–41° S) have been reported previously (González et al. 2014; Lara et al. 2014; Srur et al. 2020). The main natural disturbances in these forests are fire, volcanism, landslides, snow avalanches, wind, droughts, forest decay, insect's population explosions, and bamboo blooms (González et al. 2014). Fire has been used as an instrument of agricultural management in humid forests or hunting in the ecotone between the forest and the steppe by the native communities, being a driver of land-use change (Willis 1914; Kitzberger and Veblen 1999) and, recently, urban development. The most important anthropic disturbance factors in the region are deliberate fires, overgrazing (mainly cattle and sheep), invasion of exotic plant and animal species, and timber overexploitation (Veblen et al. 1992b; Relva and Veblen 1998: Rovere 2008; Rovere et al. 2014). The increase of urbanization in Patagonia (Lantschner et al. 2008) is another disturbance factor that modifies ecosystems and introduces numerous invasive exotic species (Rovere et al. 2014). Moreover, there is an increase demand of pristine land by wealthy foreigners with the logic of private reserves or extensive livestock production. This concentration in few landowners generates a process of local emigration to urban areas with a decrease in their life quality.

5 Ecosystem Services in Silvopastoral Systems of Andean North Patagonia

The Andean-Patagonian forests sustain a wide variety of ecosystem services (ES) including provisioning, regulating and supporting, and cultural. In general, SPS in ñire forests have been the most studied, probably because they represent the main forest type where livestock farming takes place. In northern Patagonia in particular, the high use intensity of ñire forests has triggered degradation processes due to overuse of livestock and wood harvesting (Rusch and Varela 2019). ES and the associated benefits in SPS with different use intensities occurring in forest types of northwestern Patagonia are shown in Table 6.1.

Harvestable wood and meat production constitute the main provisioning services in SPS. Lenga and ciprés de la cordillera forests represent the main timber resources in the northern region of the Andean-Patagonian forests. In the case of ñire forests, firewood, poles, and rods (maintenance of fences, construction of paddocks and small buildings) are the most important products. The use of firewood has also been strongly linked to the regional development and the establishment of rural and urban communities. For example, the average biomass firewood consumption (for heating, cooking, fuel) in a Patagonian rural community is 12,000 kg/year/home (1479 kg/year/person), with significantly higher values during winter (63 kg/day/home) than in summer (18.5 kg/day/home) (Morales et al. 2018).

Table 6.1 Identification of main ecosystem services (ES) deriving from SPS in Andean North Patagonia, based on Common International Classification of Ecosystem Services (CICES) Version 5.1

Specific ES	Division	Simple descriptor (proxy)	Service	Goods and benefits	Reference
Provisioning	Biomass	Materials from wild plants used for energy	Volume of harvested wood	Processed timber Fuel wood Fencing construction	Morales et al. (2018)
	Biomass	Livestock grazing outdoors and/ or raised in housing	Increase in weight or numbers of cattle herd per year	Meat produced at abattoir, eggs, milk sold on farm or in shops, wood	Rusch et al. (2019); Salinas et al. (2017)
	Biomass	Food from wild plants (leaves, flowers, fruits, roots, bulbs, stems, exudates, barks and seeds)	Harvestable volume of wild plants and fungi	Berries and fungi as food. Fruits for the production of jam, infusions. Fiber for dyes. Leaves for the production of infusion, resins	Morales and Ladio (2009); Salinas (2019); Rusch et al. (2017); Chillo et al. (2018); Chamorro and Ladio (2020)
	Water	Drinking water from surface, ground, and belowground	Volume and characteristics of water from rivers, creeks, and aquifers	Potable water, mineral water, reduced energy costs (irrigation)	
Regulating and supporting	Regulation of physical, chemical, biological conditions	Controlling or preventing soil loss	The capacity of vegetation to prevent or reduce the incidence of soil erosion	Reduction of damage and associated costs of sediment input to water courses	Chillo et al. (2018); Gyenge et al. (2019)
	Regulation of physical, chemical, biological conditions	Regulating the flows of water in our environment	The capacity of vegetation to retain water and release it slowly	Watershed protection	Gyenge et al. (2019); Quinteros (2018)
	Regulation of physical, chemical, biological conditions	Ensuring the organic matter in our soils is maintained	Decomposition of plant litter	Maintenance of soil formation and quality	Arias Sepúlveda and Chillo (2017); Chillo et al. (2018); Goldenberg et al. (2020)
	Regulation of physical, chemical, biological conditions	Providing habitats for wild plants and animals that can be useful to us	Important nursery habitats (forest patches, shrublands)	Sustainable populations of useful or iconic species that contribute to a service in another ecosystem	Blackhall et al. (2008); Chillo et al. (2018b); Quinteros (2018); Gyenge et al. (2019)

(continued)

Table 6.1 (continued)

Specific ES	Division	Simple descriptor (proxy)	Service	Goods and benefits	Reference
Cultural	Direct, in situ	Using the environment for sport and recreation, sports, etc.	Ecological qualities of woodland that make it attractive to hiker; private gardens	Recreation, fitness; de-stressing or mental health; nature-based recreation	
	Direct, in situ	Watching plants and animals where they live; using nature to distress	Mix of species in a woodland of interest to wildlife watchers	Agro-tourism, rock painting	
	Indirect, remote	Using nature as a national or local emblem	Spiritual and religious values. Places where religious ceremonies and various aboriginal traditions take place	Social cohesion, cultural icon	Ladio and Morales (2017)
	Indirect, remote	The things in nature that we want future generations to enjoy or use	Endangered species (huemul, pudú pudú) or habitats (Alerce forests)	Moral well-being. Sense of belonging	

Ñire, as a main source of heat energy for the region, has been gradually replaced by fossil energy. However, in some rural and peri-urban communities, ñire still represents the most important and valuable energy resource. According to surveys in rural and urban households, ñire is also one of the species with the highest commercial circulation at the regional level (Arre et al. 2015; Morales et al. 2017). In Chile, the livestock use opened forest as a result of partial cutting (Fig. 6.2) that increases forage availability (Sanchez et al. 2011; Salinas 2016). In addition, the ñire wood is used in a variety of household utensils such as baskets and containers, furniture, and instruments. These types of products are particularly important for small landowners, artisans, and indigenous communities (Salinas and Acuña 2017).

Livestock for meat production represents the most important use of the forest in the entire region in terms of area. Livestock (sheep and cattle) production in the Andean area of northern Patagonia benefit from ecosystems contribution by providing forage biomass (Rusch et al. 2019). The ñire forests are the most used forest type for livestock production in terms of stocking rates due to high forage biomass. In non-managed ñire forests located in the transition with the Patagonian steppe, native plants productivity is between 200 and 350 kg/DM/ha, and under SSP management, understory productions increase up to 2500–3300 kg/DM/ha (Salinas et al. 2017). However, there are various types that farmers use in seasonal movements of livestock depending on the availability of forage during the year (Cardozo 2014). The lenga forests are used for summer grazing and the middle-slope mixed ciprés-coihue forests during winter. In ñire and lenga forests, livestock grazing combined with firewood extraction affect natural regeneration by transforming the forest into shrubby grasslands (Quinteros et al. 2013; Quinteros 2018; Vila and Borrelli 2011; Rusch et al. 2017). In mixed ciprés-coihue forests, this negative effect on the natural regeneration of the canopy is not clear, mainly because during the summer cattle are moved to other environments (Amoroso et al. 2018).

Wild plants for nutrition, materials, or medicine have been the basis of the food and health systems of the local populations in the region. More than 500 species with important uses had been recognized, including leaves, flowers, fruits, roots, bulbs, stems, exudates, barks, and seeds (Tacón Clavaín 2004; Molares and Ladio 2009; Mattenet et al. 2015; Salinas 2019). Forests also provide plants for dyeing and aromatic use, as well as forages and edible fungi relevant to the material and spiritual culture of local communities. There have also been examples of cultivating seeds, cuttings, or transplanting useful native plants for domestication (Ladio and Molares 2017). However, there are no official records or legislation regarding to non-wood forest products. It is interesting to mention that grazing can favor the development and growth of edible fruit bushes, edible fungi (e.g., *Morchella* spp.), and/or ferns used as cut foliage (Rusch et al. 2017). Thus, sites under silvopastoral use may present high plants diversity with known cultural value and uses (Chillo et al. 2018). Furthermore, in ñire forests of Chile, 40 species are used for medicinal purposes, 36 species for food production, 16 species as ornamental, and 8 species for dyes (Salinas 2019). From these, michay (*Berberis microphylla*) and maqui (*Aristotelia chilensis*) are distinguished especially by their potential due to their antioxidant properties (Arena et al. 2017; Chamorro and Ladio 2020).

Regarding the regulating and supporting services, soil quality in ñire forests severely diminished due to water and wind erosion and soil compaction in overused paddocks. Overgrazing decreases the nitrogen content in the system due to plant cover decrease and the loss of endo- and ectomycorrhizae mainly in radal (*Lomatia hirsuta*) and notro (*Embothrium coccineum*) trees. Also, the decrease in vegetation cover due to overgrazing decreases litter quantity and quality (Gyenge et al. 2019). Conversely, decomposition rate is favored in mixed ciprés-coihue forests with intermediate intensities of silvopastoral use compared with closed forests (Chillo et al. 2018). This is mainly because canopy openings allow the development of a heliophytic understory plant community, characterized by herbaceous species with membranous leaves, higher N content, and low specific leaf area (Arias Sepúlveda and Chillo 2017).

The regulation service provided by vegetation in mountain areas is affected by silvopastoral use since tree removal modifies soil stability through changes in litter input (quality and quantity) for the formation of organic matter (Gyenge et al. 2019; Chillo et al. 2018; Goldenberg et al. 2020). In forests with different site productivity, it has been shown that the increase in the intensity of firewood extraction modifies understory plant taxonomic and functional diversity vegetation cover by increasing the soil exposure to wind and drought. Because more exposed soils are prone to compaction and moisture loss, intensity management interventions should be adjusted to avoid degradation processes. In other forests of Patagonia, Bahamonde et al. (2015) highlighted that one of the main benefits of SPS is a greater resilience of the soil to the loss of nutrients compared to grasslands. In Chile, SPS have also been recognized in the improvement of goods and services associated with soil nutrition and microbial activity (Alfaro et al. 2018; Ortiz et al. 2020).

Regarding the regulation of water flow, overgrazed ñire forests reduced soil water retention capacity and increases surface runoff due to trampling and compaction that decreases soil porosity (Gyenge et al. 2019). In the areas where cattle are concentrated, water quality in lenga forests located at the head of the watershed is affected by increasing suspended sediments by 72% and phosphorus by 50% (Quinteros 2018).

Habitat provision by SPS for wild plants and animals can be considered as a proxy of biodiversity conservation. Grazing promotes the increases abundance of opportunistic herbaceous species (native and exotic) and reduces richness and abundance of palatable plants that are not tolerant to herbivory and/or increased light (Blackhall et al. 2008; Chillo et al. 2018b; Quinteros 2018; Gyenge et al. 2019). Canopy openings that increase light availability for the understory not always imply a decrease in biodiversity but rather changes in the botanical composition associated with different intensities of use (Chillo et al. 2020). In mixed evergreen forests, intermediate intensities of use increased specific and functional diversity, and this change in the composition of species generates changes in the biophysical provision of ES (Chillo et al. 2018, 2018b).

On the other hand, there is a knowledge gap regarding the role of SPS (synergies or trade-off) in supporting habitat for specialist forest species. For example, some authors described as indirect effect of livestock use the predation of dogs on native fauna, mainly on endangered species such as the iconic huemul (*Hippocamelus bisulcus*) (Silva et al. 2011; Muñoz-Santibañez and Muñoz 2016). In ñire forests of Southern Patagonia, the increase in coarse woody debris in the soil from harvesting provided habitat for small rodents and insects or even promotes trophic interactions between microbial fauna and insects (Gonzalez-Polo et al. 2013). Additionally, open forests with livestock use benefited the group of granivorous and migratory birds, unlike the group of birds that nest in cavities (Benitez et al. 2019). In the case of plants, the provision of habitat would be favorable for those species that tolerate intermediate levels of radiation (Chillo et al. 2018). However, considering the key role of biodiversity conservation to support the processes and functions that sustain ES (Daily 1997), we need to improve the understanding of the relationships between biodiversity and ES.

Finally, there are cultural services such as the areas for recreation, leisure, outdoor sports, local and international tourism, aesthetic value, and enjoyment. It also refers to those landscapes that are fundamental for the maintenance of the local cultural identity, for example, places for religious ceremonies of original people.

The Patagonian indigenous peoples conceive forests as their home as an inseparable part of their cosmology (Ladio and Molares 2017). Recently, there has been an increase of agro-tourism in private lands the properties (mainly camping and rafting spots), but still remains unclear the local and regional impact. In this context, local ecological knowledge (LEK) assist producers to better nature management (management of water, soil, biota, animal health), governance, and resilience (Cardoso et al. 2015; Castillo and Ladio 2017).

6 Main Local Drivers and Knowledge Gaps

The introduction and further expansion of livestock have been related to the occupation of the territory through appropriation models and based on the supply of natural resources like timber forest products. However, both components (forest and livestock) of SSP have been mainly managed separately. It is therefore necessary to work on a systemic vision of SPS management by considering productive and social objectives, relational values, and the interaction between components (forests, livestock, and forages). For this, the socio-ecosystem model proposed here for SPS may be useful for managers and decision-makers, since it considers the different socio-historical, cultural, and environmental contexts. An important aspect that makes the resulting relational model even more complex is the presence of aboriginal communities and large landowners in National Park areas. Because the socio-historical and cultural contexts are changing, it is necessary to analyze the interaction dynamics according to new legislation and the tensions between different models. The comprehensive analysis of the SPS from multiple social-ecological contexts allowed us to identify the main knowledge gaps for the comprehensive management of multiple ES in this complex territory. One of the knowledge gaps detected is the need to recognize and understand the specific relational models to each forest type in SPS of the northern Argentine-Chilean Patagonia. Design new SPS from an integral vision is needed to integrate forest and livestock production with the integrity of multifunctional ecosystems and the well-being of the producer and associated communities.

There is lack of information related to synergies and trade-offs between provision, regulation, support, and cultural ES for the different forest types under SPS use. Also, our knowledge regarding provision ES (firewood, timber, and non-wood products) in SSP had been reported isolated. We need further research to determine grasslands evaluation for stocking rate adjustment and animal supplementation for reducing the browsing effect on regeneration. Still we need to address the following questions: How interventions on the socio-ecosystem can be conducted to achieve favorable changes in SPS management? How forest resources can be managed to obtain structural diversity in the landscape that allows a greater provision of firewood and forage but in turn contributes to biodiversity and forest regeneration? What anthropogenic aspects can be linked to multiple ES management objectives in SPS?

Research has focused on supporting and regulation ES on forest types (mainly in ñire forests) at stand level, without a watershed or landscape view. Thus, information related to water regulation, biodiversity, erosion prevention, and soil fertility at the watershed level are needed. For example, riparian and wetland environments provide multiple ES (provision, regulation, habitat) within these socio-ecosystems and are poorly represented in our current knowledge and research. While traditional livestock farming deteriorated river beds and streams, there are few actions in conjunction with rural residents for river corridors protection or soil recovery through restoration. There is also a knowledge gap regarding habitat provision for specialist species under different SPS intensities at a landscape level. This information is needed for the understanding of the conservation values of SPS compared to more intensive production systems.

Finally, we need to detect and know how regulation and supporting ES are modified by different cultural contexts and relational values. Key questions to be explored are: Does similar socio-historical and cultural contexts determine similar relational values? How different anthropogenic contexts modify the generation, perception, and provision – both local and regional – of regulation and supporting ES? What is the relative importance of the different socio-ecosystem contexts in the generation, perception, and provision of ES in SPS?

7 Recommendations for Decision-Making Based on the Sustainability of Silvopastoral Systems

The consideration of local actors in the decision-making and management processes of the territory is of great importance due to its socio-ecological complexity. For example, we have shown that relational values and anthropogenic aspects are key drivers in the production and provision of ES. Therefore, it is important to achieve a participatory technical-scientific process with local communities for planning. For example, Del Castillo et al. (2019) reported that only 39% of social actors included the knowledge of non-experts from local communities in the context of ecosystem services assessment. Thus, it is essential to include rural inhabitants in the co-generation of information together with the academia, since knowledge come from different sources and perceptions. This may contribute to address specific problems with integrated information on these complex socio-ecosystems.

On the other hand, historically, this region is under a strong conservation policy. For example, with the creation of the National Parks in Argentina (Nahuel Huapi in 1934 and later Lanin, Alerces, and Lago Puelo) and provincial and municipal protected areas, more than 35% of the territory is under different degrees of protection and conservation regime. This protection implies a limitation for local people (that inhabited the land before the creation of the reserves) in SPS implementation, as the grazing areas for livestock had been reduced (no seasonal movements are allowed) and impacted their life quality. In north Andean Patagonia, the paradigm of land sparing implies that land-use intensification occurs outside protected areas with strong competition between urbanization, SPS, and tourism activities. We argue that considering SPS in a complex territorial matrix as proposed in our model implies that proper and sustainable management of SPS can lead to multifunctional landscapes (Soler and Chillo 2018), where generation of provision ES does not generate trade-offs with support and regulating and cultural services at the landscape scale. The agroecological paradigm for the territorial planning is more appropriate for sustainable development in this region (Perfecto and Vandermeer 2012).

In this context, the principles and guidelines for Forest Management with Integrated Livestock (MBGI) contemplate an adaptive management strategy based on a comprehensive vision of the environment by balancing the productive potential of livestock and forestry with the capacity and integrity of forests and the preservation of their services and maintaining and improving the well-being of producers and associated communities. To achieve this policy, there is an urgent need to generate a baseline at the regional level regarding the conservation condition, productive forestry and livestock activities with respective economic analysis, and characterization of local actors involved in decision-making for the use of resources. This territorial baseline based on the description of the current physical, biotic, social, and economic environment and the development of criteria and indicators to define reference states and transition thresholds will allow the elaboration of clear guidelines for livestock and forestry sustainable management in the region.

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