Chapter 1
Native Forests Claim for Breeding in Argentina: General Concepts and Their State

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1.1 Beginnings of Genetic Studies of Forest Tree Species Native to Argentina

The first genetic studies on forest trees in Argentina were carried out with exotic fast-growing species and in relation to their productive use. These antecedents, conducted mainly by the National Institute of Agricultural Technology (Instituto Nacional de Tecnología Agropecuaria, INTA), date back to the 1950s and were based on field trials of poplars, willows, pines, and eucalypts, which were eventually developed as formal genetic improvement programs (Marcó et al. 2016).

It was not until the 1980s that genetic studies of native forest species began. The initial work was carried out at the University of Buenos Aires, where the first doctoral thesis on population genetics of a native forest species (Saidman 1985) was defended. Since the 1990s, new scientific groups commenced to develop with similar lines of research, in several INTA groups and in other national universities such as Comahue, Misiones, and Córdoba, expanding the objects of study to a variety of genera and species.

In the beginning, the lack of knowledge about the genetic resources of the forest species from Argentina promoted studies of genetic characterization of their natural populations, by means of genetic markers (initially isoenzymes and then RAPD, AFLP, RFLP, and more recently SSR). These first steps advanced toward the study of demo-stochastic evolutionary processes (i.e., drift and gene flow) using neutral genetic markers as tools, and a little later, toward the study of adaptation and phenotypic plasticity through the analysis of variation in quantitative traits in common garden trials. Currently, this type of approach continues to expand the range of species involved and questions addressed, and furthermore, the use of new tools for the

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generation of genomic resources, the identification of candidate genes, and the analysis of full transcriptomes have been added to study selection processes also with molecular markers (see Chap. 17).

Based on the knowledge gained about the genetic resources of native forest trees but focusing on their use, INTA (with the collaboration of research groups from other institutions) formally initiated domestication programs for the most relevant species in 2006, which finally led to the development of low-intensity breeding programs. Given its national projection, INTA implements these programs throughout the country, covering all forest ecosystems in Argentina. For the selection of species, in addition to practical aspects such as the region of concern of each research group, the ecological and/or productive value (current or potential) of the species considered was weighted.

1.2 Main Forest Ecoregions of Argentina

Following Cabrera and Willink (1973) and subsequent works, seven forest regions in Argentina with physiognomic and floristic identity are schematically recognized (Fig. 1.1). Below we present the basic characteristics of each of them.

1.2.1 Alto Paraná Rainforest

Known in Argentina as “Selva Misionera”, it is a subtropical rainforest that corresponds to the southern and interior extension of the Atlantic Forest (i.e., the tropical rainforest developed on the coast of Brazil). This formation covers the southern extreme of Brazil (west of the Serra do Mar), the northeast corner of Argentina, and eastern Paraguay. In Argentina, this sector is crossed by the Sierra de Misiones, which forms the watershed between the Paraná and Uruguay rivers, with a maximum altitude of 843 m asl toward the border with Brazil. Precipitation exceeds 1500 mm annually, with a dry season during winter. The average temperatures range from 16 °C to 22 °C, with the occurrence of frost (sometimes it even snows at the highest points).

Two forest districts are recognized within this ecoregion in Argentina:

1. *Jungles*, formed by trees 20 to 30 m high with vines and epiphytes and with strata of smaller trees and a dense undergrowth composed of bamboo and tree ferns. There are also some species of palm trees. The botanical families Leguminosae, Lauraceae, Myrtaceae, and Meliaceae are preponderant, but no species predominate, since more than 40 tree species are counted per ha. However, *Nectandra lanceolata*, *Balfourodendron riedelianum*, *Cedrela fissilis*, and *Aspidosperma polyneuron* stand out.

Fig. 1.1 Forest regions of Argentina. (With the permission of Unidad de Manejo del Sistema de Evaluación Forestal, MAyDS)

2. *Paraná pine forests*, which occupy areas above 600 m asl, with a colder climate than the previous district, where the main species of the dominant stratum is *Araucaria angustifolia*, accompanied by *Podocarpus lambertii*, *Drimys brasiliensis*, and several species of the families Myrtaceae and Lauraceae. Between both districts, there is a large ecotone where the emblematic "yerba mate" (*Ilex paraguariensis*) can be found, i.e., a small tree whose leaves are daily consumed as a particular infusion throughout Argentina, Uruguay, Paraguay, and southern Brazil and Chile.

1.2.2 Yungas Rainforest

Called in Argentina "Selva Tucumano-Oranense," it extends along the eastern slopes of the Andes, forming a narrow strip from Venezuela to the northwest of Argentina. Its climate is cooler than that of adjoining forest formations and has a high humidity, caused not only by the abundant orographic precipitations originated on the humidity brought by the winds coming from the Atlantic Ocean but also by the permanent fogs that characterize this cloud jungle. In Argentina, the average rainfall in this formation is from 1000 to 3000 mm per year and is concentrated in summer, between the months of December and March. Its altitudinal range goes from 400 m to 3000 m asl and is accompanied by the aforementioned gradient of precipitation and also by a gradient of average annual temperatures ranging from 26 °C at the base to 14 °C in the higher parts, with the presence of frost in all its extension and occasional snowfall in the heights. Some genera and even species are repeated in the Alto Paraná Rainforest revealing possible vicariance processes.

The altitudinal gradient thus defines three floristic districts:

1. *Piedmont Rainforest* ("Selva Pedemontana"), up to 500 m asl; it marks the transition with the Humid Chaco, with which it shares some elements. It contains species of high timber value, among which *Cedrela balansae*, *Amburana cearensis*, *Anadenanthera colubrina* var. *cebil*, *Handroanthus impetiginosus*, and *Cordia trichotoma* stand out.
2. *Montane Rainforest* ("Selva Montana"), between 500 and 1800 m asl; it is a cloud forest, dense, humid, and shady, with vines and epiphytes. Three strata characterize this rainforest, the highest formed by emerging trees over 30 m height, such as *Cedrela angustifolia*, *Juglans nigra*, and *Phoebe porphyria*; the one of the middle composed of medium-sized trees and finally the lowest stratum made of bushes and a layer of herbs and mosses.
3. *Temperate Montane Forest* ("Bosque Montano"), occupying the slopes from 1500 to 2500 m asl, it is composed of conifers and deciduous species and has a much lower biodiversity. There, pure stands of *Podocarpus parlatorei* can be found and, at the highest sites, pure stands of *Alnus acuminata*, finally appearing the small tree *Polylepis australis*, which is the woody species that reaches the transition with the meadows of the alpine tundra.

1.2.3 Chaco Subtropical Dry Forest

Better known simply as the "Chaco," it is the main forest ecoregion in Argentina, where it has its greatest development, extending to Bolivia, Paraguay, and a small portion of Brazil. It occupies a plain with warm continental climate, and average annual temperatures from 20 °C to 23 °C, but usually exceeding 45 °C in summer. Annual rainfall decreases east to west from 1200 mm to 500 mm, with a marked dry season (winter) in the west, thus allowing to recognize a wet Chaco and a dry Chaco. A deciduous xerophilous forest predominates, with a stratum of grasses and numerous cacti and terrestrial bromeliads. Among the main forest species are *Schinopsis balansae*, *Aspidosperma quebracho-blanco*, *Caesalpinia paraguariensis*, *Gonopterodendron sarmientoi*, and numerous species of the genus *Prosopis*, of which *P. alba* is the one with the highest forest value. There are also palm groves of *Copernicia alba* or *Trithrinax campestris*.

1.2.4 Sub-Antarctic Temperate Forest

It develops on both sides of the Andes Mountains, from 34° 50′ S to the south of the Tierra del Fuego archipelago. The Argentine portion is locally called the Patagonian-Andean Forest and extends in a narrow strip on the slopes of the Andes from 36° 50′ S to Ushuaia, between the border with Chile and the Patagonian steppe. The climate is cold temperate, with annual rainfall of 2500 to 700 mm, a dry summer season in the northern portion and a more homogeneous distribution of the precipitations in the south. Precipitation depends primarily on the humidity of the Pacific Ocean and forms an abrupt gradient over distances of less than 50 km.

It is a temperate mountain forest, composed of monotypic or mixed stands of two or three dominant species, with bamboo undergrowth in the northern part and some accompanying shrubs. The genus *Nothofagus* predominates with six species (Fig. 1.2), being *N. pumilio* and *N. antarctica* the most widely distributed. There are also some conifers of great regional importance, such as *Austrocedrus chilensis*, *Araucaria araucana*, and *Fitzroya cupressoides*.

1.2.5 Espinal Xerophytic Forest

It is a xerophilous forest, of exclusively Argentine distribution, similar to Chaco but lower and poorer in species, also with the presence of palm groves. The climate is warm and humid in its northern part but mild and dry in its southern portion: the average rainfall varies from 1100 mm to 350 mm in the year and the average temperatures from 20 °C to 15 °C. Regarding the specific composition of its forest elements, *Prosopis* is its emblematic genus, with several species that define three

Fig. 1.2 Autumnal specimen of *Nothofagus obliqua*, one of the species with the highest breeding potential from the Patagonian-Andean Forest. (Photo: Mario Pastorino)

floristic districts according to their presence and predominance: (1) *District of Ñandubay* (*Prosopis affinis*), in its northeastern portion (provinces of Corrientes and Entre Ríos), accompanied by *Prosopis nigra* and palm groves of *Butia yatay*; (2) *District of Algarrobo* (*P. nigra* and *P. alba*) at the center of this formation; and (3) *District of Caldén* (*Prosopis caldenia*), in the southern third of this formation. Other tree species widely present are *Acacia caven*, *Geoffroea decorticans*, and *Celtis spinosa*.

1.2.6 Monte Xerophytic Scrubland

It is a scrubland of 1 to 2 m height, which extends over a large arid region of Argentina, with sandy plains, plateaus, and low mountain slopes. It has a dry climate, somewhat warmer in the northern portion, with average annual temperatures ranging from 15.5 °C to 13 °C and average rainfall of 80 to 250 mm in the year. It forms broad ecotones with the dry subtropical forest and the Espinal forest, dominated by several shrubs, such as *Larrea* sp., *Bulnesia retama*, and *Cercidium praecox*. The genus *Prosopis* is present with species such as *P. flexuosa*, *P. chilensis*, and

P. alpataco, which form edaphic communities in which somewhat larger trees can be found.

1.2.7 Paraná Riverside Wetland Forest

This formation is a set of wetland macrosystems of fluvial origin, which occupies the flood plains of the Paraná River and the delta that forms at its mouth on the estuary of the Río de la Plata. It includes forests with floristic elements of the dry subtropical forest and the Alto Paraná Rainforest, dominated by *Salix humboldtiana* and *Tessaria integrifolia* among the outstanding trees and large areas of grasslands and reeds. These formations are commonly included in the previous ecoregions according to the predominance of species.

Of these seven ecoregions identified in Argentina, the first four are those of greatest forest importance, and we will use them to structure this book.

1.3 Native Forest Surface in Argentina

The first reliable estimate of the area covered by native forests in the country was made by the National Agricultural Census of 1937, which reported 37,535,306 ha. Fifty years later, the National Forestry Institute (IFoNa) estimated a decrease of more than two million hectares, reporting an area of 35,180,000 ha. In 1998 Argentina made its first national inventory of native forests, carried out by the Forest Directorate of the Ministry of Environment and Sustainable Development (SAyDS 2005). In this inventory, an area of 31,443,873 ha of native forest was reported, consisting of two inventory classes: forestlands, with 30,309,524 ha, and rural forests, with 1,134,349 ha. For the purposes of this inventory, based on FAO criteria, forestlands were defined as areas with trees at least 7 m high at maturity and at a density such that their canopies cover at least 20% of the surface (the minimum inventory area was 10 ha). Rural forests are defined as remnants of these forests immersed in agricultural landscapes, in fragments smaller than 1000 ha. Because of their use-pressure situation, these fragments are considered with a high probability of disappearing in the short term due to the advance of the agricultural frontier (Montenegro et al. 2005).

However, the inventory defines a third category of interest for this book: "other forest lands," which corresponds mainly to scrublands with various levels of degradation. Notwithstanding, this inventory class include, to a significant extent, groups of trees at very low density (less than 20% coverage of canopies), riparian forests, palm groves, and forest formations of a height of less than 7 m. The latter are usually made up of tree species with a bushy habit due to strong environmental stresses, such as drought, salinity, waterlogging, or high altitude, an example being the Krummholz formation in the treeline. It is necessary to mention this category since it totals 64,975,518 ha throughout the country, of which 66% corresponds to the Monte (all this phytogeographic region corresponds to this category), 20% to the Chaco, and 9% to the Espinal.

Currently, the Second National Inventory of Native Forest is underway, again in charge of the Ministry of Environment and Sustainable Development of Argentina, this time with the establishment of permanent plots in order to create a continuous system of forest inventories. The inventory categories have also been revised, lowering the minimum height of the trees from 7 m to 3 m for the classification of forestland and the minimum inventory area from 10 ha to 0.5 ha (Peri et al. 2019). Until results of this second inventory are obtained, it is those of the first inventory that provide the most reliable information on the natural forest cover of Argentina.

However, deforestation in Argentina has not stopped from 1998 to the present, maintaining significant fluctuations as throughout the entire history of colonization of the country's territory, with long-term trends and conjunctural ups and downs. In the 25-year period between 1990 and 2014, 7,226,000 ha of native forests were lost (MAyDS 2017a), at an average rate of 289,040 ha per year (Fig. 1.3). It should be noted that these forests correspond to the three inventory categories mentioned in the 1998 inventory. However, an estimate performed for the Second Biennial Update Report (BUR 2017) of Argentina to the United Nations Framework Convention on Climate Change (UNFCCC) for the period 2011–2014 showed that the vast majority (77%) of the 877,680 ha deforested in that period corresponds to forestlands, that is, high forests with a canopy cover of not less than 20%. The most current data have been published in the Third BUR (2019) of Argentina, reporting a deforestation surface of 155,851 ha for 2016.

Deforestation is the most obvious symptom of forest loss. However, a degradation process much more complex to identify and inventory usually precedes it. The predominant causes of deforestation and forest degradation in Argentina are mentioned in the following list (MAyDS 2017a):

- The shift of the agricultural frontier toward forest areas, driven by a production model of high profitability and uncertain sustainability. In this cause, the expansion of soybean cultivation plays a preponderant role, in many cases advancing over forest lands with extensive livestock that are deforested for cultivation, in

Fig. 1.3 Evolution of the deforested area in Argentina (in ha) between the years 1990 and 2016. (From MAyDS 2017a; BUR 2019)

turn displacing local livestock to more marginal sites due to its inaccessibility, lower water availability, and/or denser forest cover.

- The relocation of livestock production from the Pampas grassland (now dedicated to agricultural crops, predominantly soy) to forest areas.
- The real estate speculation associated with the urban development of the suburban belt of big and small cities surrounded by forests.
- Lack of environmental awareness that values forest services, mainly in the communities associated with them.
- Natural and anthropogenic forest fires. Between 2010 and 2016, an average of 102,041 ha of native forest were burned per year (SGAyDS 2018a).
- Precarious land tenure, with large fiscal areas occupied over generations without title to property and with permanent risk of eviction.
- Weakness of control and oversight policies and institutions, with low allocation of financial and human resources.

1.4 Official Trade Statistics for Timber and Non-timber Products of Native Tree Species

The official statistics of the National State represent the best source of information to weigh the impact that economic interests have on the use of Argentina's natural forest ecosystems. However, it must be recognized that informality and a gray economy characterize the use and exploitation of the resources provided by native forests, leaving this significant economic circuit out of consideration of official data.

Forest products accounted for just 1% of Argentine exports in 2017, while they represented 2.1% of imports, both largely defined by the trade of paper and cardboard that are produced almost exclusively with cultivated introduced species. The country's trade balance of forest products expressed in values has been clearly in deficit in recent years, with an average negative balance from 2011 to 2017 of 854.6 million US $/year (SGAyDS 2018b).

Primary forest production with native species comes almost exclusively from the natural forest. Only the plantations with *Araucaria angustifolia* (and to a lesser extent with *Prosopis* sp.) have an appreciable productive volume in formal trade. In the 2015 statistics, only 588 m^3 of *A. angustifolia* roundwood are recorded, which were produced in plantations in the Province of Misiones and destined for the plywood industry (MAyDS 2017b). However, in the medium term, an increase in the offer of wood from planted native species is expected as the plantations of the last decades with *Prosopis* sp. and *Cedrela* sp. reach the cutting period. In this sense, the planting of native species would relax the pressure of use of natural forests, at the same time that it would ensure the maintenance of markets that are reduced year by year by the depletion of the natural resource.

Annually the native forests produce 3,776,591 tons of wood products (average from 2010 to 2016) corresponding to logs, firewood as such, and firewood for

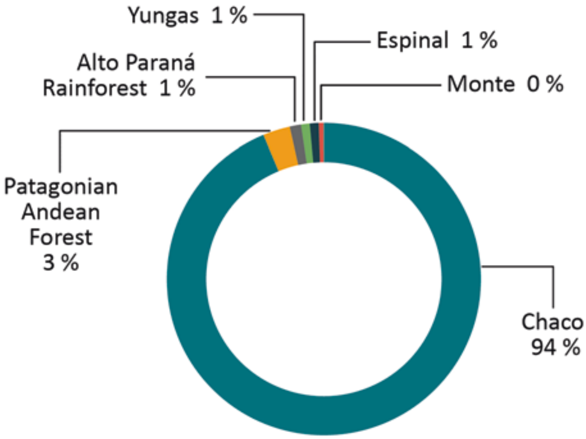

Fig. 1.4 Participation by forest ecoregion of primary wood production in native forests of Argentina, average 2010–2016 (SGAyDS 2018a)

charcoal, poles, and other products (SGAyDS 2018a). Of this total amount, 94% comes from the Chaco (Fig. 1.4). In turn, 52.4% of the total corresponds to firewood to produce charcoal, 27.3% to firewood as such, and only 18.5% are logs, of which 35.3% are shredded for extraction of tannin (SGAyDS 2018a). The official statistics for 2016 indicate that of the 682,825 m^3 registered of roundwood of native species, 41% corresponded to *Schinopsis* spp., 16% to *Prosopis* spp., 15% to *Nothofagus pumilio*, and 8% to *Aspidosperma quebracho-blanco* (MAyDS 2018a). On the other hand, of the vast majority (88%) of the 991,206 tons registered of firewood extracted from natural forests, it was not stated to which species it belonged.

In addition to feeding the industries of sawing, plywood, charcoal, tannin, posts, and sleepers, the native forests of Argentina provide non-timber forest products to the formal commercial circuit. Among the most important, the following can be mentioned: wild honey, pine nuts from *Araucaria araucana*, algarrobo flour (from the pods of *Prosopis* spp.), edible fungi, ornamental fern fronds, poles of palm trees, mosses, lichens, and plants for ornamental purposes, canes for furniture, bromeliad fibers, seeds for afforestation, and fruits for fodder and human food.

1.5 Regulations for the Conservation and Restoration of Native Forests and Promotion of Afforestation with Native Species

With the persistence and aggravation of the processes of degradation and deforestation of the forest ecosystems of Argentina, the social demands of the large urban centers (in conjunction with international trends) increased, claiming for regulations that contributed to the conservation of native forests. These demands crystallized in the enactment in November 2007 of the National Law N° 26,331 on

Minimum Requirements for Environmental Protection of Native Forests, finally regulated and implemented in January 2009.

Law 26,331 regulates, promotes, and finances the conservation of native forests (including restoration) based on a territorial planning that divides the forests into three categories according to their conservation value: *very high* (symbolized with the color red), *moderate* (yellow), and *low* (green). Each of the categories has a series of activities enabled or restricted to be carried out in them. *Red areas* should not be transformed, but they can be the habitat of indigenous communities and the object of scientific research. The *yellow areas* can additionally be utilized for tourism, gathering, and sustainable use. *Green areas* can be transformed, radically changing land use, converting them into cultivation areas or urbanization, after approval of a change of use plan.

In keeping with the 1994 reform of the Argentine Constitution, which defined the provincial ownership of natural resources, it is the provinces that must carry out this territorial planning, establishing it by provincial law adhering to Law 26,331. Consequently, as of 2009, the 23 Argentine provinces, with unequal haste, began to perform the territorial planning of their forests with the criteria of Law 26,331 and to adhere to it (the last was the Province of Buenos Aires, which enacted its provincial adhesion law only in 2017). The sum of the areas subjected to the territorial planning by each of the provinces results in the surface occupied by native forests in Argentina according to the consideration of those who have jurisdiction over them (the provinces). This value is 53,654,545 ha, some 22 million hectares more than those reported as native forest by the 1998 national inventory. The difference is explained by the valuation of its own resources that each province made, considering ecosystems of the inventory category "other forest lands" as forests. Of this total area, 19% was classified as having a high conservation value, 61% as a moderate conservation value, and 20% as a low conservation value.

The Law creates a specific fund that must be assigned annually to the provinces according to their forest area in red and yellow categories, to compensate them for the conservation of their forests, as a kind of payment for the environmental services they provide for humanity. Forest land owners receive 70% of these funds in order to perform a conservation plan, including restoration programs or simple prevention of threats such as livestock grazing. The remaining 30% of the funds are available to the provinces for (a) institutional strengthening with the objective of supervising the conservation plans of the private properties, (b) monitoring the conservation status of their forests, and (c) assisting settlers and indigenous communities who live within the forests.

Ten years after its implementation, the Law has failed to suppress deforestation in Argentina. The prolonged discussion prior to its enactment and the delay in its regulation accelerated requests for land use change permits without the restrictions of the Law, causing the undesired effect of increasing the deforestation rate until the first years of its implementation (Fig. 1.3). Even a strong increase in forest fires has been identified during the transition stage in the implementation of the Law (Egolf 2017). In the period 2009–2011, that is, while the majority of the provinces were carrying out their territorial planning of forests, the number of forest fires doubled with respect to the records prior to the enactment of the law, going from 4 to 8 fires per every 100,000 ha of forest. The possible intentionality of these catastrophic events has been suggested, with the purpose of converting forests into agricultural land, anticipating use restrictions and the possible implementation of a rigorous control system. After a peak of 375,000 ha deforested in 2010, the deforestation rate fell sharply, but still maintaining alarming values. Presumably, forest degradation, even without deforestation, also continued at a sustained rate.

There is another national law with current effect on the restoration of degraded forests and afforestation with native species: the Law of Investments for Cultivated Forests N° 25,080 (promulgated in 1998 and extended in 2008 by Law N° 26,432 and in 2018 by Law N° 27,487). This law essentially subsidizes part of the costs of industrial forestry for productive purposes. However, it also includes a section for the enrichment of degraded native forests, which, in conjunction with Law 26,331, represents an additional benefit for restoration, although with the ultimate purpose of forest exploitation. With annual resolutions of the Ministry of Agriculture, the amounts and procedures are updated for each region of the country, and for the different species and silvicultural methods, distinguishing afforestation with irrigation or rainfed, and in blocks or enrichment strips. In recent years, some native species have been explicitly included with a specific cost calculation. These are *Araucaria angustifolia*, *Austrocedrus chilensis*, species of the *Prosopis* genus (mainly refers to *P. alba*, *P. nigra*, *P. flexuosa*, and *P. chilensis*), and species of the *Nothofagus* genus (mainly refers to *N. alpina* and *N. obliqua*). There are also some tax benefits granted by the provinces for the promotion of afforestation (both with native and introduced species). Also, some provinces are considering imposing the obligation to conserve (or recover) a minimum surface of each rural property covered with forests or afforestation. In this sense, the Province of Córdoba has enacted Law N° 10,467 in 2017, which requires agricultural properties to have a forest cover of at least 2% of its surface.

Finally, the National Seed Institute (INASE) should be mentioned, which is the institution that regulates the production and trade of seeds of forest species in Argentina, through Resolution 256/99. This Institute keeps a record of the basic propagation materials (seed sources) existing in Argentina, certifying the seed produced according to different defined types. There are still no restrictions on the trade in seeds according to their provenance and place of use, although there is an increase of 10% in the subsidy of law 25,080 if the material used is of certified origin and is at least of the "selected" category, that is, seed from a genetic improvement program. Currently there are 34 seed production areas of native species registered in INASE: 4 from *Araucaria angustifolia*, 3 from *Austrocedrus chilensis*, 1 from *Cedrela balansae*, 3 from *Nothofagus obliqua*, 1 from *Nothofagus pumilio*, 8 from *Prosopis alba*, 4 from *Prosopis chilensis*, 1 from the hybrid *Prosopis chilensis* X *Prosopis flexuosa*, 2 from *Prosopis flexuosa*, 1 from *Prosopis nigra*, and 5 from *Prosopis* sp. There are also one seed stand of *N. alpina* and three of *P. alba* (https://www.argentina.gob.ar/sites/default/files/inase_guia_forestal.pdf).

1.6 International Commitments of Argentina, National Plan for the Restoration of Native Forests, and Certification of Sustainable Management of Forests and Plantations

Argentina is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol in which it participates through the Clean Development Mechanism. In 2016, through Law N° 27,270, the National State approved the subscription of Argentina to the Paris Agreement (COP21), committing not to exceed the net emission of 483 million tons of carbon dioxide equivalent ($MtCO_2eq$) in the year 2030 (advancing even to a conditional commitment of 369 $MtCO_2eq$), which represents a reduction of 18.5% of the emissions projected for that date. This goal involves mitigation measures that include the REDD + strategy, that is, avoidance of deforestation and degradation of native forests, and afforestation, reforestation, and restoration of degraded forest ecosystems. It has been estimated that in 2014, 15.6% (57.4 $MtCO_2eq$) of the total emission of greenhouse gases (GHG) in Argentina came from native forests, 89% of which were emitted by the conversion from forests to pastures or agricultural crops (PANByC 2017).

Starting in 2017, the Argentine Ministry of Environment and Sustainable Development (MAyDS) began to develop the National Action Plan on Forests and Climate Change (PANByCC), which aims to reduce emissions and increase the capture of GHGs related to the forestry sector. The capture of CO_2 through plantations can be faced with both native and exotic species. In this sense, fast-growing exotic species (i.e., pines, eucalypts, poplars and willows) seem to be a convenient alternative, since they have a higher CO_2 fixation rate. However, according to one of the UNFCCC Cancun safeguards (COP16), this increase in fixation cannot be detrimental to natural forests, and therefore its replacement by more efficient carbon fixation systems cannot be considered. On the other hand, Argentina is a state party to the Convention on Biological Diversity, which forces it to attend to the conservation of native species and ecosystems. It is also one of the 12 member states of the Montreal Process (MAGyP 2015), an international convention that sets criteria and indicators for the sustainable management of forests, obviously restricting the conversion of natural forests to exotic plantations. Therefore, planting on forest land should be considered through programs to restore or enrich the natural forest; and mass afforestation with introduced species should be limited to agricultural areas.

Strategic operational axes defined by the PANByCC include avoided deforestation, sustainable management of native forests, and restoration of degraded forests. Regarding this last axis, after the development of some pilot projects, in 2018 the MAyDS launched the National Plan for the Restoration of Native Forests (MAyDS 2018b), calling in 2018 and 2019 for the open application of projects.

Most of the approved restoration projects (still ongoing) have proposed active restoration strategies, that is, planting of foundational forest species from the degraded ecosystems to be restored. This implies the choice of the genetic materials to be used, which should be those adapted to the implantation site, with the dual purpose of avoiding maladaptation processes of the implanted individuals and preventing genetic contamination of the forest patches that remain within or surrounding the area under restoration (e.g., Vander Mijnsbrugge et al. 2010, and see Chap. 18). Some of these projects have explicitly considered the genetic origin of the seed for the production of the seedlings used. However, this is an unusual consideration in Argentina, since, for native species, commercial nurseries rarely record the provenance of the seed they are using. Technicians still need to be formed and trained on the importance of considering the genetic factor in the industrial production of seedlings of native species. Equally necessary is the generation of knowledge about the gene pools of native species, at least in the main species of each forest ecoregion. In this sense, this book hopes to contribute to the dissemination of current knowledge in this regard.

The certification of the sustainable use of native forests by independent and internationally recognized institutions is a safeguard that society is increasingly imposing to prevent the loss or degradation of natural forest ecosystems. This mode of action through non-governmental organizations is an indirect strategy of the organized civil society that resort to the “market” as a non-punitive regulator.

Since 2002, the Forest Stewardship Council (FSC) has certified in Argentina the sustainable management of forests, including all the links in the chain of custody of the transformation of the raw material to a final product. In the third quarter of 2019, FSC reported 117 chains of custody certificates in Argentina and a certified forest area of 467,585 ha distributed over 11 sustainable management certificates (https://fsc.org/es/page/datos-y-cifras).

In 2010, the Argentine Forest Certification System (CERFOAR) was created in Argentina to promote good practices in the forest and ensure that both wood and non-timber forest products are produced respecting the highest ecological, social, and ethical standards. In 2014 CERFOAR was approved in the Program for the Endorsement of Forest Certification (PEFC) scheme, which is a global scheme that establishes requirements for forest certification, including the maintenance or improvement of biodiversity and the prohibition of forest conversion (plantations resulting from the replacement of natural forests cannot be certified). In the third quarter of 2019, CERFOAR reported the certification of forest plantations of two of the largest forestry companies in Argentina, and the chains of custody of 14 companies that use raw materials of forest origin (https://www.pefc.org.ar/index.php/emp-recertificad/menuempregfs).

1.7 Domestication of Forest Tree Species

In the agricultural sciences, the domestication of wild species involves selection processes that lead to the constitution of highly productive gene pools that, at the same time, are dependent on artificial management systems. The ecologically advantageous qualities for the perpetuation of the species in a natural way are replaced by desirable characteristics for human being (i.e., high productivity of a particular organ, outstanding yield of a certain compound, resistance to pests or diseases inherent to monoculture) under a highly subsidized and artificial production system. The modification of the gene pool of the cultivar variety becomes so profound that sometimes without human intervention it would not be able to persist in successive generations.

In forest science, the concept of domestication is necessarily less strict, mainly due to the longevity of trees. Whereas in species such as cereals, 20 years imply 20 generations, in trees they can represent only one generation or even less. For this reason, when talking about forest species, domestication has not only genetic aspects but also of plantation silviculture, such as the adjustment of seedling production technologies in the nursery, planting in the field, and plantation management until the conformation of an adult population. Therefore, we can define the domestication of forest trees as the development of technologies to take this species to plantation on an industrial scale, both for productive or conservation purposes. From a strictly genetic point of view, tree domestication is limited to elemental selection that rules out gene pools that are not adapted to adjusted artificial management. This selection commonly involves a single generation, and only in some species, it has reached three or four generations.

The domesticated gene pool of a forest species is not far from the wild gene pool, so plantations maintain the ability to turning feral, and thus artificial populations could be perpetuated without the need for recurrent human intervention. This quality is not only a restriction imposed by the long generational times but also a sought-after characteristic due to the longevity of the trees. It is necessary to have a high genetic diversity in the growing populations, since the trees must be adapted to the environmental conditions at the time of planting but also need to have a high adaptability to future conditions. The environment of the future is unknown, but the longer the life cycle (or plantation rotation) of the species considered, the more likely the environment toward the end of the cycle will be different from the current one. This leads to sacrifice selection intensity for the sake of gaining adaptability. Only in highly productive species with very short cycles, the intensity of selection is maximized to the point of clonal forestry, that is, the cultivation of a few select clones.

Historically, since the beginning of civilizations, in species of food relevance and with an annual or very short life cycle, domestication has represented a cultural rather than a technological process. Just in the last century, domestication and genetic improvement have resulted from a planned and directed technical process (large-scale forest tree breeding programs began in the 1950s, White et al. 2007). Currently, a genetic improvement program commonly begins with the generation of information on the genetic variation patterns of the species in question, that is, its level of genetic variation, in general, and how it is distributed among its natural populations. This basic information is essential to outline a selection as well as a conservation strategy.

The genetic characterization of the natural populations of a species can be approached with genetic markers in laboratory studies or with quantitative characters in plant growth chamber, nursery, or field genetic tests. The former (e.g., isoenzymes, microsatellites, AFLP, SNPs; see Box 1.1) are genes or portions of the genome that do not have expression on the phenotype and therefore are not susceptible to selection; therefore they are defined as selectively neutral. The latter, on the other hand, are phenotypic characters (i.e., morphological, physiological, phenological, growth; see Box 1.2) and therefore potentially adaptive, measured in provenance, progeny, or clonal trials. The two sources of information are valuable and complementary. Genetic markers will allow us to identify differences between and within populations due to past demo-stochastic processes (fundamentally genetic drift and gene flow processes modeled by demographic fluctuations in populations), while variation in quantitative traits of individuals with known kindship relationships will allow us to recognize differences due to processes of adaptation to current or modern conditions.

Box 1.1: Characteristics of the Main Genetic Markers Used in the Study of Forest Trees

A genetic marker is a gene or a fragment of DNA sequence with a specific location on a chromosome that is associated with a gene or a trait, shows polymorphism, and allows the distinction of different individuals. There are three conceptually different classes of genetic markers: protein variants (isozymes), DNA sequence polymorphism, and DNA repeat variation (Schlötterer 2004). Isozymes were the first markers used in studies of forest trees, back in the 1970s (Bergmann 1971). With the advent of techniques that allowed the screening of the DNA molecule, more powerful DNA markers became available which allowed detecting higher levels of variability. Some of the most used markers in forest tree species are described below:

Isozymes: Are isoforms of an enzyme, encoded by one or several genes, having the same function, which can be separated through gel electrophoresis. Variants that are coded by alleles at the same locus are called allozymes. Their main advantage as genetic markers relies upon their Mendelian inheritance with codominant expression of the alleles. Given the degenerated condition of the genetic code and the fact that some mutations result in the same net charge of the molecule, many mutations are not detectable. The level of polymorphism is therefore moderated to low.

RAPD (random amplified polymorphic DNA): Is a PCR-based technic that uses aleatory primers to amplify non-specific DNA fragments. It is cost-effective and produces highly polymorphic markers, but the main disadvantages are its dominant expression and its low repeatability.

AFLP (amplified fragment length polymorphisms): Is a DNA fingerprinting method that uses restriction enzyme digestion followed by selective amplification of a subset of fragments. The main advantage is the hypervariable level of diversity; the main disadvantage is the dominant expression.

Nuclear microsatellites or SSRs (simple sequence repeats): Microsatellites are tandemly repeated DNA motifs (from one to six nucleotides), distributed throughout the genome. Their main advantages are the codominant expression and the high level of polymorphism detected. The need to know the flanked sequences to design the primers was the main disadvantage for their use, although with the advance of massive sequencing methods their development became easier and cheaper.

Organelle DNA markers (chloroplast and mitochondrial DNA): They consist in the amplification and sequencing of non-coding regions of the organelle genomes. Due to the uniparental and clonal inheritance of these genomes, they show moderate to low levels of polymorphism, allowing phylogeographic and phylogenetic reconstructions.

SNPs (single nucleotide polymorphisms): Are loci with alleles that differ in a single base, with the rarer allele having a frequency of at least 1% in a set of individuals. SNPs can occur in coding or non-coding regions and are highly frequent in the genomes of plants and animals and codominantly expressed.

Box 1.2: The Quantitative Perspective of Genetic Variation Patterns

Because the phenotype is the expression of the genotype modulated by environmental conditions, the analysis of the variation between individuals in phenotypic characters allows us to gain knowledge about the gene pools that determine them. For this, it is necessary to set up a trial in which the environmental effect can be controlled. Essentially, this trial seeks to raise the different genetic entities (i.e., provenances, families, clones) under the same environmental condition (common garden experiment), with the expectation that the differences that appear in the phenotype are the reflection of the genetic variations. These trials will have an experimental design defined by the environmental conditions and the entities to be tested, and their conclusions will be valid for the trial conditions.

The variables to consider can be of different kinds, some measured simply with a ruler (e.g., seedling height) and others with sophisticated devices such as a spectrophotometer (e.g., chlorophyll concentration). Some variables are of greater productive importance, while others will provide information particularly on adaptability. In this sense, juvenile characters may be the most relevant when the main interest is to ensure post-plantation survival.

The main statistical method to analyze the variation in quantitative characters is the analysis of variance (ANOVA), which can be applied to additive linear models of fixed effects, random effects, or mixed effects. A typical test in a low-intensity breeding program is the comparison of different provenances of a species and, within them, open-pollinated families. Such a trial can be set up by collecting seeds from 10 to 30 trees in each of about 20 populations of interest. All plants obtained with the seeds of one of the trees will be an open-pollinated family, and the kindship relationship between them will be at least half siblings. It is commonly of interest to test the difference between the means of provenances assayed (considering therefore that this factor is of fixed effects) and if the variability of the open-pollinated families has a significant influence on the character of interest (and consequently this factor is considered to have random effects). These considerations define a mixed linear model, which in the case of having an experimental design in blocks with single tree plots, its symbolic expression would be the following:

$$y_{ijk} = \mu + \rho_i + \varphi_{j(\rho_i)} + \beta_k + \varepsilon_{ijk}$$

where y_{ijk} is an observation of the variable of the seedling from the *j*th family within the *i*th population, located in the *k*th block, μ is the overall mean of the variable, ρ_i is the effect (fixed) of the *i*th population, $\varphi_j(\rho_i)$ is the effect (random) of the *j*th family within the *i*th population, β_k is the effect (random) of the *k*th block, and ε_{ijk} is the general error $\sim NID(0, \sigma^2)$.

Knowing the kinship relationships among the individuals of the trial allows estimating various genetic parameters such as additive genetic variance (V_A), narrow sense heritability (h^2), coefficient of additive genetic variance (CV_A), or quantitative differentiation (Q_{ST}). With them, it is possible to characterize the patterns of genetic variation of a species (inter- and intra-population variation) analogously to that achieved with genetic markers, although including the adaptive portion of the genome. In addition, they allow selecting provenances, families, or individuals in an improvement program, through the estimation of breeding values, the prediction of genetic gains, and finally the establishment of genetic rankings.

After the first steps in gaining baseline information on the path to domestication, pilot afforestation trials continue on an "almost-industrial" scale. Indeed, these assays overlap chronologically with the genetic trials, at least partially. For both, it will be necessary to adjust previously the technology for the production of seedlings in the nursery, from the harvesting and stocking of seeds to the development of sowing, irrigation, and fertilization protocols. The development of this technology requires knowledge of the autoecology of the species, its reproductive system, and its physiology, especially up to the seedling ontogenetic stage.

1.8 Low-Intensity Breeding of Forest Tree Species

Low-intensity (or low input) breeding is characterized by being cheap, simple, robust, locally projected, undemanding in record keeping and central control, capable of being continued after periods of neglect, and not dependent on high technology or highly complex specializations, in short, possible to be sustained on a small and uncertain budget (Lindgren and Wei 2006). In return, the genetic gains achieved are of course modest (Namkoong et al. 1980). However, the low-intensity breeding strategy turns out to be the most effective for species with a low annual planting rate (50–100 ha; White et al. 2007) and in particular for those used in active forest restoration programs, in which the interest for a high adaptability (and therefore high genetic variability) prevails over the productive ones. Many times the main objective is the establishment of basic propagation materials (i.e., seed-producing areas, seed stands, seed orchards) to ensure the provision of seeds for seedling production (Kjaer et al. 2006), and only a low degree of genetic gain that simple ensures good health and a not-inferior-to-the-average quality in the traits of interest.

In a low-intensity strategy, the improvement cycle is shorter, and the tools used are fewer and more direct in effect than those applied in high input programs, which use more complex technologies (complexity that depends on each species). Recurrent mass selection and open pollination are the basis, and instead controlled crosses and vegetative propagation are rarely used techniques. The selection of individuals for their phenotype can be carried out in natural populations or in existing plantations if the species has begun to be domesticated. In the first case, individual selection is recommended by the baseline method (Ledig 1974), while for the second, what is more effective is selecting by comparison with the neighbors.

In a low input program, the same physical population usually represents different populations of the improvement cycle. The selected population (set of selected individuals in the base population) usually coincides with the breeding population (the set of individuals that cross freely to start a new improvement cycle, thus regenerating genetic variability). In turn, it can also coincide with the propagation population, generally in the form of a seed orchard. Usually the breeding program does not pass this stage, petering out in the first cycle. An evaluation of the progeny of the selected population, even in the productive plantations, can lead to a genetic purification of the orchard already installed, achieving a 1.5 generation orchard.

Any breeding program should begin by identifying the breeding zones based on environmental criteria (i.e., edaphoclimatic). Each breeding zone requires a particular program, which produces the propagation material to be used within it (White et al. 2007). All accessible populations (natural or artificial) included within the breeding area will represent the program's base population. The next step will be the identification and evaluation of provenances, which will require a wide and adequate sampling for the good representation of each one. In a low-intensity program, a provenance trial will not only test the provenances best suited for the breeding zone but may also constitute the base population for the next generation. In this case, starting from trees that have already demonstrated their adaptation to artificial management might be an advantage, and additionally the selection can be based on the comparison between neighboring trees. However, conforming the selected population from these selections requires avoiding open pollination when propagating selected trees (i.e., controlled pollination or vegetative propagation should be used), since otherwise the progeny of the selected trees would include genes from unselected individuals and provenances.

Once the selection of provenances has been performed, progress can be made to define seed-producing areas (SPA), which usually represent the most elementary basic propagation material. SPA are natural stands or plantations, with good accessibility to the trees and their crowns, high productivity and low periodicity in seed production, high specific purity in the case of possible inter-specific hybridization, and with a mode of trees of good phenotype. The objective of the SPA is the provision of seeds from a known provenance. A thinning that eliminates undesirable individuals (i.e., unhealthy, phenotypically diminished) will lead to the formation of a seed stand (SS). This new basic propagation material already involves genetic gain, even when it is based on light phenotypic selection.

The next step is the establishment of seed orchards (SOs), which are plantations made with selected genetic material and with the specific purpose of producing seeds for the plantation program. Clonal SOs are often the core product of the first cycle of a high-intensity breeding program and require mastering the vegetative propagation technique by grafting or rooting of cuttings. Progeny SOs allow dispensing with vegetative propagation, which is important to simplify the process and occasionally crucial since in some species the percentage of success is very low (or null) or depends on the genotype. In a low-intensity strategy, these progenies will be the product of open pollination of the selected mothers. Thus, progeny orchards will have greater genetic diversity than clonal orchards, which may be a particularly sought-after effect if the goal is to increase adaptability rather than productivity. However, open pollination involves the inclusion of many undesirable genes, leading to the need to test individuals in the orchard. In this way, the same group of trees is a progeny trial and, simultaneously, the future seed orchard, which will only be established when the genetic thinning prescribed by the trial evaluation is carried out.

However, monitoring and evaluating a progeny trial often exceed the possibilities of a low-intensity breeding strategy. Gene source plantations (GSP) have been proposed as an alternative to progeny SO (Lindgren 2000). These are plantations established with seedlings from open pollinated selected trees, usually mass selected in previous plantations or directly in the natural forest. They may be established in a similar fashion to regular plantations and may serve concurrently several functions, such as production of desirable commercial products, conservation of the genetic diversity of the species, and as a local demonstration plot or as seed source for plantations, while retaining options to initiate a more regular improvement program. If it will effectively function as a seed source, it should be thinned aiming to eliminate undesirable individuals. The original material should include the seed of a high number of mothers, since an intense thinning of their progeny could leave a limited number of families in the GSP, thus favoring inbreeding.

Summarizing, recurrent selection cycles with recombination and infusions of new material typical of high-intensity breeding are replaced, in low-intensity breeding, by linear chains leading to the development of a program with a predicted end (Fig. 1.5). This does not mean that if the demand for seeds for productive or restoration purposes increases more than expected, the initial low-intensity program cannot be reformulated toward a new improvement cycle, moving in this case to a classic high-intensity program.

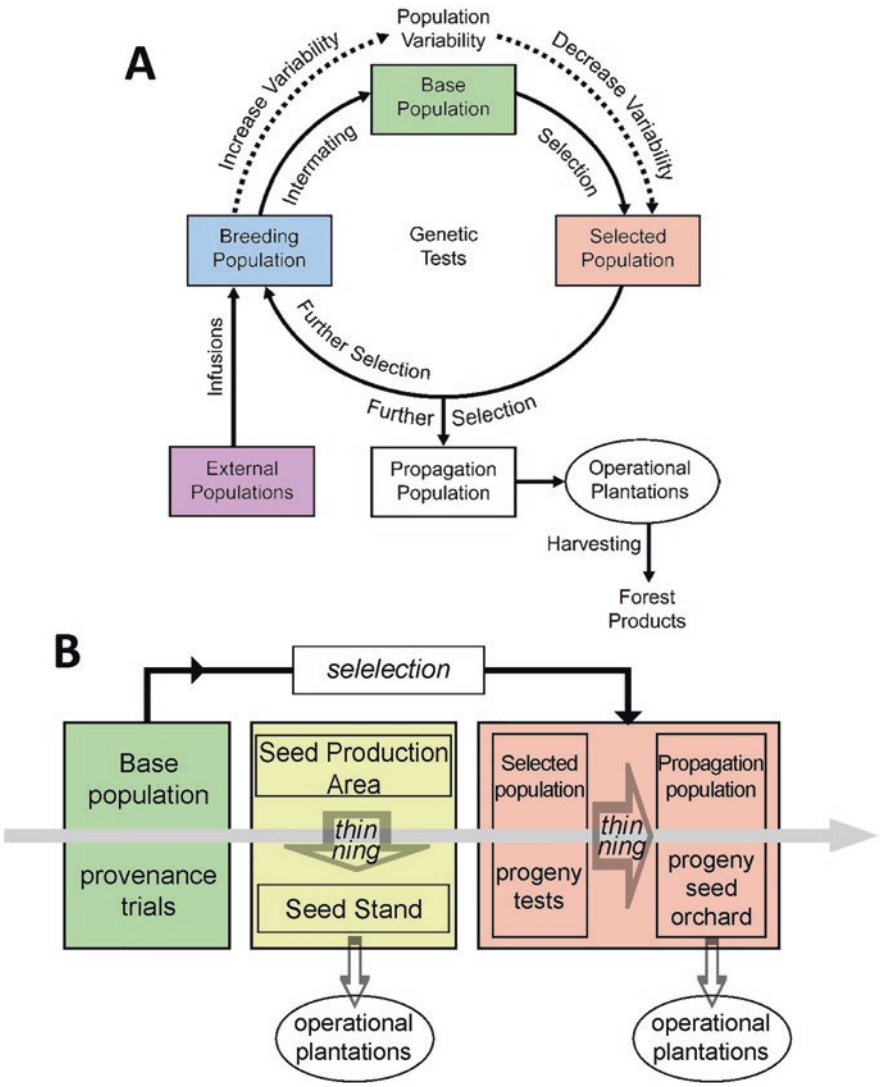

Fig. 1.5 Schematic diagrams of the breeding process for trees. (**a**) Classic breeding cycle of a high-intensity improvement program (from White 1987). (**b**) One possible breeding chain of a low-intensity improvement program. Different colors imply different physical populations

1.9 Aim and Scope of the Present Contribution

The development of forestry in Argentina has been based on the cultivation of fast-growing introduced species, mainly from the *Pinus*, *Pseudotsuga*, *Eucalyptus*, *Populus*, and *Salix* genera, for which both private companies and the National State through INTA have developed high-intensity genetic improvement programs.

However, in the late 1990s, three complementary reasons gave impetus to the development of a domestication program at INTA: (i) a certain social consensus (first international and finally national) on the importance of conserving and restoring natural forest ecosystems, (ii) sympathy for native species per se, and (iii) the baseline information that had been generated in previous years on the genetic resources of native forest species. Initial efforts were unstructured and responded to different projects with varying objectives, but finally a formal program started in 2006.

In addition to INTA's initiative to domesticate potentially productive native species using low-intensity breeding strategies (see Marcó and Llavallol 2016), efforts were also made by other institutions that had also started studying the genetic resources of forest species in Argentina. These actions make up the Argentine experience in the matter, at times systematic and well-structured and sometimes dispersed and with a varied level of depth. It is the intention of this book to summarize the most relevant experiences, trying to make visible the effort of many technicians and researchers who have managed to chart a path that, despite the years, has only just begun.

The book is organized through the main forest ecosystems in Argentina. In each one, the advances referred to the knowledge of the genetic resources of the most studied species are presented, together with the implementation of actions for their domestication and genetic improvement. The most prominent results are reported, avoiding accounting for failures or low impact results. Toward the end of the book, we present the latest advances in the development of tools by means of high-throughput sequencing in native species of Argentina that will be the basis of the next technological generation for their genetic improvement. Finally, we conclude with essential considerations inherent in the planting of native species in the frame of climate change.

We are addressing a wide and international public that seeks to know what has been achieved and what is being worked on in Argentina with respect to its native forest genetic resources. The interested reader should look for the most scientific details in the articles of the extensive list of bibliographic citations.

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