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Chapter 1

ECOSYSTEM SERVICES OF THE *PROSOPIS CALDENIA* WOODLANDS IN THE ARGENTINEAN PAMPAS

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ABSTRACT

The arid and semi-arid areas in Argentina occupy more than the sixty percent of the country. The genus *Prosopis* dominates these environments with approximately 21 species. The driest part of the Argentinean Pampas is dominated by caldén (*Prosopis caldenia*) forests which cover approximately 27,000 km2. For many years, caldén woodlands were considered as a main source of wood due to its praiseworthy quality. At the beginning of the last century it was widely used as railroad firewood and for paving the streets of Buenos Aires, the capital city of Argentina. As a result, only 18% of the original area of these forests remain nowadays. Today, new paradigms allow us to value the caldén forests not only for their wood but also for the many services that they can provide such as food, medicinal products, dyeing materials, apiculture, regulation of water basins, stabilization of sandy soils, recycling of nutrients, carbon sink, forage for livestock and recreation. In a context of global change, the fact that these forests are a refuge for a large proportion of mammals and birds emphasizes their value as a source of biodiversity. Despite the many functions that these forests have and regardless of the ecosystem services that they provide being valued at USD 2,000 ha-1, they are currently subject to the highest deforestation rates in Argentina. Valuing these forests is a complex task and challenge in a globalized economy that constantly struggles between productive systems which require the replacement of forests and the need to preserve them for the generations to come.

Keywords: semi-arid, ecosystem services, *Prosopis caldenia*, Pampas, Argentina

CALDÉN (*PROSOPIS CALDENIA* BURKART) WOODLANDS IN ARGENTINA

Biogeography: *Caldén* Woodlands in *El Espinal* Phytogeographic Region

The *caldén* (*Prosopis caldenia* Burkart) district, together with the *Algarrobo* (*Prosopis* sp.) and the *Ñandubay* (*Prosopis affinis* Spreng.) districts, belongs to the phytogeographic region of *El Espinal,* which belongs to the *Chaqueño* domain of the Neotropical Region (Cabrera and Willink 1980). The limits of the *caldén* district are not precise since there are extensive ecotones with the *Monte* region to the west and with the *Pampeana* region to the east, where species from the different regions intertwine. The *caldén* district is the driest and southernmost district of *El Espinal* region and it extends from 32° to 43° South (Cabrera 1976) (Figure 1).

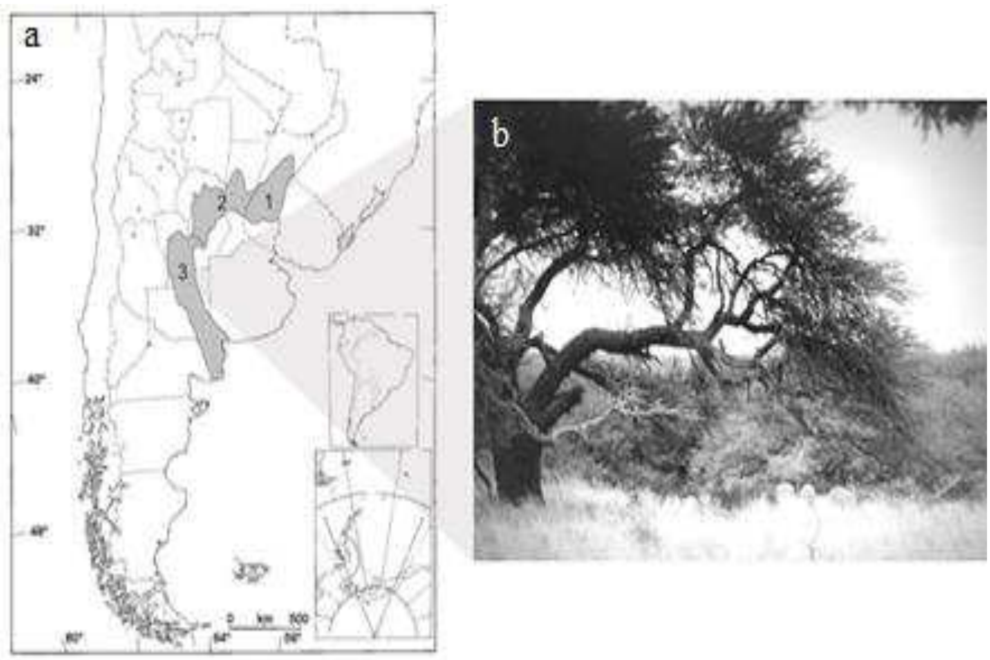

Figure 1. (a) *El Espinal* región (gray area in the map). (1) *Ñandubay* (*Prosopis affinis*) district, (2) *algarrobo* (*Prosopis* sp.) district and (3) *caldén* (*Prosopis caldenia*) district (Adapted from Cabrera 1976). (b) *Caldén* woodlands.

The caldén district is dominated by the *P. caldenia* species (80% frequency among the woody species) which is oftentimes accompanied by *P. flexuosa* D.C var. *flexuosa* (*algarrobo dulce*), *Geoffroea decorticans* (Gillies ex Hook. & Arn.) Burkart (*chañar*), *Schinus fasciculatus* (Griseb.) I.M. Johnst. (*molle negro*) and *Jodina rhombifolia* (Hook. & Arn.) Reissek ssp. *rhombifolia* (*peje* or *sombra de toro*). On the northern limit of the *caldén* distribution area *Celtis ehrenbergiana* (Klotzsch) Liebm. var. *ehrenbergiana* (*tala*) can be found sporadically (SAyDS 2007). The *caldén* district is remarkable in that it only exists in Argentina and it comprises 100 endemic species such as *P. caldenia*, *Condalia microphylla* Cav. (*piquillín*), *Senecio subulatus* D. Don ex Hook. & Arn. var. *subulatus* (*romerillo*), *Gaillardia megapotamica* (Spreng.) Baker var. *megapotamica* (*botón de oro*), *Junellia hookeriana* (Covas & Schnack) N. O'Leary & P. Peralta var. *hookeriana (verbena*) and *Justicia tweediana* (Nees) Griseb. (*quiebrarao*) (Cano et al. 1980; Gabutti 2001). From the 169.333 km^2 originally covered by the *caldén* forests approximately 27.622 km^2 remain nowadays (SAyDS 2007). The main disturbances which have affected this ecosystem are overgrazing, unregulated forestry, fires and the advance of agricultural land. These disturbances have shaped the structure and functionality of the woodlands and have consequently affected the goods and services that they provide.

Caldén Woodlands' Botanical Composition: Trees, Shrubs and Herbaceous Species

The *caldén* district comprises several plant species being *P. caldenia* the dominant one. This composition has been shaped by environmental factors such as topography, climate and soil which create heterogeneity in the structure and composition of the different layers of the woodlands. This heterogeneity increases towards the borders with other ecological formations such as *El Monte*, creating transition areas of variable range (Table 1) (Llorens and Frank 1999; Morici et al. 2009; Hepper et al. 2013). Roughly one thousand plant species mainly belonging to the *Poaceae,* *Asteraceae* and *Fabaceae* families can be found in the *caldén* woodlands (Cano et al. 1980; Gabutti 2002; 2005). Aproximatelly 75% of those species are native, some are medicinal and others are toxic (Cisneros et al. 2002).

The tree layer is characterized by individuals with variable profiles which can sometimes surpass 12 m in height. Nevertheless, the most common configuration in these woodlands, which has been shaped by the anthropic pressure of the last decades, is a dense intermediate stratum where *P. caldenia* presents a shrub-like aspect with multiple branches (Llorens and Frank 1999; Morici et al. 2009; Hepper et al. 2013).

The shrubs layer includes individuals which can measure between 1 to 3 m. The main species in this stratum are *Condalia microphylla* Cav. (*piquillín*), *Lycium chilense* Miers ex Bertero var. *chilense* (*llaollín*), *Lycium gilliesianum* Miers (*piquillín de víbora*), *Schinus fasciculatus* (*molle negro*) and *Chuquiraga erinacea* D. Don ssp. *erinacea* (*chilladora*). The canopy cover varies and is directly related to disturbances such as overgrazing and fires which favour the dominance of shrubs.

Finally, the herbaceous layer is very diverse with grasses reaching up to 1 m in height. Most of the species in this stratum are grasses such as those in the genera *Amelichloa, Aristida, Bothriochloa, Bromus, Cynodon, Digitaria, Elionurus, Eustachys, Hordeum, Jarava, Nassella, Panicum, Pappophorum, Piptochaetium, Poa, Schizachyrium, Setaria* and *Sporobolus*. Another component of this layer are broadleaf species including those in the genera *Bidens, Carduus, Chenopodium, Conyza, Medicago, Oxalis, Salsola* and *Solanum*. Furthermore, the proportion of each species within the community varies being the winter species replaced by summer species from North to South. The herbaceous layer is the most diverse within the *caldén* district and is the result of the interaction between management and the inherent characteristics of the plant species (Anderson et al. 1970; Llorens and Frank 1999; Morici et al. 2009).

Overgrazing in the *caldén* woodlands has caused the establishment of dense non-palatable grasslands of low nutritional value with species such as *Elionurus muticus* (Spreng.) Kuntze (*paja amarga*), *Nassella tenuissima* (Trin.) Barkworth (*paja fina*), *Jarava ichu* Ruiz & Pav. var. *Ichu* (*paja blanca*) and *Amelichloa brachychaeta (Godr.)* Arriaga & Barkworth (*pasto* *puna*). There are a few areas of mixed grasslands where species of high nutritional value like *Poa lanuginosa* Poir. var. *lanuginosa* (*pasto hilo*), *Poa ligularis Nees* ex Steud. var. *Ligularis* (*unquillo*), *Nassella tenuis* (Phil.) Barkworth (*flechilla fina*), *Nassella clarazii* (Ball) Barkworth (*flechilla grande*) and *Piptochaetium napostaense* (Speg.) Hack. (*flechilla negra*) can be found.

Lastly, as we move closer to dryer areas such as the transition area with *El Monte* region, other species like *Larrea divaricata* Cav., *Aloysia gratissima* (Gillies & Hook. ex Hook.) Tronc. var. *gratissima*, *Acantholippia seriphioides* (A. Gray) Moldenke, *Erythrostemon gilliesii* (Wall. ex Hook.) Klotzsch var. *gilliesii* and *Prosopidastrum angusticarpum* R.A. Palacios & Hoc can be found (Anderson et al. 1970; Llorens and Frank 1999; Morici et al. 2009).

Table 1. Main plant species of the *caldén* (*Prosopis caldenia*) woodlands

Strata	Main Species		
Trees >10 m	*Prosopis caldenia* Burkart	*Prosopis flexuosa* DC. f. flexuosa	
Trees 6-10 m	*Prosopis caldenia* Burkart *Prosopis flexuosa* DC. f. flexuosa	*Geoffroea decorticans (Gillies ex Hook. & Arn.) Burkart*	*Jodina rhombifolia* (Hook. & Arn.) Reissek ssp. Rhombifolia
Trees 2-6 m	*Prosopis caldenia* Burkart *Prosopis flexuosa* DC. f. flexuosa	*Geoffroea decorticans* (Gillies ex Hook. & Arn.) Burkart *Jodina rhombifolia* (Hook. & Arn.) Reissek ssp. Rhombifolia	*Celtis ehrenbergiana* (Klotzsch) Liebm. var. ehrenbergiana
Shrub 0,5-2 m	*Acantholippia seriphioides* (A. Gray) Moldenke *Aloysia gratissima* (Gillies & Hook. ex Hook.) Tronc. var. gratissima *Atamisquea emarginata* Miers ex Hook. & Arn *Celtis ehrenbergiana* (Klotzsch) Liebm. var.	*Austrobrickellia patens* (D. Don ex Hook. & Arn.) R.M. King & H. Rob. var. patens *Geoffroea decorticans* (Gillies ex Hook. & Arn.) Burkart	*Prosopis caldenia* Burkart *Prosopis flexuosa* DC. f. flexuosa *Prosopis humilis* Gillies ex Hook. & Arn. *Schinus fasciculatus* (Griseb.) I.M. Johnst.

Strata	**Main Species**		
	ehrenbergiana *Cestrum parqui* L'Hér. *Chuquiraga erinacea* D. Don ssp. erinacea *Condalia microphylla* Cav. *Clematis montevidensis* Spreng. var. montevidensis *Ephedra triandra* Tul. emend. J.H. Hunz. *Erythrostemon gilliesii* (Hook.) Klotzsch var. burkartiana (Ruíz Leal) Roger	*Hyalis argentea* D. Don ex Hook. & Arn. var. argéntea *Larrea divaricata* Cav. *Lycium chilense* Miers ex Bertero var. chilense *Lycium gilliesianum* Miers *Monteverdia spinosa* (Griseb.) Biral *Porlieria microphylla* (Baill.) Descole, O´Donell & Lourteig *Prosopidastrum angusticarpum* R.A. Palacios & Hoc	*Senecio subulatus* D. Don ex Hook. & Arn. var. subulatus *Senna aphylla* (Cav.) H.S. Irwin & Barneby var. aphylla *Ximenia americana* L. var. americana
Grasses-annual herbs	*Amelichloa brachychaeta* (Godr.) Arriaga & Barkworth *Aristida adscensionis* L. *Aristida mendocina* Phil. *Aristida subulata* Henrard *Baccharis artemisioides* Hook. & Arn. *Baccharis crispa* Spreng. *Baccharis gilliesii* A. Gray *Baccharis ulicina* Hook. & Arn. *Bidens pilosa* L. var. pilosa *Bothriochloa springfieldii* (Gould) Parodi *Bromus catharticus* Vahl var. rupestris (Speg.) Planchuelo & P.M. Peterson *Carduus nutans* L. *Cenchrus spinifex* Cav. *Chascolytrum subaristatum* (Lam.) Desv. *Chenopodium album* L. *Conyza bonariensis* (L.) Cronquist var. bonariensis *Conyza sumatrensis* (Retz.) E. Walker var. leiotheca (S.F. Blake) Pruski & G. Sancho	*Erodium cicutarium* (L.) L'Hér. ex Aiton *Eustachys retusa* (Lag.) Kunth *Gaillardia megapotamica* (Spreng.) Baker var. megapotamica *Gamochaeta subfalcata* (Cabrera) Cabrera *Glandularia tenera* (Spreng.) Cabrera *Heterotheca subaxillaris* (Lam.) Britton & Rusby *Hysterionica jasionoides* Willd. *Hordeum stenostachys* Godr. *Jarava ichu* Ruiz & Pav. var. ichu *Leptochloa crinita* (Lag.) P.M. Peterson & N.W. Snow *Medicago minima* (L.) Bartal. var. minima *Nassella longiglumis* (Phil.) Barkworth *Jarava plumosa* (Spreng.) S.W.L. Jacobs & J. Everett *Nassella tenuis* (Phil.)	*Pappophorum caespitosum* R.E. Fr. *Pappophorum pappiferum* (Lam.) Kuntze *Phalaris angusta* Nees ex Trin. *Piptochaetium napostaense* (Speg.) Hack. *Plantago patagonica* Jacq. *Poa lanuginosa* Poir. var. lanuginosa *Poa ligularis* Nees ex Steud. var. ligularis *Pseudognaphalium cabrerae* (S.E. Freire) S.E. Freire, Bayón, Baeza, Giuliano & C. Monti *Rynchosia senna* Gillies ex Hook. var. texana (Torr. & A. Gray) M.C. Johnst. *Salsola kali* L. var. kali *Schizachyrium condensatum* (Kunth) Nees

Table 1. (Continued)

Strata	Main Species		
	Cynodon incompletus Nees var. hirsutus (Stent) de Wet & J.R. Harlan *Digitaria californica* (Benth.) Henrard var. califórnica *Elionurus muticus* (Spreng.) Kuntze	Barkworth *Nassella tenuissima* (Trin.) Barkworth *Nassella trichotoma* (Nees) Hack. ex Arechav. *Oxalis corniculata* L. var. corniculata *Panicum urvilleanum* Kunth	*Setaria lachnea* (Nees) Kunth *Setaria leucopila* (Scribn. & Merr.) K. Schum. *Setaria pampeana* Parodi ex Nicora *Setaria verticillata* (L.) P. Beauv. *Solanum elaeagnifolium* Cav. *Solanum juvenalle* Thell. *Sphaeralcea crispa* Hook. & Baker f. *Sporobolus cryptandrus* (Torr.) A. Gray

Characterization of Climate and Soils in the *Caldén* Woodlands

The Semi-Arid Climate in the Caldén Woodlands

The climate is tempered and semi-arid in the *caldén* woodlands with variable intra- and inter-annual precipitations as well as variable daily and seasonal temperatures. The mean annual temperature goes from 16º to 15º C from North to South being January the warmest month with a mean temperature between 23º and 25º C and July the coldest month with a mean temperature between 7º and 9ºC. There is a notable variation in temperature between seasons with maximum temperatures reaching 45.7ºC in summer and minimum temperatures going below -15ºC in winter (De Fina and Ravelo 1985; Cano et al. 1980).

Regarding precipitations, the *caldén* woodlands are within the 300 and 600 mm annual isohyets from West to East. Being this a semi-arid environment, the variation in precipitation is notable within years as well as between years. Precipitation records for the past 100 years show a variation in annual precipitation between 250 and 1100 mm for this region (Veneciano et al. 2000). Furthermore, the high temperatures and strong winds, characteristic from this type of environment, result in high potential evapotranspiration (Figure 2). These environmental conditions result in a remarkable water deficit for 6 to 7 months out of the year, most commonly during the spring and summer months but usually extending throughout the year. *Prosopis* species are well adapted to this peculiar environment which makes them capable of keeping their maximum leaf area during the hottest and driest months (Debandi et al. 2020).

Another important aspect, which has been observed in the past decades, is the increase in the annual precipitations in the center of Argentina. In the *caldén* area in particular, annual precipitations increased from roughly 600 to 900 mm in average in the 1960-2000 period (Cisneros et. al 2002) which brought about an expansion of agricultural lands into the West resulting in the fragmentation and degradation of the woodlands.

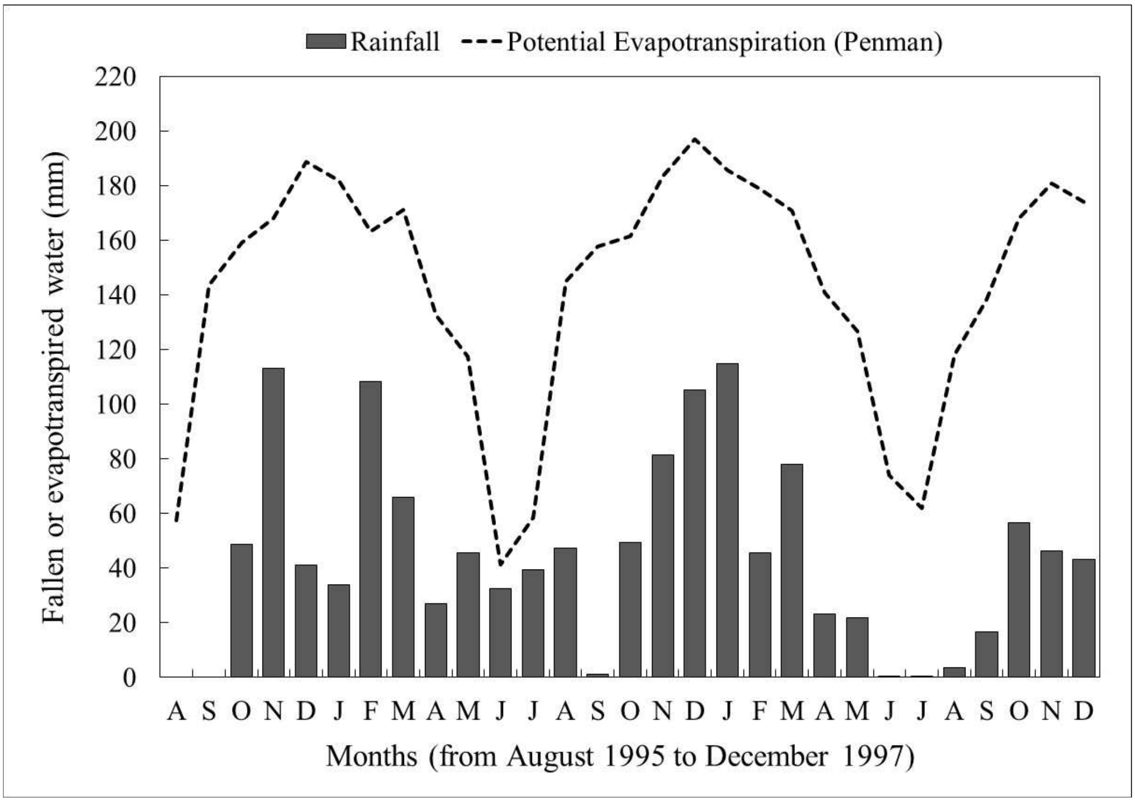

Figure 2. Monthly precipitation and evapotranspiration (August 1995 to December 1997) in the central north region of the *caldén* woodlands (data not published, Estancia Los Caldenes, Luán Toro, La Pampa, 36°12'15," 65°06' 58," Estelrich et al. 1998).

Geological and Edaphic Characterization of the Caldén Woodlands

The *caldén* district is characterized by the presence of an ancient crystalline basement above which several sedimentary layers have developed. Those layers were originated at different times and by a variety of processes and had been fractured and dislocated by the tectonic movements of the Andes mountains during the tertiary-mesozoic. The main forming factors are the accumulation processes caused by the wind and the shaping caused by the water which manifests in different scales along the valleys and is of great importance in the *Río Colorado* area (Chiozza and Figueira 1981). The characteristic landscape of the *caldén* district is a well drained wavy plain with soft slopes which goes from 50 to 600 m a.s.l. from East to West (Russo et al. 1979; Cano et al. 1980; Chiozza and Figueira 1981).

Soils in the *caldén* district are mainly Mollisols and Entisols (Cano et al. 1980; Peña Zubiate et al. 1998; Cisneros et al. 2002). These soils were shaped by semi-arid conditions with variable humidity of ustic type (restricted humidity sometime in the year). In general, they are poorly evolved, have not clear differentiated horizons, are well drained, have low water retention capacity and have variable organic matter content which varies with the latitude and from 1.5 to 8%. They often contain calcium carbonate either broken down or in concretions and caliche. Due to their poor structure, water and wind erosion have led to sandy dunes formation which can be seen throughout the area (Cano et al. 1980; Boyero 1985; Peña Zubiate et al. 1998).

Mollisol soils are characterized by a thermic temperature regime, little differentiation between horizons and poor structure. Their texture is variable between loamy and sandy-loam and they are well drained and permeable. Their pH varies between 6 and 8. Furthermore, mollisols have a superficial dark horizon, which has high organic matter content and is relatively dense, and other horizons underneath such as calcareous crusts (caliche) and a cambrian horizon (Cano et al. 1980). Entisols, on the other hand, have a thermal temperature regime, are poorly evolved, have poor structure, sandy texture, excessive drainage, fast permeability, low humidity retention and pHs which can vary from 6 to 6.6 (soils without lime) and 7.5 to 8.4 (Cano et al. 1980).

Caldén woodlands soils vary spatially as a result of the physiognomy, structure and composition of the plant community which affect the soils chemical and physical properties (Llorens and Frank 1999; Morici et al. 2009; Hepper et al. 2013; Larroulet et al. 2016). Different tree and herbaceous species and their combinations result in variable contributions of carbon and nitrogen (Young 1997, Galantini et al. 2008; Vázquez 2008; Morici et al. 2009; Hepper et al. 2013, Uribe 2014). Moreover, the decomposition rate of plant debris, and therefore organic matter dynamics, are affected by the quality of vegetation which influences the soil temperature (Buschiazzo et al. 2004) and the physical and chemical characteristics of the media and the composition and abundance of the soil biota (Berg 2000; Prescott et al. 2000).

The tree layer has a notable influence in nutrient availability since most of the debris in these ecosystems come from tree canopies (Prescott 2002) which can contribute with significant amounts of nitrogen and phosphorus (Laiho and Prescott 1999; Hepper et al. 2013). For instance, the presence of legumes such as *P. caldenia* creates high quality nitrogen-rich layers which favour nitrogen fixation (Hepper et al. 2013; Larroulet et al. 2020). Furthermore, soils in areas where *P. caldenia* is present have shown higher content of extractable phosphorus in contrast to those where this species is not present. Moreover, in areas where there are trees, soils have higher total organic carbon content which decreases the bulk density and favors physical conditions which make them less susceptible to compaction (Thompson and Troeh 1988; Hepper et al. 2013; Uribe 2014). Finally, it is important to highlight the impact that management techniques which seek to improve the structure of the woodlands can have in the edaphic properties of the *caldén* woodlands soils (Larroulet et al. 2016; 2020).

Fauna Characterization

Caldén woodlands extend over a vast area and present several transitions areas as well which make fauna characterization of high complexity. The multilayer structure of these woodlands, trees, shrubs and herbaceous, enables the existence of a rich fauna with a high diversity of mammals and birds (Figure 3) (Bazquez et al. 2002; Codesido and Bilenca 2004; SAyDS 2007). Nevertheless, the *caldén* district fauna is less abundant compared to its neighbouring regions as a consequence of the disturbances of the habitat and having less endemic species (Bertonatti and Corcuera 2000, Arturi 2005). Until the creation of the First National Inventory of Native Forest (FNINF), there had not been any comprehensive record of the *caldén* woodlands fauna, however, there are some older records of endangered species of international interest such as *Buteogallus coronatus* (Vieillot, 1817) (*Chaco* eagle).

Approximately seventy mammal species have been registered in the *caldén* woodlands including carnivores such as *Puma concolor* (Linnaeus, 1771) (cougar), *Lycalopex gymnocercus* (Fischer, 1814) (pampas fox), *Conepatus chinga* (Molina, 1782) (Molina's hog-nosed skunk) and *Galictis cuja* (Molina, 1782) (lesser grison); herbivores such as *Lagostomus maximus* (Desmarest, 1817) (plains viscacha); and edentates as *Chaetophractus villosus* (Gray, 1865) (big hairy armadillo), *Cabassous chacoensis* (Wetzel, 1980) (chacoan naked-tailed armadillo), *Chaetophractus vellerosus pannosus* (Gardner, 2007) (screaming hairy armadillo) and *Zaedyus pichiy* (Desmarest, 1804) (patagonian piche) (SAyDS 2007).

There are roughly 178 registered bird species in the *caldén* woodlands (Table 2) (SAyDS 2007) being this diversity favored by the multilayer structure of these woodlands. Somes bird species are well adapted to the various physiognomies within these woodlands whereas others depend exclusively on the trees to survive like *Thectocercus acuticaudatus* (Vieillot, 1818) (blue-crowned parakeet) which needs holes in the tree trunks to nest. Furthermore, these woodlands play an important role as an arrival point for migratory birds from the Andes in the winter months such as *Phrygilus* *fruticeti* (Kittlitz, 1832) (mourning sierra finch) (Narosky and Izurieta 2003) (Figure 3).

The aquatic fauna is very diverse as well due to the existence of fresh water lagoons throughout the landscape. *Cygnus melancoryphus* (Molina, 1782) (black-necked swan), *Phoenicopterus chilensis* (Molina, 1782) (chilean flamingo), *Phalacrocorax brasilianus* (Gmelin 1789) (neotropic cormorant), *Ciconia maguari* (Gmelin 1789) (Maguari stork), grebes, egrets, herons, ibis, ducks, teals, pintails and coots are some of the aquatic species that can be found in the *caldén* area (Narosky and Izurieta 2003; De la Peña and Tittarelli 2011).

In the planes and open areas two species stand out, a bird, *Rhea americana* (Linnaeus, 1758) (ñandú, greater rhea), and a mammal, *Ozotoceros bezoarticus* (Linnaeus, 1758) (Pampas deer). In recent years, the Pampas deer has been pushed away from its normal distribution area in the grasslands, and has moved towards the North of the *caldén* woodlands due to the anthropic disturbances which have changed their habitat.

The anthropic impact in these ecosystems has positioned several bird species into vulnerable conditions. Some of the species which are nowadays threatened local or globally include the *ñandú*, *Chaco* eagle, *Gubernatrix cristata* (Vieillot, 1817) (yellow cardinal), *Phoenicopterus chilensis* (Molina, 1782) (Chilean flamingo) and *Spartonoica maluroides* (D'Orbigny & Lafresnaye, 1837) (bay-capped wren-spinetail) (DRN and Asio 2012).

The increase in the area of distribution of foreign fauna which was introduced a century ago such as *Lepus europaeus* (Pallas, 1778) (European hare), *Cervus elaphus* (Linnaeus, 1758) (red deer) and *Sus scrofa* (Linnaeus, 1758) (wild boar), has had a severe environmental impact. The wild board has become increasingly disruptive in recent years (Figure 3).

Figure 3. *Caldén* woodlands fauna: (a) Ñandú (*Rhea americana*), (b) pampas fox (*Lycalopex gymnocercus*), (c) coypu (*Myocastor coypus*), (d) earwig (*Tyrannus savana*), (e) pampas deer (*Ozotoceros bezoarticus*) and (f) female and male of cinnamon teal (*Spatula cyanoptera*).

Amphibians and reptiles of the *caldén* woodlands belong to the Chaco fauna (Cei 1980) and comprise approximately 83 species according to the FNINF (SAyDS 2007). The reptiles in this ecosystem are mainly snakes, vipers and big size lizards as the ones in the *Tupinambis* genera which are common in semi-arid areas (Cei 1986).

Some of the species extinct today prevail in toponymes which remain as witnesses of the presence of magnificent species such as *Panthera onca* (Linnaeus, 1758) (jaguar), *Chrysocyon brachyurus* (Illiger, 1815) (maned wolf) and *Pecari tajacu* (Linnaeus, 1758) (collared peccary) (SAyDS 2007; Gonzalez Mazzoni 2014).

In this section we made a simple description of the *caldén* woodlands fauna. Of equal importance is the microfauna, which we have not described here, due to its role in the food chain and because of all the services that insects and microorganisms provide such as pollination and air aeration, among many others.

Table 2. Main bird and mammal species of the *caldén* (*Prosopis caldenia*) woodlands

Group	Main species	Common name
Birds	*Coragyps atratus* (Beckstein, 1793)	Black Vulture
	Buteo swainsoni (Bonaparte, 1838)	Swainson's Hawk
	Tyto alba (Scopoli, 1769)	Western Barn Owl
	Spartonoica maluroides (Orbigny & Lafresnaye, 1837)	Bay-Capped Wren-Spinetail
	Phoenicopterus chilensis (Molina, 1782)	Chilean Flamingo
	Gubernatrix cristata (Vieillot, 1817)	Yellow Cardinal
	Rhea americana (Linnaeus, 1758)	Greater Rhea
	Buteogallus coronatus (Vieillot, 1817)	Chaco Eagle
	Phrygilus frutiseti (Kittlitz, 1832)	Mourning Sierra Finch
	Thectocercus acuticaudatus (Vieillot, 1818)	Blue-Crowned Parakeet
Mammals	*Pecari tajacu* (Linnaeus, 1758)	Collared Peccary
	Chrysocyon brachyurus (Illiger, 1815)	Maned Wolf
	Panthera onca (Linnaeus, 1758)	Jaguar
	Sus scrofa (Linnaeus, 1758)	Wild Boar
	Cervus elaphus (Linnaeus, 1758)	Red Deer
	Lepus europaeus (Pallas, 1778)	European Hare
	Ozotoceros bezoarticus (Linnaeus, 1758)	Pampas Deer
	Zaedyus pichiy (Desmarest, 1804)	Dwarf Armadillo
	Chaetophractus vellerosus pannosus (Gray, 1865)	Quirquincho Chico
	Cabassous chacoensis (Wetzel, 1980)	Chacoan Naked-Tailed Armadillo
	Chaetophractus vellerosus (Desmarest, 1804)	Big Hairy Armadillo
	Lagostomus maximus (Desmarest, 1817)	Plains Viscacha
	Galictis cuja (Molina, 1782)	Lesser Grison
	Conepatus chinga (Molina, 1782)	Molina's Hog-Nosed Skunk
	Lycalopex gymnocercus (Fisher, 1814)	Pampas Fox
	Puma concolor (Linnaeus, 1771)	Cougar

Land Use History of the *Caldén* Woodlands

Caldén woodlands history can be divided into three main periods. The first period which took place during the colony times from the XVI century to the end of the XIX century and was linked to the indigenous inhabitant economy and lifestyle. The second period (1879 – 1950) which started at the end of the XIX century in concordance with the argentinean national government consolidation and the implementation of the farming model. Lastly, the third period which began in the middle of the XX century and extends to the present and which was shaped by the agro-industrial model. Even though these three moments are not strictly defined and their limits in time are intertwined, this classification is helpful to understand how past events shaped the native woodlands of today.

The First Period: XVI Century to the End of the XIX Century

One of the most impactful events which shaped the *caldén* woodlands was the introduction of cattle and horses. There are records of these animals entering what today is Argentina from the year 1536 when 14 mares and 72 horses were brought in association to the founding of the Buenos Aires village (Ghersa and León 2001). Cattle introduced to the Pampas by Juan de Garay in 1573 quickly reproduced and became wild. In the year 1774, the Jesuit priest Thomas Falkner described how herds of horses could be seen passing by for two to three hours uninterrupted. Horses became a crucial resource for indegenous people whose practices were greatly impacted by the fact that now they could ride (Ghersa and León 2001).

Ethnological and archaeological studies describe populations of native inhabitants managing big herds of livestock throughout the *caldén* woodlands since the second half of the XVIII century. Their economy was based on cattle trade in the trans-Andean market and it has been estimated that between 20,000 to 40,000 heads of cattle were traded during the second half of the XIX century (Carreño 2004). Accounts of travelers and government members describe herds of cattle being carefully managed with purposely organized seasonal movements (Zink and Tarquini 2008). Given the lack of big herbivores in this region since the end of the Pleistocene, the rapid increase and spread of cattle caused a big impact in the vegetation (Bucher 1987; Llorens 1995; Distel 1996). The expansion of woody species and the replacement of low grasses for others of larger shape are examples of some of these changes in the landscape structure (Llorens 1995; Distel 1996).

After Argentina's independence from the Spanish crown in 1816, an "internal colonization" process started embedded in complexity and influenced by plenty of conflicts of interest. Clear examples are the confrontations for the cattle and the use of fire by the native inhabitants to improve the grasslands and as a defense tool against the advancement of the military as accounted by Charles Darwin (1840).

The Second Period: End of the XIX Century to the Middle of the XX Century

The year 1879 is considered key since, in the context of the consolidation of the argentinian national government, military campaigns were initiated by political decision and carried out by the argentinean army, with the objective of claiming vast lands which were being used by native inhabitants at the time. Those lands were to be used for food and main goods production with the final goal of exportation. This economic model eventually positioned Argentina as the "granary of the world" in the global economy. The military campaigns resulted in masive genocide, forceful serfdom and the physical and cultural extermination of the native inhabitants of these lands. These procedures were justified by the national government as necessary to achieve sovereignty over all the territory and in time gained the popular name of "The Desert Campaign." Nevertheless and in full truth, this was an ethnocide which ultimately favoured the enrichment and empowerment of big landowners (Zink and Tarquini 2008).

From the year 1879 onwards, cattle grids and water troughs started to be built throughout these lands. Trenches construction was a rural type of job which later evolved into the "fencer" job frequently carried out by people from Ireland (Sbarra 1973). These fences created a web of borders and corridors which modified the original structure of the landscape (Ghersa and

León 2001). Even though this transformation process started in the Pampas region it rapidly expanded to the *caldén* territory.

During the period of consolidation of the national government there are two key events which deeply impacted the configuration of the native woodlands, the construction of the train system and the first and second world wars. The development of the train system resulted in a concentrated economic system and enabled the access to native woodlands and their high quality wood. The extraction criteria from these woodlands was unsustainable, cutting down the best trees without taking into account the natural recruitment rates. This resulted in the woodlands degradation with low offer of roundwood (SAyDS 2007; Lluch 2008). On the other hand, the two main military conflicts of the XX century, the first (1914–1918) and the second (1939–1945) world wars, created a great demand for wood what lead to the "big cuttings" with the purpose of exporting wood to supply the shortage of coal in the countries at war (Figure 4).

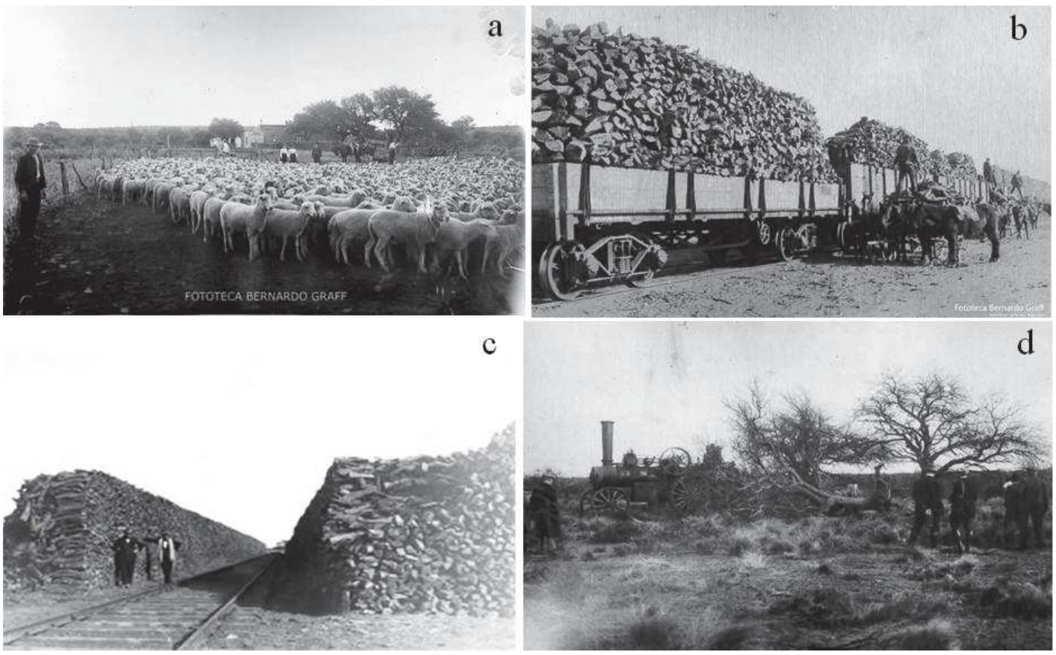

Figure 4. Historic images from the "big cuttings" where the magnitude of the exploitation of the woodlands can be appreciated. (a) Sheep flock in the *Santa Camila* farm of Sr. Dewavrin, year 1902, (b) wagon loaded with wood, year 1908, (c) wood ready to be loaded in the train at *La Maruja*, *La Pampa* and (d) woods clearance. Source: Photographic library Bernardo Graff, Provincial historical archive Professor Fernando E. Aráoz.

Moreover, the increasing number of new farms created a big demand for wood for rural infrastructure leading to the boom of sawmill factories. In the middle of the XX century, 60% of the labor force was employed by this industry in the South area of the caldén woodlands. The clearings mainly affected mature woods and especially older specimens giving place to secondary forests in some cases.

Third Period: Mid XX Century to the Present

From 1950 onwards, the expansion of agricultural land started to go beyond the Pampa region. A mean increase in precipitations, the economic depreciation of wool and the development of new technologies propelled land use changes which brought about the replacement of woodlands by agricultural lands.

The biggest land use changes happened between 1999 to 2000 and 2005 to 2006 with an annual deforestation rate of -0.82% (SAyDS 2007). The deforestacion rate in the last 30 years and the consequent loss of the ecosystem services that woodlands provide favored the creation of the national law 26,331 also called the "Minimum Budgets Law for the Native Forests Protection." This law encourages the protection and territorial ordering of native woodlands. An important matter to highlight is the inclusion of the environmental services of the woods in this law (Article 5) with the objective of assigning economic value to these services. According to this law, those farmers who implement sustainable management plans which try to enhance the woodlands as an economic and ecological resource should be monetarily compensated.

After land use change, fires are considered the second main disturbance in the *caldén* woodlands. Fire is a natural phenomenon which has historically shaped these ecosystems, nevertheless, in these new landscapes with high biomass concentration, fires have become a devastating disturbance factor (SAyDS 2007). Studies in the central area of the *caldén* woodlands show a change in the frequency of fire events between 1787 to 1879 and 1911 which went from an average of every 14 years to every 7.25 years. During this period there was a profound change in the management and occupation of the land going from the presence of native inhabitants to the colony. Moreover, fires occurrences in the XX century match the periods of intense deforestation and the beginning of prescribed fires in this area (Medina et al. 2000; Medina 2008). As a result of all these disturbances the *caldén* woodlands are currently fragmented forests with different levels of degradation (Gabutti 2001; Peinetti et al. 2019).

Changes in the Physiognomy and Structure of the Woodlands as a Historic Process

The first descriptions of the physiognomy of the *caldén* woodlands from the beginning of the XX century were based in the Classical Succession Theory of Clements (1916). These woodlands were described as climatic savanna type forests with grasslands and all the other physiognomies were considered intermediate states which resulted from the cattle impact. According to the successional theory, these intermediate states would disappear with time as the result of successional processes if cattle were to be removed. Elisabeth Schmidt de Ortiz Echagüe described these forests physiognomy when her family bought *La Holanda* farm in 1900:

> "These lands were at that time, virgin and practically uninhabited. They were nearly clean, covered only with open stands of beautiful caldén trees of large or medium size. The majority of the grasses were fine with very little of what is called "mid-grass." The impenetrable jungles of young caldén, and other brush were unknown" (SIC) (Hickey and Knudtsen 1961).

Koutche and Carmelich (1936) also highlighted the open aspect that these forests had.

Nowadays, the non-equilibrium paradigm (Picket 2013) explains better the different physiognomies in these woodlands. According to this paradigm, the different states are the result of ecological and anthropic factors which cause structural and floristic changes of big magnitude. The transition processes, on the other hand, are linked to recurrent disturbances such as climate, grassing, land use change or fires of variable temporal and spatial magnitude (Anderson et al. 1970; Boyero 1985; Cano et al. 1980; Lerner 2004; Roberto et al. 2005).

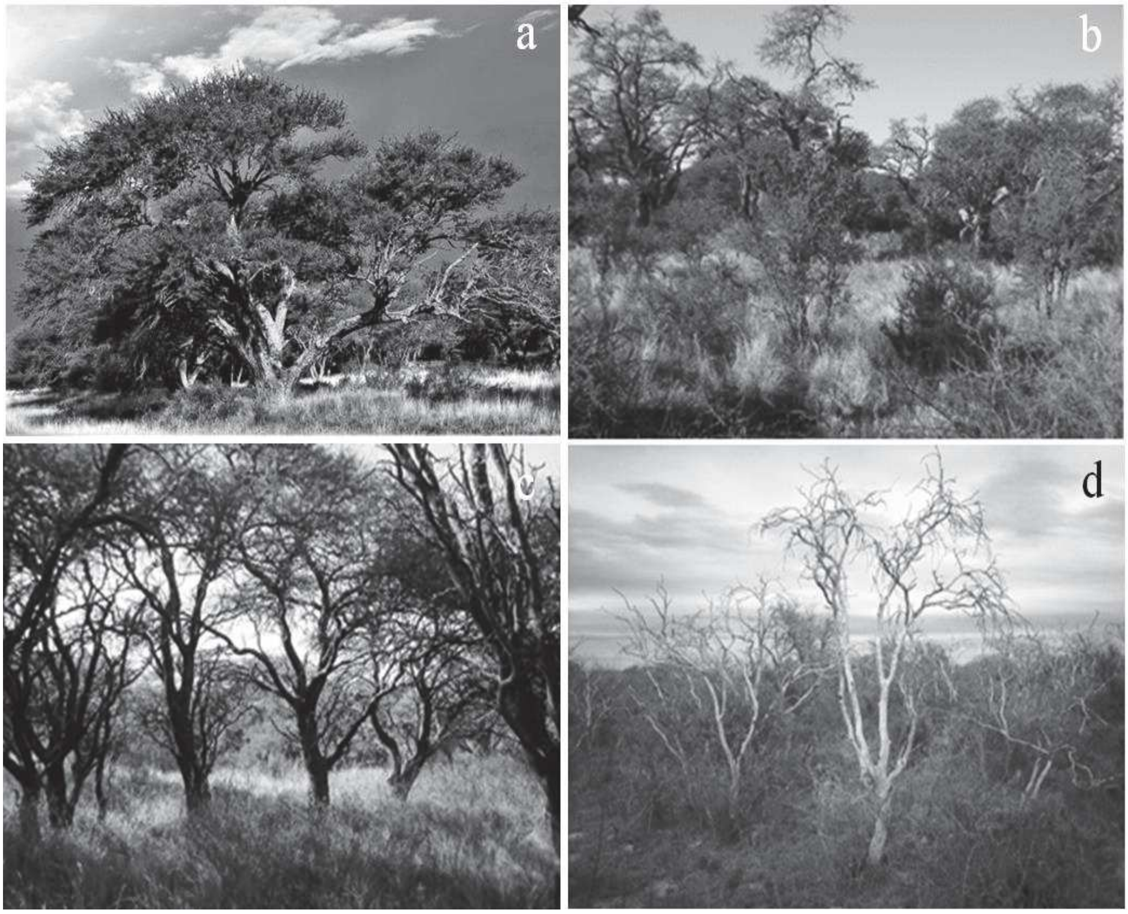

Figure 5. States of the *Prosopis caldenia* woodlands. (a) Open forest with isolated trees; (b) closed forest with shrubs, mid grasslands and palatable species; (c) closed forest with high density of trees, scarce shrubs, mid grasslands and annual herbaceous species and; (d) thicket shrubs.

Another criterion, the Peinetti et al. (2019) state and transitions model, describes four characteristic physiognomies of the *caldén* woodlands. The fours states are open woodlands with isolated trees and grasslands dominated by forage species; closed forests with high tree density, scarce shrubs, grasslands and annual herbs; closed forest with shrubs, grasslands and palatable species; and lastly, thicket shrubs (Figure 5 a, b, c and d, respectively).

Nowadays, open forest with isolated trees and grasslands of forage species are scarce and have been replaced by thicket shrubs and woods with high tree density and mixed grasslands and annual herbs (Morici et al. 1996; 1997; Estelrich et al. 2005; Peinetti et al. 2019). Oftentimes, thicket shrubs are the result of synergistic degradative processes which have been affecting the *caldén* woodlands for decades now. The local name thicket shrubs is given to woods which wood density increases creating a shrubby structure (Lerner 2004). There can be a predominance of single-stemmed trees, as a result of seeds disseminated by livestock, or multi-stemmed trees, product of the regrowth after deforestation or fire events (Lell 2004; Estelrich et al. 2005).

Ecosystem Services of the Prosopis Caldenia Woodlands in the Context of Global Change

Ecosystem services (ES) are the conceptual linkage between the ecosystems, their components and the processes and benefits that the societies get from nature (Boyd and Banzhaf 2007). ES are all the ecosystem components that are directly consumable, that can be enjoyed, or that contribute to human welfare (Quijas et al. 2010). Forests' ES can be classified as (a) goods that are tangible such as wood, fruits and medicinal plants; (b) regulation services such as erosion control, water cycle regulation and carbon sinks; (c) cultural goods such as scientific investigation and recreational areas; and (d) supporting services such as nutrient cycles and biodiversity (MEA 2005).

ES concept comprises economical, social and ecological factors from an anthropocentric point of view (Greêt-Regamey et al. 2017). Despite the increasing importance of the ES in the international agenda, the linkage between assessments and conservation policies are not still precise. It is difficult to find a balance between the long term processes of the ecosystems and the desired short term assessment of humankind. Forests are the most complex and diverse terrestrial ecosystems and the biggest challenge for humanity in the XXI century is to consider itself as part of this complexity and not a mere outsider.

Caldén woodlands in the Argentinean pampas provide essential ES. A clear example is forage for livestock which nowadays is one of the most important sources of revenue from *caldén* forests (Gabutti et al. 1999; 2008). Another example is sawlog wood production which in the past used to be of main importance but today is a marginal activity as a result of overexploitation (Viglizzo and Frank 2006). In the last years, some of the more intangible ES, such as the water cycle regulation, have gained attention due to hydrological changes in the region which had caused the appearance of new rivers, as a result of land use change and an increase in the mean annual precipitations (Contreras et al. 2013). The purpose of this chapter is to classify and analyse the ES of *caldén* woodlands, a unique forest in the world.

Goods of the *Caldén* Woodlands

Goods Derived from Wood

Wood Production

Wood from tree and shrub species of the *caldén* woodlands has been used and overexploited throughout the last three centuries. *Caldén* wood was used by indigenous people to build housing, farmyards, fences and structures to contain water such as *jagüeles* (freshwater holes surrounded by woody fences). Other fundamental uses that native people made of *caldén* wood was the making of tools, mortars, dishes, spoons, glasses, maces, stakes, tethering posts, plows, shovels and looms, furthermore, the bark was used to dye wool (Steibel 1997) (Figure 11a).

After the end of "The Desert Campaign" a massive introduction of sheep promoted deforestation in this region since thorny species affected negatively the quality of wool. The wood from the biggest trees was used for the production of wood floors and cobble to pave the streets of Buenos Aires, whereas smaller size trees were used as a source of power to propel the locomotives. Nowadays, the vast railway network which transformed the landscape and the forests at the end of the XIX century is almost dismantled. Currently, wood from these forests is mainly used as firewood but this use has also been decreasing since 1994 as a result of an increase in the use of natural gas as a heating source (Pérez 2019). Another important use of *caldén* wood these days is fencing, posts and bars of *P. caldenia* are preferred over other species such as *P. flexuosa* because of higher durability and less tendency to rot (Steibel and Troiani 1999). As a matter of fact, all the East and central area of these forests has been fenced with post of *caldén*. Lastly, a few entrepreneurships use *caldén* wood for coal production.

Caldén forests overexploitation has led to wood scarcity and as a consequence only eight sawmills with outdated equipment and low technology remain today in the area (Pérez 2019; Ministerio de Agroindustria 2017). Despite the resources depletion, the overexploitation criterion is still in place and the management strategies are influenced by the economic policies which do not contemplate the relevance of these woodlands as important providers of ES. Roughly 16000 tn of *P. caldenia* wood was extracted in the South of the *caldén* woodlands in the year 2000 (SAyDS 2007), 70% of which was used as firewood (good with the lowest economic value) in spite of the high value of this wood for carpentry. Due to fire scars, a few individuals can be used as roundwood. At present, firewood is still the main good extracted from these forests followed by posts, coal and round wood.

Goods Derived from Sources Other Than Wood

Prosopis Caldenia Forests as Forage and Shade Sources

In the *caldén* area, livestock production has been the main economic activity thanks to the woodlands forage supply. Cattle were introduced in the XVI century (Ghersa and León 2001) and from 1879 up to the middle of the last century livestock activities increased, being sheep the main production. Large scale clearings were conducted in order to free land for more intensive farming systems (Garbarino 2008). After the clearings, the fields were said to be “tidy” since they were left free of forests with the exception of some isolated trees used for cattle protection (Lasalle and Lluch 1990). Records in the memoirs of governors of La Pampa show that timber exploitation activities affected 1,496,816 hectares of *caldén* forests between 1880 and 1935 (Garbarino 2008). From 1940 onwards, sheeps were replaced by cattle which remains as the main economic activity in the *caldén* forests (Figure 6).

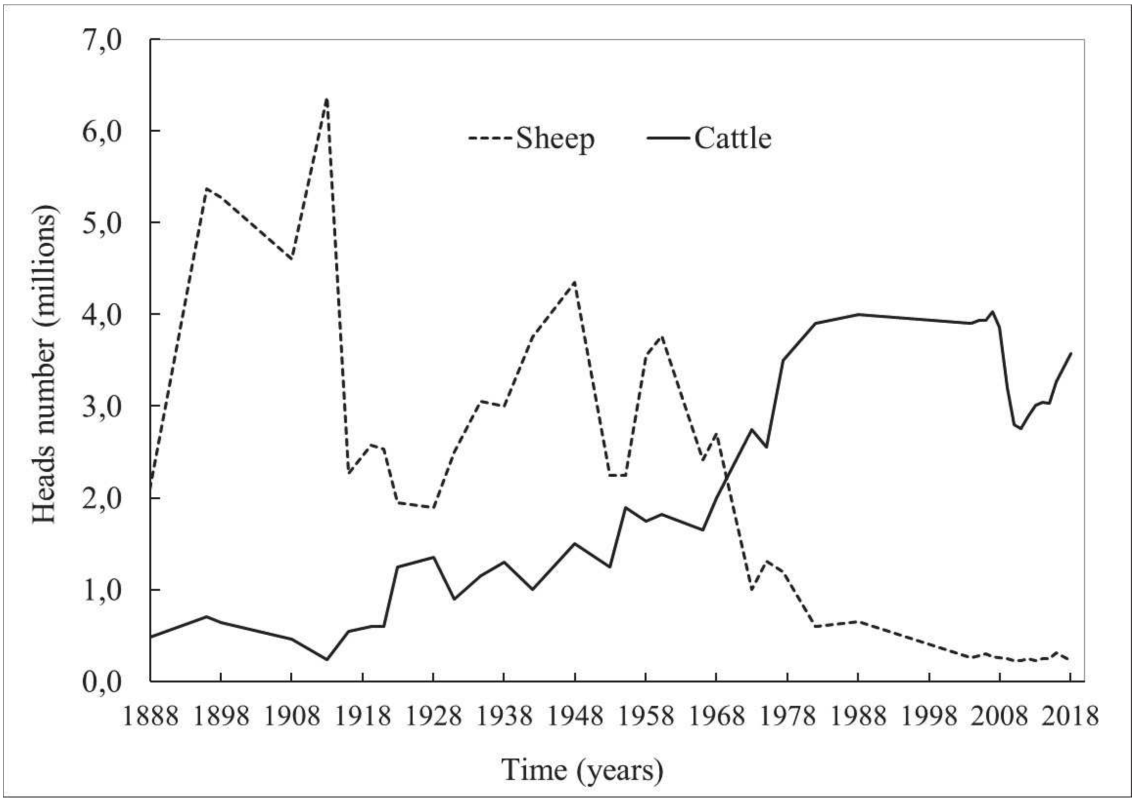

Figure 6. Changes in cattle and sheep heads count in the province of La Pampa from 1888 up to the present (Modified from Viglizzo and Roberto 1990 and statistics yearbook of the Province of La Pampa 1979-2018).

Unregulated grassing together with the implementation of new technologies necessary for livestock production as fences and water troughs have modified the structure and functionality of these ecosystems. The intensification of land use during humid periods and the strong pressure on the natural resources during dry periods have led to the increase of no-forage species (Estelrich and Castaldo 2014). Furthermore, growth dynamics have changed and woody species recruitment, mainly of *P. caldenia,* have increased (Estelrich et al. 2005) (Figure 7a). In addition, an increase in shrubs and mid grasslands has led to higher fire frequencies with devastating consequences (Cano et al. 1985; Sipowich 1994; Gabutti et al. 2008).

Continuous grazing has been the most commonly used system in the area and it still is nowadays. Livestock management with high animal load and continuous grazing has led to the replacement of palatable for no-palatable grasses, with a consequent reduction in the capacity of these systems to keep livestock (Estelrich et al. 2005; Morici et al. 2009) (Figure 7b). At present, new management techniques are used such as rotational grazing and high animal loads for short stay periods in each paddock. Thanks to this new approach the grasslands have appropriate no-grassing periods of at least eight months which favors palatable species.

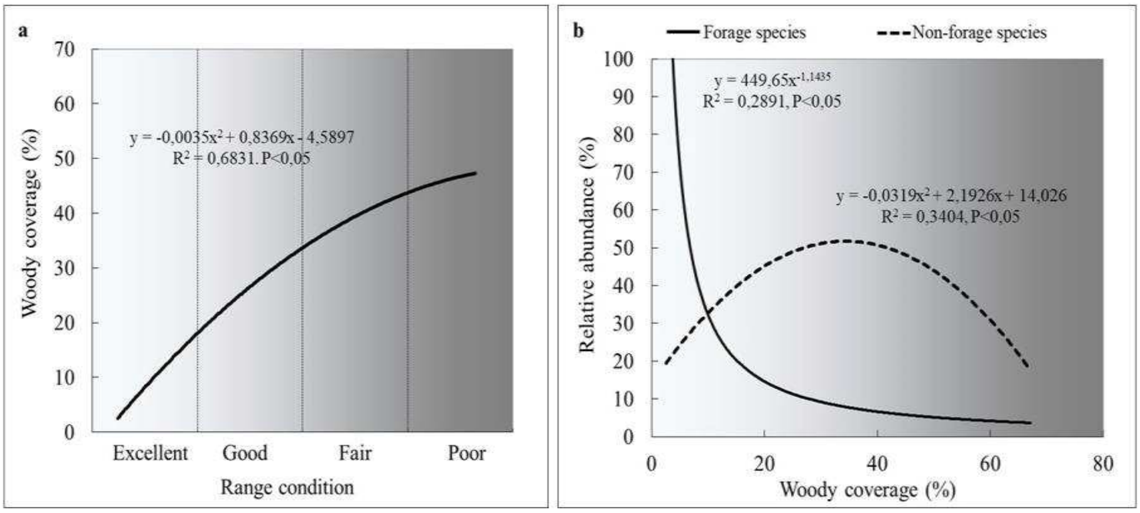

Figure 7. Wood species coverage in the *Prosopis caldenia* woodlands. (a) Relation between woody species coverage and grasslands condition and (b) Relation between relative abundance of forage and non-forage grasses, and woody species availability (Modified from Estelrich et al. 2005).

Grasslands of excellent or good condition can provide approximately 2,000 kg DM. ha^{-1-} of forage. The poorer the condition, the lower the forage availability which is almost null in some cases (Estelrich et al. 2005) (Figure 8).

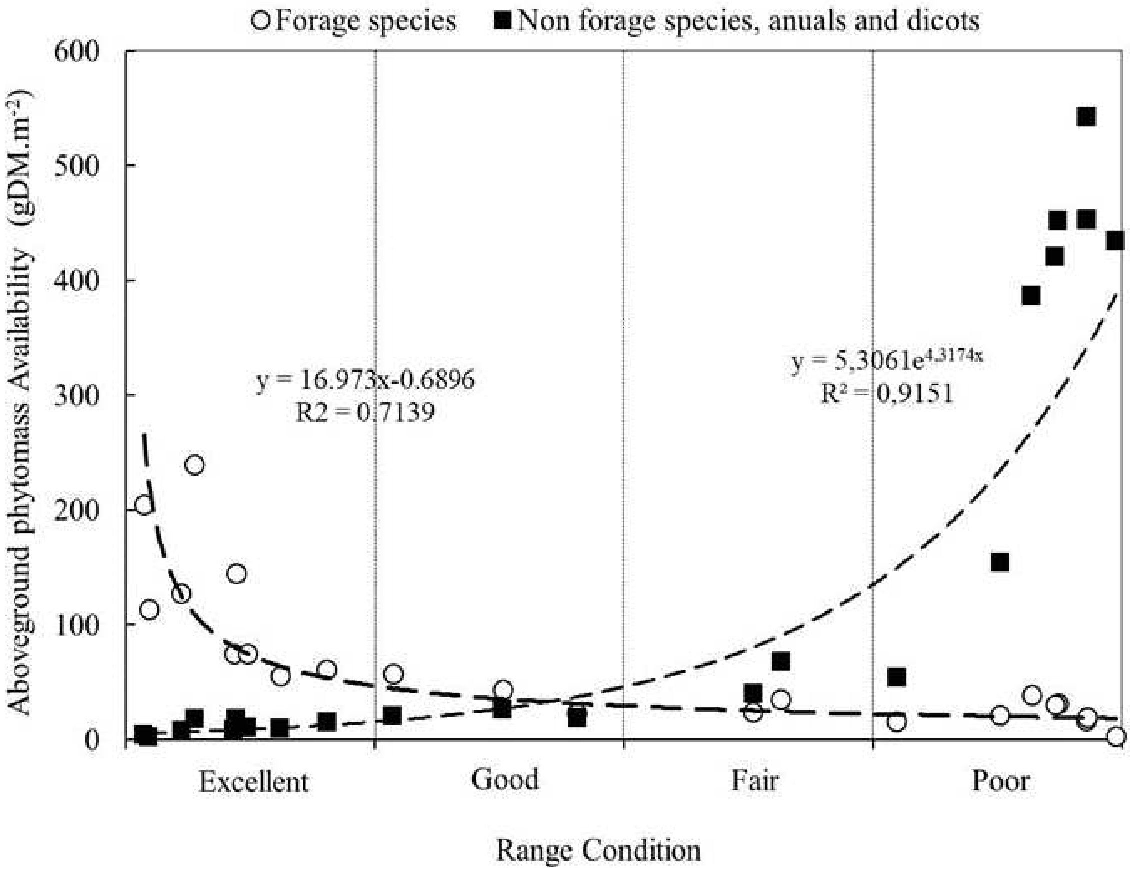

Figure 8. Aerial phytomass available for palatable and non-palatable species according to the grassland condition in the *Prosopis caldenia* woodlands.

Studies of the grasslands condition in the northern part of the *caldén* forests by Gabutti et al. (1999; 2008) determined that 35% were good to very good, 30% were regular and 45% were poor. They also found that the forage resource was composed by 61% of summer and 39% of winter species. In the center of the *caldén* woodlands, on the other hand, the grasslands condition and seasonality were different, being 14% good to very good, 30% regular and 56% poor (Estelrich et al. 2005). Moreover, these grasslands are mainly composed of winter or springtime species with a scarce presence of summer species (between 5 to 10% of the forage availability). As a result of the grasslands quality variability, cattle meat production can vary significantly between 10 to 80 Kg meat. ha^{-1}. $year^{-1}$.

The improvement of grasslands condition is of great importance due to their value as a structural ecosystem resource as well as their economic regional interest. Nowadays, new management techniques, besides rotational grazing, are being used in order to improve grasslands conditions and to decrease the presence of woody species. Some of these new approaches are prescribed burning (Kunst 1993; Bravo et al. 2001; Bilbao et al. 2020), forage species introduction (Covas and Carnie 1985; Petruzzi et al. 2003; Privitello et al. 2004), sowing of indigenous species (Terenti et al. 1990) and different mechanical techniques (Suárez et al. 2018; Ernst et al. 2020).

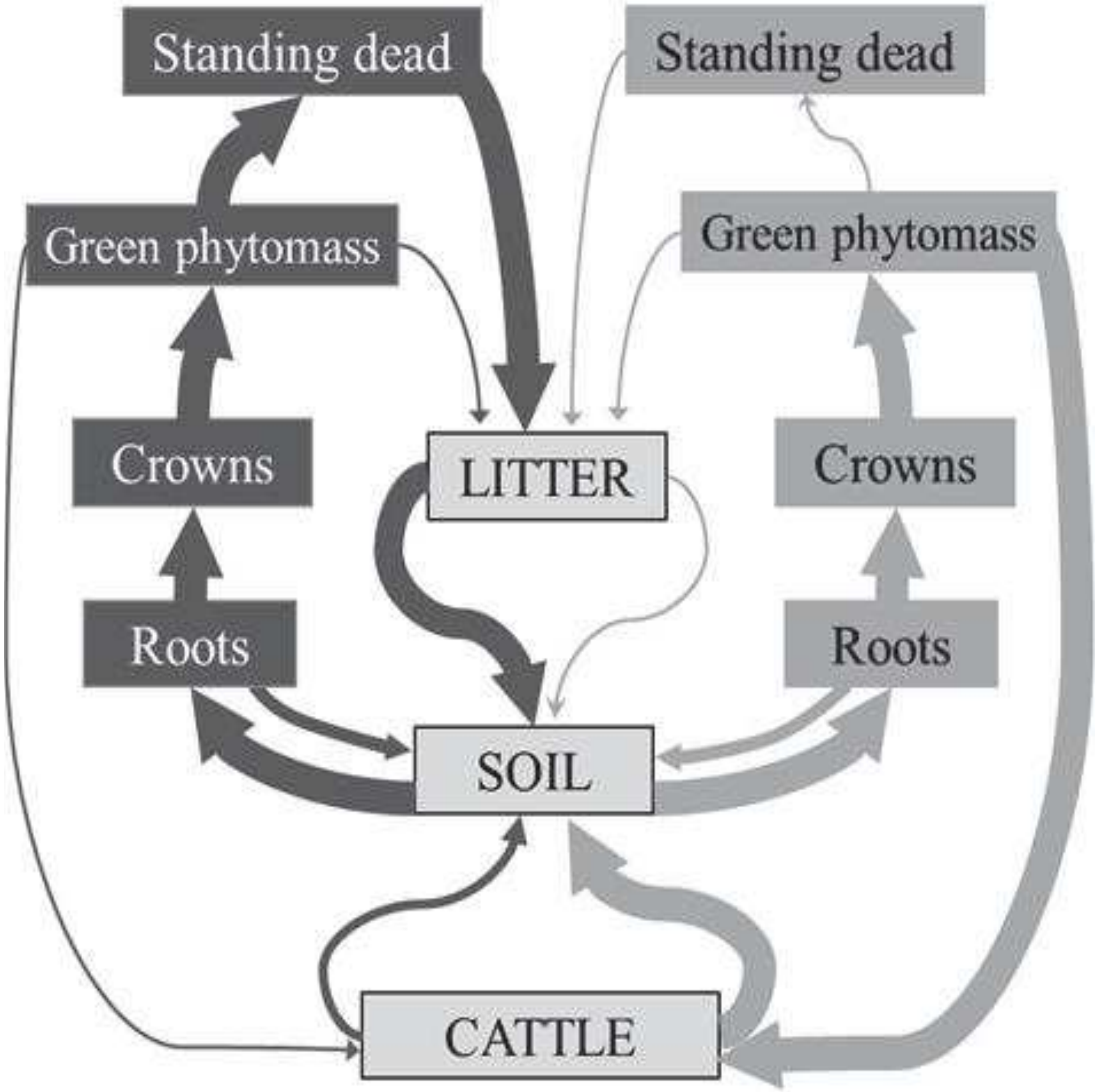

Figure 9. Conceptual model of the nutrients cycle in vegetation patches with dominance of forage (clear gray) and no-forage species (dark gray) (H.D.Estelrich).

Forage availability and production also affects soil nutrient supply since the circulation rate of the nutrients depends on the quality and digestibility of the vegetable species (Estelrich and Cano 1996; Chirino et al. 2020). The quality of the grasslands affects nutrient circulation in the soils, good and very good quality grasslands favour higher nutrient circulation rates, whereas mid quality grasslands, such as scrublands, are characterized by high rates of immobilized nutrients in the aerial and underground phytomass as well as in the brush (Estelrich et al. 2005) (Figure 9). Herbivores grazing on plant species of low lignin, cellulose and hemicellulose content enhance nutrient circulation rates in the soils in that area.

Apart from grasslands, the fruits of *Prosopis* species, which have a high nutritional value, are a valuable forage resource for herbivores. Even though this is not a consistent resource due to its high interannual variability (Steibel and Troiani 1999), its value lies on its availability during the periods of lower forage supply between the months of May and June (Privitello and Gabutti 1988; Gabutti et al. 2013). These fruits are very important for livestock since in some farms are the only dietary source during winter (Covas 1964; Menvielle and Hernández 1985; Privitello and Gabutti 1988) (Figure 11b).

Caldén forests, furthermore, provide a pleasant environment for cattle due to the microclimate that they create. The lack of shade can cause heat stress which has a negative physiological effect increasing the respiratory rate as a way of body heat elimination (Escobar et al. 2001, Rovira and Velazco 2007). The shade provided by these forests causes a decrease in air temperature and incident solar radiation which helps in the regulation of the animals' body temperature balance (Figure 10a, b). Under the canopy, depending on the forest and tree structures, temperature may decrease between 2 and 9°C compared to the open land. Furthermore, forests protect cattle against winds and other adverse extreme climatic events (Panadero 2010) (Figure 11c).

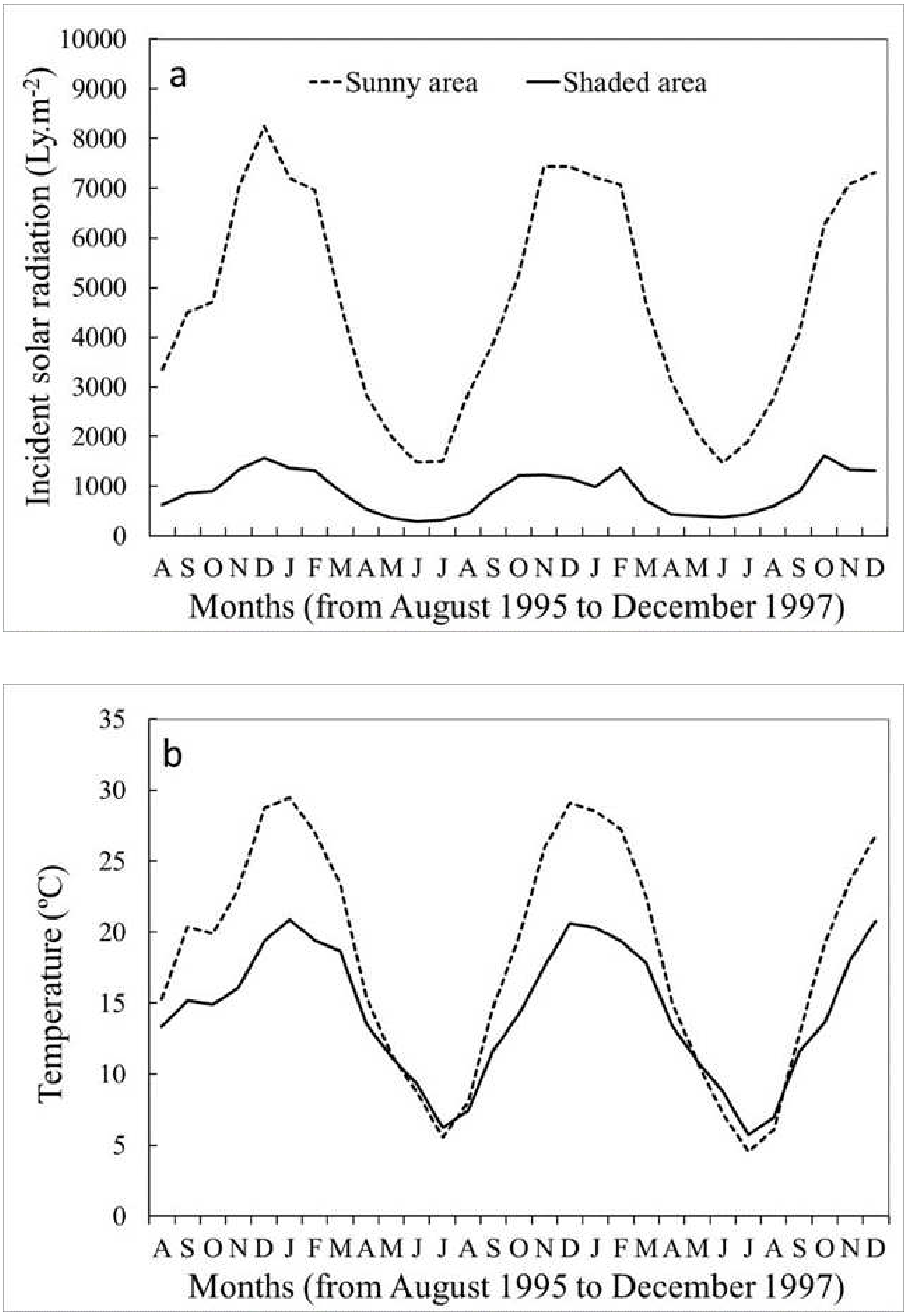

Figure 10. Average mean temperature at ground level (a) and incident solar radiation (b) in sunny (dotted lines) and shaded areas (continuous lines) (Unpublished data Estelrich et al. 1998, Estancia Los Caldenes, Luán Toro, La Pampa).

Apiculture

Honey is another of the many goods that can be obtained from the *caldén* woodlands. Apicultural activity started in these forests at the same time as agriculture and livestock production, nevertheless, it took off as a business in the 1970s as a result of a massive hive movement from the humid pampas to the semi-arid region due to land-use changes (Real Ortellado 2004). Nowadays, there are more than one thousand beekeepers in the *caldén* forests whose hives produce between 20 to 40 kg of honey. $hive^{-1}$. $year^{-1}$ between October and December (Gabutti et al. 2008).

Caldén forests and apiculture coexist in symbiosis, the woods create a safe and rich environment whereas the bees favor pollination in their search for nectar. The diverse botanical composition of these woodlands extends the hives "work period" since different plant species bloom at different times extending the period of nectar availability. Among the most valuable plant species for honey production that can be found in this area we can name *P. caldenia, P. flexuosa, Geoffroea decorticans, Schinus fasciculatus, Jodina rhombifolia*, *Condalia microphylla, Aloysia gratissima, Lycium chilense* and *Larrea divaricata* and two alien species, *Chamaemelum nobile* (L.) All. and *Mentha pulegium* L. Moreover, the woodlands protect hives against extreme climatic events buffering extreme temperatures, strong winds and heavy rainfall (Gabutti et al. 2008) (Figure 11d). Together with all the factors described above, the non use of agrochemicals prevents bee mortality due to toxicity and consequently a better quality and quantity of honey production (Hardstone and Scott 2010; Laurino et al. 2013).

Caldén pollen is the main honey component in dry years since this species compensates the scarce nectar production of other species affected by water stress (Gabutti et al. 2008). This is coincident with a higher rate of fruit production in years with less than 64% of relative humidity in the summertime implying that the lesser the rainfall, the higher the flowering for this species (Privitello et al. 2001). *Prosopis* species, furthermore, have an extra value in bee production since they bloom twice a year, in spring and in summer.

Devastating fires and the lack of an appropriate network of roads connecting production sites are the two main challenges for honey production in these areas (Real Ortellado 2004). Besides, the change in climate conditions also poses a problem since changes in flower availability make it difficult for long term planification which positions apiculture as a secondary economic activity within other productive systems (Naab and Tamame 2011). Even though bee products from the *caldén* forests are of the highest quality according to international standards and markets that value organic products could be a promising opportunity, apiculture will remain a secondary productive system unless policies favoring it are developed and implemented.

Food and Medicine

The medicinal use of plants is as ancient as humanity itself and, as a matter of fact, many of the prescription drugs nowadays are plant based. *Caldén* woodlands provide a wide range of medicinal species (Cantero et al. 2019). As an example, the fruit of *Geoffroea decorticans* (*chañar*), an edible, sweet drupe, is used to produce a fermented drink called *aloja de chañar* which has anti-asthma properties. *Arrope de chañar* is another medicinal beverage which is made by soaking and boiling the fruits of this plant and is used after for relieving cough and congestion (Del Vitto et al. 1997; Petenatti et al. 2004). Furthermore, *chañar* fruits can be used to make gluten free flour and the bark can be employed to make an expectorant drink (Orrabalis 2014).

Prosopis pods were used as a main food resource by indigenous people in Argentina. They gathered big quantities of mature fruits and preserved them for times of food shortage (Roig 1993; Steibel 1997). Flours made from the pods of some of the *Prosopis* species have medicinal applications since they help in the prevention of breathing diseases. These flours can be used for baking, to make tea or as sweeteners (Atanasio 2018). *Prosopis* flour is included in the Argentinean National Food Code which discriminates between seed flour (made with clean, healthy and dry seeds) and fruit flour (made with the entire fruit including seeds). At present, the price of *Prosopis* flour is increasingly surpassing wheat flour price due to its gluten free nature.

Cultural and Recreational Goods: Tourism and Hunting

In Argentina, countryside tourism was propelled by a big agricultural crisis due to the low national and international prices of agricultural goods in the 1990s. Many farms needed alternative sources of income and the development of tourism in rural areas was a consequence of that (Barrera 2006). Nowadays, some of the touristic attractions in the *caldén* woodlands are ethnic activities, gastronomy, hunting, fishing, photography, safaris, participation in traditional rural activities, birdwatching and the listening of the deer rut. Unfortunately, locals are not always aware of the value of the countryside tourism and no more than 20% of local tourism agencies promote it (Calderón 2015).

Tourism in natural areas can be a double edge sword. Ideally, tourists and natural environments should be able to coexist, but currently, tourism is considered as a big disturbance (Heil et al. 2007) which is drastically affecting the natural habitats (Fernández-Juricic 2000; Fernández-Juricic and Jokimak 2001; Heil et al. 2007). As an example, in the *caldén* woodlands, edged and generalist birds, which are a sign of human disturbance, are more frequent in recreational areas than in non-touristic areas (Heil et al. 2007; Sosa et al. 2010). For this reason, rural touristic activities should aim people who are interested in a conscious contact with the environment and the locals (Viñals Blasco and María 2002; Barrera 2006) (Figure 11e).

Hunting is an ancient activity which has served humans as a way to obtain food, a sport as well as a business. Red deer and *jabalí* shooting in hunting grounds is a main economic activity in the *caldén* area, practiced by locals as well as international visitors. The hunt of alien species is allowed in private farms and hunting grounds in the central part of caldén woodlands between March the 1st and September the 30th (DA La Pampa 2020) and can be of great help in keeping the populations of foreingn species under control. Nevertheless, the indiscriminate hunting of cougars, which are the main predators in these ecosystems and are seen as a threat for cattle, has caused an imbalance (Boyero 1985). As a consequence, the number of plain viscachas and other rodents has increased and with them the tunnels and burrows that they build which leave bare soils prone to wind erosion. Plain viscachas are a problem for farmers due to the tunnels that they build which are a risk for horse riding and farm equipment and because of their acid urine which burns the plants in the areas surrounding their burrows. *Parque Luro*, which is a State Natural Reserve, is the only officially protected area in this region. There are also private enterprises which help in the protection and preservation of these ecosystems, such as *La Holanda* farm which promote birdwatching, trekking, and guided visits to its museum, the *Antonio Ortiz Echagüe* atelier and museum.

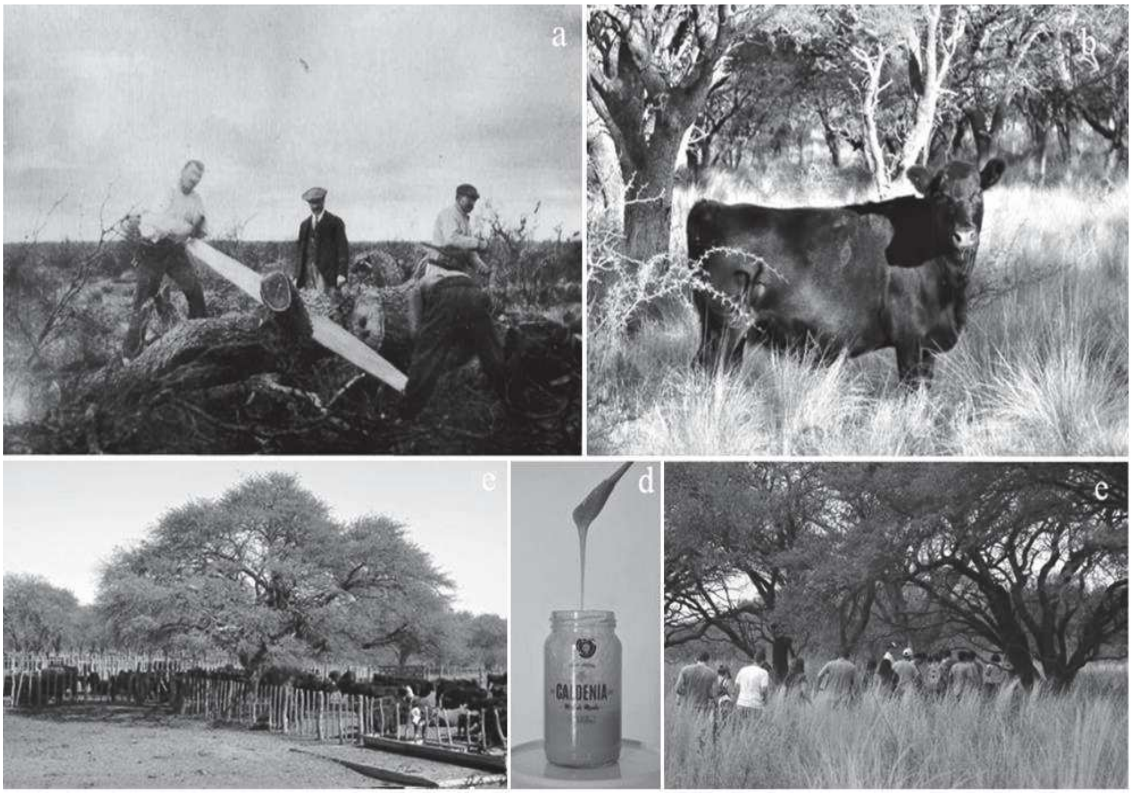

Figure 11. Goods of the *caldén* (*Prosopis caldenia*) woodlands. (a) Log cuttings in the year 1908, (b) forage for livestock production, (c) shade supply for indigenous and introduced species, (d) honey, and (e) countryside tourism.

Caldén Woodlands Services

Regulation Services: Mitigation of Water and Wind Erosion Processes

Arid and semi-arid areas are especially vulnerable to the effects of climate change (UNDP 2013). The northern part of the *caldén* district has been affected in the last 20 years by changes in groundwater dynamics related to severe changes in land use. This area is a closed basin where the replacement of forests and perennial pastures by agricultural crops caused a ecosystem hydrological imbalance, due to the lower water consumption by plants, triggering an overflow of the edges of the basin and causing the appearance of new water courses (Contreras et al. 2013) (Figure 12 a,b,c). The deforestation rate of -0.82% (SAyDS 2007), similar to that of tropical forests, is one of the causes of the severe hydrological changes in the area. Historical data mention the oscillation in the water table depth in this region which went from 15 m deep in 1965 to 1 m deep in 2016 (Bogino, pers. Comm.).

Forests drive soil water dynamics by improving the efficiency in water retention, decreasing runoff and evaporation and increasing effective precipitation (Gabutti et al. 2008). Some studies show that the *caldén* crown can intercept approximately 28% of the precipitation which would otherwise run off. Besides, the topsoil water content under tree canopies exceeds 2076 g.m^2 whereas in open sites it only reaches 302 g.m^2. Furthermore, although it is not yet quantified for *P. caldenia* specifically, studies have shown that trees can consume up to 15 l. month^{-1} (Zohar and Schiller 1998). All these factors make forests a key element in water erosion prevention.

Another important aspect is the positive effect of the *caldén* woodlands in the prevention of wind erosion processes (Figure 12d). This environmental problem had a drastic social impact in the area, causing massive human migrations in the 1920s, a time known as "*la gran penuria agrícola*" (the big agricultural penury) (Bogino 2014). In recent years, land use change and the incorporation of pastures for livestock with total vegetation removal technology, has caused the formation of sand dunes in the northern area of the *caldén* woodlands, being this a problem of particular importance in years of low rainfall (Peña Zubiate et al. 1998; Viglizzo and Frank 2006; SAyDS 2007).

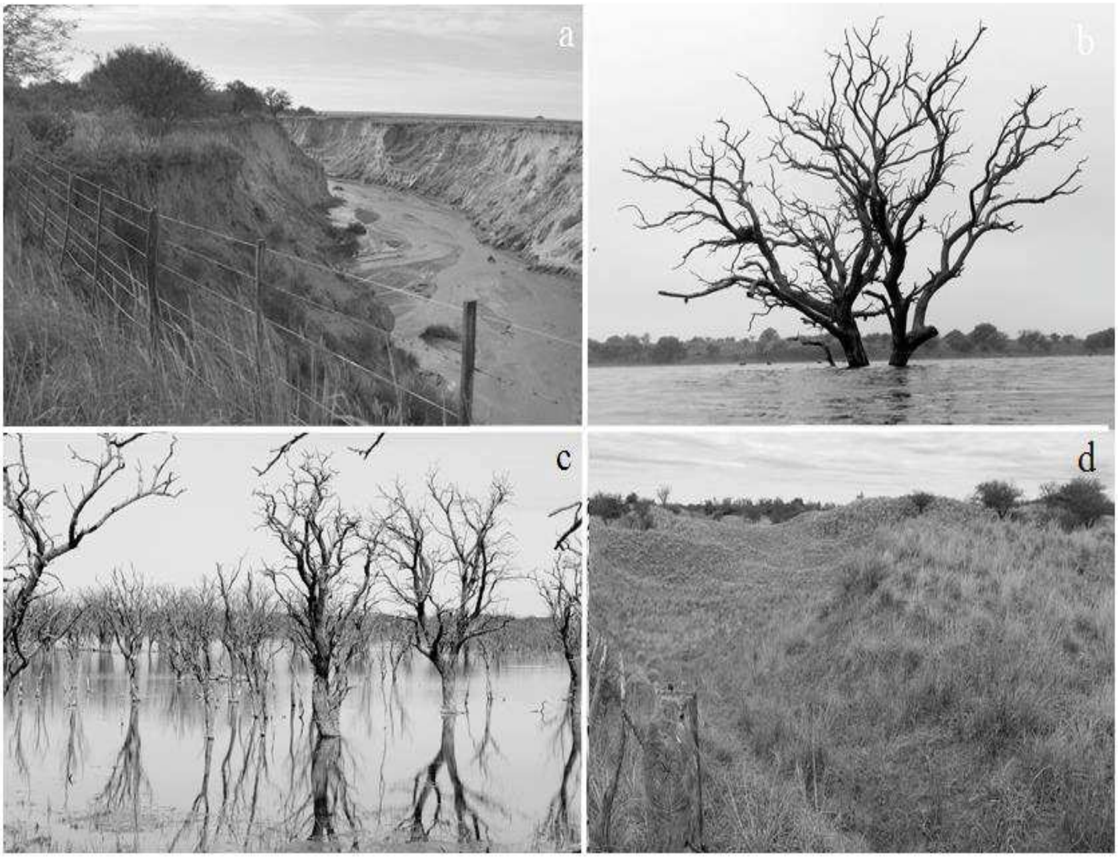

Figure 12. The effects of land use change in the *caldén* ecosystems (a) New superficial water courses, (b,c) collapse of woodlands due to the increase in the water table and (d) stabilized sand dunes due to *caldén* recruitment (Photo c: Gerardo Salonia).

But which are the steps that have been taken to protect these fundamental environmental components? In the first place, it is necessary to keep in mind that most of the *caldén* woodlands are in private property leaving their future at the discretion of the land owners. Furthermore, the National Law No. 26,331 (2007) for the protection of native woodlands, continues to be easily violated in certain areas of the *caldén* forests such as in the San Luis province. To make matters worse, the San Luis province strategy in the face of the water crisis has been to coerce the land owners to apply very costly strategies, such as the planting of exotic woody species which most of the time do not prosper, and in no case considered the importance of native forests and grasslands to mitigate environmental catastrophes.

Biomass in Prosopis Caldenia Woodlands, Its Role in the Carbon Cycle and Its Value as a Bioenergetic Source

The carbon cycle in arid and semi-arid ecosystems has been studied scarcely in spite of the fact that more than 50% of the earth's surface is covered by these types of environments (Bonino 2006). This is probably due to the fact that an important part of the biomass in these ecosystems is underground, which is the most expensive and complicated portion to quantify (Lal 2004).

Determining the carbon balance of the *caldén* woodlands is a complex task since the potential carbon sequestration of a forest depends on many factors and, in particular in these forests, patches of vegetation coexist in different states of conservation. Some patches, such as overmature woodlands in a senescent state, can behave as sources of CO_2 and others, such as grasslands, can behave as a sink (Risio et al. 2014). The constant expansion of agriculture as well as the abandonment of lands add another level of complexity to these estimations.

The quantification of the average wood volume and the biomass of *caldén* trees is a valuable proxy to understand the carbon cycle of these ecosystems where this species dominates. Using the classification of the Argentinean forest inventory which classified the *caldén* woodlands into two categories, open (90 trees. ha^{-1}) and closed (290 trees. ha^{-1}), it can be estimated that the wood volumes are 21.5 and 77.1 $m^3.ha^{-1}$ respectively (SAyDS 2007), with an average volume of $29m^3.ha^{-1}$ for all the area. Understanding the biomass distribution within the *caldén* tree is also important for these quantifications. Risio et al. (2014) found that the highest biomass percentage (46%) is in the crown (branches and leaves), followed by roots (35%) and finally the stem (19%). Furthermore, the relationship between aboveground and underground biomass showed a mean value of 0.58 with a maximum of 1.88 and a minimum of 0.065 (Figure 13). The same study found that for a 24 years old *caldén* woodland, dry matter was 11.5 Mg. ha^{-1} if only *P. caldenia* specimens were considered.

In recent years, wood products and subproducts started to be considered as more sustainable energy sources, in comparison to fossil fuels, which has changed the perspective about the traditional productive systems of the native forests. The new bioeconomic paradigm proposes the use of biomass as a main input to the energy system (Mercado Ramos 2016) which could become an important source of income favoring rural development in the *caldén* region.

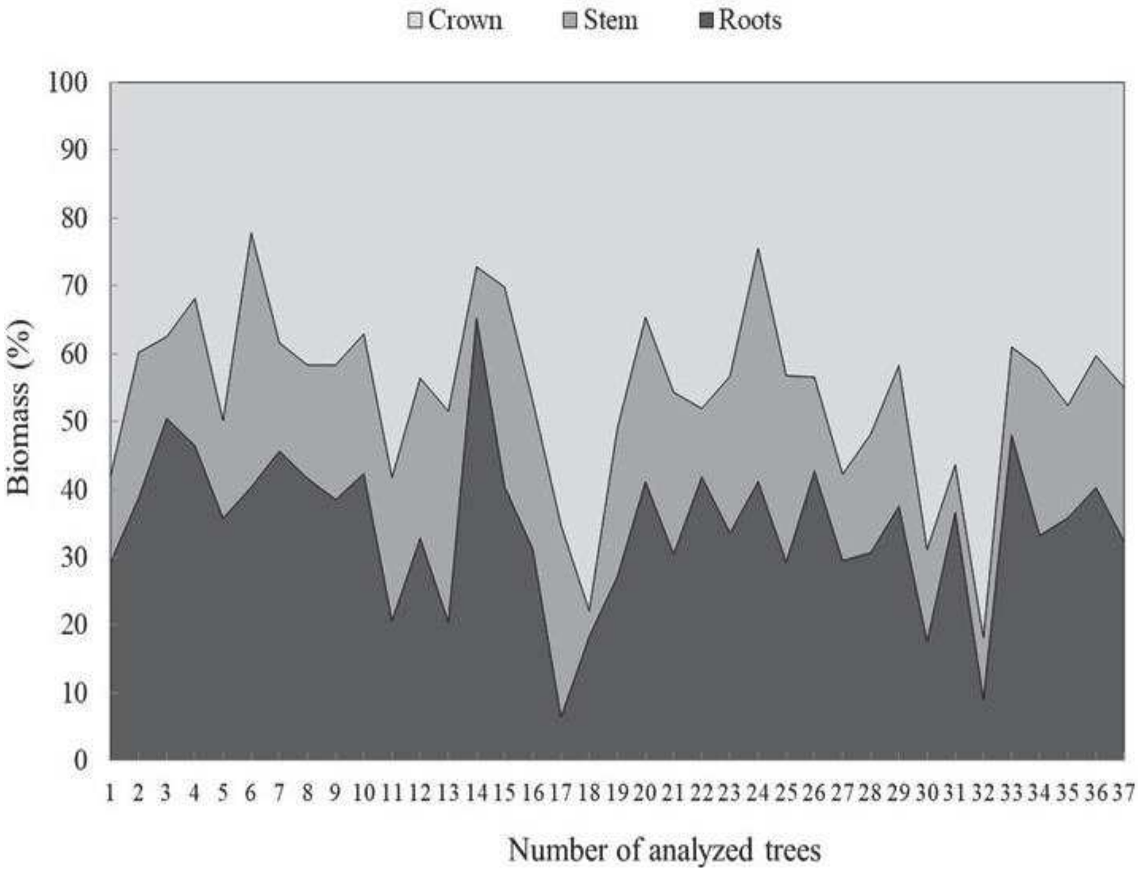

Figure 13. Biomass partition within each *caldén* (*Prosopis caldenia*) tree, divided in crown, stem and roots (n=38) (modified from Risio et al. 2014).

By applying the WISDOM methodology (Woodfuel Integrated Supply/Demand Overview Mapping (FAO 2009; 2016)) the biomass production potential of the *caldén* woodlands in the province of La Pampa was estimated to be roughly 1,145,629 t. year^{-1}. Due to the woodlands degradation in the *caldén* region, the main part of the biomass concentrates in the medium stratum which is dominated by shrubby like species (SAyDS 2007). Taking into consideration that the majority of the management plans in the frame of the 26,331 National Law attempt to reduce the medium stratus of these woodlands in order to increase forage availability and decrease fire risks, the biomass coming from those strati could become a valuable input for bioenergy production.

The regional government together with La Pampa State University have started promoting bioenergy projects such as the use of *caldén* phytomass to produce electrical energy. Since the plants to process this biomass will need to be located in strategic places according to the emplacement of *caldén* woodlands, these projects may bring socioeconomic and environmental development at local and regional levels by means of competitiveness, diversification and extra value to the local economic activities in a sustainable way.

Prosopis Caldenia Woodlands Ecosystem Regulation Services: Biodiversity and Human Health

Woodlands are the most biodiverse terrestrial ecosystems; this biodiversity has a key role for human health since it acts as a buffer for different viral loads diluting them among the species. This dilution prevents high concentration of viral loads in a single species which may become dangerous if transmitted to human beings. In other words, the loss of biodiversity due to the extinction of one or more species, concentrates the viral load in fewer species and increases the probability of a zoonosis (Morand and Walther 2020). The decrease in biodiversity has been happening since the massive extinctions of the megafauna in the late Quaternary period which reduced the dispersal of seeds, microbes and parasites, and therefore the dilution of pathogens, this tendency has increased even more in recent years (Doughty et al. 2020).

For many years, the literature has warned us about the relationship between deforestation and forest fragmentation and the appearance of new infectious diseases in the world. Wilcox and Ellis (2006) suggested that deforestation together with the use of new agricultural technologies and greater human mobility are determining factors in the appearance of new diseases. An example is the predator *Canis lupus* (Linnaeus, 1758) (wolf) in Europe, which indirectly regulates the bacillus which causes tuberculosis

(*Mycobacterium tuberculosis* (Zopf, 1883)) through the control of its host, the (*Sus scrofa*) (wild boar) (Tanner et al. 2019). Another example is dengue, considered a new emerging infectious disease which used to be limited to tropical areas but today is moving towards temperate zones. So much so that, in the last summer (2019-2020) dengue cases were registered in the *caldén* woodlands (San Luis, Ministerio de Salud 2019). Quantitative analysis of vector and non-vector species, demonstrates that the net effect of deforestation favors mosquitoes which serve as vectors of human disease as is the case for dengue (Burkett-Cadena et al. 2018).

To put in perspective, the importance of biodiversity for human health, the estimated cost to prevent a pandemic, which includes forest preservation, is between USD 17 to 27 billions, while the cost of dealing with a pandemic like COVID19 has been estimated to be between USD 8 and 16 trillions. Prevention is feasible if deforestation is reduced, species trafficking is limited, and an early warning network for pandemics is established (Dobson et al. 2020).

Forest Support Services: Biocontrol Agents

There are various studies around the world which show that mammals, mainly bigger carnivores such as foxes and cougars, and carrion-feeding birds, are true providers of ecosystem services (Donazar et al. 2016). As an example, an economic estimation of the carrion-feeding golden jackal (*Canis aureus*) concluded that this bird removes more than 3700 t. year^{-1} of animal waste with an estimated monetary value of USD 0.58 million. year^{-1} (Ćirović 2016). Another example of these beneficial species is *Falco novaeseelandiae* (Gmelin, 1788) (New Zealand falcon) whose diet is in 97% passerine birds which cause severe damage to vineyards in New Zealand (Kroos and Gottschall 2012). Moreover, raptors such as *Falco tinnunculus* (Linnaeus, 1758) (common kestrel) and *Tyto alba* (Scopoli, 1759) (western barn owl), were also proven to limit the growth of the population of harmful small mammals such as *Microtus arvalis* (Pallas, 1778) (common vole) in European agricultural patches (Paz et al. 2013).

In the *caldén* woodlands as well as in agricultural areas, *Buteo swainsoni* (Bonaparte, 1838) (swainson's hawk) makes a great contribution by controlling the populations of the genus *Acrididae* (grasshoppers and locusts), which causes severe damage in these environments (Cigliano et al. 2002).

Unfortunately, at the end of the last century, this raptor was affected by the death of more than 20,000 individuals due to the mortal effect of phosphorus insecticides used for insects control (Goldstein et al. 1999). At present, these chemicals have been banned.

In addition to their role as biocontrol agents, some species are of great importance to human health, such is the case of *Tyto alba* (nocturnal western barn owl) and *Elanus leucurus* (Vielliot, 1818) (diurnal white tailed kite) which are predators of the mammalian *Oligoryzomys longicaudatus* (Bennett, 1832) (long-tailed colilargo) transmitter of the Hantavirus infection (Muñoz-Pedreros et al. 2016) (Figure 14a). In Argentina, studies in agricultural areas have confirmed the predation by barn owls of micro mammals, which can host and transmit the Argentine hemorrhagic fever (Sarasola et al. 2007).

Figure 14. *Prosopis caldenia* woodlands ecosystem regulation services (a) *Elanus leucurus* predating a rodent and (b) carrion feeding *Coragyps atratus*.

Various wild fauna species play an important role in the *caldén* forest ecosystem providing multiple services which have not been quantified until today. An example is the Chaco eagle, the largest eagle in this area, which is a great consumer of poisonous snakes (Galmes et al. 2018). Another fundamental species is the *Coragyps atratus* (Bechstein, 1793) (black vulture) which plays a very important role in consuming carrion and thus "cleaning" and "recycling" the remains of dead animals (Figure 14b).

Biodiversity Conservation

The loss of biodiversity in the world as a result of anthropic impact is of main concern. El *Espinal* region, which includes the *caldén* woodlands, has experienced the destruction of its ecosystem habitats due to the exploitation and deforestation, the shifting of the agricultural frontier, the introduction and subsequent invasion of alien species and the introduction of technology associated with livestock production (Bogino and Villalba 2008).

As a consequence of these degradation processes, *caldén* forests are currently fragmented and highly lignified, and have gone through an enormous loss of goods and services. Many plant and animal species have been displaced or are extinct as a result of the changes in their habitats. Furthermore, at a systemic level, the rates of nutrient circulation, the infiltration capacity, the water retention and the fire dynamics have been modified (Medina 2008; Bogino et al. 2015; Velasco et al. 2018). Even though the National Law No. 26,331 was enacted in order to regulate the use and management of the woodlands, its implementation is of regional jurisdiction, which means that the interpretation of its scope is diverse and in some cases can result in contradictory regulations.

The conservation of the *P. caldenia* woodlands is of utmost importance as they provide the habitat for a great diversity of species with different levels of conservation which offer invaluable goods and services. The study of biodiversity in terms of composition, structure and functionality allows us to emphasize the underlying resilience capacity of ecological systems (Pickett et al. 2013). With this approach, it is possible to dig deeper into the interaction networks of these ecosystems and unveil the many services that the *caldén* woodlands have to offer.

LOSS OF ECOSYSTEM SERVICES: THE CHALLENGE OF SAFEGUARDING THE GOODS AND SERVICES OF THE *CALDÉN* WOODLANDS

The main losses of ecosystem goods and services, both in *El Espinal* region in general and in the *caldén* district in particular, are associated with changes in land use. The consequences of these processes are complex and hard to predict since they are determined by the intricate net of relationships between the different components of the system and can manifest themselves at different scales of bio-ecological processes.

The process of removing large forested areas, for instance, modifies the habitat of the organisms that inhabit the *caldén* woodlands, such as *Ozotoceros bezoarticus* (pampas deer) which is nowadays confined to a relict population within the area of grasslands and isolated *caldén* trees in the southern part of the San Luis province. In addition, changes in the landscape reshape the nutrients and water cycles which have an effect on the overall functioning of these ecosystems. Today, land use change in rural areas is driven by market dependent forces while essential ecosystem functions are being neglected and the design of sustainable land use strategies in the region is not still a priority for policymakers (Viglizzo and Frank 2006).

The quantification of the economic losses due to the environmental services that the woodlands cease to provide, such as protection against erosion and desertification, the decrease in soil fertility and the decrease in the habitat for native fauna, is fundamental for the protection of these ecosystems. The private benefit-cost assessments as well as the farmers' perception of what is more profitable have led so far to an augmentation in deforestation rates since as of today, there is a very high opportunity cost for removing woodlands. Sadly, the legislation and rules currently in place do not encourage the conservation of the resources, but instead, prompt the payment of fines which are minimal compared to the economic benefit of incorporating new agricultural lands (Tello and de Prada 2017).

Attempts to assign value to these resources are being made. Carreño and Viglizzo (2007) estimated the economic value of the ecosystem services of *El Espinal* region at approximately USD 1900. ha^{-1}. Furthermore, a study on the public opinion of the economic valuation of ecosystem services showed that in two cities in the *caldén* district, the households are willing to pay USD 11.45 ± 1.76 monthly on average per household to maintain or increase woodland ecosystem services (Tello et al. 2018). This is an important new variable to consider in the opportunity cost analysis within the regional economic activity, but can also be a challenge since it includes the willingness to pay for the woodlands services by the urban population. Guvernamental protection and regulation of forests as providers of ecosystem services is fundamental for society. In order to reduce the opportunity cost that encourages deforestation a multiple factor criteria should be used based on multiple uses in forest areas, payment for ecosystem services and penalties for deforestation (Tello and de Prada 2017).

In Argentina, the National Law No. 26,331, makes a classification by categories of “woodlands use” which can have marked discrepancies between neighbouring provinces. In other words, certain areas of the woodlands with similar characteristics but which belong to two different provinces, can have contrasting “use categorizations” and consequently different approaches in terms of management practices, which is a real concern. This same law is the regulatory framework for the conservation of the ecosystem services of the *caldén* woodlands.

The pristine physiognomies of open forests with dense grasslands that the *caldén* woodlands used to be have been replaced by transitional states of shrubby species with mid-grasslands in vast parts of the territory. The degradation processes of these forests, which started with the introduction of cattle centuries ago and which have mutated throughout history in response to human needs, have shaped these ecosystems and the goods and services that they provide. Even though the *caldén* forests that we know nowadays are not the same ones described by the European travelers that first set foot on these lands or the ones that sustained the native populations of these parts of the world for thousands of years, they are still extraordinary and rich. These forests, with their intricate net of biotic and abiotic components are a unique ecosystem in the world capable of providing exceptional and invaluable goods and services. The complexity of their composition, structure and functionality, together with the human factor as a constant source of disturbances, make their management a great challenge that needs to be planned with a comprehensive approach which involves all the sectors of society.

There is still plenty to unveil about these magnificent ecosystems and their complex dynamics and research is key to develop comprehensive management plans that can keep the *caldén* woodlands providing ecosystem services for the generations to come. Throughout this chapter we have presented many of the ecosystem services that the *caldén* woodlands have to offer and we have shown how diverse and unique they are and what an important role they have in the context of global change.

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