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Authors: Arzamendia, Yanina, Rojo, Verónica, González, Natividad M., Baldo, Jorge L., Zamar, María Inés, et al.

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The Puna Pastoralist System: A Coproduced Landscape in the Central Andes

Yanina Arzamendia[1,2]*, Verónica Rojo[1,3], Natividad M. González[4], Jorge L. Baldo[1,5], María Inés Zamar[6], Hugo E. Lamas[6], and Bibiana L. Vilá[1,7]

** Corresponding author: yanina.arzamendia@gmail.com*

[1] VICAM (Vicuñas, Camélidos y Ambiente), Luján, 6700 Buenos Aires, Argentina
[2] INECOA (Instituto de Ecorregiones Andinas), CONICET UNJu (National Research Council and National University of Jujuy), Faculty of Agricultural Sciences, National University of Jujuy, Alberdi 47, 4600 San Salvador de Jujuy, Argentina
[3] Department of Technology and Department of Basic Sciences, National University of Luján. Avenida Constitución and RN 5, 6700 Buenos Aires, Argentina
[4] CIITED (Centro Interdisciplinario de Investigaciones en Tecnologías y Desarrollo Social para el NOA), CONICET UNJu, Faculty of Human Studies and Social Sciences and Faculty of Economic Sciences, National University of Jujuy, Otero 369, 4600 San Salvador de Jujuy, Argentina
[5] CONICET and Faculty of Agricultural Sciences, National University of Jujuy, Alberdi 47, 4600 San Salvador de Jujuy, Argentina
[6] INBIAL (Instituto de Biología de la Altura), National University of Jujuy, Avenida Bolivia 1661, 4600 San Salvador de Jujuy, Argentina
[7] CONICET—Department of Social Sciences, National University of Luján, Avenida Constitución and RN 5, 6700 Buenos Aires, Argentina

In mountain socioecological systems, the interaction between nature and people is at the core of planning local long-term sustainable development strategies. Pastoralism is the main traditional socioeconomic livelihood in dryland mountains. It is strongly associated with long-established land use practices that provide essential material and relational contributions, both of which shape human populations and nature. The aim of this work is to characterize the traditional pastoralist system of the Puna (northwest Argentina) in a framework that highlights its diverse values and valuations within nature–people coproductions. We use the conceptual framework of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services as a tool to analyze and understand these socioecological systems. We also identify 3 coproduction types at different steps of the benefit flow from ecosystems to quality of life. Pastoral livelihood persists in the Argentine Puna, cocreating a landscape with natural and anthropic (water sources, grasslands, wildlife, livestock, and techniques) elements interacting through complex mechanisms involving environmental conditions and cultural and economic practices. Some drivers that threaten the system's sustainability are overexploitation and land use change. These are visible as poaching or conversion of pasturelands into mining areas. Finally, we identify a number of knowledge gaps. These include lack of information on some regulatory contributions of nature to people, biodiversity status, and trends and statistical information on Indigenous Peoples and local communities; the flow of relationships; and coproductions related to the local expression of the quality of life. We also highlight the need for spatially explicit information and comprehensive knowledge of drivers and socioecological dynamics of the landscape.

Keywords: *pastoral livelihood; camelids; Puna Argentina; highlands; rangelands; socioecological systems.*

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Introduction

A good grasp of interactions between nature and people, especially for mountain socioecological systems, is crucial in planning local long-term sustainable development strategies. These strategies are important for safeguarding both the natural assets that support and enhance human wellbeing in mountain environments and the key contributions of those ecosystems to human populations in either mountains or other environments (Payne et al 2020).

Pastoralism is the main traditional socioeconomic livelihood in dryland mountains. It is strongly associated with long-established land use practices that make relational and material (such as proteins and fiber) contributions, thus sustaining the poorest human populations of the planet (Nori and Davies 2007). Pastoralism and dryland management practices extend over almost 70% of rangelands all over the globe and preserve 46% of the world's livestock diversity (McGahey et al 2014).

The Altiplano or Puna in the Central Andes includes areas of Argentina, Perú, Bolivia, and Chile. Its southern area has challenging conditions for crops. Throughout the environmental history of the Puna, some animals have become domesticated through a coproduction process that took thousands of years of human–animal interactions. This generated 2 livestock species: llamas (*Lama glama*) and alpacas (*Vicugna pacos*) (Franklin 2011). Extensive grazing by llamas, alpacas, and sheep (*Ovis aries*) that frequently share grazing sites with wild *vicuñas* (*Vicugna vicugna*) provide the main income for at least 1 million pastoralists in the region (Leon-Velarde et al 2000; Quispe et al 2009; Devenish and Gianella 2012; Arzamendia et al 2014; González 2014). Pastoralist

systems usually combine llamas and sheep to both increase the system's flexibility and reduce its vulnerability (Postigo et al 2008). They also increase animal protein supply for families while leaving a smaller freshwater footprint than that of industrial livestock systems (Göbel 2001; Quispe et al 2009). Mobility is another strategy that pastoralist societies (spatially scattered and low in density) use to address environmental heterogeneity, such as resource availability and climatic conditions, especially during drought periods (Khazanov 1994; Yacobaccio 2014).

The rural space is experiencing a long-term gradual process of depopulation that threatens the continuity of pastoral livelihood as a socioeconomic system (Gil Montero 2007; Gil Montero et al 2007; González 2021). In recent decades, social processes and changes have resulted from countercultural policies, modifications in consumption patterns and life expectancy, and the establishment of megamining, all under a climate change scenario (Göbel 2003; Bergesio and González 2020; Postigo 2020).

Payne et al (2020), in line with Martín-López et al (2019), emphasized the necessity for mountain systems acknowledgment, considering both their commonality and their singularity. They called for the use of comprehensive conceptual frameworks (CFs), such as those of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al 2015) to improve interdisciplinary research and knowledge codesigned with stakeholders and actors related to mountain conservation.

The IPBES CF (Díaz et al 2015; IPBES 2019) is a particularly useful tool for analyzing and understanding socioecological systems, such as those of the Puna. This CF makes a distinction between main components (nature, nature's contributions to people [NCPs], good quality of life, anthropogenic assets, direct drivers of change, and indirect drivers of change) and their interactions (Martín-López et al 2019). Bruley et al (2021: 1) have refined the study of interactions considering NCPs by "distinguishing three coproduction types at different steps of the benefits flow from ecosystems to quality of life." This approach helps to identify how nature–human coproduction brings about socioecological trade-offs and synergies among several NCPs and collaborations or conflicts among beneficiaries. It can also create new opportunities for ecosystem services research, addressing the involvement of both humans and nature in quality-of-life objectives. The main idea is that human intervention is required to obtain a benefit from nature (Bruley et al 2021), in some way balancing the relevance of direct and indirect drivers, which may be evinced as a result of scaling (of time, space, or an actor's program).

In their review, Payne et al (2020) identified that there is limited information on mountain biodiversity and ecosystems, and current data on the status and trends of species is usually incomplete. This hinders the informed choice and consistent use of specified actions and indicators of ecosystems and their diversity. Moreover, spatially explicit knowledge is required in relation to supply and demand of ecosystem services, including service bundles, trade-offs, and flow (Schirpke, Candiago, et al 2019; Schirpke, Tappeiner, et al 2019), when making decisions on environmental issues (Vannier et al 2019). Further research is needed to study the impacts of multiple drivers of change on mountain biodiversity and ecosystems and thus on their services (Martín-López et al 2019).

The aim of this work is to characterize the traditional pastoralist systems of the Puna (northwest Argentina) in a framework that highlights its diverse values and valuations within nature–people coproductions. We identify social (economic, political, and global) conditions, threats, and some resilience processes. We apply the IPBES CF through a comprehensive analysis of field data and literature about this region, identifying the current status of research and knowledge gaps.

Methodology

Study site

The study site is located in the Puna of Jujuy, northwest Argentina. The Puna or Altiplano is a high mountain plateau associated with mountain peaks and located at 3500 masl in the Central Andes region. It has a cold climate, high levels of solar radiation, low atmospheric humidity, and wide thermal amplitude (Aceituno 1996). The water regime decreases to the south, where the climate is extremely dry. The study site is part of both the Puna ecoregion (3500–4000 masl), specifically the semiarid Puna complex, and the High Andes ecoregion (above 4000 masl; Morello et al 2012). In the study area (66°10′W and 22°26′S), the main towns (Santa Catalina, Cieneguillas, Cienega de Paicone, and Cusi Cusi) were founded in the 17th century and mainly consist of adobe (dried mud) houses clustered around a historical heritage church. These towns have fewer than 500 residents and have administrative, political, sanitary, commercial, religious, celebratory, and educational (elementary and high school) institutional infrastructure. The main rural activity is sheep and llama herding (and sometimes goat rearing) to produce fiber, skins, and meat. Besides mining jobs, state jobs and aid programs constitute a significant source of income for many households. These towns and other minor settlements are socioeconomically linked, and they are interconnected by gravel roads to the only 2 cities of the area: Abra Pampa and La Quiaca. The remaining population is found in rural areas.

Data collection

We gathered information on stakeholders' interaction with nature and their perceptions of it over the last 2 decades through intercultural and participatory processes. These processes involved diverse stakeholders (men and women were equally represented): pastoralists and other members of Indigenous Peoples and local communities (IPLCs), members of ranger cooperatives and local and regional production and nature conservation institutions, local government authorities, researchers, university and school students (11–28 years), traders and truckers (buyers of fiber and wholesalers of processed food), and people attending local fairs.

Field data were obtained by observations and unstructured interviews during the Binational Camelids Fair (2003–2008), Santa Catalina annual fairs (2011–2019), the Manka Fiesta (2014–2019), llama caravans (2011–2018), and field activities related to the *vicuña* management plan (2010–2020) (Vilá et al 2020). Semistructured interviews were also conducted during communal and cooperative meetings in Santa Catalina (25 interviews from 2010 to 2019), during the

Santa Catalina fair (91 interviews from 2015 to 2019), and in Cusi Cusi (35 interviews from 2010 to 2020).

We obtained data on land use, economic activities in the area, social organization, policies, knowledge and technologies, and perceptions on ritual and scenic beauty landscapes. Biological data were surveyed at different scales using various approaches and are explained in Zamar (2011); Arzamendia, Baldo, and Vilá (2012); Arzamendia, Neder, et al (2012); Arzamendia and Vilá (2012); Arzamendia et al (2014); Szumik et al (2016); Rojo et al (2019); and Vilá et al (2020). The information obtained from fieldwork was complemented by a comprehensive review of the literature on the Southern Puna.

Methods

To identify the NCPs in the Puna, we incorporated our field data and the information gathered from the available literature on the area into IPBES's generalized categories of NCP (Díaz et al 2015; IPBES 2019). These categories are regulating, material, and nonmaterial (Díaz et al 2015). We also included an analysis of NCP coproduction considering the 3 types identified by Bruley et al (2021: 4): "(1) ecosystem management; (2) mobilization, harvesting, and physical access; and (3) appropriation, social access, and appreciation."

We analyzed the local trends in the capacity of nature to keep providing contributions to good quality of life from 1990 to the present. For this, the indicators proposed by IPBES (2019) served as a reference and were adapted to the local scenario. This allowed us to compare our field data with the data published by Cendrero et al (1993) and the information collected from the literature reviewed in this work.

Results

We identified the components and drivers of the pastoralist systems of the Puna region according to the IPBES CF. In Box 1, we list the main natural and coproduced elements of biodiversity of this system at different scales (species or populations, community, and functional traits). In the following, we present the NCPs, NCP coproduction types, drivers, and indicators of good quality of life.

Nature's contributions to people

Regulating NCPs

- *Habitat creation and maintenance, as well as regulation of freshwater:* High-elevation Andean grassland and steppes are grazing land for livestock and wildlife. Our observations, supported by intercultural dialogues, showed that grasslands of *Festuca rigescens* and peatlands (*vegas*) constitute a key grazing resource during dry seasons. The latter also offers permanent freshwater bodies in the study area (Rojo et al 2019). Rock glaciers are composed of 40–60% ice and thus are important reservoirs of freshwater and regulators of the water cycle (Morello et al 2012). They are located in the Cusi Cusi area. A diverse set of wetlands (Vilama complex lagoons, the Pozuelos lagoon, and *vegas* of the Sarcarí river) supports endemic and migratory water birds.
- *Pollination and seed dispersal:* Some granivorous *Formicidae* are involved in the dynamics of plant communities, modifying species abundance and composition. *Pheidole* is one of the dispersal genera recorded in the Puna. Frequent pollinators are *Colletinae* (Hymenoptera: *Colletidae*), with many oligophagous species, such as *Megachile* (*Dasymegachile*) *golbachi* and members of the *Tiphiidae* family, whose adults feed on nectar and are secondary pollinators. Other pollinators include *Sphingidae, Noctuidae,* and *Nymphalidae* taxa. Other anthophyllous insect, such as thrips, have also been described (reviewed by Zamar 2011).
- *Regulation of climate and air quality:* There are local information gaps on these factors despite their relevance for both carbon dioxide stocks (McGahey et al 2014) and cryosphere preservation (Ruggeri 2018).
- *Formation and protection of soils and sediments:* The dung of both camelids and sheep and the excavating activity of *Ctenomys* cause important changes favoring certain biochemical cycles and structural processes within soils (Galiano and Kubiak 2021). IPLCs perceived the activities of *Ctenomys* as a negative contribution.
- *Regulation of hazards and extreme events:* Wetlands are key water sources during drought events, maintaining food and freshwater availability when they are scarce in the rest of the landscape. Pastoral systems evolved and are sustained by developing traditional adaptation strategies to manage existing and emerging risks in dry environments. Within limits, then, pastoralism is better prepared to handle climatic uncertainty than other forms of land use, because it can be adjusted to different resources and climatic zones and has been managing these variables over time.
- *Regulation of biological processes, pests, and diseases:* Mite and lice infestations are the most common parasitic diseases of South American camelids. They play ecological and sanitary roles.
- *Predators:* Carnivores are important in regulating the abundance and behavior of prey populations (Perovic 1998). However, IPLCs perceive them as enemies.

Material NCPs

- *Food and feed:* Llamas provide meat and bones. Their meat is the main protein contribution to the diet of IPLCs. Sheep and goats also provide meat, and goats can be milked to produce cheese.

  Suri eggs are collected by IPLCs as food for traditional and special occasion meals.

  Wild vegetables, such as *soldaque* (*Hypseocharis pimpinellifolia*), *ancañoca* (*Ombrophytum subterraneum*), and *Cactaceae* fruits are usually collected for food.

  Native crops include *quinua* (*Chenopodium quinoa*), tubers (*Solanum tuberosum* and *Ollucus tuberosus*), and maize (*Zea mays*). These are cultivated for self-consumption and local commerce.
- *Materials and assistance:* Fiber and clothes are sourced from a range of animals. *Vicuña* fiber is one of the softest and finest animal fibers (12–14 µm in diameter) and the most valued (US$ 300–500/kg). One individual produces 200 g collected during *chakus* (roundups) every 3 years. Llamas also provide fiber. In the province of Jujuy, 48% of the llama population has fine fiber (21–24.9 µm). The most common colors are white, brown, light brown, and gray (FAO 2005; Paz et al 2011). Sheep produce low-quality wool (27 µm), which is mostly white and is not classified by

BOX 1: Natural components of IPBES CF of the pastoralist systems of the Puna region

Biodiversity

Species diversity shows a high level of endemism. The Puna is the least transformed biome of America (Payne et al 2020).

Species or populations

- *Vicuña*s are the foremost wild ungulates in the high-elevation grasslands of South America (Vilá et al 2020). Their populations have increased in the northeast of the study area in recent decades. Populations have mean densities of 3–14 individuals/km^2.
- *Suri*s are large flightless herbivorous birds that inhabit pastoral systems. Their population is declining, with high local extinction rates. In the Laguna de los Pozuelos Biosphere Reserve, their density decreased from 0.95 to 0.52 *suri*s/km^2 in the 1980s and 1990s (Cajal 1998) to 0.21 *suri*s/km^2 today.
- Several wild carnivores inhabit the region. There are 2 species of canids, the Andean fox (*Lycalopex culpaeus*) and the gray fox (*Lycalopex gymnocercus*), locally called *atuj* or *antuko*; a mustelid, the lesser grison or *unchuchukuy* (*Galictis cuja*); the skunk or *añazco* (*Conepatus chinga, Mephitidae*); and 4 felids: Geoffroy's cat (*Leopardus geoffroyi*), the *osjo* cat (*Leopardus colocolo*), the Andean cat or *oskhollo* (*Leopardus jacobita*), and the puma (*Puma concolor*) (Perovic 1998; Díaz and Barquez 2002).
- Other mammals include the chinchilla (*Chinchilla brevicaudata*), which is a critically endangered endemic species; the armadillo or *quirquincho* (*Chaetophractus* spp); and *tojos* (*Ctenomys* sp), a widely distributed fossorial rodent.
- Scavengers include the condor (*Vultur gryphus*) and *carancho andino* (*Phalcoboenus megalopterus*).
- Llamas are native domestic herbivores coproduced from wild guanacos 5000 years ago in the Central Andes. There are about 80,000 llamas in the study area.
- Sheep are nonnative ungulates, coproduced in the Middle East 8000 years ago. They were introduced into the area 500 years ago. Currently, 205,000 sheep inhabit the area.
- Other introduced livestock include goats (*Capra hircus*), cows (*Bos taurus*), and donkeys (*Equus asinus*), which have feral populations in some areas. Farm animals, such as chickens, can also be found in houses.
- Working and companion animals have included dogs (*Canis familiaris*) since preconquest times. Their presence was later reinforced by the postconquest introduction of shepherd dogs.

Community and functional traits

- Natural vegetation is the source of energy in the ecosystem. It is conveyed through trophic interactions to local ungulates and several other herbivore populations. The diversity of vegetation communities identified in the study area is mainly correlated with geomorphology and soil type, with differences in composition, cover, biomass, and the presence of different strata. Vegetation dynamics are also influenced by intra- and interannual variations (Rojo et al 2019). The vegetation communities with the highest vegetation cover and biomass are *Festuca* spp grasslands (*chillaguale*s), peatlands (*vega*s), shrublands of *Parastrephia* spp (*tolares*), and short grasslands. Other communities widely spread in the region are shrublands of *Baccharis boliviensis, Fabiana densa,* and *Tetraglochin cristatum* (as described by Cabrera 1957; Ruthsatz and Movia 1975; Bonaventura et al 1995), which show the lowest cover and biomass values (Rojo et al 2019).
- Between the Puna and the upper limit of vegetation growth, in the High Andes ecoregion, the main communities are grass steppes (*Festuca* spp and *Jarava ichu*) and other grasslands composed of some endemic species of grasses (*Deyeuxia* spp, *Poa* sp, and others). In addition, cushion and rosette plants and dwarf shrubs of the genera *Azorella, Pycnophyllum, Nototriche, Werneria,* and *Xenophyllum* (Mateucchi 2012) abound.
- There are only 2 native tree species within the study site: *queñoa*s (*Polylepis tomentella*) and *churquis* (*Prosopis ferox*). These are grouped in small patches. Other species associated with these trees include various cacti, such as *Maihueniopsis glomerata, Oreocereus trollii,* and *Opuntia soehrensii* (Bonaventura et al 1995).
- Peatlands or *vega*s form specialized wetlands supported by groundwater. They are frequently located in hollows and valleys and often include surface water, especially during the wet season. Most water bodies are shallow lentic aquatic habitats—*lagunas*—which are various internally drained salt flats or *salares*. These water bodies often have peripheral aquatic habitats like *vega*s. In the study area, there are also rivers that drain into endorheic and arheic basins, such as La Plata basin.
- Wetland bird communities include charismatic and endangered species such as flamingos (*Phoenicopterus chilensis, Phoenicoparrus andinus,* and *Phoenicoparrus jamesi*), shorebirds, and migratory waterfowl.
- Arthropods include Hymenoptera, the best represented insects of the taxa *Formicidae, Colletinae, Tiphiidae,* and *Megachilidae* (eg *M.* [*D.*] *golbachi* that is endemic to the Andes). Lepidoptera include the representative taxa of *Sphingidae, Noctuidae,* and *Nymphalidae* (Arce de Hamity and Neder de Román 1998; Szumik et al 2016). The main ectoparasites detected in *vicuña*s and llamas are *Microthoracius mazzai, Microthoracius praelongiceps,* and *Sarcoptes scabiei* (Arzamendia, Neder, et al 2012).

any system. Livestock skins are also used, typically layered as sleeping mattresses.

The dung of llamas, sheep, and goats are used by IPLCs as fertilizer.

IPLCs use natural clay, stone, and fibers to produce crafts and domestic tools, such as pottery (cooking pots, platters, etc), carved flagstones, and textiles. These are used for domestic tasks or sold at local fairs and extraregional markets.

Materials such as tussock grasses (*Jarava ichu* and *Festuca* spp) are used as construction material for rural structures such as roofs.

NCPs provide energy. Shrubs, such as *tolas* (genera *Parastrephia, Baccharis,* and *Fabiana*), and trees, such as *queñua* and *churqui,* are used as firewood.

Animals are used as transport. "[L]lama caravans transport llama fiber and dry llama meat in llama fiber woven sacks secured by llama ropes. Llamas can carry 25 kg (2 *arrobas*) each. Groups of 30–80 llamas are driven by 3 to 5 people" (Vilá and Arzamendia 2020: 14). During the last decade, llama caravans arriving in Santa Catalina that were surveyed yearly showed a great decline, leading to a possible extinction of the practice.

- *Plants used as medicine:* There are many medicinal species. The most common are *pupusa* (*Xenophyllum poposum*), *chachacoma* (*Senecio nutans*), *rica rica* (*Acantholippia deserticola*), *muña muña* (*Satureja boliviana*), and *yareta* (*Azorella compacta*) (Vignale 1996; De Lucca and Zalles 2007).

Nonmaterial NCPs: Andean cosmology integrates biological and symbolic entities in a whole living system. Llamas, mountains, *Pachamama* (Mother Earth), crops, people, and more are together in a multifaceted idea of life. All these components are present in different rituals that highlight their importance and connection. Many activities are accomplished through community work.

The most important ritual of the Andean culture is *Corpachada*. In August, families gather together to celebrate. They make offerings, recognize their lands, cook local recipes (mostly made using potatoes, maize, and meat), and sing *coplas*. In this ritual, people emphasize the bonds among humans, domestic animals, and *Pachamama*. Llamas are celebrated in *la señalada,* which is organized in rural houses and is attended by families and friends, including emigrants. *Suris* are represented in rituals such as *los samilantes* dance, where dancers are ornamented with *suri* feathers, and in rituals (with eggs) to foretell a good life for families moving into a new house. *Vicuñas* are considered the livestock of *Pachamama* (Vilá and Arzamendia 2020). Besides the Andean cultural heritage, this is an area of natural and traditional landscapes of great scenic beauty, especially for recreation and tourism related to biodiversity observation.

Figure 1 shows some NCPs, and Figure 2 describes the local trend of NCPs in relation to the capacity of nature to keep contributing to a good quality of life over the last 30 years. In Table 1, we show the anthropogenic assets associated with NCPs and the following NCP coproduction types.

NCP coproduction types

Different types of coproduction operate in the flow from ecosystems to quality of life (Figure 1).

Ecosystem management: Ecosystem management consists of traditional and culturally diverse practices, grazing multispecific (native and exotic) herds, and the conservation and use of wild species.

Vegetation-use norms and herding practices, including transhumance, reflect pastoralist knowledge. The purpose is to use available water sources and forage that are within a family's range. Mobility varies according to elevation, climate, vegetation type, and herd availability and composition (Wawrzyk and Vilá 2013; González 2020). Movement can be either daily—typically carried out by women or children—or seasonal.

At the end of the dry season, animals keep grazing on the forage remaining from the previous wet season. In some cases, livestock are moved to reserved grazing areas. Supplementation with grains and alfalfa (*Medicago sativa*) bales is sometimes an alternative. Although pastoralism might be adapted to drier conditions because of climate change, there is a limit. If precipitation falls below a certain threshold, the carrying capacity of rangelands will decline, triggering land degradation processes.

Weak or sickly animals at this time of the year are treated with an ethnomedicine called *ulpado,* which is made with corn, barley, water, and salt (Vilá and Arzamendia 2016). Other traditional practices are also related to specific periods of the year, such as harvest, animal slaughter, soil preparation, *chaya* (communal libations, part of ceremony to pay tribute to the *Pachamama*), and planting (Vilá and Arzamendia 2016). These activities include the preservation of genetic diversity of crops and their wild relatives. Traditional practices to manage *vegas* are relictual in this area.

Extra-Andean practices started in the Pozuelos basin in the 1970s. These include fencing, which allows the handling of livestock loads, the separation of species, and a narrowing of the breeding season (Cendrero et al 1993; González, Golovanevsky, and Cabrera 2014).

Sanitary management of livestock is also carried out to control ectoparasites (lice and mites) with veterinary products. A few shepherds use natural substances.

Wildlife is also managed. The wild *vicuña chaku* is a traditional, community-based management method involving a management plan for capturing and releasing wild *vicuñas* to harvest their fiber. Plans are developed by IPLCs and researchers using adaptive management. This includes welfare protocols and assessment to evaluate population status and management effects on *vicuñas,* as well as other environmental impacts (Arzamendia, Baldo, and Vilá 2012; Baldo et al 2013; Vilá et al 2020).

Management plans for national protected areas in the region are diverse. The Laguna de los Pozuelos natural monument (National Park Administration) and the United Nations Educational, Scientific and Cultural Organization's Pozuelos Biosphere Reserve are updating their management plan. The Ramsar sites of Pozuelos and Vilama protect wetlands and biodiversity. The Chinchilla High Andean Reserve was created in the 1970s to promote the survival of *Chinchilla brevicaudata* and has recently established a house for a local park ranger.

Mobilization, harvesting, and physical access: Besides annual and daily movements, llama caravans connect different landscapes and elevations. When they relocate, *llameros* (llama herders) usually collect medicinal species, which are highly valued.

Butchering is usually a family task (or is done as a community) in a domestic space. After slaughter, the parts of the animal are prepared according to their purpose: some parts are sun dried and become *charqui* (without bone) or *chalona* (with bone). Butchering takes place in winter when animals are thin. This also satisfies the higher demands for meat during New Year and Easter festivities. There are no active slaughterhouses in the area.

Harvesting family crops is important, is intensive, and requires a great quantity of labor in a short period. Here, community work usually takes 2 forms: one includes relatives in urban areas that move back to their home areas to help, and the other involves reciprocity among friends and neighbors. Harvest usually occurs from February to April and entails harvesting, cleaning, and classifying, which can take several days. Women are in charge of selecting the best seeds for sowing in the following year.

Livestock shearing is also community work. Sometimes shepherds sell the fiber (to major collectors) and may invite

FIGURE 1 Collage showing nature, NCPs, and livelihoods in the pastoralist Puna system. (Photos and collage by Silvina Enrietti and Bibiana Vilá)

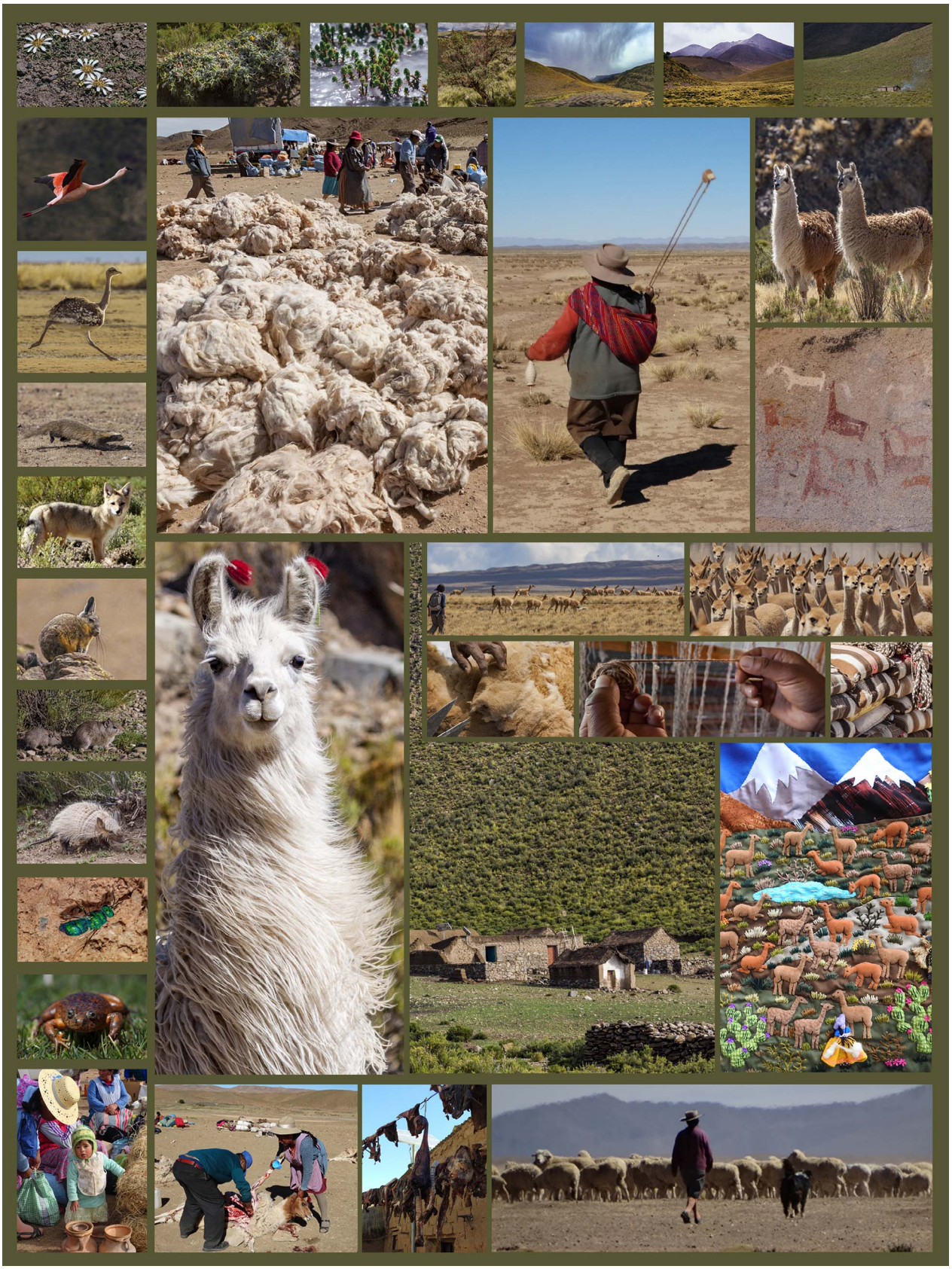

FIGURE 2 Local trends in the capacity of nature to keep providing contributions to good quality of life from 1990 to the present. Most data used to determine trends are derived from our research results and the published data analyzed in this study. The applied indicators are those proposed by IPBES (2019). (Drawings by members of the communities of Santa Catalina, Canchillas, Tolamayo, Morritos, and La Cruz; the indigenous associations Atu Saphi, Yurax Rumi, and Aucarpina Chambi; the Santa Catalina high school community; and the Santa Catalina, Rodeo and Pozuelos Schools)

		NCP	Indicators	Values	30-year trend
REGULATION		Habitat creation and maintenance	Grazing land integrity	I – M – R	↘
			Vicuña population	I – M – R	↑
			Suri population	I – M – R	↓
		Pollination and dispersal of seeds and other propagules	Pollinators Wind pollination and dispersal	I – M	●
		Regulation of climate and air quality	Grasslands Cryosphere	I	●
		Regulation of freshwater	Rock glaciers – *vegas*	I – R	↘
		Formation and protection of soils and sediments	Dung *quirquinchos*/*tojos*	I – M – R	↘
		Regulation of hazards and extreme events	Productivity/vegetation cover	I – R	↘
		Regulation of biological processes, pests, and diseases	Predators Parasites	I – R I – R	↓ ↗
MATERIALS		Food and feed	Llama: meat/*charqui* Sheep: meat *Suris*: eggs/feathers Quinoa Wild vegetables	I – M – R M – R I – M – R I – M – R I – M – R	↗ → ↓ ↗ ↓
		Materials and assistance	Fiber and clothes Llama dung Crafts and domestic tools Construction materials	M – R M M – R M – R	↗ ● → ↓
		Medicinal, biochemical, and genetic resources	Wild plants	I – M – R	↘
		Energy	Firewood	I – M – R	↘
NONMATERIALS		Physical and psychological experience	Rituals of the Andean culture	R	→
		Supporting identities	Recreation and tourism	R	↗
		Learning and inspiration	Wildlife observation	R	↗

I, intrisic; M, material; R, relational ● Established ● Established but incomplete ● Knowledge gaps

TABLE 1 Anthropogenic assets of the Puna pastoralist system.

Anthropogenic assets	Description
Pastoralist knowledge	Reflected in grazing land use norms of IPLCs, as well as herding practices that "include ancestral techniques for loading, driving, and unpacking the animals" (Vilá and Arzamendia 2020: 14).
Traditional community work	Community-level practices related to taking the communal level as a major kind of partnership. This idea is reflected in different activities and even in other ways of grouping, such as associations and cooperatives. Conflict is not absent.
***Vicuña* management plan and activities (*chaku*)**	Includes "(1) Knowledge: scientific research on *vicuña* population trends. Capture and shearing procedures with animal welfare techniques. Observations by Indigenous and local communities. (2) Technology: capture infrastructure and procedures. (3) Funding. (4) Formal and non-formal education and capacity building" (Vilá and Arzamendia 2020: 8).
Trade and international market	All material and nonmaterial components of international trade.
	Technology: Both physical objects and procedures and financial assets.
Luxury fashion industries and European designers	Technology and financial assets in textile industries.
Traditional local fairs	Includes trading, cultural, and social activities (football, music, children's games, food, and others). The Santa Catalina, Manka Fiesta, and Cienega de Paicone fairs are the most important.
Interinstitutional development projects	The Corporation for the Conservation and Development of Pozuelos Basin is an executive council with local inhabitants and members of local city halls, the provincial government, the national park administration, the university, and nongovernmental organizations (Cendrero et al 1993).
	It has the infrastructure to support IPLCs.

relatives to help them. Those who belong to cooperatives or associations may coordinate with partners. These groups clean, classify, and typify fiber by fineness and color, thus gaining better products and higher prices (Lamas 2011; González 2014).

In some places, *vicuña* fiber harvesting in *chakus* is carried out during spring and requires many people. It is an intercultural joint activity among communities, local associations such as cooperatives, and professionals and is controlled by government authorities (Arzamendia et al 2014; Vilá et al 2020).

Water supply is a central point for animals. Waterholes are constructed on bare ground with excavating machines. Most only have surface water during the wet season. Aqueduct construction has recently been implemented in some areas.

Appropriation, social access, and appreciation: Traditionally, herders are dispersed across the region: they access different environments and are efficient at managing risk. Rights to access land in the study area belong to extended families. Even when people move to another town or area, they keep these rights.

Indigenous communities, as owners of ancestral territories, are recognized by Argentine laws. These spaces constitute sources for grazing, cropping, and preserving wild animals. This communal model has a correlative form in cooperatives and associations for helping people achieve common goals (selling llama and sheep products, performing a *chaku*, or undertaking collective work with crops) (González 2012, 2014; Arzamendia et al 2014; Vilá et al 2020).

Another way of integrating large territories into domestic life is by holding fairs (González, Bergesio, and Golovanevsky 2014; González, Golovanevsky, and Cabrera 2014; Bergesio et al 2019; González and Bergesio 2020). People living far away come together at the same spatiotemporal point to share their products, information, and necessities. Most fairs are periodical; people know when they take place and who is going to be there. Therefore, fairs are important for social and cultural integration of scattered population groups in this wide area.

Governance, institutions, and indirect drivers of change

Consumption patterns of capitalism and their cultural correlations have profound effects, such as the switch from using caravans to vehicles (Schulte 1996). Changes in raw materials for clothes, tools, and construction have a significant environmental impact, because plastic and nonbiodegradable elements have been introduced. A cultural lifestyle (including education) has emerged that results in migration—mostly permanent—to cities (in the province or farther away), especially by the young. Some houses in rural locations are retained, but many are abandoned.

Mining jobs have become a scarce but real source of formal local income for many reasons. There are few or no incentives from state and local governments to undertake and support agricultural and livestock practices, and formal jobs (mainly in public offices) are underpaid. Therefore, young people (mostly males) may stay as mine workers, accelerating cultural changes. Some traditional products, such as *quinua* and *vicuña* fiber, are promoted by government programs. Other products, such as livestock and other crops, receive little government assistance, largely restricted to supplementing cereals and bales in drought seasons.

International commodity markets determine the price of camelid fiber at the Puna fairs. Pricing occurs within the context of an unequal relationship in which distant western players from international textile industries achieve huge immediate profits with low investments, whereas IPLC profits are very low (Vilá and Arzamendia 2020). In this

sense, national institutions and governance systems play a critical role in reducing asymmetries and ensuring fair trade.

Community territory is recognized by the Argentine Constitution and several laws and agreements (International Labour Organization [ILO] Convention 169). International and national conservation laws protect *vicuñas* (Vilá and Arzamendia 2020), *suris,* and biodiversity. Although there are several protected areas, some of them, such as the Chinchilla High Andean Reserve and Pozuelos Biosphere Reserve, have a weak or no management plan.

The state is somewhat present in the form of primary schools, security forces, and basic health services in almost all small towns. The most important towns have secondary schools; universities and hospitals are located in the cities. Connectivity infrastructure (roads, telephony, and the Internet) was originally related to large-scale mining and later developed by national government agencies.

Good quality of life

Good quality of life involves improving social conditions of IPLCs, which may include biocultural heritage valuing cultural identity, biodiversity, and nature contributions in goods and services. Basic materials for living, equal access to health and education services, enhanced market possibilities for herding products, and real and complete compliance with ILO Convention 169 and related laws for IPLCs are essential for freedom of choice about land use—community decisions—and the individual choice of staying on the land or leaving.

Discussion

Pastoral livelihoods in the Puna of northwest Argentina are based on cocreating an environment with natural and anthropic elements (water sources, grasslands, wildlife, livestock, and techniques) interacting through complex mechanisms embraced by environmental conditions (climate and geomorphology) and cultural and economic practices. In a dry and harsh environment, risk management is a key component of pastoral livelihoods. This gives resilience to threats related to climate and other natural aspects of the system (McGahey et al 2014). In contrast, when stressors come from outside the Andean world as social (cultural and economic) pressures, the system shows weakness and has less plasticity and strength. "Fewer people are choosing to remain in the rural Andean Altiplano, which is a local expression of a global pattern of abandonment" (Vilá and Arzamendia 2020: 15), and the system is becoming feminized and aged. This has major consequences: a shorter life of the system, related to aged people; a lack of workforce, which shapes decisions such as those on which livestock species will be raised; and a lack of innovation. In this sense, Postigo (2019) pointed out that the adaptive capacity of the system could be overwhelmed by the speed and intensity of current climate change combined with the effect of local management strategies.

A major social change is related to urban consumption patterns and the establishment of mines, which attract young people to the well-paid jobs correlating with the abandonment of rural activities. Even though the state is somewhat present by issuing camelid programs and "ovine law" and by developing *vicuña chakus,* these programs are abandoned when mining projects are launched, even in Indigenous community territories or protected areas.

When policies are solely based on an association between environmental degradation and overgrazing, it becomes evident that there is not a good grasp of rangeland management (McGahey et al 2014). In Argentina, pastoralists are frequently excluded from decision-making and policy planning; therefore, their knowledge and understanding of ecology and natural resources are skipped. Even with an existing declaration of support to IPLCs, government policies favor mining and other forms of overexploitation of nature. In this way, although Argentina applies ILO Convention 169, and the province of Jujuy has recognized communal lands of Indigenous communities, not every community has access to land (Carrasco 2000).

In the 1990s, in some areas of Argentina, such as the Pozuelos basin, an institutional framework was established (Corporation for the Development of Pozuelos Basin [CODEPO, for its Spanish initials]). The aim was to create, promote, and implement plans to enhance pastoral livelihoods by creating bonds among a diverse range of actors and interested parties (Cendrero et al 1993). CODEPO developed agricultural plans, but the lack of a multiple valuation agreement from stakeholders impeded the success of this initially promising initiative.

Nowadays, the pastoral landscape of the Puna is strongly influenced by mining. The power held by mining companies can significantly affect the dynamics of the pastoral system, because mining companies use territory and natural components (soil, water, and basins) for a single goal (their project) and make solely economic valuations. Although the social valuation of the pastoral system and the rural way of life is acclaimed in Argentina, the lobbying power of mining companies erases good intentions. This power is exercised in different ways (Flintan 2008), sometimes in a visible coercive way that generates environmental conflicts but also as an invisible or hidden power, making people believe that wage labor in mining is more modern and evolved than pastoralism.

In Argentina, as well as at a global level, there has been an increasing number of reports from pastoral groups that are losing access to significant rangeland resources. There is large-scale acquisition of land, particularly in areas of Africa, Asia, and Latin America, which are characterized by weak governance and poor land use planning (McGahey et al 2014).

Local risk is a component in this system, but extralocal risk—such as cultural change, monistic valuation of processes, land pressure, and climate change—may signify a real hazard. The aim of this paper was to show both significant interactions between natural components and social pressure. Historically, this pressure was efficiently addressed, but this pressure is increasing.

We identified some knowledge gaps and limited information on (1) several regulating NCPs (Table 2); (2) status and trends for a range of species and species groups, such as plant communities, arthropods, and their interactions and flows; (3) updated statistical information on IPLCs; (4) the flow of relations and coproduction, considering the local expression of quality of life; and (5) the impact of mining employment on the sociocultural system. Some of these research gaps match those identified by Payne et al (2020), who stressed the need for spatially explicit

TABLE 2 Direct drivers of change identified in the Puna pastoralist system.

Direct drivers	Description
Direct natural drivers	
Climate	It is arid, with a negative water balance that is variable (seasonal and interannual). This limits biodiversity maintenance.
Natural vegetation/ pastures	Wild herbivores and livestock feed are based on natural vegetation.
Predators and parasites	Regulate wildlife populations.
Direct anthropogenic drivers	
Overexploitation	Hunting of *vicuña*s and *suris,* collection of *suri* eggs, and overexploitation of wetlands and freshwaters threaten biodiversity. *Vicuña* poaching increased during the last decade and constitutes an illicit cross-border activity that is difficult to manage (Acebes et al 2018; Vilá et al 2020).
	Feral dogs, wild pumas, and foxes are regarded as threats to domestic and other wild animals and are hunted (Reppucci et al 2011; Arzamendia and Vilá 2012).
	Overgrazing causes a mismatch between forage availability and livestock demand. This can trigger severe degradation processes in the ecosystem, especially in drought periods and when combined with the presence of alien species (eg *Eragrostis curvula*).
	Sanitary and productive management can affect the presence and prevalence of ectoparasites in llamas and *vicuña*s (and the fiber obtained from them) when they share grazing sites.
	Arthropods can be affected by grazing pressure and land degradation.
Land use	Land use change is visible in grazing and conversion to pastures and mining. Other land cover changes, such as drainage works, roads, and other infrastructures, are major threats to mountain wetlands and aquatic ecosystems. In the Pozuelos basin, there are 84 mining projects (21 mining rights granted up to 2021).
	Fencing has been referred to as having positive and negative effects over natural vegetation and wetlands.
Climate change	A reduction in mountain rainfall and warming of 1°C in the Argentine Andean region is predicted (Devenish and Gianella 2012). During recent decades, rainfall has decreased in the Altiplano (Vera et al 2019).

knowledge on drivers and socioecological landscape dynamics.

By using the CF and identifying cocreations and contributions of nature, we were able to present the Andean pastoral landscape framed in a useful systematic way. We consider that proper environmental policies for the area must include the scientific input, as well as local knowledge and desires.

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