Chapter 5
Building New Human–Natural Systems for Sustainable Pasture Management in South America

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Abstract On the basis of research conducted in three contrasting South American ecoregions (southern Patagonia, Argentina; the central Pampas and Campos, Uruguay; and western Amazonia, Brazil), this chapter aims to better understand the complex sets of reasons that have recently led local societies to adopt more sustainable pasture management in South America. After a brief overview of each of the three biomes, representative social–ecological systems of pastoralism are identified with the objective to describe their respective pasture management history, especially the colonization process and the settlement of the pioneers, and the successive farming systems, mainly the practices related to herd and pasture management, are compared. Finally, the main local and national policies regarding the livestock sector and landownership are analyzed. The evolution of the social–ecological systems of pastoralism in these ecoregions was assessed with a three-dimensional model of vulnerability based on the agroecosystem resilience, livelihood improvement, and institutional capability. The evolution of the mental models about livestock has also been analyzed to better understand the current perceptions of the local people and their scenarios for the future of livestock in their social–ecological systems. The results focused on the dynamics of rangeland management, the vulnerability of the pastoral social–ecological systems,

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and the evolution of the mental models of local people about livestock, so as to discuss the different rhythms of transformation and the existence of critical thresholds. Besides diverse land and social issues, it is imperative to intensify livestock production and increase the offer of new technologies, as well as to identify some relevant human dimension factors, such as the demand of local societies for collective livelihood improvement, the recent national and international environmental policies related to global warming and biodiversity, and the stronger awareness of consumers for sustainable development. In the context of global change, the practices of rangeland management will change in a more sustainable way, resulting in better society–environment interaction and human–nature integration.

5.1 An Overview of Pastoralism in South America

In geography and history, South America offers an excellent opportunity to explore the main drivers of change in the interaction between society and environment referred to pastoral production systems. Geography, or indeed paleogeography, explains the fact that the pastures of this continent have evolved void of the big herds of herbivores that conditioned the early relationship between rangelands, herds, and humans in the Old World and North America (Melville 1997; Milchunas et al. 1988). There are large areas of grasslands, steppes, savannas, and shrublands for grazing pastures according to the vegetation map of South America (Fig. 5.1), which were void of big ruminants until the arrival of Europeans in the sixteenth century , which is the point where history contributes to the uniqueness of the opportunity mentioned above. The multiple ecological processes triggered by this dramatic transplantation can be termed "ecological imperialism" (Crosby 2004); within the huge extent of this biogeographic revolution, the concerns regarding pasture-based animal husbandry are but one topic we intend to consider in this chapter.

Since the sixteenth century and for half a millennium, the human–nature relationship in South America has been based on the practices involved in mining natural resources of the soil (water, natural vegetation, and biodiversity) and the subsoil, especially gold and silver in the past, and more recently oil, gas, coal, and numerous minerals. European settlers and their descendants found that the best way to settle new lands and progressively develop the hinterlands from the already colonized areas. In less than five centuries, new societies have been built mixing Amerindian people with migrants from diverse regions of the world, especially from Europe, but also from sub-Saharan African, the southern and eastern Mediterranean, Japan, and China. In these societies, the pioneer spirit is a part of the heritage, as in North America. Furthermore, the advance of democracy since the end of the last century has opened up new opportunities to develop sustainable social–ecological systems.

Arriving in the plains, pioneers early introduced cattle and sheep to the savannas and steppes, profiting from the natural forage of the rangeland to feed the herds. So, cattle breeding quickly developed in several South American areas of rangeland, including the Pampas and Patagonia, the lowlands of the Pantanal and the Llanos, the

Fig. 5.1 Vegetation map of South America. (Adapted from Blanco et al. 2013)

alpine meadows of páramo and puna in the Andean highlands, and some Amazonian islands, such as Marajó. Livestock was of major importance at the onset of rural societies in these regions. On the other hand, in the forest ecosystems, such as the Amazon rainforest and the Atlantic Forest located along the Atlantic tropical coast, the European settlers usually started to slash and burn forest plots to cultivate the land, using ash from natural vegetation to fertilize their annual and perennial crops. Ruminants were farmed to produce food for home consumption, goods to sell, saving, and diverse services. In exchange, the cropping system produced forage and grain to feed the herds. The situation was intermediate in the savanna biomes, such as the Cerrado and Gran Chaco located in the center of South America, and Caatinga in the northeast of Brazil. In the farms in these regions, animals and herds also had essential functions; for example, for tillage, transport, and other farm work. So, in all South America, animal breeding had a major and diversified role in the postcolonization farming systems and livestock was always a key factor in the coupled human–natural systems and their dynamics.

The period of colonization differed according to the location of the ecosystems. Those near the coast where the migrants arrived, in the case of the Pampas and the Atlantic Forest on the Atlantic coast, were usually settled much earlier than the ones located in the center of the continent, such as Amazonia, the Cerrado, and Gran Chaco. Despite its maritime position, Patagonia was colonized quite late, because of the severity of the environment. Obviously the ability to progress was a determinant factor everywhere. So, the steppes and savannas were generally colonized before the forest areas. The resistance of local populations interfered a lot; for instance, in some Andean zones where the local Amerindian societies were strongly organized, or Araucanians in the Pampas of Argentina and the Tobas in Gran Chaco.

The weak sustainability of pasture management has led to a gradual degradation of natural and cultivated grasslands, at a pace depending on the bioclimatic conditions, the ecosystem, and the set of practices, especially overstocking, bad use of burning, or no respect for the vegetative cycle. In the center of Patagonia for example, the degradation process was very fast, in just four decades, between 1880 and 1920, mainly due to too high overgrazing coupled with low rainfall and strong wind erosion. In the case of Amazonia, the grassland degradation resulted from a set of unsustainable practices, starting from forage seeding until grazing. In the Pampas, light degradation of the natural grasslands/rangelands had been noticed for some centuries, especially regarding the native trees of the rangeland used for a long time for construction, cooking, and heating. However, the main impact on Pampa rangeland is the transformation of natural vegetation into cultivated grasslands, and more recently the replacement by tree plantations (eucalyptus and pines) and annual crops (mainly soybean) for exportation.

The Pampas, Patagonia, and Amazonia are three contrasting South American biomes in term of bioclimatic conditions and natural vegetation, but also the period of colonization and the settlement process, current socioeconomic development, the National context, etc. In this comparative research, the reference social–ecological systems are the Pampas in Uruguay, Patagonia in Argentina, and Amazonia in Brazil. The Pampas were colonized from the sixteenth century to the eighteenth century, Patagonia was colonized at the end of the nineteenth century and the beginning of the twentieth century, and Amazonia was colonized in the past half century. Rainforest is the natural vegetation of Amazonia. Arid steppe and prairie are respectively the natural vegetation of Patagonia and the Pampas. The current pastoral societies herded the natural socio-ecosystem, although these have been strongly transformed since the beginning of the colonization. They are currently changing even more because of global changes and their diverse components, especially changes to the global economy and the huge demand for food and feed, for which South America is becoming one of the world's breadbaskets. Moreover, other global changes are impacting the social–ecological systems, such as climate change, whether in Amazonia or in the Pampas and Patagonia, new demands of young people in terms of life and work conditions, social networks, and new information and communication technologies.

In the context of global changes affecting the South American biomes differently, the objective of this chapter is to use case studies to describe the changes in the structure and the functioning, and the current and future trends of the social–ecological systems in the three livestock production ecoregions, mainly the new human–nature

partnership in the rangeland/grassland management. Comparisons between the three ecoregions allow us to identify similar and dissimilar factors acting in each case that determine singularities in the process regarding spatial extension and temporality as well as the existence of thresholds and nonreversible situations. The comparisons are based on three different tools: the vulnerability of the social–ecological system, the mental models of local people about livestock, and the identification of different ecological thresholds. Here, the concept of three-dimensional vulnerability (agroecosystem, livelihood, and institutional capacity) of pastoralism proposed by Dong et al. (2011) is used to compare the resilience of the social–ecological systems in the three cases. The successive situations concerning the stability of the agroecosystem, the livelihood of farming families, and the institutional capacity are defined assess the resilience and the vulnerability of the social–ecological systems of pastoralism and their trends. The comparison of mental models of local people about livestock activities in the past, now, and in future scenarios is another tool used to better understand the trends of the social–ecological systems in the three cases.

5.2 Dynamics of Social–Ecological Systems in Pasture Management in Campos of the Pampas, Uruguay

The area now occupied by Uruguay was qualified as good for nothing on the arrival of the European conquerors in the sixteenth century. With this qualification, the region was settled very late compared with other regions that offered the beloved metals, gold, and silver, mainly in the Andes, or the natural vegetal and animal resources, principally in forest areas. On the other hand, this low interest in Uruguayan soil and subsoil was compensated for by the easy land access linked to the proximity of the Atlantic coast, the ability to move in the rangeland, and the mildness of the climate. For these reasons, European settlement occurred very early compared with that in the two other regions we are studying in this chapter.

At the beginning of the seventeenth century, some cattle from Paraguay were left in the open rangelands in the south of Uruguay. This was the start of an activity that has evolved since then but remains the main one in terms of area involved and economic importance. At the same time, Jesuits where organizing their famous “missions” and occupied the north of the country and left their cultural traits and the names of rivers (Uruguay, Cuareim, Tacuarembó) as heritage. According to Moraes (2008), the south of Uruguay was organized as private property and was occupied by about 10,000 people by the middle of the eighteenth century, whereas the north, organized as communal lands and ruled by Jesuits, was inhabited by more than a 100,000 people.

The Uruguayan rangelands or prairies are usually called “Campos” (Allen et al. 2011). These grasslands consist mainly of grasses, along with herbs, small shrubs, and occasional trees on an undulating and hilly landscape, with variable soil fertility (Fig. 5.2). Campos differ from the Cerrado by having fewer trees, longer and severer winters, and a relative abundance of native legumes. Campos are found in the northern part of the Pampas biome, located in Uruguay, southern Brazil, and northeastern Argentina. The subtropical climate is humid, warm in summer and mild in winter.

Fig. 5.2 Photographs of the Pampas with cattle and sheep in Uruguay

Fig. 5.3 Gaucho culture based on rural housing (*left*), meat food (*middle*), and collective/cooperative structures (*right*)

The annual grass production is about four metric tons of dry matter per hectare, with a typical seasonal distribution, with a minimum of 14 % of total production in winter and a maximum of 35 % in spring (Guido et al. 2014). This production distinguishes natural grasslands of this region as being among the most productive in the world. The stocking rate of the natural grasslands has not changed very much since the early days—no more than one cow per hectare. The production, its distribution, and its variability are now fully described and understood by remote sensing. The grasslands have certainly changed, but not very much during the past four or five centuries (Morales 2007). It is thought that originally taller grasses and perhaps more trees were present. The presence of big ruminants has an impact on carbon and nitrogen cycles, among others. Piñeiro et al. (2006) and Paruelo et al. (2010) estimated that a fifth of soil carbon has been lost in the last five centuries.

However, the living conditions and livelihoods of farming families have changed a lot like the gaucho society, which has built one of the most famous and productive cattle breeding systems in the open range in the world (Fig. 5.3).

Moreover, the gaucho society became a reference in breeding societies in just a few centuries, when others needed several centuries or millennia; for example the Peulhs in West and Central Africa, the Bedouins in the southern and eastern Mediterranean, and Mongols, Uighurs, and Tibetans in Central Asia. Events strengthened the livestock image of gaucho breeders, especially during the First World War, when the Pampas provided meat and cereals for European countries.

One important characteristic of gaucho social–ecological systems is the ecological uniqueness. The region is subtropical humid. It is not tropical because it has too

many frosts, on average 25 per year, and is not temperate because of a too hot summer, with temperatures up to 42 °C; rainfall is about 1200 mm/year in an irregular but on average well-distributed manner.

The first product was meat for local consumption, and the practice of slaughtering a cow to eat only a little portion of it astonished many voyagers. The industry was chiefly launched by the end of the eighteenth century and consisted of hides. Before then, the main product was leather. The meat was a by-product without any value until the beginning of another important activity; salted meat to be consumed by the slaves in the plantation industries; cotton, coffee and sugarcane that flourished in Cuba, Brazil, and North America. This activity was dominant until the end of the nineteenth century, when a typical industrial product—Liebig's Meat Extract—was sent to nearly everywhere in the world to feed the British Army. This industrial serving activity was established with the legalization of land as property, fencing, and genetic improvement to make the original cattle more suited to the new situation. The change was nearly complete by 1910, when new and modern slaughterhouses sent refrigerated meat to Europe, beginning an activity that is still very vigorous.

From an ecological and also economic point of view, the development of the wool industry was also very important. The presence of two species—cattle and sheep—is to some extent complementary, and another important reason was to manage two types of risk: economic and climatic. In times of drought, sheep are better adapted and can to some extent compensate for the loss of cattle, and also wool and meat are slightly correlated to markets, although when one of them has a low price, the other can have a high price, contributing not only to the resilience of the farm enterprises but also that of the whole industry.

Wool and meat accounted for more than 85 % of Uruguayan exports from 1870 to 1970 (Moraes 2008), and the resulting wealth created a type of dependence for the country, which even with great effort failed to develop other successful economic activities, resulting in a big political crisis in 1973 as one of its consequences (Fig. 5.4).

The most important attempt to promote development started with the mechanization after the Second World War by the plantation of cultivated pastures in the natural grassland/rangeland to increase the productivity per hectare. By the end of the 1970s it was clear that the traditional beef and wool production would only change a little with the promoted technology (Jarvis 1981), but it was also clear that milk

Fig. 5.4 Cattle (*left*), sheep wool (*middle*), and a gaucho on his horse (*right*)

production would benefit from an improved and enlarged pasture management technology. As this become evident, major change continued with the development of agribusiness, tree plantations from the 1990s, and the production of crops for exportation, with an expected result. For the first time, agricultural products were more important as exports in 2010 because of the huge increase in soybean culture that had taken place since 2001 and had boosted grain production. Another important activity that has replaced grasslands is afforestation. Eucalyptus and pines grow very well in Uruguay, and with the support of a law passed in 1987 have become important industries and a pole of attraction for foreign investors. North Americans, Chileans, Spaniards, Finns, and others have bought land, developed plantations, and set up related industries in Uruguay.

The relationship with the open spaces is one of the main features of the cultural dimension of cattle raising in this area, and its main output is the ever presence of horses. Ranches are organized in several manners according to the general strategy of the owner, who sometimes can be a lawyer who comes every 3 months to his property, but the family farm, based on family labor, is the most important type of farm. Farms are divided into several paddocks to facilitate cattle handling but also manage the natural pastures, which are very variable, and one paddock can be more suitable for calves, another for culled cows, and so on. Until now, horses have been used to move cattle inside the properties (Fig. 5.4), and also sometimes among properties, even if trucks are now the main transportation method. Farmers unions are very important, and are present all over the country, being the loudspeakers for farmers and also centers of technical and social exchange.

As we have already explained, young people do not think that this is a fashionable way of living, so it is rather difficult to imagine what the farm organization—or even the industry organization—should be in the next few decades. Even if there are fewer and fewer people working or living in the countryside, traditions are increasingly present in social activities such as commemorations or sports or simply local feast days, where horses and riders are more and more becoming central attractions.

At the same time, some controversies are being examined by Uruguayans and will probably remain unresolved in the near future. The first question addresses national disposal of natural resources. Is it worth promoting nonlocal users of local natural resources? The beneficiaries and affected people are different and are located in different parts of the world. Should Uruguay put at risk its electricity production, which is partly dependent on runoff water, which is diminished by tree plantations? The second question refers to the necessity of introducing norms for the use of natural resources, where two different but related issues can be identified. Good knowledge and accepted mathematical models support land use decisions, and are used by the government to induce limited erosion of agricultural soils, and the Livestock Production on Natural Grassland National Board is deliberating about whether to promote natural grass conservation. Both measures should be adopted by people without their receiving extra money for actions of this type, as it is usual in the USA or Europe (Cattan 2014), and discussions are being held about the possibility of enforcing these norms. How much should a little country engage Pastoralism in South America: itself in global issues such as global warming or biodiversity loss?

5.3 Dynamics of Social–Ecological Systems in Pasture Management in Southern Patagonia, Argentina

Until the late nineteenth century, the dry steppes of Patagonia were void of permanent settlement and supported only a tiny population of nomadic hunter-gatherers. Once the young South American republics of Argentina and Chile had achieved internal organization, they could afford territorial expansion over neighboring Patagonia. By 1880, the "Conquest of the Desert" by the Argentine Army appeared to be not only an internal issue but much fostered by western European countries willing to expand agriculture, especially animal breeding in temperate regions (Fig. 5.5).

This led to the fast occupation of the fertile plains of the Pampas with cattle and crops, whereas the less fertile Patagonia was settled by huge sheep farms for the greater benefit of British, Flemish, or German wool companies (Fig. 5.6).

According to the recorded stocking rates during that early period in most of Patagonia, the early settlers overestimated the carrying capacity of the rangelands and overstocked them. The following figures must be considered in relation to the low primary productivity of the Patagonian steppes (610 kg/ha/year on average for the whole region, according to Paruelo et al. 1998): stocking rates of about two sheep per hectare may sound very modest in productive rangelands elsewhere but they are extremely high in Patagonian terms, and too high for the arid steppe. Nevertheless, those were the initial stocking rates in extensive areas regardless of

Fig. 5.5 The huge Patagonia was settled to develop livestock production using the natural steppe

Fig. 5.6 Wool production at the beginning of twentieth century (*left)*, mainly based on the merino breed (*right*)

their actual (and by then ignored) carrying capacity. It is likely that the initial overstocking could have been maintained for a couple of decades because of the biomass reserve the region had accumulated in the past, considering it was void of large herbivore herds (because guanacos cannot be considered as such).

Sheep farms boomed at the turn of the nineteenth century, and for four decades occupied 0.75 million square kilometers. The First World War especially fostered this explosive expansion of sheep. The process continued and sheep numbers peaked in the 1950s, when about 22 million animals were recorded. From then on, overgrazing started to become evident to open-eyed scientists, who anticipated a decreased productive capacity of Patagonian rangelands and, thus, advised there should be lower stocking rates. However, the question of the health and sustainability of pasture did not really start to get the attention of farmers until the 1980s, when the damage became too obvious and costly in terms of reduced production. For wool, this decrease was estimated as 0.5 % per year from 1940 to 1987 in well-managed ranches in northwestern Patagonia (Soriano and Paruelo 1990).

Even if many small farmers (fewer than 1000 sheep) exist in marginal areas, the core of sheep farming is performed on a very extensive basis in plots ranging from 10,000 to 30,000 ha, which support flocks of 2000 to 15,000 sheep. The numbers are much larger for company-owned ranches. Only differing in the larger size of the paddocks, this model was mostly based on the ones that had built the wealth of the Pampas and the Falklands, wetter regions next to Patagonia in which sheep colonization of the latter started.

Decreasing productivity, along with difficulties in wool and meat commercialization, forced the adoption of nonsustainable ecological and economic dynamics in the recent decades (Ares 2006), yet the stocking rate steadily decreased during the last three decades, as evidenced by a regional Patagonian stock as low as ten million sheep in the late 1990s. The current average stocking rate is about 0.3 sheep per hectare but may be as low as 0.1 sheep per hectare (Fig. 5.7). Beyond this threshold it is considered that economic sustainability no longer exists. This explains the closure of many sheep farms in Patagonia, (about one third or two thirds of them, depending on the area), since in most cases reconversion is utterly impossible because of ecological constraints.

Thus, less than a century after the beginning of pastoral colonization, the process has transformed much of the vast steppes of central and eastern Patagonia into desertlike areas. Despite the dramatic decrease in the stocking rates in the last three decades—or even the closure of ranches—pasture recovery (if any) is extremely slow.

Patagonian rangelands have proved to be more resistant than resilient. In fact, they "resisted" heavy stocking during the early period—thanks to the biomass previously accumulated—and maintained a good secondary production for several decades. Once the pasture degradation was evident and stocking rates started to be conscientiously diminished, resilience did not appear as the traditional model predicted, and it became obvious that the "state and transition model" (Westoby et al. 1989) was more accurate for most of the Patagonian rangelands, in which, most likely, a new lower state had been reached.

Fig. 5.7 Harsh conditions—low rainfall, wind erosion, and overgrazing—explained rangeland degradation

Although the lessons had been learned by academics and decision makers, ranchers did not realize that changes in range management should be made to cope with the new (poorer) environmental context. Compelled by the exigencies of everyday life, they insisted on overestimating the carrying capacity of their pastures, and used to blame the climate and the vagaries of the Argentine economy as well as the great variations in the international wool and mutton markets.

Some intensive campaigns in the 1990s and a constant effort to adjust public policies in the first decade of this century eventually led to a widening of the point of view of the traditionally conservative rural milieu. The learning is reflected by new words freshly incorporated into the rural Patagonian lexicon and currently quite often used. Desertification, shrub encroachment, rotational grazing, electric fencing, prelambing shearing, or even feedlot are now meaningful concepts among Patagonian sheep ranchers.

The learning of this agronomic lesson was not a mere top-down process but in many cases a painful personal experience about how to not perish in a degraded environment and an unstable market. In the first few years of the last decade, sheep ranching in Patagonia suffered a deep crisis owing to pasture impoverishment and economic instability added to some episodes of drought and volcanic ash spill. However, this almost generalized collapse served to somehow "reset" sheep farming in the whole region, by causing the abandoning the nonviable ranches and forcing survivors to adopt a more careful rangeland management.

The abandoning of ranches could be interpreted as an ecological victory, because once sheep have been removed, the grasslands/rangelands can be rested and given a (tiny, as seen) chance to regenerate. With both sheep and fences removed, remnant wildlife populations will have access to an unfragmented habitat and the chance to survive and flourish. In such a case, collision with contiguous persistent sheep flocks is unavoidable, either with herbivores (guanacos, rheas) competing for pastures or water, or with predators (foxes, pumas) attacking sheep.

Eventually, these "threats" to sheep farming could be considered as ecologically tolerable. The same cannot be said of the increasing threat of Metal mining and shale hydrocarbon production are fairly well distributed in Patagonia. The discussion about the environmental future of this region is currently open.

It is clear from this case study that at the beginning of the colonization the Patagonian rangelands resisted sheep grazing because of the cold and dry condi-

tions of the natural steppe. The livelihoods of farming families improved thanks to the income from sheep's wool. The local society started to organize itself, focusing on the wool trade and the supply chains for sheep production. However, the permanent overgrazing, the overuse of shrubs for heating and cooking, and with low rainfall and strong wind erosion progressively destroyed the rangelands. At that time, just a few scholars mentioned the challenges to change the practices to sustain the sheep farming system. So, three decades after the beginning of colonization, the decreasing productivity of the sheep farms because of pasture degradation was partially hidden by the high demand for animal products linked to the First World War in Europe, even thought the opening of the Panama Canal significantly reduced the major role of Patagonia in transoceanic trade. Hence, sheep production continued to increase slowly during the first decades of the twentieth century. Then mining exploration, especially oil and gas, and tourism became the pillars of the Patagonian economy. And now, sheep farming is perceived as a heritage, especially by young people and those in urban areas.

5.4 Dynamics of Social–Ecological Systems in Pasture Management in Eastern Amazonia, Brazil

From the middle of the 1960s until the end of the twentieth century, the Amazon rainforest was the northern agricultural frontier of the South American colonization process led by the descendants of European pioneers (Morales et al. 2011). In the two decades before, the Cerrado had been the agricultural frontier (Fig. 5.1). This forest biome was colonized by transformation of the natural forest and savannas of Brazil and Bolivia into crop–livestock landscape.

Currently, the main land use in the Cerrado is maize and soya bean production for human food and animal production, and pastures for cattle ranching. Only 10–15 % of the natural Cerrado biome area has been preserved. The same process was logically applied to the Amazon rainforest until it was progressively stopped from the 1990s with increased environmental awareness among local populations and global governance. Sayago et al. (2010) showed all nine Amazon countries have been affected by the same colonization process. It was more significant in Brazil because of the huge area of Brazilian Amazonia, 65–70 % of the Amazon rainforest.

As decided by the Brazilian government, the colonization of Amazonia aimed to achieve a triple objective: social, economic, and political. First, the Brazilian government wanted "to give land to landless" (*terra sem homem para homens sem terra*). This aimed to attract migrants settle Amazonia but also to face the rural exodus linked to mechanization and land concentration in southern and eastern Brazil. Second, the Brazilian government and national companies wanted to exploit the huge natural resources of soil and subsoil of the Amazon rainforest, to incentivize and directly support the national development of all the country. Third, the military, which ruled the country at that time, wanted to secure the borders and avoid the interest of neighbors, considering that diverse plans had been proposed by foreign companies to exploit the Amazonian resources. One of them was the Rockefeller

plan in 1933, which proposed the building of a huge dam at the mouth of the Amazon to facilitate oil exploration and transportation (Veiga et al. 2004).

So, the clear aim of successive Brazilian governments was to use the Amazonian natural resources to support local and national development. Years, decades, and centuries before, there had been diverse valorizations of Amazonian natural resources. Scholars reported that leathers and hides of animal wildlife, drugs and medicines, and fruits were collected by explorers who traded with Indian and *Cabocla*[1] communities from the seventeenth and eighteenth centuries (Vaz 2013; Veiga et al. 2004; Poccard-Chapuis 2004). It was the time of *drogas do sertão*, the word *sertão* meaning "bush," the hinterland of the Northeast Region, far from the coast, where the ports and cities were located. At the end of the nineteenth century, the rubber of *Hevea brasiliensis* became the main resource for exportation. The rubber trade allowed the development of and resulted in the wealth of the main cities, such as Manaus, Belém, and Santarém. The Brazil nut was also a significant Amazonian resource for national consumption and exportation.

Fifty years after colonization, several minerals (especially iron, aluminum, nickel, copper, and zinc) are being extracted from Amazonian subsoil and have significantly contributed to Brazil's development. Hydropower is another Amazonian resource with a significant contribution on a national scale. For example the huge Tucuruí Dam produces energy for local populations but also for mining and transformation (e.g., aluminum). The effect of mining on the social–ecological system is different from that of agriculture. The impact on the ecosystem is usually low because of the subsoil activity and the small land area involved. However, the effect is high on local employment and distributed salaries.

The main impact on the social–ecological system was linked to the development of the agricultural frontier. "The Amazon colonization through the cattle foot" (Santiago 1972) was the leitmotiv during the two first decades, until the middle of the 1980s. Slash and burn was the reference practice to transform forest plots into pasture (Fig. 5.8).

The process was as follows: (1) cutting and burning of the natural vegetation in September to October, at the end of the dry season; (2) sowing an annual crop, in January to February, at the beginning of the rainy season, usually rice, and maize if it is a secondary forest; (3) seeding the forage directly into the cereal, in March to April, 6 or 8 weeks later; (4) harvesting the cereal in May to June; (5) leaving the forage to grow until September to October, before cattle graze it. Every year, every smallholder cultivates 2–4 ha of land by following this process.

In this smallholder farming system, cereal production secured food security: human food, feeding of small animals (pigs and poultry), and sale to provide other goods and cover other expenses. Cattle produce milk and can be used as saving. Livestock multifunctionality, including crop–livestock integration, helped smallholders survive. The same process also allowed cattlemen to expand their ranches, planting year after year some tens of hectares. So, cattle ranching is the main land use after

[1] Community settled by *metis* (cross-breeding) of Amerindians and descendants of Europeans migrants.

Fig. 5.8 Cattle ranching expansion transformed rainforest into large and small ranches

deforestation for several reasons (Veiga et al. 2004). Fifty years after the start of colonization, about 1,000,000 km^2 of the rainforest (i.e., approximately 15–20 % of the Amazon basin), has been transformed into pasture, about 70 % occurring in Brazil.

At the beginning of colonization, some farmers settled on rich soil and planted perennial crops, especially cocoa, coffee, and pepper, in Amazonia of Brazil. However, the crisis regarding perennial crop prices at the end of the 1980s forced many farmers to abandon their plantations and plant forage. More recently, some farmers decided to plant perennial crops again but usually in diversified farming systems. Timber exploitation began with colonization but it became a significant activity only in the 1980s, when foresters started to exploit the public rainforest reserves. Timber exploitation had a strong impact on the ecosystems, mainly in opening tracks in the forest for that the pioneers and landless used to access new land to slash, burn, and cultivate it. Except for some individual cases, the foresters never adopted sustainable timber exploitation. On the contrary, for several decades they preferred to cut and exploit the two or three interesting trees per hectare before to slash and burn the plot and transform in pasture (Fig. 5.9).

Exploitation of soil and natural vegetation by pioneers, cattlemen, and foresters does not explain all the transformation of the natural forest into an agricultural landscape. Landownership access has also been a strong factor in deforestation. Several scholars stated that in different part of the Amazon rainforest, migrants used the colonization process to occupy private and public land and developed farming systems while waiting for the regularization of their landownership by the local government. Treccani (2001), Veiga et al. (2004), and Vaz (2013) mentioned that in the 1950s and at the beginning of the 1960s, some pioneers were occupying the land and registering it so they could sell it to new migrants.

Progressively, the migrants settled in communities. Usually, the community is defined as some families living in the same area and sharing some services and social activities, such as church, school, and soccer team. Mutual work is also done at the community level (Veiga et al. 2004). On the basis of the life trajectories of several Amazon pioneers, Tourrand et al. (2012) showed that migrants are not adventurers. The migration to Amazonia is usually a well-prepared event in the life of future migrants. When they migrate, they know where they are going and who will receive him, often a relative who has already migrated. The migrants know in which community they will live when they arrive, what kind of work they could do, and what their prospects are. Sometimes, they have already visited the region to know better the new land and community.

Fig. 5.9 Perennial crops (cocoa; *left*), timber exploitation (*middle*), and cattle ranching (*right*) in Amazonia in the 1990s

A community is not independent. It depends on the county, which has the administrative rights to the land. Some communities depend on two counties, but this is not frequent. According to the demand at the community level and its elective power, mainly after the return of democracy in 1985, the county has to implement institutional services such as health and school services, maintenance of roads and tracks, electricity, mail services and telecommunications, and extension services. Usually, a community has to elect one member to serve on the county council. That person is responsible for defending the rights of the community in the county.

The communities grow with as new migrants arrive. Some of them will become villages with their own communities. When a certain size is reached, a village and its communities can demand the right to create their own county, especially when the county town is far away or when the context is very different. This was the case for the villages of migrants located along the colonization routes which were linked to the administrative centers located near the river (Fig. 5.10).

During the 50 years of colonization, different social organizations have been created at local and regional levels. At the county level there is the Union for Rural Workers (Sindicato dos Trabalhadores Rurais) and the Rural Union (Sindicato Rural) for smallholders and medium-sized to large agribusinesses respectively. Along the Trans-Amazonian Highway, especially in the state of Pará, there is the Movement for Transamazon Survival (Movimento Pela Sobrevivência da Transamazônica). There is the Council of Rubber Tappers (Conselho Nacional dos Seringueiros) in the state of Acre. Some organizations are at national level, such as the Land Pastoral Committee (Comissão Pastoral pela Terra), linked to Catholic Church.

Until the middle of the 1980s, to quickly settle the Amazonian agricultural frontier, the public policies subsidized the deforestation through special loans from two public organizations: the bank Banco da Amazônia and the Superintendência do Desenvolvimento da Amazônia. Moreover, at least 30 % deforested land was the criterion for a potential owner of this land to receive loans. The public policy changed from the middle of the 1980s. Banco da Amazônia and Superintendência do Desenvolvimento da Amazônia, but also the Bank of Brazil, offered only loans to recuperate degraded land, and not to deforest more land.

At the same time, the control of deforested areas became easier with remote sensing, on both a local scale and a regional scale. Progressively during the first decade of this century, farmers were considered responsible for the deforestation of their land. Furthermore, they had to submit an individual plan aiming to recuperate

Fig. 5.10 Settlement of pioneers (*left*), urbanization (*middle*), and development of a social society (*right*) in Amazonia

a significant part of natural forest on their land. In addition, all the titles of landownership had to be proved, especially for medium-sized and large farms, and have been linked to the recuperation plans for natural forest.

It is clear from this case study that during the 50 years of colonization of Amazonia that the Brazilian government has strongly supported the settlement of the agricultural frontier to profit from the huge natural resources of the rainforest for national development. The Brazilian government is now trying to reduce the impact of deforestation and recuperate part of the natural ecosystems through a set of policies based on subsidies, but also penalties and strong sanctions, including removal of landownership. At the same time, the Brazilian government is aiming to alleviate poverty through special policies focused on the livelihoods and living conditions of smallholders.

5.5 Strategies for Sustainable Pasture Management in Tropical and Subtropical South America

On the basis of interviews with diverse livestock stakeholders (breeders, traders, agroindustry, extension services, local governance, etc.), information in public databases, especially the successive census, and a review of literature, we examined the three cases in tropical and subtropical regions of South America to create a better understanding of the actions developed by societies regarding the livestock sector. We analyzed the interactions between a livestock-raising area (currently or potentially) and a society willing to occupy such territory and practice cattle breeding as the tool for doing so. We describe how the different sets of historical conditions and ecosystem capacities have modified the dynamics of the process in three case study areas, a process lasting five centuries in the Pampas, 150 years in Patagonia and 50 years in Amazonia. One of the essential aspects that we have identified is the nonlinearity of the interactions and the different periods, which characterize the arrival of irreversibility in these contexts. The presence of thresholds, which mark the irreversible transition between two successive states of the social–ecological system, shows how two more and less similar initial situations could diverge a lot in a short time. Consequently, it is not easy to assess and

monitor the evolution of the social–ecological system of pasture management and adapt to its dynamics, justifying many surprises.

5.5.1 Similarities Among the Three Case Studies

Although roughly 3000 km separates the core of the Amazon rainforest from the Uruguayan prairies and a further 2000 km separates the latter from the southern Patagonian steppes in Argentina, with the entailing climatic and agronomic differences, the three case study areas share some geohistorical features, allowing a comparative analysis among them. Firstly, the three were marginal areas for the imperial powers that colonized South America from the eighteenth century. In fact, the Portuguese and Spanish empires never achieved permanent settlement either in Amazonia or in Patagonia, and even Uruguay was a frontier (and litigious) area between both imperial powers. None of the three regions had a well-developed Amerindian civilization, such as in the Andes and Central America, which thus became the centers of the Spanish American Empire, nor the mineral wealth supporting the core of the Portuguese Empire in southeastern Brazil (Droulers 2001). So, if the marginality of the fertile prairies of Uruguay can be explained because of their situation at the fringe of two territories, and which has geopolitical origins, that of Amazonia and Patagonia is clearly due to environmental constraints, which repelled permanent economic occupation. In the three cases, regardless of the time at which they happened, the process of permanent economic occupation started with livestock. Since the three case study areas also shared the capitalist way of arranging territory, livestock husbandry was in all three areas the first step to eventually secure landownership, except until the end of the eighteenth century in the Jesuit/Amerindian area in the north of Uruguay. This process occurred quite early in Uruguay, at the turn of nineteenth century in Patagonia, and as late as the end of the twentieth century in Amazonia.

Livestock farming triggered the permanent occupation of these areas previously void of attractive activities. In fact, animal husbandry (cattle in Uruguay and Amazonia and sheep in Patagonia) was the pioneer activity that attracted migrants and initiated ensuing economic activities. Cattle rearing were almost the only economic driver in Uruguay during most of the nineteenth and twentieth centuries. Sheep rearing boomed in Patagonia in the first decades of the twentieth century but collapsed in the last decades. Tropical breeds of cattle are now booming in Amazonia. Other economic drivers followed and currently compete with pastoralism in leading the regional economies. This is forcing adaptive changes of animal husbandry in the three regions.

The three landscapes were part of a continent with a low human pressure. Some 10,000 years ago, humans entered America by the north of the continent, and by the time of the arrival of Europeans some very impressive civilizations existed and others had already disappeared. In the areas that we are studying, the populations were very low, there was only some very primitive agricultural activity, and the societies were

not very complex. People organized themselves into somewhat errant tribes, without an important architecture and without any appreciably sophisticated agriculture.

The three regions offered an opportunity for people to earn a living who had suffered difficulties in their original locations, and this was the real reason behind the colonization. The reasons of the immigrants were always similar: they needed a new area where they could develop a better life.

The existence of organized societies that were eager to occupy more space for its functioning was another common point. The eastern part of Uruguay, along the Atlantic coast, was a disputed area between the Portuguese and the Spanish empires. Patagonia was claimed more or less clearly by Argentina, Chile and England. Brazilians were eager not only to give opportunities to poor Brazilians but also wanted to establish firmly their presence in Amazonia.

The original existing wildlife was very rich in the three case study areas, with an important common point being the absence of big herbivores. It has been established that an important loss of big mammals occurred some 10,000 years ago, and this characterized the situation. In grassland/rangeland areas of both Uruguay and Patagonia, little ruminants (deer and guanacos, selvage llamas, etc.) were present but their impact on vegetation was not important.

The drivers that induced pastoral production were the same in the three cases. Initially, local consumption explained its development, but soon after the arrival of Europeans, foreign and distant markets influenced and boosted the process. For Uruguay, initially hides and wool for the European cloth industry and then beef and recently soybean—wool in the Patagonian situation and beef ("the hamburger connection") and also soybean in the Amazonian situation—explained the characteristics of the advance of humans over nature in our case studies, the organization of local societies, and the environmental impacts.

Another important shared characteristic is the difficulties to develop crops. Even though in Uruguay and in Amazonia some areas are dedicated to crops or wood production, in both situations this activity is risky because of fragile or shallow soils, weather variability, market vagaries and the distance to harbors, and also because of problems of adapting temperate crops that originated in Europe or Asia to a different situation. In the case of Patagonia, dryness is so marked that cultures are not possible without irrigation, and water is not abundant.

5.5.2 Differences Among the Three Case Studies

The three case study areas are, from south to north, southern Patagonia in Argentina, the Campos in Uruguay, and eastern Amazonia in Brazil. Several sharp differences exist among these three case study areas, and more generally between the three biomes.

First, as already stated, the climate is dry and cold in southern Patagonia, temperate in Uruguay, and tropical in Amazonia. This climatic difference has some important consequences for the human population. The agricultural potentials for European settlers were very different. European agriculture did not have the knowledge, tools,

and genetic resources to develop a tropical agriculture, so it is easily understood why this region was the last one that was incorporated by the colonialists.

Clearly, because of these conditions, Uruguay was best suited for European herbivores: cattle, horses, and sheep. The Campos are very good for cattle, and their excellent availability of surface water promoted the herds. The Campos are not always well suited for temperate crops (wheat, oats, and maize), but they can be cultivated for local consumption, and also in some circumstances, as nowadays, can produce grain for export. This is not the case for Patagonia, where it does not rain enough, there are not good wells, and there are only a few rivers. Some cultures are present in the valleys, but their importance is low.

When we compare pastoral potential, there are huge differences. The Patagonian steppe, with harsh winters and scarce rainfall, allows annual grass growth of less than 500 kg of dry matter per hectare, compared with 4000 kg of dry matter per hectare in Uruguay and from 3000 to 5000 kg of dry matter per hectare according to the soil conditions for the grass patches in Amazonia. Good grass management norms allowed commercial production while maintaining the resources, which was easy in Uruguay, but extremely difficult in Patagonian conditions, where the price paid for learning has been very high in some cases. It consisted in destroying the resource. The Pampas case study in Uruguay is very different for the reasons previously mentioned. In contrast to the Patagonian case study, at the beginning of colonization in the sixteenth century, pasture management started with a very low stocking rate regarding the carrying capacity, both in the south and in the north of the country, which were settled by European migrants and Jesuit communities respectively.

The situation is contrasted among the Amazonian social–ecological systems. The natural prairies located on several islands of the Amazon, especially the eastern part of Marajó, and along some riverbanks have productivity near to that of the natural prairie of Uruguay, with a sustainable stocking rate of about one cow per hectare. In contrast, in the Amazon rainforest there were no grass management norms because the grass can grow only after being slashed and burned. A few tropical forages come from South America, but the main part is imported from Africa, especially diverse *Panicum* and *Brachiaria* species. These cultivated pastures opened up a whole new range of opportunities, making possible beef and milk production, and transforming Amazonia to first-class world player for these products. The livestock breeds are also different. In Patagonia and in Uruguay, the Europeans breeds proved to be well adapted, but this was not the case in Amazonia, where the grazing systems are the result of human-induced synthesis of initially not connected living beings. Cattle breeds came from India, buffaloes came from India and the Mediterranean, and grass species came mainly from West Africa to this South American location with a human population dominated mainly by European descendants.

Moreover, even though the three case study areas were colonized by Europeans settlers and their descendants, their histories differ, especially the colonization and the origin of the migrants. From the sixteenth century in Uruguay, European settlers from Spanish Kingdom in the south and Jesuit communities, including Europeans migrants and Indian native families, in the north developed livestock farming systems based on the grazing of the grassland/rangelands. From the end of the nine-

teenth century, the Argentine Army seized Patagonia from Native Americans to allow colonization by shepherds from the Falklands and the Pampas, and by European and Mediterranean migrants. From the 1960s, the Brazilian government decided to colonize the Amazon rainforest with the three objectives of securing Brazilian landownership, exploiting the natural resources from the soil and the subsoil, and giving land to the landless from other regions.

The contrast regards the land-use change and the herd management practices. Large areas of the Patagonian natural steppe have been seriously degraded by inadequate pasture management, mainly overgrazing associated with low rainfall and strong wind erosion. At present, many farms have become unviable or have even been abandoned because of desertification. The natural vegetation has disappeared and the steppe has been degraded to desert. Large areas of the Amazon rainforest have also been changed by pioneers using slash and burn practices to plant pastures for their cattle herds. However, the bioclimatic conditions allow the progressive regeneration of the rainforest after several years. In Uruguay, the natural grasslands had been softly grazed by cattle and sheep herds for almost five centuries before they were recently partially destroyed to plant cultivated pastures from the 1970s and tree plantations and grain crop systems from the 1990s.

Finally, global environmental stakes probably make the most important difference. Turning the Uruguayan campos into tree plantations or crops, adjusting grazing management in Patagonia to maintain sheep farming, and transforming the Amazon rainforest into crop–livestock land have an impact on global issues such as climate change and biodiversity loss, but also human dimension issues. The impact of transforming the Amazon rainforest into pastures is suspected of changing human life on Earth.

5.5.3 Three-Dimensional "Vulnerability" Coordination Framework in Assessing Vulnerability

The three social–ecological systems of pastoralism in Amazonia, the Campos, and Patagonia have been projected into Dong et al.'s model (2011), which is based on the three-dimensional vulnerability/resilience. We consider that before colonization, the three social–ecological systems of pastoralism were in similar positions regarding vulnerability. The of agroecosystem dimension (vertical axis) was abundant with limited livelihoods (transverse axis) and low institutional capacity (horizontal axis). The red star gives this position, located in octant 7 of the model (Fig. 5.11).

Assessing the present positions of the three social–ecological systems of pastoralism gives the following result. The Amazonian system of pastoralism is located at junction 1–2. The few counties located at the border of the Amazon basin were the first to be colonized. They were almost totally deforested, mainly along the roads where were settled by the migrants. The other counties, colonized more recently, usually still have a significant area of rainforest, especially far from the roads. Mostly, the forest is not exactly the natural rainforest, because the best trees

have already been exploited. Despite the differences between the counties, a significant part of the ecosystem has to be considered as degraded, about 20–25 % of the area. This justifies the evaluation of the agroecosystem as neutral, not robust, and not fragile. In contrast, the livelihoods on the Amazon frontier have been strongly improved compared with the beginning of colonization, mainly in the past two decades with specific public policies. The improvement concerns all the public services, including health, education, road maintenance, loans, rural extension, energy, and communications. The same can be said for the institutional capacity, particularly after the return of democracy in the 1980s. Directly linked to the current social and environmental policies implemented by the Brazilian government, the resilience of the agroecosystem should be improved, as should the livelihoods and the institutional capacity (Fig. 5.11).

Nowadays, the Campos social–ecological system of pastoralism is located near the one for Amazonia one in the model in Fig. 5.11. The livelihoods and the institutional capacity have been improved greatly since the beginning of colonization, especially in the last few decades, and for the same reasons as in Amazonia. With regard to the agroecosystem, the natural grasslands/rangelands did not change much from the sixteenth century to the seventieth century until the middle of the twentieth century, when the development of mechanization allowed the transformation of natural rangeland into cultivated grassland with the objective of increasing the productivity per hectare. However, the no change concerned only a small part of the area, especially in northern Uruguay. In contrast, the recent development of tree plantations and soya bean for exploitation is significantly changing the context. Of the 16 million hectares of natural or cultivated grassland, about two million has been transformed into tree plantations or soya bean fields in less than 10 years. Even though the future of the Campos social–ecological systems of pastoralism will greatly depend on the choice of social and environmental policies, it is assumed that the core of the basaltic area—three million hectares—located in the north of Uruguay and unfit for cropping or forest production, will remain in state ownership.

The current position of the social-ecological system in Patagonia is different because of the degradation of the natural ecosystem and the low natural recuperation process. Even after 15–20 years without grazing, there is no significant improvement of the land cover. Moreover, the livelihoods are not good because of the degradation of the common ties that stems from the loss of the rural population (whose density may be as low as 0.01 inhabitant per square kilometer) and the distance between the farms, usually some tens of kilometers. These reasons also explain the weak institutional capacity, even if the institutions are present in the urban centers and extension staff is quite active. So, the Patagonia system has been located as straddling octants 6 and 8 in Fig. 5.11. The outlook for the future is pessimistic because of the low natural recuperation process of the Patagonian steppe and the high cost to replant it. Nevertheless, if resilience is seen not as recovery but as transformation, it must be said that Patagonian society is looking for different ways of transformation to cope with a henceforth degraded ecosystem. The choices range from opencast mining to national parks and reserves, with intermediate alternatives such as agrotourism or durable methods of sheep farming (Coronato et al. 2011), but once again, the final outcome will depend on competition between a broad set of actors, from local to international (Schmink and Wood 1992).

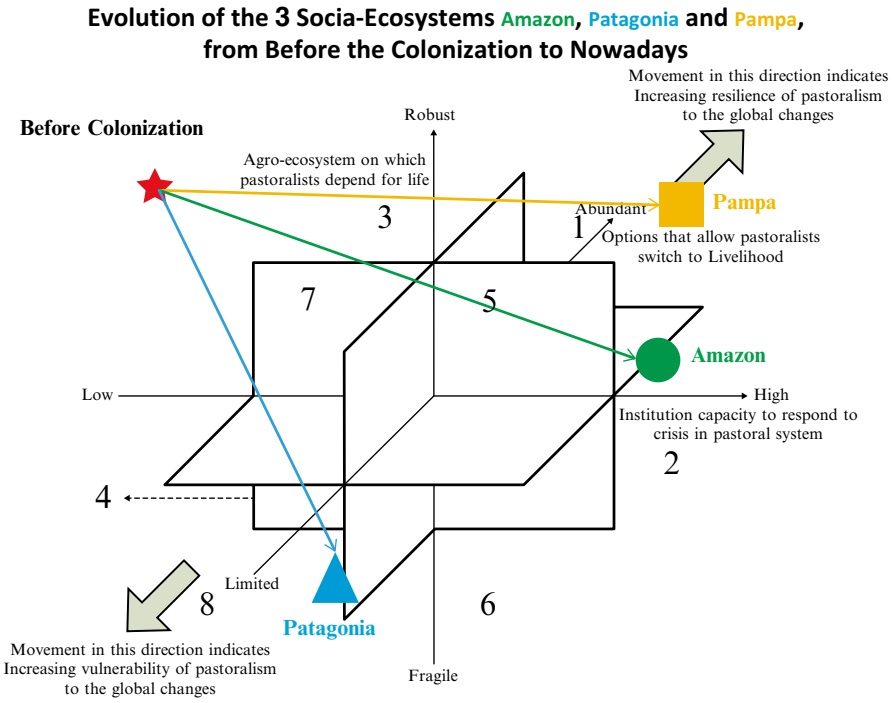

Fig. 5.11 Evolution of social–ecological systems of pastoralism in Amazonia, Patagonia, and the Pampas from before colonization to the present time

5.5.4 Irreversibility Thresholds and Learning Adaptation Possibility

As analyzed in Chap. 2, resilience can be seen as stability (buffer capacity), recovery (bouncing back), and transformation (creativity). These three processes mark important differences among our three case studies. Moreover, as stated by March (2010), it is not always possible to learn from experience, especially if the effects and consequences of actions are distant in time or space. Furthermore, the ability to learn from experience is central in adaptive management (Walker and Salt 2006), which consists in taking practice as an experiment, monitoring, reflecting, and proposing changes to increase adaptation, and can be seen as the equivalent of creativity as already discussed. But even if this definition is broadly accepted, successful examples of adaptive management of natural resources are scarce in the international literature (Williams and Brown 2014). Our case studies give us the opportunity to analyze this important subject: can social–ecological systems of pastoralism adapt to different dynamic environments? And what are the learning results from the comparative analysis of our three contrasting case studies?

The usual answer is: it depends. Initially we discuss these characteristics in the two grassland/rangeland regions: Patagonia and Uruguay. Then we include the Amazonia case study.

After five centuries of grazing, the Campos ecosystem appears to be mostly in a very good situation, even though it has been stated that a fifth of its initial content of carbon has been lost because of the presence of European grazers during this time (Piñeiro et al. 2006). It is difficult to establish if this trend will continue in the next five centuries. But for the moment there is no evidence of production capacity loss. The pasture management practices did not significantly degrade the natural ecosystem. In other words, the natural ecosystem is not vulnerable to grazing applied by the ranchers. So, the Campos social–ecological system is resilient, and in this case, resilience means stability (buffer capacity).

Furthermore, the recovery (bouncing back) appears to be very present in the Uruguayan grassland/rangeland conditions. It is well documented that grass growth can completely recover after a drought, even a very severe one as that experienced in 1989.

In contrast, in the Patagonian case, the type of social–ecological system caused large areas to collapse in less than 50 years from the end of the nineteenth century to the first decades of the past century; in less than a half century, large areas of the central Patagonian arid steppe were destroyed by inadequate management practices. The social–ecological system collapsed and some of these lands have been abandoned because they are no longer productive. So, there was no stability because thresholds have been surpassed (buffer capacity). It is interesting to notice that, at this time, the shepherds have adopted these practices, thinking they were in a ecosystem similar to that in the Pampas or Campos where many of them had previously settled.

In the past and even recently, some ranchers tried to restore their rangeland by reducing the stocking rate or adopting pasture rotation until they stopped grazing for many years. But when the steppe is strongly degraded, the natural regeneration (if any) is very slow and reduced to some small plots, because a too large part of the land is uncovered, the soil having disappeared with wind erosion. Artificial restoration is possible, but the very high cost limits this to very small plots, such as those destroyed by mining or oil exploration. Moreover, the low price of wool for many decades was not attractive to possible investors. So, the central Patagonian social–ecological systems would not be resilient because they too degraded according to their restoring capacity. In other words, the resilience of these systems would reach an irreversibility threshold.

The same management practices were adopted in the southern lands of Patagonia, and near the Andes. In these zones, the climatic conditions are better—namely, more rainfall and less dry and strong wind, which means the climatic conditions are quite similar to those of the driest zones of the Campos (even if much colder). Consequently, the degradation of natural rangeland was lower, and sometimes there is no significant degradation of the natural steppe, as it was noticed in the Campos. Most obviously, there is almost no abandoned land in these areas. So, the vulnerability and the resilience of the Patagonian steppe appears strongly linked to the type of pasture management, mainly the balance between the grazing impact and the regenerative capacity of the local rangeland.

The context is different in the Amazon rainforest, where the natural vegetation was destroyed to plant pasture. Many scholars have reported the strong degradation of the pasture in a few years, leading to the temporary abandoning of the degraded plots and consequently the deforestation of new plots to feed the herds. Veiga et al. (2004) linked this degradation to inadequate pasture management. Planted just after the burning of natural vegetation or directly in the first food crop, the pasture profits from the ash to grow, quickly and cover the soil and compete with weeds, including the regrowth of natural vegetation. But after some years of grazing, the soil fertility decreased, areas without forage cover appeared, and natural vegetation grew and competed with forage, until it dominated. However, the natural regeneration allows the progressive restoration of secondary forest in the degraded pasture in time, which depends on the level of degradation and the type of soil. So, after some years, usually 4–5 years, ranchers slash and burn the secondary vegetation to start a new cycle. It was the process most commonly applied during the three decades of colonization.

According to Veiga et al. (2004), sustainable pasture management needs (1) a stocking rate adapted to the forage biomass, (2) rotational grazing management to respect the cycles of pasture, (3) control of weeds, and (4) use of some fertilizers to replace the soil nutrients. Since the end of the 1980s, many degraded pastures have been recuperated on the basis of this set of practices. The process occurred firstly in large and medium-sized farms, which can obtain the funds to finance it, and secondly in small farms.

On the basis of this set of practices, the resilience of the new social–ecological system in Amazonia would be high (buffer capacity) with real restoration potential (bouncing back), even it results from the destruction of the natural forest ecosystem. In this case, the ranchers have transformed the natural ecosystem into a resilient social–ecological system (creativity) where the natural ecosystem is still present in protected forest reserves in specific areas such as near the sources, along the riverbanks, and on the strong to avoid soil erosion and maintain a minimum of biodiversity. In this case, resilience as appears as the capacity of radical transformation of the environment, from forest to grasslands, and eventually cultures, is the objective to allow people to earn their living. Moreover, this ability is directly connected to the ability to interact with distant regions. Without the interaction with African rangeland scientists, who created forage varieties, Indian farmers, who created resistant zebu breeds, and the skill of Brazilian scientists to build efficient farming systems and the pioneers who had no alternative to survive, the grasslands/rangelands in the Amazon rainforest would have never existed.

In this context, in the face of the dynamical complexity of social–ecological systems, stability can be present for centuries as in the core Campos region, the basaltic zone, it can last only some decades, or it can adopt a truly new configuration as in Amazonia. Adaptation uncertainty is linked to the presence of not perceived thresholds, as illustrated by the Patagonian farmers.

5.5.5 *Mental Models of the Human–Nature Relationship in South American Pasture Management*

On the basis of data collected by the Livestock Farming and Local Development (LiFLoD) network in 13 livestock social–ecological systems located in contrasting biomes on the five continents, Tourrand et al. (2014) have identified similarities between groups of stakeholders regarding their mental models of livestock. The main groups are ranchers (from smallholders to large-scale cattlemen), traders and input providers, managers of agroindustries, extension services, funding agencies, scientists, policymakers, union representatives, association leaders, and consumers.

Tourrand et al. (2014) defined a mental model as a collective representation system—livestock in our case—shared by a group of people. Built over the long term, the mental model is relatively stable and, consequently, does not change much in a short period. Any representation of livestock can be defined as complex set of eight livestock mental models (Fig. 5.12), which were defined as:

- *Lifestyle*: Livestock is the basis of the rancher's life, mainly represented in pastoral societies.
- *Security*: Livestock provides goods, income, and saving. This is particularly dominant in the communities of smallholders.
- *Business*: Livestock is a business on farm, local, and global scales. This is very frequent in the discourse of people working in the supply and market chains, and a part of extension services.
- *Investment*: The livestock sector is a good investment option. Always in the past but more frequent nowadays.

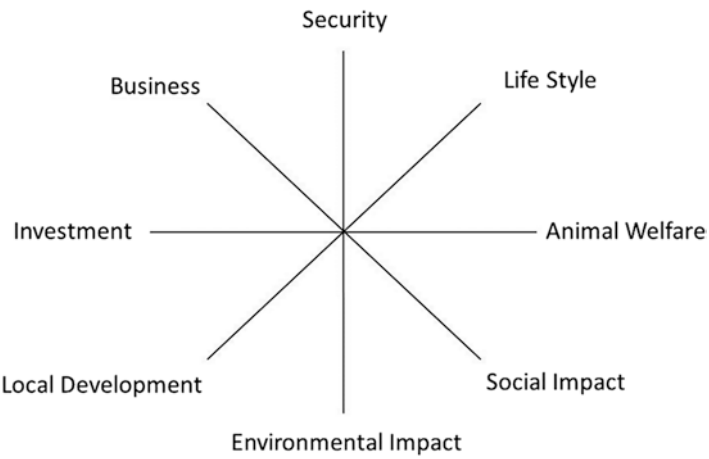

Fig. 5.12 The eight elementary mental methods

– *Local development*: Livestock has a significant role in local development. Discourse mainly in local governance and policymaking, development agencies, universities and research centers, etc.
– *Environmental impact*: Especially focused on greenhouse gas emissions, but also the other impacts. This mental model is more frequent nowadays with the "Green Wave" and the stronger awareness of environmental issues liked to global warming.
– *Social impact*: Livestock leads to social differentiation. This mental model frequently occurs in the discourse in social science community.
– *Animal welfare*: An animal is first of all a living creature very close to humans and which has to be respected, and not eaten.

When we apply these to the three social–ecological systems in the case studies, we find different mental models are interacting according to the period. For example, if we adopt the leitmotiv "the colonization of Amazonia by the feet of cattle," the mental model of the Brazilian policymakers should be a complex combination of mental models including *investment*, mainly national to make a profit with natural soil resources; *security*, especially food security for the survival of migrants; *business* because livestock is business at the frontier; and *local development* to settle and integrate the social–ecological systems into the national territory. At that time, nobody talked about the environmental impacts of livestock, with the exception of some scientists and local NGOs, which were aware of the negative social impacts of livestock (Veiga et al. 2004).

In the same way, Coronato (2010) stated that the colonization of Patagonia at the end of the nineteenth century was also the result of set of factors defined by different and complex mental models. At that time, the Argentine Army aimed to secure the region and to incentivize local development. The British wool companies wanted new lands for investment and to develop their business. Migrants were mainly interested in their food security, some of them using their skill in sheep farming and their lifestyle with livestock. At that time, nobody yet talked about the environmental impact of livestock. In contrast, the size and the location of the land were doing Significant differences among between the settlers.

According to Moraes (2008), in the eighteenth century, at least two main mental models coexisted during the settlement of the Pampas. South of the Rio Negro, the Spanish Kingdom settled the area by allocation of small and large plots of land to European migrants and their descendants to develop cattle and sheep breeding. They did not have an alternative because of the dominance of natural grasslands/rangelands. In the north, the Jesuit communities aimed to join Amerindians and European migrants or descendants in common management of the land. Directly linked to the importance of exportation of animal products, the livestock business always had a significant place in the Uruguayan mental models. The gaucho society has been progressively built during the past three centuries. It is one of the results of the interaction of livestock and natural rangeland (Litre 2010; Morales et al. 2011).

The situation is now changing, especially in Brazilian Amazonia. For different reasons, the Brazilian government recently decided to implement more constrained

environmental policies regarding development in Amazonia. Those measures have strongly motivated the stakeholders with mental models dominated by *environmental impact*. At the same time, the same Brazilian government has launched efficient programs to develop small farm agriculture. These programs incentivize and directly support the stakeholders with mental models more oriented on *social impact* and *local development*. So, facing the new context focused on sustainable development, all other stakeholders have to adopt a friendly discourse regarding environmental issues. For some of them, this is easy because of their natural skills. For others, it is more difficult, and they have to force themselves to present more sustainable strategies. Even so, the discourses have changed; the mental models have not radically changed until now, because they are strongly resilient, as already mentioned. They need more time to change, frequently some years to one generation.

In Patagonia, the situation of stakeholders is different from that in Amazonia because of the lack of direct responsibility of current breeders for the pasture degradation that happened several decades ago. Just a few stakeholders recognize the significant contribution of overgrazing to pasture degradation. Some others consider the low annual rainfall and the frequent drought periods to be the main factors for this pasture degradation. Moreover, several stakeholders do not assess the enormous decrease of grassland/rangeland productivity compared with the beginning of colonization, at the end of the nineteenth century. For them, the weakness of the sheep and wool market and the lack of efficient farming policies have led many breeders to stop breeding sheep and then to abandon their farms. Despite this, the mental models are changing. Linked to the development of tourism, some farmers and policymakers are aware of the role of sheep farming in local development. Coronato (2010) showed that sheep are one of the most frequent images of Patagonia for tourists, along with the beautiful landscapes and wildlife. Furthermore, for almost all stakeholders, sheep farming is the only activity capable of maintaining settlement in the region. In addition, in the long term strong international demand will encourage sheep farming and incentivize investors in this sector and in the region.

The context is also different in Uruguay regarding both the market and the environmental impact. Until a few years ago, all stakeholders considered livestock farming in Uruguay as a natural activity with no significant environmental impact (Morales 2007). Livestock was a very relevant component of the natural landscape in Uruguay. So, the publication in 2006 of the FAO's report "Livestock's Long Shadow," which described in detail the strong environmental impacts of animal production, was a shock in the Uruguayan livestock sector. Despite the credibility of the FAO in that country, many people thought it an aggressive strategy of environmental lobbies against livestock activity on a global scale. Nowadays, some stakeholders are aware of the significant greenhouse gas emissions of ruminants, especially in the extensive livestock production as in the Pampas ecosystems. Other stakeholders know of the problem but do not accept it. Finally, others do not believe in the environmental impacts of their livestock farming systems. And they continue to think about the strategy of environmental lobbies. In contrast, many stakeholders are aware of the impact of soya expansion on soil erosion or the impact of pine and eucalyptus plantations on soil acidification and biodiversity loss (Arbeletche

et al. 2011). Consequently, policymakers are currently launching a set of environmental measures aimed at controlling soil erosion through the crop rotations to avoid more serious environmental impacts in the future. However, the environmental policy is not yet very restrictive for animal production and tree plantations. In addition, livestock mental models in Uruguay have been built on the change in the international meat market, especially the frequent and sudden variations of the meat price with the alternation of long periods of low prices and short periods of high prices. Linked to strong international demand, especially from Asia, the high price of meat since 2008 has affected the entire Uruguayan livestock sector. Some stakeholders think that it is a permanent change in the international meat market, whereas others consider the process is just a temporary artifact.

It is clear from this analysis that the livestock mental models are engaged in a process of change, mainly due to the new environmental policy from the global to the local scale, but also due to the strong international market for animal products and social development issues in rural areas. The relevancy of these factors is building a new context with consequences for the livestock mental models. Nowadays, all the mental models have to integrate an environmental component, at a minimum to know that any question about environmental impact is relevant. External speeches have radically changed both those supporting environmental policies and those against them. In contrast, internal talks are moving slowly because of the resilience of the mental models. The changes due to the market and social issues are a little different because all the stakeholders recognize these changes. The difference is in the permanence or the temporality of this change. Furthermore, another relevant change in the consumers on other continents, especially in China, Southeast Asia, and Europe, is the higher importance of food safety and food quality. Directly linked to recent crises concerning animal products (e.g., melanin in milk powder, horse meat mixed with beef meat, and avian flu), this change could durably impact the consumption and international demand in terms of meat origin and production systems.

5.6 Conclusion

In the past, new agricultural frontiers in South America were available for European migrants and their descendants, associated or not associated with Amerindian communities. They developed diverse social–ecological systems focusing on grassland/rangeland-based animal production. Some of these social–ecological systems are sustainable, as in the case of the gaucho society in the north of Uruguay, cattle ranching in the natural grasslands/rangelands of the Amazon basin, and sheep farming in a few areas of Patagonia. In other places, nonsustainable livestock social–ecological systems and pasture management practices have strongly damaged or destroyed the natural ecosystems. The process was slow, in two or three centuries, or very fast—in a few decades—as in central Patagonia. Sometimes, it was based on the destruction of the ecosystem, as in the case of the Amazon rainforest. Moreover, linked to the strong international demand for food, the process is

continuing; for example, in the biomes of Gran Chaco, the Pampas, and the Cerrado, where there was a huge expansion of exportation agribusinesses, mainly soya bean, cellulose, and biofuels, in past years. Also, the process is still continuing in the Amazon rainforest of the Andean countries for several sociopolitical and economic reasons. In contrast, the process has strongly been reduced in Brazilian Amazonia because of severe environmental policies.

However, presently global ecological challenges make it very controversial and probably impossible in the short term to continue the expansion of agricultural lands, transforming natural grasslands/rangelands and especially forests into croplands. As mentioned for Brazilian Amazonia, the environmental law require ranchers to preserve or restore and maintain the natural forest in at least half of their lands, above all specific areas, such as sources, riverbanks, and strong slopes. Moreover, the law compels them to adopt sustainable pasture management practices (e.g., no burning). In Uruguay, new environmental policy is forcing the exportation agribusiness to integrate sustainable practices, especially crop–livestock integration, to reduce the soil erosion.

Progressively, all the agricultural sectors have to adopt ecological and also social sustainable practices because this is becoming a real exigency of the global economy directly linked to the growing awareness of consumers and the demand of some key actors who have a very important and strategic role and use new information and communication technologies. One of the most relevant examples is that of the Brazilian beef agribusiness, which is forcing the Amazon rainforest producers and partners to reduce their environmental impacts so it can keep its new dominant position in the international beef market.

To monitor these changes, the model of three-dimensional vulnerability allows us to share with breeders and local stakeholders the trends of the resilience of social–ecological systems, and define the possible scenarios on the basis of local knowledge, scientific results, and possible policies or changes. Because it its easy use, and can be applied in both interviews and participative workshops with focus groups or a large population, this model can be used to define the hopes and fears of people, debate scenarios, and above all produce relevant results for policymaking. Moreover, it can be applied on farm, local, and regional scales.

One of the main challenges of participative actions using this model is also to share and discuss the changes (stability, restoration, and creativity) and some irreversibility thresholds along the three axes— agroecosystems, livelihoods, and institutional capacity—which define the vulnerability and the resilience of the social–ecological systems.

However, as already mentioned, the mental models are stable and change slowly. Facing the new exigency in terms of environmental policies, the individual and institutional agents generally choose between resistance with the risk of being marginalized and progressively disappearing, or adapting their discourses and practices to the new environmental contexts. This decision does not mean they are changing or have changed their mental models. They have just accepted the idea to start an adaptation process. The case studies from both Amazonia and the Pampas showed the slowness of these processes, usually at least one generation. The set of environ-

mental policies aiming to build sustainable social–ecological systems started about 25 years ago in the Amazon region and have achieved some significant results, especially in terms of stopping the deforestation. They regret the period before the environmental constraints. In the Pampas, the process is different because of the progressive change from grassland/rangeland to pastureland, then to cropland, and it not being necessary to destroy the natural ecosystem to develop animal production. However, even with the awareness of agribusiness to the growing environmental demand of the market, the implementation of a more sustainable policy is and will be a great challenge for many years, mainly because of the lack of an accepted mechanism to enforce the respect of norms in the absence of financial incentives. The challenge to develop sustainable social–ecological systems seems huge in central Patagonia because of both the degraded agroecosystem and weak livelihoods, which are not attractive for young farmers and investors. With regard to other sheep farming systems, including environmental issues and services, ecotourism development and significant subsidies could be the right way. In all the cases, the scenarios for sustainable management need efficient long-term policies and strong monitoring based on participative methods involving all the local people, from breeders to local governance.

Sustainable development as resilience can have many meanings. Livestock production seems to be perfectly able to adapt to ecological, social, or economic constraints and the very intricate mix of drivers of different types and different scales that operate in the grassland/rangeland ecosystems**.** Farms could face many more difficulties, and probably different production organizations will appear soon, as has already happened with crop production.

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