Chapter 20
Ethnobotany and Ex situ Conservation of Plant Genetic Resources in México

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Abstract In this chapter, the importance of ex situ conservation is discussed to safeguard plant genetic resources on relationship to its ethnobotanical relevance. It also highlights the importance of preserving the germplasm of species that are closely associated to human being. The diverse forms and intensities of human–plant relationship lead to the accumulation of traditional knowledge and the modification of the characteristics of plant populations as a result of human manipulation. When the germplasm of plant populations that are important to human being is protected, the information associated to this relationship is also protected, so that the conservation of biological diversity of useful plant species favors the protection of cultural diversity associated to its plant use. The urgency to conserve and protect the Mexican germplasm is associated to the fast and dramatic change of habitats that the country is facing.

In megadiverse countries with serious institutions, such as the Seed Bank FESI-UNAM, has undertaken efforts to conserve seeds from species of wild plants and particularly useful wild species, so that it is possible to have the raw material to carry out taxonomical, ethnobotanical, genetics, ecological and phytochemical studies and sustainable projects.

Biodiversity in Mexico

Out of the nearly 30 million species that the least conservative estimates suggest that we currently know between 10 % [1] and 12 % of the natural capital [2]. In other words, we barely know between 180,000 and 216,000 species. In Mexico, over 100,200 species have been described from the 200,000 species that are estimated [3].

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Mexico is a spectacular country. It has a highly heterogeneous territory in terms of environment and culture, which makes it one of the 17 so called “megadiverse” countries, which altogether bear around 65–70 % of the world’s natural capital [3]. In its nearly two million square kilometers, the country bears diverse ecosystems ranging from humid and deciduous tropical forests to desert scrub-like vegetation to pine forests in the highlands.

According to the information provided by the IUCN [4], in the world there are 13,025 fern species, 980 gymnosperms species, 199,350 dicotyledonous species and 59,300 monocotyledonous species. Particularly, in Mexico the plant biodiversity recorded includes 21,841 Magnoliophyta species, occupying the third place worldwide, only surpassed by Brazil and Colombia [5]. The ten states of the country with the highest diversity on vascular plants are Veracruz, Chiapas, Oaxaca, Jalisco, Guerrero, Puebla, México, Michoacán, Hidalgo, and Morelos [2, 5].

In addition, Mexico shows a high endemism rate of its vascular flora, reaching up to 50.4 % with almost 11,001 species endemic to the country [5]. The richest biomes in terms of endemism are the temperate forest followed by the tropical rainforest. In particular, the highest floristic richness in Mexico is found in the temperate forest followed by the desert scrub-like vegetation and the tropical rainforest.

Unfortunately Mexico is facing a systematic deforestation and change in the land use, mainly caused by extensive cattle rising and the cultivation of a few crop species. Other factors, such as the construction of industrial complexes and highways, illegal extraction and traffic of exotic species, among other things, have also contributed to the current alarming vulnerability of many plant species of major commercial importance [6], also the vegetation has suffered extensive anthropic alterations. Very few areas of the national territory still hold unaltered ecologic communities.

Such vulnerability becomes even more critical considering the climate change, by which species are facing a number of environmental changes and their success will depend on their capacity to maintain their populations, to inhabit new zones and to generate strategies that allow them to resist different temperatures and precipitation rates [7].

Under these conditions, the alternative that brings elements to face such grave consequences over the rural productivity and the conservation of biodiversity, emerges as an urgent priority and includes the development of procedures to revert this terrible deterioration in an intelligent way [8].

Accordingly it is urgent to conserve and protect the plant germplasm of Mexico because potentially most of the species can be used for different purposes that can be identified by means of the ethnobotanical studies.

Ethnobotany

Since the origin of humanity, people used the natural resources for surviving and obtaining all the needed supplies, such as fuel, food, medicines, wood, forage, coal, oil, construction and ritual materials, among others. Consequently, since the beginning of humanity a very close bond between plants and human being was established.

Since the beginning, human being needed to know the properties and uses of plants, and on the basis of these knowledge diverse ideas on relationship to the living organisms emerged that differentially influenced each ethnical group that inhabits the different regions of the world. In other words, the various ethnical groups have their own way of interpreting their environment or their own world view [9].

The way people from the rural areas live and approach their natural resources is quite different from those living in the cities. However, both types of communities have in common that all live and benefit from these resources [9].

The bond formed between human beings and natural resources has caused, in many regions, an abuse in the way the biodiversity is used. The inadequate use of biodiversity has affected the vital cycles and the ecological relationships of many living organisms that depend one from each other [1]. The industrialization that emerged in the late eighteenth Century caused a deep change, not only in the way in which the relationship between humans and their natural resources takes place, but also in the form that natural capital is seen, which since then started to be comparable to the financial capital and infrastructure [10].

Within the industrialization development, people behavior dramatically changed, because it not only brought benefits and comfort, but also a striking economic inequality, creating very poor social groups with a profound imbalance in terms of rights, goods, and services. In addition, it caused different kind of pollution; change in the land use; and lack of care of the natural habitats, among other things. All of these problems have caused the global warming, which is modifying and destroying the world's biodiversity [1].

The big change regarding the way natural resources are seen by people and politicians, as well as, the policies for protecting them began in the 90s, when as a result of the change in the international markets, the growth of global economy and the political and social reorganization in some countries (mainly in Europe), a social growth occurred, not only in terms of the number of individuals, but also in the way such resources were used and distributed. However, history has shown us that such a change has not taken place along with the economic development. For instance, many human communities that are living in the Natural Protected Areas (NPA), from which most of the natural resources are obtained, still live in very limited and deficient conditions, compared to those who live in the cities, where a high percentage of the environmental services available are consumed [1].

Over the last decades, politicians have proposed the creation of "green" political parties and organizations, in order to solve the environmental issues that were being considered since the 70s. The first global conference regarding the environment, known as the "Stockholm Conference" in 1972, set the tone for the modification and redirection of environmental policies worldwide [1]. Nonetheless, the attending of these issues is a matter of national security and it must have an important place in each country's development plan [10].

In the late 70s, John Harshberger proposed the concept of "Ethnobotany," as a discipline that aims to analyze the interrelation between human societies and plant communities in terms of both environmental and sociocultural aspects [11].

This discipline considers, since its inception, the close relation between human beings and plants, not only as a simple compilation and description of plant species uses, but for understanding their changes due to domestication and evolution processes, as a result of their interaction with human beings. Also within the framework of Ethnobotany, many studies are carried out, in order to find and propose diverse strategies for sustainable use of plants in their natural environments.

Since the emerging of Ethnobotany in Mexico, many authors have contributed to improve and develop this important discipline. In particular, Efraín Hernández Xolocotzi concluded that the human–plant interrelation is determined by two factors: (a) the environment (the ecological conditions) and (b) the culture. By studying such factors in a time range, he was able to recognize that there are qualitative and quantitative changes in the used plants. Thus, the environment changes because of modifications in its components and by the action of man, while the culture changes due to the accumulation, and sometimes the loss, of human knowledge [12].

Likewise, Toledo et al. [13] suggested that Ethnobotanical work attempts to integrate those issues that usually are disintegrated. In other words, it integrates the botanical science to other disciplines, by a multicultural and multilinguistic approach, in order to answer the current social crisis with a truly committed science.

More recently, within the framework of Ethnobotany, many studies have contributed to the understanding of the man–plant relationship [14], which have shown that the traditional knowledge of the native people that inhabit the NPA, or any other relevant regions, is essential to detect the important species from the economic point of view and to define the minimum surface needed for their conservation.

It is not casuistic that, as Harmon [15] pointed out, at a planetary scale, human being diversity is closely associated to the main existing biodiversity concentrations. Indeed, this fact is the main reason for the overlapping between the areas with greater biological richness and those with high linguistic diversity. This overlapping is the best indicator for distinguishing a culture. Therefore, if biodiversity is endangered, cultural diversity is also so; this is precisely what Nietschmann [13] named "*symbiotic conservation*", concept that accounts for the mutual dependence of both types of diversity [13].

Domestication is not an instantaneous event by which wild plant populations are suddenly transformed in domesticated populations. It is an evolutionary process involving gradual changes in the relationship "plant–human being" by which a certain degree of interdependency occurs, in parallel to the effects caused by the artificial selection undertaken by human beings [16–18]. As a result of this selection, when domesticated plants are compared to their wild representatives, the former ones show morphological modifications in their useful parts, life cycle and genetic diversity and structure [19]. Some of these changes are not unidirectional or do not follow the same direction, because they are influenced by the biology of each species and the culture of the human beings involved in the domestication [18].

The diverse ethnobotanical studies undertaken have enabled to estimate that in Mexico there are between 5000 and 7000 useful plant species [20–22]. In particular, in the Tehuacán-Cuicatlán Valley, there are 1608 useful plant species recorded, from which 610 have at least one management type other than simple gathering [23, 24]. Among these managed plant species there are some annual weeds that grow spontaneously in cultivated fields, roads, or in home gardens [25–28]. Some others are perennials, particularly columnar Cactaceae in which it is possible to differentiate wild populations from those that are either morphological or genetically different due to their management [14, 29–39, 41].

It is worthy to mention the project entitled "Strategies for ex-situ conservation and propagation of useful plant species in the Tehuacán Cuicatlán Biosphere Reserve", which was carried out in the community of San Rafael Coxcatlán, Puebla, Mexico (Fig. 20.1), as part of the collaboration between FES Iztacala UNAM and Millennium Seed Bank of the Royal Botanical Gardens of Kew [14, 23–27, 29–45].

In San Rafael Coxcatlán, a total of 368 useful species have been recorded [46] and the community has made efforts to conserve all of them by propagating them in a greenhouse and in some specific locations. For doing so, 29 workshops were performed in which kids, adults, and young people from the communities (957 people in total) participated. In these workshops, 11,688 plants of 19 plant species (11,007 by seed and 681 by vegetative means) were propagated. A total of 2602 plant individuals (2462 derived from seeds and 147 from vegetative propagation) were successfully established and now are growing in the greenhouse of San Rafael Coxcatlán.

In relationship to the active components of the useful species, a research on plant physiology and phytochemistry was also carried out. A series of studies have been done regarding the content of secondary chemical compounds found in *Gymnosperma glutinosum* (Asteraceae), *Lippia graveolens* (Verbenaceae), and *Castela tortuosa* (Simaroubaceae), as well as about the seed aging deterioration of several species of Cactaceae. In addition, phytochemical studies have been done to evaluate therapeutic properties attributed to diverse plant species. The results obtained from these studies show that some of these species have antibacterial, antifungal, and antioxidant properties (Fig. 20.2).

In situ Conservation

Such an important place as the Tehuacán-Cuicatlán Valley, where their diversity and endemism rates are high, and so is the number of useful plants, deserves a well-planned conservation program including *in situ* and *ex situ conservation* actions. The former are those related to the "conservation activities that are undertaken in the natural habitat of organisms." It includes the protection of endangered species

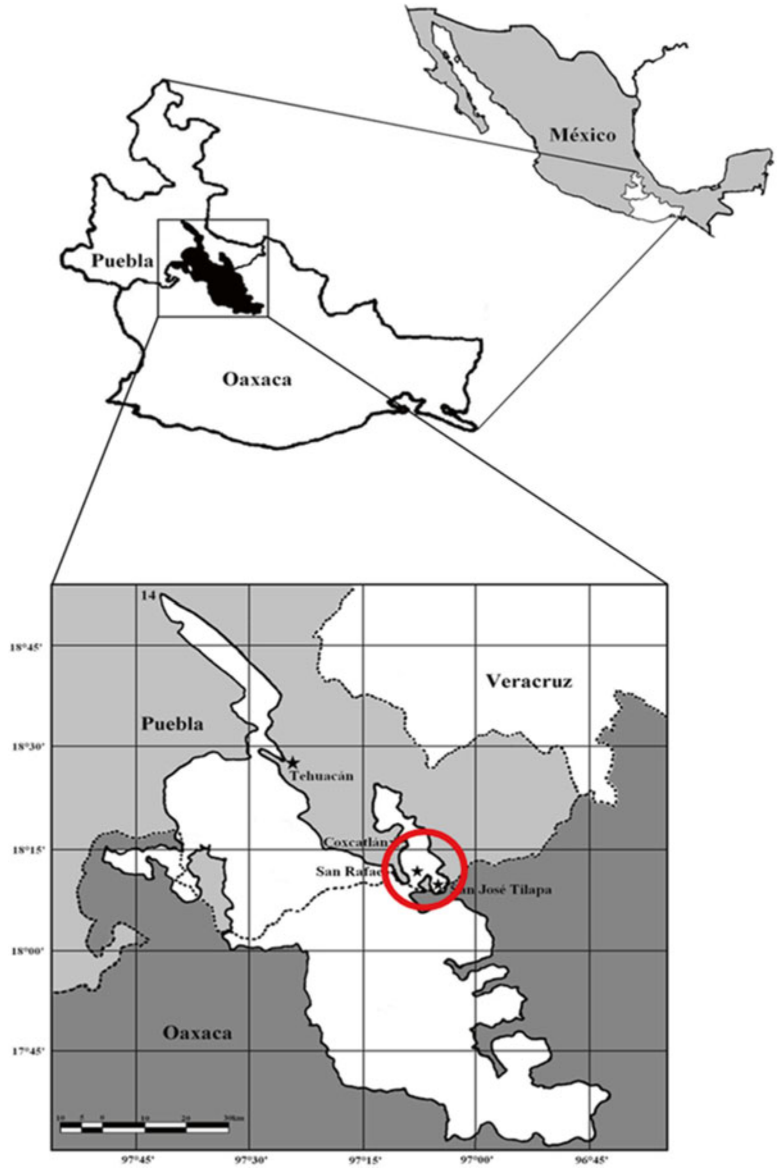

Fig. 20.1 Community of San Rafael Coxcatlán, Puebla, Mexico

and their habitats, as well as the biotic and abiotic interactions that take place between them [47].

In Mexico, the way to optimize the *in situ conservation* activities has been through the decree of NPA leaded by the National Commission for Natural Protected Areas of the Mexican Environmental Ministry (SEMARNAT, Secretaría de Medio

Species / Activities	A	B	C	D	E	F	G	H	I	J
Acalypha monostachya	✓	✓	✓	✓	x	x	x	x	✓	-
Ampypteringium adstringens	✓	✓	✓	✓	x	x	x	x	✓	✓
Bursera aptera	✓	-	✓	-	-	-	-	-	✓	✓
B. arida	✓	-	-	-	-	-	-	-	✓	-
B. biflora	✓	-	-	-	-	-	-	-	✓	-
B. fagaroides	✓	-	-	-	-	-	-	-	✓	-
B. morelensis	✓	✓	✓	✓	✓	✓	✓	x	✓	✓
B. schlechtendalii	✓	-	-	-	-	-	-	-	✓	-
B. submoniliformis	✓	-	-	-	-	-	-	-	-	-
Caesalpinia melanadenia	✓	-	-	✓	-	-	-	-	-	✓
Castela erecta	-	-	-	-	-	-	-	-	-	-
Ceiba aesculifolia ssp. *parvifolia*	✓	✓	✓	✓	x	x	x	x	✓	✓
Cordia curassavica	✓	-	-	-	-	-	-	-	-	-
C. globosa	✓	-	✓	✓	-	-	-	-	-	-
Cyrtocarpa procera	✓	✓	✓	✓	x	x	x	✓	✓	
Gymnolaena oaxacana	✓		✓	✓	-	-	-	-	-	-
Gymnosperma glutinosum	✓	✓	✓	✓	x	x	x	x	✓	
Jatropha neopauciflora	✓	✓	✓	✓	x	x	x	x	✓	✓
Lantana camara	✓	-	-	-	-	-	-	-	-	-
Lippia graveolens	✓	-	✓	-	-	-	-	-	-	✓
Porophyllum tagetoides	-	-	-	-	-	-	-	-	-	✓
Rosa centifolia	✓	✓	✓	✓	x	x	x	x	✓	-

A = Antibacterial activity; B = Antifungal activity; C = Antioxidant activity; D = General toxicity; E = Analgesic activity; F = Anti-inflammatory activity; G = Scaring activity; H = Contents of carbohydrates, lipids, proteins and vitamin C; I = Phytochemical screening; J = Photo protective and antioxidant effect.

Fig. 20.2 Species considered by local people as being of high conservation priority

Ambiente y Recursos Naturales). Despite the fact that the NPAs represent the best current option for conserving and protecting the natural capital and the services it provides, the current coverture on the national territory for such areas is still insufficient, for they barely represent 9.85 % of the whole territory [48]. Once the NPAs are decreed, it is necessary to develop a conservation and management program that integrates and sets actions to be carried out in short, medium, and long terms [47].

Even when *in situ conservation* is an excellent strategy, the main problems associated to the NPA decree indicate that after being appointed as such, they must be well protected against intrusions or anthropic destruction, which is difficult and expensive. Besides, the size of the NPA must be determined for each protected species, examining the population density in natural situations, for they must be large enough to maintain an adequate number of individuals of the species under protection. This situation is important, due to the fact that the population size of the species protected in these areas must gather the minimal genetic variability needed to survive. By doing so, these populations may be able to continue evolving in time. The ANPs decree brings serious social, political and even economic problems, because they limit the economic activities that were formerly done.

Accordingly, in Mexico, there is still much to be done regarding *in situ conservation*; the State has a big task in terms of promoting and generating strategies whose main and final objective is the conservation of the natural capital.

A particular case that deserves a special attention in this matter is the decree of the Tehuacán-Cuicatlán NPA, which is considered a very important reserve in Mexico. With approximately, 10,000 Km^2, the region bears almost 3000 species of vascular plants, from which 365 are endemic and 1608 are useful species.

Ex situ Conservation

Given the problems and challenges of *in situ conservation* and complementing its efforts, the *ex situ conservation* actions are also important for conserving and protecting our natural capital. They include those actions undertaken outside the natural habitat of the organisms. All these actions are mentioned in the ninth article of the Biological Diversity Convention and in the eighth objective of the Global Strategy for Plant Conservation [49].

The last 50 years have witnessed an unprecedented evolution of our knowledge on conservation and its interrelations with the goal of achieving sustainable development. Given the fact that world biodiversity is quickly diminishing; immediate conservation actions are required in order to safeguard many of the species that are currently disappearing [50].

Ex situ conservation consists in the maintenance of some biodiversity components outside its natural habitats, which includes, storing genetic resources in genebanks, as well as establishing field collections and managing species in captivity. The main objective of the *ex situ conservation* is to ensure the survival of the species and it must be considered complementary to *in situ* conservation, especially when working with critically endangered species [51].

Accordingly, *Ex situ conservation* aims to preserve taxa outside of their natural habitat, through different methods:

- *Gene and seed banks*, including germplasm, sperm, and egg cells banks.
- *Collections of In vitro,* including plant tissues and microbial cultures.
- *Reproduction of animals in captivity and artificial propagation of plants*, including the possibility, at least in some cases, of their reintroduction to their natural habitats.
- *Recollection of confined living organisms*, including zoos, aquariums and botanical gardens for research, education, and public awareness.

A key factor for biodiversity conservation is the genetic resources, defined as a material consisting of genes, proteins and metabolites or crude fragments of plants, animals or microorganisms of intrinsic or utilitarian value (actual or potential), which represent a fundamental characteristic of biocomplexity and therefore are part of the cultural and technological heritage of mankind [52]. Particularly, the plant genetic resources that have or might have any anthropocentric value are a product of its evolution, but also are useful for the improvement of genetic engineering [53].

The importance of plant genetic resources in Mexico can be seen, when it is realized that there are 50 native and 179 introduced taxa in the country that produces about 73–119 millions of pesos every year [53]. Nevertheless, all the species that are used and are sold locally, are not included and there is no way that we can have a real estimation of their economic input.

The expression "genetic resources" often replaces the concept of germplasm by referring to a group of species or genera (plant genetic resources, microbial genetic resources, etc.) that offer an economic or environmental utility. However, strictly speaking, the term germplasm is formed by the etymological root *germ* (beginning or inception) and *plasm* (formation). Thus, the term germplasm can be used for naming any genetic material that can regenerate a life form that is equal or similar to the original [53]. The centers responsible for the conservation of biodiversity contained in the germplasm are often called germplasm banks or *Seed banks*.

From the moment that human societies developed agriculture, the conservation of seeds became a necessary activity to maintain the cycles of recollection and sow, as well as to preserve contemporary plant diversity [50]. Consequently, the idea of preserving seeds of different plant species from all around the world in special places for guaranteeing their long-term viability, emerged at the beginning of the twentieth century. This idea highlights the proposal of the Russian scientist Nicolai Ivanovitch Vavilov [54], who aimed to increase the germplasm supplies of those species recognized for food or industrial uses, but also to improve the genetic material, at the time Russia was a very poor country. In order to achieve this goal, in almost 30 years Russians created and ordered huge biological collections which enabled them to preserve ex situ plant germplasm in a systematic way and defining some of the basic procedures for seed preservation [50].

The techniques to manipulate genes are developing and improving all the time. However, we are still unable to create them. Consequently, if a plant species with a unique genetic character disappears, there is no way of recovering it. This is the reason why millions of dollars are invested on seed banks, which represent one of the most important strategies of *ex situ conservation*. In fact, in some countries, germplasm banks specialized in the conservation of wild plants have a key role in the biodiversity conservation policies. In fact, each time it is more frequent that the technicians and researchers of the *ex situ conservation* centers actively participate in the design, development, and execution of *in situ conservation* programs [8, 50].

The presence of botanical gardens and seed banks stimulates and strengthens the implementation of strategies on those zones where conservation species concern occur. This task and the generation of original scientific knowledge by the academic research institutions are helping to protect the ecosystems [52].

Although it is true that *ex situ conservation* is a very useful approach, it is important to point out that its main "inconvenience" lies on the amount of economic resources needed. Nevertheless, in Mexico thanks to the efforts of the UNAM, the Millenium Seed Bank of the Royal Botanical Gardens of Kew and the CONABIO, the seed bank for wild species of Mexico exists formally since 12 years FESI-

UNAM Seedbank (BSFESI-UNAM), Registration: MEX-FLO-150-0903. This seed bank is a reservoir for the long-term conservation of wild plant species of the arid and semiarid regions of Mexico. Currently, the BSFESI-UNAM stores over 3500 seed accessions that represent close to 1700 species belonging to 137 botanical families, including Asteraceae, Mimosaceae, Cactaceae, and Fabaceae, among many others.

The BSFESI-UNAM has an active collecting program for obtaining plant materials from new regions and, in some cases in previously visited locations, given the fact that although collections with a larger number of seeds are needed. The BSFESI-UNAM also continues to carry out efforts to collect seeds from endemic, restricted distribution, endangered or useful species. In addition, researchers are also interested in tree species, as well as those related to domesticated plants. The work done in the Seedbank is also related to the development of diverse research activities that aim to identify, conserve and adequately use our flora.

Since our point of view, *ex situ conservation* is an excellent choice to protect many species without the need of large areas of land. In this sense, the seed banks allow the possibility of storing a great number of species for very specific purposes. For instance, in the case of the conservation of wild useful plant species, not only the plant germplasm is protected but also the ethnobotanical information associated to the collections, which is the starting point for carrying out studies about very specific subjects regarding the close man–plant relationship.

In the different research laboratories associated to BSFESI-UNAM, several research efforts have been implemented, in order to understand the interactions between people and plants, ethnofloristic richness, the relative importance of useful plant species richness in relation to general plant species richness, and plant management in the Tehuacán–Cuicatlán Valley of central Mexico (VTC). These studies recorded a total of 1605 useful vascular plant species (61.2 % of the total species richness of the regional vascular flora), this being the region with the highest absolute richness of useful plant species in Mexico recorded [24].

Also there have been studies, in order to document the floristic composition, richness, diversity, and traditional knowledge of the weeds growing in the cornfields of San Rafael, Municipality of Coxcatlán, Puebla. For that purpose, twelve cornfields were sampled using Canfield's lines, and 20 farmers were interviewed, whom ages fluctuate between 32 and 80 years. A total of 43 species of 12 families of vascular plants were recorded. From them, farmers were able to recognize between 20 and 31 plant species and there was not a significant correlation between farmer's age and the number of identified species. Only 11 species were recognized as useful, and there were not evidences of manipulation in any of them [25].

In San Rafael Coxcatlán, a total of 368 useful species have been recorded [46], from which the seeds of 134 were stored in the FESI Seed Bank, including 17 that are considered by local people as being of high conservation priority (Fig. 20.2).

The stored seeds from the 134 species belong mainly to the following plant families: Asteraceae, Mimosaceae, Euphorbiaceae, Solanaceae, among others (Fig. 20.3).

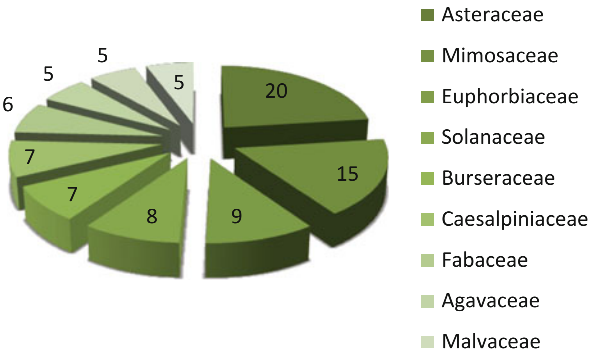

Fig. 20.3 Dominant plant families among the useful plants conserved in the seed bank

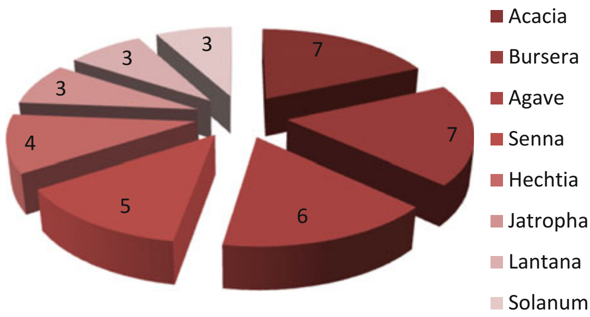

Fig. 20.4 Dominant genera among the useful plants conserved in the seed bank

The most common genera in the seed bank are *Acacia*, *Bursera*, *Agave*, *Senna*, among others (Fig. 20.4).

In addition, from the seed collections of useful plant species stored in BSFESI-UNAM, various studies regarding the therapeutic properties of some useful wild plant species from Mexico have been done. Once the uses of plants are identified in any area, then it is possible to select some plants species, in order to recognize and correlate their phytochemical features and their therapeutic consequences. Accordingly, such studies have been implemented on the basis of the ethnobotanical knowledge of the VTC and by using the germplasm stored in the seed bank. The species that have been so far studied are *Lippia graveolens* [55], *Cordia curassavica* [56], *Gymnosperma glutinosum* [57], *Acalypha monostachya* [58], *Bursera morelensis* [59], *Buddleja perfoliata* and *B. scordioides*, and *Yucca* [45].

In summary, the biodiversity inventory, the generation of information regarding its distribution, uses, ecological and environmental requirements, and phytochemical features are the basic platform that we need to have, in order to be able to propose their sustainable management for ensuring their protection and conservation. Accordingly, all the germplasm stored in the seed banks represents the raw material for doing so. In particular, the bond between the ethnobotanical studies and the seed banks should always be strong, in order to generate the information of our useful plants.

The educational and *ex situ conservation* activities undertaken in San Rafael Coxcatlán located in the Tehacán-Cuicatlán NPA, is an example of a sustainable management project that enables the protection of the natural capital and the benefit of the people, within the framework of the activities leaded by a seed bank.

References

1. Carabias J. Autores. El podcast cultural de la Universidad. Descarga Cultura.UNAM.mx. 2008. Disponible en: http://descargacultura.unam.mx/app1?lang=es#autoresAPP1. Accessed 15 Aug 2014.
2. Llorente-Bousquets J, Ocegueda S. Estado del conocimiento de la biota. Capital natural de México, vol. I: Conocimiento actual de la biodiversidad. México: Comisión Nacional para el Conocimiento y uso de la Biodiversidad; 2008. pp. 283–322.
3. Sarukhán J, et al. Capital natural de México. Síntesis: conocimiento actual, evaluación y perspectivas de sustentabilidad. México: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad; 2009.
4. Baillie JEM, Hilton-Taylor C, Stuart SN. 2004 IUCN red list of threatened species. A global species assessment. Switzerland: IUCN; 2004.
5. Villaseñor JL, Ortiz E. Biodiversidad de plantas con flores (División Magnoliophyta) en México. Revista mexicana de biodiversidad. 2014;85:134–42.
6. Velázquez A, Durán E, Ramírez I, Mas JF, et al. Land use-cover change processes in highly biodiverse areas: the case of Oaxaca, Mexico. Global Environmental Change. 2003;13:175–84.
7. Williams S, Shoo L, Isaac J, Hoffman AA, Langham G. Towards an integrated framework for assessing the vulnerability of species to climate change. Plos Biol. 2008;6:2621–6.
8. Vázquez YC, Batis M, Alcocer S, Gual D, Sánchez D. Árboles y arbustos nativos potencialmente valiosos para la restauración ecológica y la reforestación. México: Instituto de Ecología; 1999.
9. Moreno AI, Vallejo RM, Casas A, Blancas JJ. Los sistemas agroforestales tradicionales del valle de Tehuacán y su diversidad biocultural. Ciencias. 2014;111–112:43–9.
10. Sarukhán J, et al. Capital natural de México: Acciones estratégicas para su valoración, preservación y recuperación. México: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad; 2012.
11. Alcorn JB. Ethnobotany: evolution of a discipline. London: Chapman & Hall; 1995.
12. Hernández X Efraím. El concepto de etnobotánica. La etnobotánica, tres puntos de vista y una perspectiva. Xalapa, Veracruz: Instituto Nacional de Investigaciones sobre Recursos Bióticos A.C.; 1979. pp. 13–8.
13. Toledo VM, Alarcón-Chaires P, Moguel P, et al. El atlas etnoecológico de México y Centroamérica: fundamentos, métodos y resultados. Etnoecológica. 1982;8:7–41.
14. Casas A, Otero-Arnaíz A, Pérez-Negrón E, Valiente-Banuet A. In situ management and domestication of plants in Mesoamérica. Ann Bot. 2007;100:561–76.
15. Harmon D. The status of the world's languages as reported in "Ethnologue". Southwest J Linguist. 1995;14:1–28.
16. Darwin C. On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life. London: John Murray; 1859.
17. Gepts P. Crop domestication as a long-term selection experiment. Plant Breed Rev. 2004;24:1–44.
18. Zeder MA, Emshwiller E, Smith BD, Bradley DG. Documenting domestication: the intersection of genetics and archaeology. Trends Genet. 2006;22:139–55.

19. Harlan JR. Crops and man, Foundations for modern crop science series. 3ath ed. Madison: American Society of Agronomy; 1992.
20. Caballero J. Recursos comestibles potenciales. In: Reyna TT, editor. Seminario sobre alimentación en México. México: Instituto de Geografía, UNAM; 1984. p. 114–25.
21. Casas A, Viveros JL, Caballero J. Etnobotánica mixteca: sociedad, recursos naturales y subsistencia en la Montaña de Guerrero. Instituto Nacional Indigenista/Consejo Nacional para la Cultura y las Artes/Instituto Nacional Indigenista. México; 1994. 230pp.
22. Casas A, Caballero J. Traditional management and morphological variation in *Leucaena esculenta* (Fabaceae: Mimosoideae) in the Mixtec region of Guerrero, Mexico. Econ Bot. 1996;50:167–81.
23. Blancas J, Casas A, Rangel-Landa S, et al. Plant management in the Tehuacán-Cuicatlán Valley, Mexico. Econ Bot. 2010;64:287–302.
24. Lira R, Casas A, Rosas-López R, Paredes-Flores M, et al. Traditional knowledge and useful plants richness in the Tehuacán-Cuicatlán Valley, México. Econ Bot. 2009;63:271–87.
25. Albino-García CO, López M, Cervantes H, Ríos-Casanova L, Lira R. Diversidad y etnobotánica de las plantas arvenses presentes en milpas de San Rafael, municipio de Coxcatlán, Puebla. Revista Mexicana de Biodiversidad. 2011;82:1005–19.
26. Blanckaert I, Swennen R, Paredes M, Rosas R, Lira R. Floristic composition, plant uses and management practices in homegardens of San Rafael Coxcatlán, Valley of Tehuacán-Cuicatlán, Mexico. J Arid Environ. 2004;57:179–202.
27. Blanckaert I, Vancraeynest K, Swennen R, Espinosa-García F, Piñero-Dalmau D, Lira R. Biodiversity of useful non-crop resources and the role of indigenous knowledge in their management in semi-arid crop production systems in Mexico. Agric Ecosyst Environ. 2007;119:39–48.
28. Paredes-Flores M. Manejo, abundancia y variación morfológica del torito *Proboscidea louisianica* (Mill.) Thell. ssp. *fragans* (Lindl.) Bretting (Pedaliaceae), en Zapotitlán Salinas, Puebla. Tesis de Maestría, Posgrado en Ciencias Biológicas, Universidad Nacional Autónoma de México, México; 2006. 65pp.
29. Arellano E, Casas A. Morphological variation and domestication of *Escontria chiotilla* (Cactaceae) under silvicultural management in the Tehuacán Valley, Central México. Genet Resour Crop Evol. 2003;50:439–53.
30. Avendaño A, Casas A, Dávila P, Lira R. Use forms, management and commercialization of "pochote" *Ceiba aesculifolia* (H.B. & K.) Britten & Baker f. subsp. *parvifolia* (Rose) P.E. Gibbs & Semir (Bombacaceae) in the Tehuacán Valley, Central México. J Arid Environ. 2006;67:15–35.
31. Avendaño A, Casas A, Dávila P, Lira R. *In situ* management and patterns of morphological variation of *Ceiba aesculifolia* subsp. *parvifolia* (Bombacaceae) in the Tehuacán-Valley. Econ Bot. 2009;63:138–51.
32. Blancas J, Casas A, Caballero J, Lira R. Traditional management and morphological patterns of *Myrtillocactus schenckii* (Cactaceae) in the Tehuacán Valley, Central Mexico. Econ Bot. 2009;63:375–87.
33. Casas A, Valiente-Banuet A, Soriano J, Dávila P. Morphological variation and the process of domestication of *Stenocereus stellatus* (Cactaceae) in Central Mexico. Am J Bot. 1999;86:522–33.
34. Cruz M, Casas A. Morphological variation and reproductive biology of *Polaskia chende* (Cactaceae) under domestication in Central Mexico. J Arid Environ. 2002;51:561–76.
35. González-Soberanis MC, Casas A. Traditional management and domestication of tempesquistle, *Sideroxylon palmeri* (Sapotaceae) in the Tehuacán Valley, Central Mexico. J Arid Environ. 2004;59:245–58.
36. Oaxaca-Villa B, Casas A, Valiente-Banuet A. Reproductive biology in wild and silvicultural management populations of *Escontria chiotilla* (Cactaceae) in the Tehuacán Valley, Central México. Genet Resour Crop Evol. 2006;53:277–87.
37. Otero-Arnaiz A, Casas A, Bartolo MC, Pérez-Negrón E, Valiente-Banuet A. Evolutionary trends in Polaskia chichipe (Cactaceae) under domestication in the Tehuacán Valley, Central Mexico: reproductive biology. Am J Bot. 2003;90:595–604.

38. Otero-Arnaiz AC, Hamrick JL, Cruse J. Genetic variation and evolution of *Polaskia chichipe* (Cactaceae) under domestication in the Tehuacán valley, Central Mexico, analyzed by microsatellite polymorphism. Mol Ecol. 2005;14:1603–11.
39. Parra F, Pérez-Nasser N, Lira R, Pérez-Salicrup D, Casas A. Population genetics, and process of domestication of *Stenocereus pruinosus* (Cactaceae) in the Tehuacán Valley, Mexico. J Arid Environ. 2008;72:1997–2010.
40. Tinoco A, Casas A, Luna R, Oyama K. Population genetics of wild and silvicultural managed populations of *Escontria chiotilla* in the Tehuacán Valley, Central Mexico. Genet Resour Crop Evol. 2005;52:525–38.
41. Casas A, Vázquez MC, Viveros JL, Caballero J. Plant management among the Nahua and the Mixtec of the Balsas river basin: an ethnobotanical approach to the study of plant domestication. Hum Ecol. 1996;24:455–78.
42. Casas A, Caballero J, Mapes C, Zarate S. Manejo de la vegetación, domesticación de plantas y origen de la agricultura en Mesoamérica. Boletín de la Sociedad Botánica de México. 1997;61:31–47.
43. Casas A, Valiente-Banuet A, Viveros JL, et al. Plant resources of the Tehuacán-Cuicatlán Valley, Mexico. Econ Bot. 2001;55:129–66.
44. Rodríguez-Arévalo I, Casas I, Lira R, Campos J. Uso, manejo y procesos de domesticación de *Pachycereus hollianus* (F.A.C. Weber) Buxb. (Cactaceae) en el Valle de Tehuacán-Cuicatlán, México. Interciencia. 2006;31:677–85.
45. García-Bores AM, Hernández T, Arciniegas AR, et al. Photoprotective activity of some Mexican plants. Natural antioxidants and biocides from wild medicinal plants. UK: CABI Publishing (UK); 2013. pp. 254–66.
46. Rosas L.R. Estudio etnobotánico de San Rafael-Coxcatlán. Tesis de licenciatura. Universidad Nacional Autónoma de México. Facultad de Estudios Superiores Iztacala. Tlalnepantla, México; 2003. 94pp.
47. CONANP (Comisión Nacional de Áreas Naturales Protegidas). Programa de Conservación y Manejo Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado. México: Secretaría de Medio Ambiente y Recursos Naturales; 2007.
48. Bezaury-Creel J, Gutiérrez Carbonell D, et al. Áreas naturales protegidas y desarrollo social en México. Capital natural de México, vol. II: Estado de conservación y tendencias de cambio. México: Comisión Nacional para el Conocimiento y uso de la Biodiversidad; 2009. pp. 385–431.
49. Sarasan V, Cripps R, Ramsay MM, Atherton C, Mcmichen M, Prendergast G, Rowntree JK. Conservation *in vitro* of threatened plants. Progress in the past decade. In Vitro Cellular & Developmental. 2006;42:206–14.
50. Bacchetta G, Bueno Sánchez A, Fenu G, Jiménez-Alfaro B, Mattana E, Piotto B, Virevaire M. Conservación *ex situ* de plantas silvestres. España: Principado de Asturias/La Caixa; 2008.
51. Lascuráin M, List R, Barraza L, et al. Conservación de especies *ex situ*. Capital natural de México, vol. II: Estado de conservación y tendencias de cambio. México: CONABIO; 2009. pp. 517–44.
52. CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad). La Biodiversidad en Puebla: Estudio de Estado. México: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Gobierno del Estado de Puebla, Benemérita Universidad Autónoma de Puebla; 2011.
53. Villareal R, Gil MJ, Hernández GA, et al. Los recursos genéticos como componentes de la biodiversidad. Biodiversidad, Biodiversidad de Puebla: un estudio de Estado. Puebla: CONABIO; 2011. pp. 195–235.
54. Koo B, Pardey P, Wright B. Saving seeds. Wallingford: CABI; 2004.
55. Moreno RA, Vázquez-Medrano J, Hernández-Portilla LB, et al. The effect of light and soil moisture on the accumulation of three flavonoids in the leaves of mexican oregano (*Lippia graveolens* Kunth.). J Food Agric Environ. 2014;12:1272–9.

56. Hernández T, Hernández D, Orozco J, et al. Temporal variation of chemical composition and antimicrobial activity of the essential oil of *Cordia cuassavica* (Jacq) Roemer and Schultes: Boraginaceae (barredor) of San Rafael Coxcatlán, Puebla, México. Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas. 2014;13:100–8.
57. Serrano R, Hernández T, Canales M, et al. Ent-Labdane type Diterpene with antifungal activity from *Gymnosperma glutinosum* (Spreng.) Less. (Asteraceae). Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas. 2009;8:412–8.
58. Canales M, Hernández T, Rodríguez-Monroy MA, et al. Evaluation of the antimicrobial activity of *Acalypha monostachya* Cav. (Euphorbiales: Euphorbiaceae). Afr J Pharm Pharmacol. 2011;5:640–7.
59. Serrano-Parrales R, Vázquez-Cruz B, Segura-Cobos D, et al. Anti-inflammatory, analgesic and antioxidant properties of *Bursera morelensis* bark from San Rafael, Coxcatlán, Puebla (México): implications for cutaneous wound healing. J Med Plants Res. 2012;6:5609–15.