Ethnobotanical Knowledge in Mexico: Use, Management, and Other Interactions Between People and Plants

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Abstract

This chapter shows a general panorama of ethnobotanical research and information generated during the twentieth and twenty-first centuries among Mexican cultures, according to the database Base de Datos Etnobotánicos de Plantas Mexicanas (BADEPLAM) of the Botanical Garden at the Institute of Biology, UNAM. This is the most complete database with ethnobotanical information in Mexico, whose

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construction started nearly 40 years ago. It was a pioneer effort to systematize biocultural information in this country, which has continued until now and has stored nearly 60,000 records on plants used and managed by different cultural groups in different ecosystems of Mexico. It includes information on nearly 7823 useful plant species, which is approximately one-third of the total native vascular flora of the country. Through different approaches, it is estimated that the real number could be more than 11,500 species, which gives an idea of the effort still required to complete the inventory. The current listing has information from numerous Mestizo people communities, but only 32 of the 68 main linguistic groups of Mexico; not all the states of Mexico have been studied, and ethnobotanical research has concentrated in half of the states composing Mexico. All this information indicates that although BADEPLAM is probably the oldest project of biocultural informatics in Latin America, there is a long way to complete the task of inventorying the ethnobotanical knowledge of the country. BADEPLAM has records for 4222 medicinal plant species, 2265 ornamental, 2051 edible, 1974 used as fodder, and 975 for fuelwood, among other uses. Most species (nearly 64%) are wild and weedy plants collected from forests, mainly tropical dry forests (1995 species), tropical rain forests (1928 species), temperate forests (1440 species) and xerophytic vegetation (1361 species), grasslands, and agricultural areas. However, nearly 3000 species are managed through one or more forms, some of them showing incipient or intermediate signs of domestication. Nearly 500 species are fully domesticated crops, approximately one-half of them (251 species) being native to the Mesoamerican region. Plant families contributing with the highest richness of useful plants are Fabaceae (752 species), Asteraceae (727), Poaceae (476), Cactaceae (474), Euphorbiaceae (233), Malvaceae (198), and Solanaceae (195). Associated with BADEPLAM, several research groups have articulated our work coordinating different approaches to generate inventories of knowledge, management techniques, and different forms of interactions between people and plants. These inventories have been performed at rural community (more than 150 communities) and regional levels (17 main biocultural regions of Mexico) feeding the database while constructing theoretical frameworks on traditional classification and worldviews, use, management and domestication, and bases for sustainable use of plants and ecosystems. Several approaches have enhanced our

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studies, but plant management and domestication have been some of the most important issues. We understand that management is a crucial expression of interactions between people and plants, reflecting their knowledge and worldviews, and it is a topic that allows connecting ethnobotany with social, cultural, and economic topics. In addition, studying plant management allows establishing socioecological bases for sustainable management and studies on evolution of plants through domestication at populations and landscape levels. In this chapter, we show general insights of the research approaches developed by our teams. Most of our studies have been conducted in mountainous regions since Mexico is an eminent mountainous country. Therefore, this text provides general perspectives of the ethnobotanical knowledge of Mexico, as well as methodological approaches that are helpful to contextualize the entire volume of this book.

Introduction

Mexico and the Mesoamerican region in the neighboring countries of Central America is one of the areas with the highest biocultural diversity of the world (Maffi 2005; Toledo and Barrera-Bassols 2008; Boege 2008). This region includes more than 300 native languages (284 only in Mexico, according to Ethnologue; Eberhard et al. 2022) and more than 39,300 species of vascular plants (Hanelt 2001), which is nearly one-third of the flora of the Americas (Ulloa et al. 2017), as well as a high diversity of vertebrate and arthropod species. Such diversity has a notable expression in the ethnobiological knowledge and the systems of management and domestication of plants, animals, mushrooms, and microorganisms, as well as the regional ecosystems, their components and functions, and landscapes. As recently reported by Clement et al. (2021), nearly 6500 native plant species of Mexico and the Mesoamerican area, belonging to 265 families, have been recorded to have one or more uses by the Indigenous cultures and other rural people of the region. Among the main families providing plant resources are Fabaceae (699 species), Asteraceae (571), Cactaceae (438), Poaceae (335), Euphorbiaceae (205), Malvaceae (171), Solanaceae (162), Rubiaceae (159), Asparagaceae (143), Apocynaceae (133), and Lamiaceae (133). Compared with information from the Andean region of Peru and the Amazonia and lowlands of Brazil, these numbers are outstanding, not only because of the high biocultural diversity, but also due to the active and long tradition of ethnobotanical research conducted in the area and, importantly, because of the extraordinary efforts to systematize the information in databases (Clement et al. 2021).

Most native plant species in Mexico and the Mesoamerican area are medicinal (3478 species), edible (1810), fodder (1637) and used for construction (1224) and as fuelwood (883). Interactions between people and plants are mostly through gathering, since nearly 6000 species are obtained this way from forests. However, 1555 species receive some form of management: (i) tolerance or let standing of plants in areas cleared for different purposes, (ii) enhancing or promotion actions directed to increase abundance of desirable plants, (iii) special protection and care of plants against herbivores, competitors, frosts, or for procuring water, shade, or sunlight, or (iv) their cultivation by planting seeds, vegetative propagules, and/or (v) transplanting of complete individuals with the purpose of cultivating or relocating them. These forms of management may involve selection on particular phenotypes and have determined that at least 727 species have incipient signs of domestication. Other 170 species can be considered semidomesticated, and 251 species are fully domesticated plants, with clear signs of domestication syndrome, phenotypic divergence from wild populations, and marked dependence on humans for survival and reproduction (Clement et al. 2021). These native species were complemented with others introduced from different regions of the Americas throughout history, and then, after European colonization, numerous wild, weedy, and domesticated plant species from the Old World were introduced and adopted by the human cultures of the Americas (Corona et al. 2021).

Scholars studying management and domestication of plants have recognized that Mexico and the neighboring Mesoamerican area are one of the most ancient and dynamic scenarios where management and domestication can be documented in the Americas (Vavilov 1992; Harlan 1975; Hawkes 1983; Smith 2006). But also, because these are ongoing processes. Studying how and why they are initiated, maintained, and innovated may contribute to understanding how and why these processes occurred in the past.

The region called Mesoamerica was originally proposed by Paul Kirchhoff (1943) as a cultural area with special features that distinguish it from other regions of the Americas. According to Kirchhoff (1943), Matos-Moctezuma (1994), and others, in Mesoamerica flourished human cultures with distinctive settlements and buildings, agricultural systems and techniques, food patterns, and numerous other cultural aspects compared with the neighboring northern arid region of Mexico, called Aridoamerica, and other cultures further North America, as well as those of the Andean, Amazonian, or Patagonian regions in South America. The human cultural features considered by Kirchhoff (1943) have been partly confirmed or refuted by several archaeological and anthropological studies conducted for decades in the region and the whole American Continent. However, the term continues being used and it is still a helpful reference to studies of both cultural and biological diversity.

According to Matos-Moctezuma (1994), the Mesoamerican region comprised the southern half of Mexico until the north-western area of the current Costa Rica, but he and other authors have discussed the dynamic limits of this region throughout time. In addition, it is pertinent to say that cultural elements and products of the regional biodiversity from the Aridoamerica and from South America arrived at Mesoamerica continually since prehistory (MacNeish 1967, 1992; Piperno and Pearsall 1993; López-Austin and López-Luján 2002; Clement et al. 2021; Corona et al. 2021). This illustrates that the frontiers, if these really existed, were not only dynamic but also with high porosity. The early presence of maize in the Andean region (Piperno and Pearsall 1993; Clement et al. 2021) and the ancient presence of cacao (*Theobroma cacao* L.), manioc (*Manihot esculenta* Crantz), peanuts (*Arachis hypogaea* L.), sweet potato (*Ipomoea batatas* (L.) Lam.), and other South American crops in Mesoamerica are indicators of the antiquity and intensity of technological interactions and interchange of crop species and varieties among regions (Pease et al. 2016; Zarrillo et al. 2018; Kistler et al. 2020; Corona et al. 2021). Archaeological remains and ethnohistorical sources, as well as studies from anthropology, ecology, population genetics, phylogeography, and genomic approaches, have been progressively clarifying the biocultural history of the region and will continue doing it with new research tools and approaches. The information available now appears to suggest that the discontinuities proposed by Vavilov and other scholars among the biocultural regions are hypothetical and deserve more research to be confirmed or modified. In this chapter, we will summarize information of the ethnobotanical knowledge documented among peoples from the Mesoamerican and Aridoamerican regions of Mexico, including the current scenario of native and introduced species that became adopted by human cultures occupying the area. This is part of the information that requires to be analyzed to contribute to reconstructing the biocultural history of the area.

Cultures of the Mexican Mesoamerica started developing techniques to manage biotic resources and ecosystems that led to early domestication of plants and food production systems, approximately 9000–10,000 years ago (MacNeish 1967, 1992; Benz 2006; Smith 1997; Piperno et al. 2009) and have continued doing it until the present (Casas et al. 1997, 2017; Parra et al. 2010; Clement et al. 2021). Cultures of Aridoamerica, apparently, adopted in some areas these experiences of management and domestication and initiated their own processes (Nabhan 1985). Different practices like gathering, interchange of products, and incipient management and domestication have been reconstructed based on archaeological information and strongly supported by ethnobotanical and ethnographic studies of how current cultures perform activities that configure these processes (Alcorn 1984; Zizumbo and Colunga 1982; Casas et al. 1994, 1996, 1997; Blancas et al. 2010; Rangel-Landa et al. 2016). In addition, since much of these practices are still carried out, important details about the perception of variation, targets of selection, mechanisms to put it in practice, and their evolutionary consequences can be documented through ethnobiological, ecological, and evolutionary biology approaches (Casas et al. 1997, 2007; Blancas et al. 2010, 2013; Aguirre-Dugua et al. 2012, 2013, 2018; Rangel-Landa et al. 2016; Moreira et al. 2017; Clement et al. 2021; Arévalo-Marín et al. 2021). Although the current social and ecological contexts are different to those occurring in the past, the current processes are valuable empirical bases that can be used as models to understand the motivations that enhanced people to manage plants in the past and ways that could have operated (Casas et al. 1997, 2007; Parra-Rondinel et al. 2021; Rangel-Landa et al. 2016; Clement et al. 2021; Arévalo-Marín et al. 2021). Our research groups have conducted studies on plant management and domestication in several regions of Mexico, in different ecological contexts, different cultural groups, and different groups of plants, including annual herbaceous, shrubby, small trees, agaves, cacti, and long-lived perennials. These studies could provide information and theoretical frameworks to support an interpretation of what happened in the past.

Our groups have systematized ethnobotanical information for the whole Mexican territory for nearly 40 years, through the Base de Datos Etnobotánicos de Plantas Mexicanas (BADEPLAM, Database of Ethnobotanical Information of Mexican Plants, in English), of the Botanical Garden at the Institute of Biology, UNAM. Both the database and field studies in ethnobotany, ecology, and evolutionary biology related to management and domestication allow identifying general patterns of the processes analyzed and how and why these are currently occurring. The information generated is now being useful not only to analyze plant management in Mexico, but also may be helpful to our colleagues working in the Amazonian and Andean regions, which are exceptional areas related to the human culture of plant management. Our research groups started their work with the coordination by the first author of this chapter and then developed their own profiles but maintained most of the original purposes, among them, to: (1) systematize the ethnobotanical information generated among peoples and plants of Mexico, (2) analyze the information on uses, management, traditional nomenclature and classification, habitats, and ecological information of plants Mexican cultures interact with, (3) identify general patterns on the groups of plants mostly incorporated in human subsistence by cultural groups of Mexico, (4) identify the factors motivating people to practice plant management, the different types of practices, and those involving processes of domestication, (5) develop views on sustainable management of nontimber forest products at population and ecosystem levels, (6) document the general trends of morpho-physiological, reproductive, and genetic changes in plants associated to domestication, (7) analyze how landscape domestication influences domestication processes on particular species and vice versa, and (8) analyze how different evolutionary forces operate to influence domestication.

To address these issues, our research groups have combined ethnobiological, ecological, and evolutionary approaches. Our ethnobotanical studies have inventoried the diversity of forms of use and management of plants, and we have systematized our own research, as well as that published in the scientific literature and that registered in herbarium specimens. Those are the basic sources of information stored in BADEPLAM. In the field, we have worked in these inventories at community and regional levels, while the information of BADEPLAM allows a general panorama of the state of ethnobotanical knowledge for the whole country. During decades, most ethnobotanical studies in Mexico have emphasized collecting information on use of plants; therefore, since the 1990s our research has emphasized studying cultural, ecological, and evolutionary aspects related to plant management. We have documented the diversity of plant management forms in forests (silviculture), agricultural systems (horticulture and agriculture), agroforestry systems (agro-silviculture), and livestock-raising systems (plant management associated with pastoralism, free raising of goats and cattle, and agro-silvo-pastoralism). These studies look for understanding the different management techniques and the social and ecological factors motivating and influencing the way the management practices are. More particularly, how the need to ensure the availability of desirable products, esthetic purposes, curiosity, and other factors move people's inventiveness, their interest in innovation, how they transmit their experiences to others, and how they adopt techniques developed by others. We are especially interested in understanding why and how these mechanisms enhance decision-making, as well as the consequences of management and domestication on different sociocultural, ecological, and evolutionary aspects. These are topics that could help to analyze how domestication and food production started and changed the human ways of life and, also, to the understanding of current processes of technological innovation, adoption, and diffusion in traditional rural contexts.

After the "Origins of Species" (Darwin 1859), by the end of the nineteenth and throughout the twentieth centuries, several studies explored the areas of origin of domestication. Among the most outstanding works are those by De Candolle (1882) and Vavilov (1992), who collected information from botanical, geographical, anthropological, linguistic, ecological, and genetic fields to suggest some regions of the world that were supposed to be the areas of origin of cultivated plants. The regions proposed were valuable hypotheses that led archaeologists to investigate remains to test the suppositions and to support information about the process of domestication of the most important crops. Then, after several classic archaeological and genetic studies appeared the proposals by Harlan (1975), Bruce Smith (1989, 2006), Zeder (2008, 2011, 2012, 2015, 2017), and other scholars that have had important dissertations about the origins and causes of domestication of plants and animals, which are still in debate, particularly about the questions of where, when, how, and why management and domestication started and developed. Periods of scarcity of resources associated with climate change or demographic growth of humans determining pressures on ecosystems are among some of the explanations, while for other authors environmental pressures and technological innovation should be integrally analyzed (Flannery 1986; Harris and Hillman 1989; Harris 1996).

The research groups of the authors of this chapter consider that both management and domestication of plants are ongoing processes and, therefore, studying and understanding them provide elements to analyze the past, with reasonable bases for the interpretation of archaeological data. Looking for answers to the general questions referred to in the previous paragraph has, therefore, theoretical value, particularly in relation to how knowledge, management, and domestication of plants interact with social-cultural needs and the ecological conditions of the organisms used to satisfy them, as well as in relation to evolutionary-ecology issues. Management and domestication of plants and the systems where these are performed progressively configured a valuable biocultural heritage of the Mexican cultures from both Mesoamerican and Aridoamerican regions. This heritage is now a valuable experience to contribute to construct a general repertoire and catalogue of management techniques that are highly important to understand the past, but, at present, to construct strategies of sustainable management that several sectors of Mexico are interested in.

Our research groups have conducted studies in more than 150 communities (see Appendix 1, Fig. 1) of Ch'ol, Cuicatec, Ixcatec, Lacandon, Mazatec, Mixtec, Mayan groups, Mazahua, Nahua, Popoloca, P'urhépecha, Rarámuri, Huastec or Teenek, Tlapanec, Tlahuica, Zapotec, and mestizo people in different regions of México (Fig. 1, see Caballero 1994; Caballero and Mapes 1985; Caballero et al. 1998; Caballero and Cortés 2001; Mapes et al. 1981, 1996, 1997; Casas et al. 1994, 2001, 2007, 2014, 2017; Pérez-Negrón and Casas 2007; Camou-Guerrero et al. 2008; Lira et al. 2009; Blancas et al. 2010, 2013; Cano et al. 2012; Torres 2004; Torres-García et al. 2013, 2015a, b, 2019, 2020; Martínez-Ballesté et al. 2005, 2006; Bunge-Vivier and Martínez-Ballesté 2017; Cuevas et al. 2021; Lotero-Velásquez et al. 2022; Farfán et al. 2007, 2018a, b; Ubiergo-Corvalán et al. 2019, 2020, 2021).

Fig. 1 Regions of Mexico where the more than 150 rural communities studied by our research groups are located. From north to south, Peninsula of Baja California, Sierra Tarahumara, Cuatrociénegas Valley, Huasteca, Northern Sierra of Puebla, Mountains of Northern Michoacán, Morelia Region, Monarch Butterfly Biosphere Reserve, Pátzcuaro Lake Basin, Tierra Caliente of Michoacán, Highlands of the state of Morelos, Balsas River Basin of the state of Morelos and Guerrero, Mountain of Guerrero, Tehuacán-Cuicatlán Valley, Central Valleys of Oaxaca, Highlands of Chiapas, and Yucatán Peninsula. See details in Appendix 1

We have promoted similar research with colleagues of the Andean region (Velásquez-Milla et al. 2011; Torres-Guevara et al. 2019; Pancorbo et al. 2020; Parra-Rondinel et al. 2021) and the Brazilian lowlands, especially the Caatinga (Lucena et al. 2014, 2016, 2017; Lins Neto et al. 2014; Trindade et al. 2015; Lima-Nascimento et al. 2021), Amazonia, and Mata Atlantica (Clement et al. 2021). One of the first attempts to show systematized ethnobotanical information on use and management in these regions was recently published (Clement et al. 2021). To achieve it, we put in practice a process of interaction involving conceptual and methodological interchange, looking for constructing databases with similar format compatible for further analyses and comparisons. In this process, we also started to include the information available for the neighboring Mesoamerican region of Central America. These activities are configuring a new stage in the systematization process that will require several years of effort while local and regional studies must continue, especially in those cultural and ecological areas with scarce or no studies available.

Research Strategy

BADEPLAM

The initiative of constructing BADEPLAM started in 1982 as part of an institutional project at the Botanical Garden of the Institute of Biology, UNAM. The work was initiated by designing the format of the database in a time when the technological tools for storing information were still limited and the personal computers were restricted. In fact, the earliest systems established failed to recover the stored information, and the format and storing system had to change from time to time. It was until the 1990s when BADEPLAM became more operative and dynamic for storing and providing services. In the first stage of construction, BADEPLAM had the name of Banco de Información Etnobotánica sobre Recursos Genéticos (BIERGEN). It was part of an ambitious project to integrate the Botanical Garden at UNAM as part of a research unit called Unidad de Recursos Genéticos (UNIRGEN), which was conceived and enhanced by Dr. José Sarukhán, who was the director of the Institute of Biology, and who some years later founded the National Commission for the Knowledge and Use of Biodiversity (CONABIO), the most important governmental institution in Mexico systematizing information on biodiversity.

The project UNIRGEN started with the collaboration of several scholars, and BIERGEN was the main responsibility of the first author of this chapter (Javier Caballero). UNIRGEN aspired to carry out multidisciplinary work, in which ethnobotany was considered to be the direct source of information from the field about genetic resources for food and other purposes, emphasizing the documentation of information about management and domestication by different ethnic groups of Mexico. The project aspired to know the diversity of genetic resources, mainly used as food, and identify some of them with high potential to attend problems in Mexico. The general team of UNIRGEN included ethnobotanists, geneticists, taxonomists, and plant physiologists specialized in in vitro propagation (Caballero 1984; Caballero et al. 1985).

The starting group of ethnobotanists was formed by Cristina Mapes, José Arellano, Javier Caballero, and Robert Bye, who conducted regional studies in the Isthmus of Tehuantepec, Oaxaca, the P'urhépecha region of Michoacán, the Yucatán Peninsula, and the Sierra Tarahumara, respectively. Later, Carmen Vázquez, Juan Luis Viveros, and Alejandro Casas were included in the team, investigating in different areas of the Balsas River Basin region and then in the Tehuacán-Cuicatlán Valley. In addition, the group of Miguel Angel Martínez-Alfaro, Francisco Basurto, and Alberto Villa in the Sierra Norte of the state of Puebla. Their regional approach included fieldwork, bibliographic compilation of inventories of useful plants, as well as studies on some plant groups (Amaranthaceae, Arecaceae, Fabaceae, and Solanaceae, among others) which were followed more deeply by collecting information from herbarium specimens at MEXU.

The database was designed and coordinated by Javier Caballero and implemented by a mathematician (Juan Antonio Toledo), and a biologist (Laura Cortés), who captured and curated the entries of information. Juan Toledo elaborated an algorithm in algol language, which allowed the following: (1) loading all programs to manage the database, (2) uniting text files captured in a PC for “5/4 floppy disks” which were then carried to a terminal of the supercomputer Burroughs B-7800, and (3) storing the files in magnetic tapes for later use through the database program. The ethnobotanical information was coded, and a dictionary of translated information was used.

Such complex systems and processes made it difficult to manage the database and obtain results. The database included different fields which were discussed and carefully selected by the team of ethnobotanists. The information systematized included taxonomic information (plant family, species, subspecies, and other intraspecific categories), ecological information of the specimens recorded (location, vegetation type, elevation, climate, and soil), and the use and management types, among the most important.

In the 1990s, each field of information was reconsidered, which allowed decreasing the previous huge structure of the database, adjusting it to the real information captured until that time, when information of important ethnobotanical works was already collected. Among the studies whose information was then captured, we counted those by Alcorn (1984) with the Huastec, Berlin, Breedlove, and Raven (1974) with the Tzeltal, several works by Maximino Martínez for the whole country (Martínez 1959, 1979, 1989), Felger and Moser (1985) with the Seri, Barrera-Marín et al. (1976) with the Maya, Pennington (1963) and Bye (1976) with the Tarahumara, and Pennington (1969) with the Tepehuan, among others, as well as information of useful species of the families Fabaceae, Arecaceae, and Amaranthaceae, among others. Also, several theses by students and collaborators of the project, and other unpublished works. Another important decision was to change the name BIERGEN into Base de Datos Etnobotánicos de Plantas Mexicanas (BADEPLAM).

BADEPLAM is an application created and developed by Laura Cortés in Access 2016 Microsoft, Office. At present it has 59,487 records, from a total of 361 bibliographic sources of information, as well as information from herbaria and data from field studies by our research groups and others. It is a database with good curatorial work, with tables of relational reference which complement and help to minimize capture errors. There is in addition a good collection of works that are being captured. An aspect in progress is the restructuring of BADEPLAM according to international standards. Although it is important to maintain an original version of the information captured, it is continually necessary adjusting and updating taxonomic nomenclature and content of the information fields, which should be widely reviewed by ethnobotanists, taxonomists, geographers, and anthropologists with experience in bioinformatics. But importantly, the changes should not increase the basic structure of BADEPLAM but adjust some pertinent underlying concepts in the information fields.

BADEPLAM is currently coordinated by Dr. Andrea Martínez-Ballesté who is also responsible of managing and using the information. The use has lacked specific operative rules, but these should be constructed in the near future to prevent misuse and misappropriation of information.

BADEPLAM was a pioneer project in biodiversity informatics, with the vision of being a source of valuable information on nontimber forest products for academic and conservation programs. The experience has been adopted by several research groups, some of them have allowed the correct compatibility to feed the main database and strengthen its capacities, and this should be a process to enhance ahead.

Field Studies

Our field studies have included regional and communitarian scales, including three main dimensions: one of them sociocultural, in which the main approach is ethnobiology and ethnobotany. It has been directed to inventory and document cultural information on plants, their economic value, and mechanisms of interchange at local and regional levels, the regulations existing in communities, municipalities, and regions, among other topics. The second dimension is ecological. In part, but not only we have analyzed the consequences of management on individuals, populations, biotic communities, and ecosystems; but we also have studied the influence of these aspects on the decision of people to manage populations, communities, and ecosystems. The third dimension is directed to analyze evolutionary processes associated with management, including domestication (Fig. 2).

The ethnobiological studies look for understanding the cultural bases of use and management of plants, and we aspire to complement them with social research on institutions regulating access to resources; these regulations and commercialization of products in markets reflect the importance of resources to people.

Ecological studies have had in principle the purpose of documenting the distribution and abundance of the most important plant resources, their diversity, biomass, and spatial and seasonal availability (Pérez-Negrón and Casas 2007; Blancas et al. 2013; Rangel-Landa et al. 2016). This information diagnosed in the vegetation types and anthropogenic areas of communitarian territories allows identifying possible use

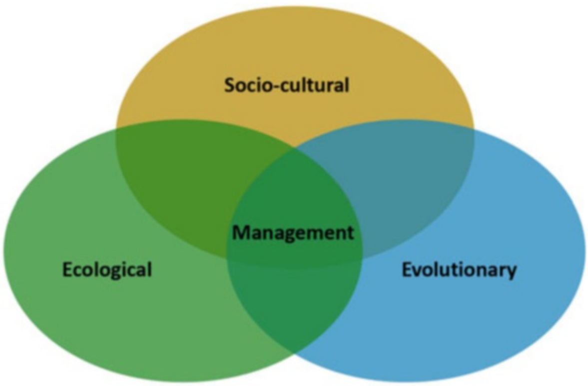

Fig. 2 Processes studied by our research groups. In the intersection of these processes, the management of plants is a main issue of our research, which expresses knowledge, practices, and worldviews of people on plants they interact with. Management is influenced by the sociocultural context, including social and economic relations, forms of social organization and regulations constructed about the interactions among households and other communities and among these social units and the environment, and the technological aspects available for the interaction, among other relevant issues. In addition, management is markedly influenced by the contexts of ecosystems where it occurs, and in turn the management influences and drives changes in ecosystems, their components, and functions. Management influences evolutionary processes through domestication, which in turn is influenced by the natural evolutionary processes occurring in plant populations

patterns that may endanger the permanence of particular plant populations. But in addition, it allows documenting the ecological complementarity of the environmental units in people's subsistence (Lotero-Velásquez et al. 2022). Also, ecological studies allow identifying the biotic interactions (pollinators, seed dispersers, facilitation, and other mutualist interactions) that should be maintained when planning use of forest products (Casas et al. 1999; Otero-Arnaiz et al. 2003; Torres-García et al. 2013, 2015a; León-Jacinto and Torres 2015; Rangel-Landa et al. 2015; Cuevas et al. 2021). Therefore, ecological studies together with ethnobotanical information allow constructing proposals on sustainable management at the community assemblages in territories.

Another important approach developed by our research groups has been conducted at the population level. We have worked with populations of species particularly endangered or that may be endangered due to human activities. From this perspective, we have studied species of palms (*Sabal* spp. and *Brahea dulcis* (Kunth) Mart.; Martínez-Ballesté et al. 2005, 2006, 2008; Martínez-Ballesté and Martorell 2015; Martínez-Ballesté and Caballero 2016; Pulido and Caballero 2006; Rangel-Landa et al. 2014), several species of *Agave* (Torres-García et al. 2013, 2015a, 2019, 2020) mainly those extracted from forests to produce mescal, as well as some trees intensively used in some communities (*Ceiba aesculifolia* (Kunth) Britten & Baker f., by Arellanes et al. 2018) and *Bursera bipinnata* (Moc. & Sessé ex DC.) Engl. by Abad-Fitz et al. 2020). We are interested in documenting the effect of management on survival and reproduction of individuals that are under management and the populations they form part of. This information aspires to identify thresholds that are able to maintain or collapse the populations used and, therefore, develop ecological criteria to define sustainable rates of harvesting the useful products.

These studies allow identifying how ecological processes influence plant management and the impact of management on ecosystems (Blancas et al. 2013). Through these studies, we explore hypotheses related to the influence of the scarcity or uncertain availability of resources of high cultural value on the people's decisions to manage them. But in addition, the information allows analyzing the conditions for sustainable management at population and community levels. From this approach, aspects such as life form, length of life cycle, part or parts used, the type of reproduction system, distribution, abundance, and phenology are all relevant issues.

The third dimension of our research is studying evolutionary processes associated with management: domestication, which involves adjustments in morphology and physiology of plants according to human purposes. Domesticates commonly diverge from wild and weedy plants, whose fitness is high in those environments while domesticates are successful in managed environments only through human assistance. Divergence between wild or weedy and the domesticates is not binary but may include a continuum of intermediate conditions, depending on the purposes of humans and the level of intensity of human selection (Casas et al. 1996, 1997, 2007). It is not unidirectional since multiple features, not only one, may motivate humans to practice selection. And complete domestication is not the unique destiny of management. In Mexico, hundreds of plants remain in a state of low divergence with respect to their wild or weedy relatives and may remain in that state for a long time since with that intensity of management and selection the desired actual sociocultural benefits are obtained.

At ecosystem level, we are particularly interested in how the management of populations or groups of populations influence changes at landscape level. And, in turn, how changes deliberately performed at landscape level influence changes of plant populations (Casas et al. 1997; Parra et al. 2015; Clement et al. 2021).

Ethnobotanical Diversity of Mexico

México harbors a high biocultural diversity, and this is especially expressed in the ethnobotanical knowledge. The Mexican territory is inhabited by Indigenous peoples representing diverse cultures that speak nearly 291 languages (Eberhard et al. 2022). According to Ethnologue 284 are Indigenous languages, 84 are developing, 74 are vigorous, 88 are in trouble, 44 are dying, and 6 languages are extinct (Eberhard et al. 2022). The existing languages are catalogued by the Instituto Nacional de Lenguas Indígenas (INALI 2008) in 68 linguistic groups, each one with different linguistic variants that totalize the 284 Indigenous languages referred to above. It has been estimated that after the European invasion and conquest, nearly one half of languages became extinct because of wars, diseases, and extermination of a high percentage of people living in this country. All those cultures were configured for thousands of years. The recent discoveries of Ardelean et al. (2020) in the Chiquihuite Cave at the state of Zacatecas reveal that humans have been present in the territory that currently is Mexico since about 25,000 and possibly around 30,000 years ago. The diversity of flora is also high, the inventory of the native vascular plants, according to Villaseñor (2016), is 23,314 species, and according to Toledo and Ordóñez (1993), the native and introduced flora occurring in Mexico is nearly 30,000 species. And this is the setting of biocultural processes that molded what ethnobotanists working in Mexico have documented since the early twentieth century.

The most recent information from BADEPLAM indicates that peoples of Mexico interact, know, use, and manage nearly 7823 plant species. This is an inventory documented among 32 of the 68 main linguistic groups of Mexico. Table 1 indicates the number of records by cultural group, which in turn indicates that nearly half of the cultural groups have been studied, some of them scarcely, and those with no ethnobotanical records would be one of the priorities to enhance studies about. Table 2 shows the number of ethnobotanical records by state, indicating that most studies have been conducted in the states of Puebla, Veracruz, Oaxaca, Chiapas, and others that are bioculturally diverse, whereas more efforts are required in the states of Querétaro, Colima, Baja California, and Zacatecas, among others. Similarly, Fig. 6 indicates tropical and temperate forests are the most studied vegetation types, whereas the xerophytic vegetation, grasslands, and cloud forests require more research effort.

Figures 3, 4, and 5 show a general panorama of the inventory of use types, plant families, and life forms providing more plant resources, respectively. Figure 6 shows

Table 1 Ethnic groups and the number of records about use and management of plants in BADEPLAM. (Records are the references found in the different sources of information, among them literature reference, collection number referred to in documents or herbarium specimens)

Ethnic group	Number of records
Maya	4356
Tarahumara	1918
Náhuatl	1824
Teenek	1572
Totonaco	1432
Mixteco	1144
Mayo (yoremes)	1084
Zoque	1046
Seri	1007
Zapoteco	892
Tzotzil	859
Otomí	847
Tzeltal	669
Chinanteco	484
Cuicateco	464
Ixcateco	372
Guarijío	324
Chontal (Tabasco)	309
Purépecha	284
Tepehuanes	258
Lacandón	181
Kikapú	168
Tepehuanes (Durango)	168
Mazateco	166
Mazahua	154
Mixe	138
Popoluca	111
Pápago	83
Huave	79
Chol	74
Pima	20
Cora	8
Huicholes	8
Mestizos (in Spanish)	35,378
Others	1606

the general panorama of vegetation types providing useful plant species. Figure 7 shows a panorama of the types of plant management recorded while Fig. 8 shows the panorama of the types of interaction in the main groups of plants under management: edible and medicinal plants.

However, information from regional studies suggests that the inventory in BADEPLAM could be substantially increased, especially when the total flora is compared with the flora reported with use. For instance, in the Tehuacán-

Table 2 Number of records about use and management of plants per state in BADEPLAM. (Records are the references found in the different sources of information (literature reference, collection number referred to in documents or herbarium specimens))

State	Number of records
Puebla	10,575
Veracruz	4848
Oaxaca	4544
Chiapas	3332
Nuevo León	3025
Quintana Roo	2622
Morelos	2621
Chihuahua	2530
Guerrero	2374
Sonora	2305
Yucatán	2186
San Luis Potosí	1914
México City	1745
Hidalgo	1676
Michoacán	1597
Tabasco	1549
State of México	1463
Tamaulipas	1381
Guanajuato	905
Coahuila	826
Sinaloa	782
Aguascalientes	617
Nayarit	582
Campeche	474
Jalisco	425
Durango	382
Tlaxcala	305
Zacatecas	248
Baja California	163
Baja California Sur	156
Colima	154
Querétaro	79
Total	58,385

Cuicatlán Valley we have found that while the total flora is about 3000 plant species, the useful plants is nearly 2000 plant species (Casas et al. 2017), which is nearly 60% of the whole flora. Similar comparisons in other regions allow estimating that on average about 38.9% of the plant species in a region may be expected to have one or more uses (Table 3). This cipher, compared with the general inventory of native vascular plant species in Mexico, and 23,314 species according to Villaseñor (2016) would lead to expect 9069 useful native plant species. However, considering both native and introduced species, according to Toledo and Ordóñez (1993) nearly 30,000 plant species, in Mexico, the

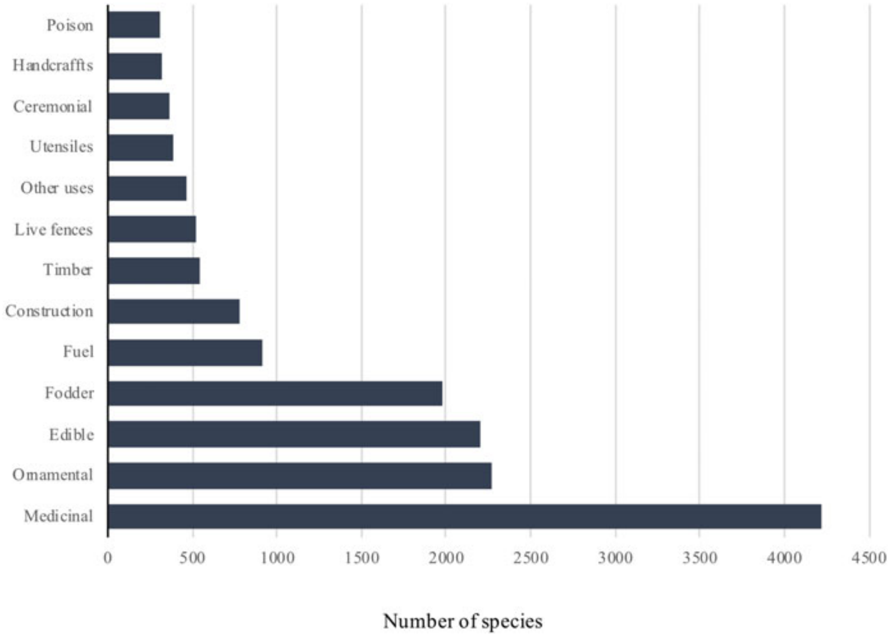

Fig. 3 Number of plant species used with different purposes by the different cultures of Mexico according to the Base de Datos Etnobotánicos de Plantas Mexicanas BADEPLAM of the Botanical Garden, Institute of Biology, UNAM

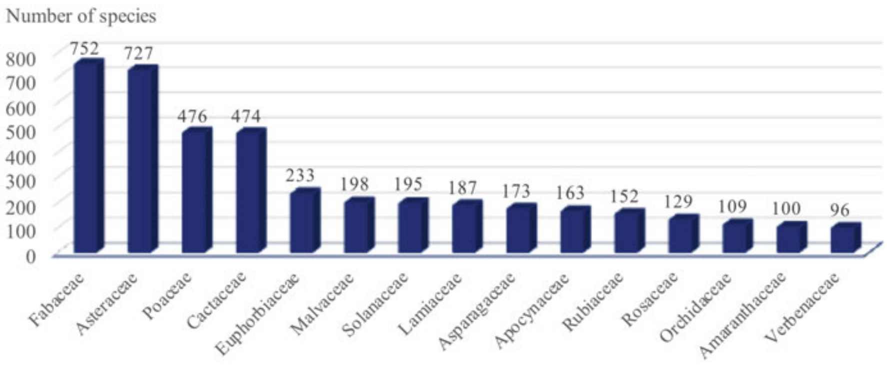

Fig. 4 The plant families providing more useful species in Mexico, according to BADEPLAM

estimation allows expecting 11,670 useful plant species, native and non-native, disseminated throughout the Mexican territory.

Through another approach, based on the number of species accumulated in the sources consulted for constructing BADEPLAM, and projecting the number of species that could potentially be included in the database, the curve of Fig. 9 was

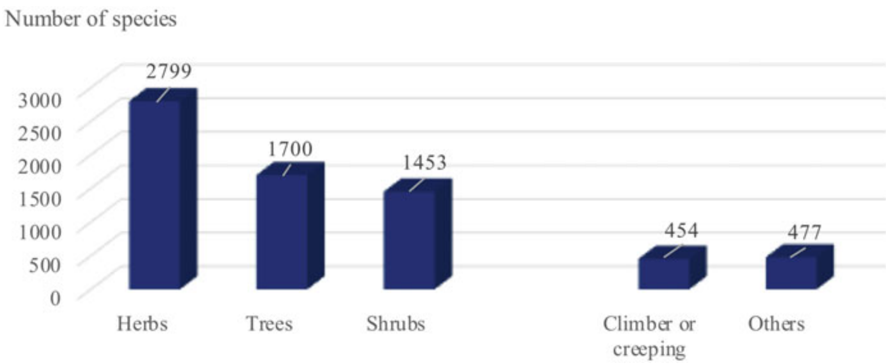

Fig. 5 Life forms of the plant species used in Mexico by peoples of different cultures according to the Base de Datos Etnobotánicos de México BADEPLAM of the Botanical Garden, Institute of Biology, UNAM

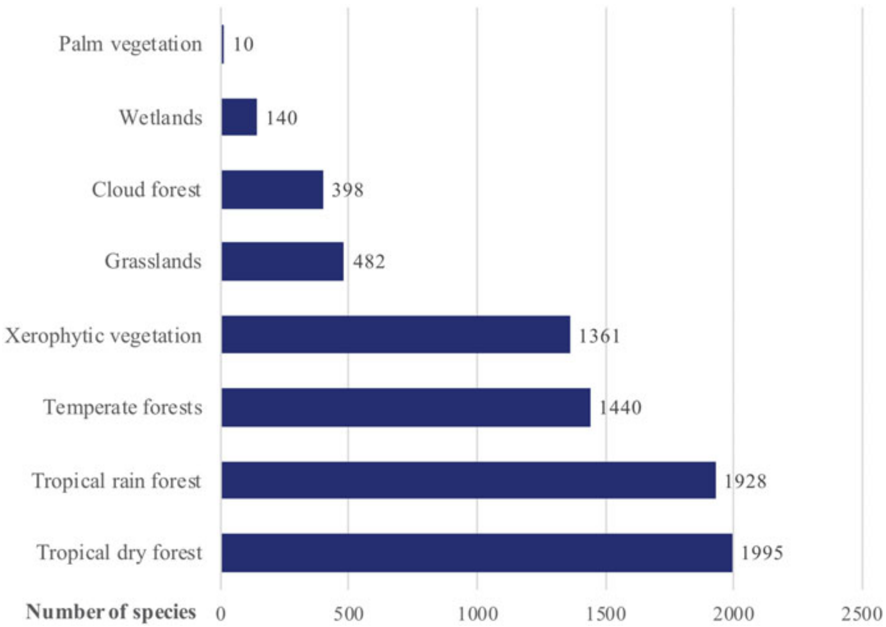

Fig. 6 Vegetation types providing the highest richness of useful plants

obtained. This approach suggests that the number of useful species in Mexico could be about 11,500, a number similar to the estimation referred to above, which is reasonable since BADEPLAM stores information on native and non-native species.

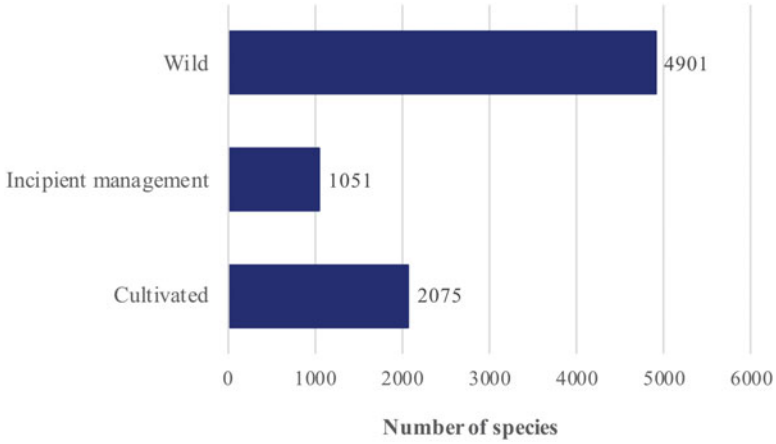

Fig. 7 Number of species under different management types. The category incipient-management includes 570 species tolerated or let standing, 417 plant species promoted or enhanced, and 186 species under special protection by local people, according to the management categories by BADEPLAM

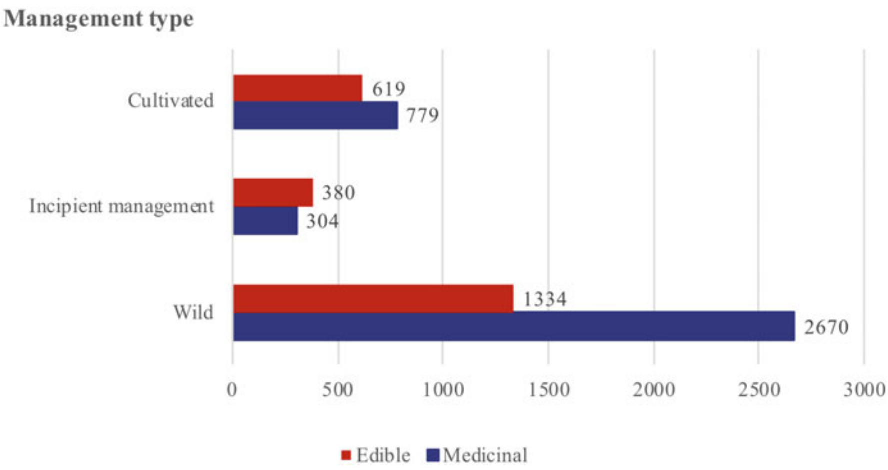

Fig. 8 Number of medicinal and edible species that are collected in the wild, managed incipiently, and those that are cultivated. (Information from the Base de Datos Etnobotánicos de Plantas Mexicanas BADEPLAM of the Botanical Garden at the Instituto de Biología, UNAM)

Diversity of Management Forms

Different authors have proposed that food production like horticulture, agriculture, and pastoralism arose as strategies to decrease uncertainty in the availability of food and other products (Flannery 1986; Harris 1996). However, for thousands of years,

Table 3 Total number of plant species recorded in different regions of Mexico, compared with the general plant species richness recorded in those regions

Region	Total spp.	Useful spp.	%
Tehuacán-Cuicatlán Valley[a]	>3000	>2000	66.7
Sierra de Manantlán[b,c]	2983	650	21.8
Sierra Norte de Puebla[d]	1730	720	41.6
Selva Lacandona[e]	1660	415	24.9
Los Tuxtlas[f]	2697	730	27.1
Tuxtepec[e]	737	296	40.2
Uxpanapa[e]	800	336	40.6
Península de Yucatán[g]	2900	1000	23.4
Sian Ka'an[e]	558	316	56.6
Montaña de Guerrero[h]	800	430	53.8
Huastec region[i]	1113	445	40.0
Sierra Huichola[a]	1652	532	32.2
Sierra del Abra Tanchipa[j]	427	116	27.2
Sierra de Huautla[k]	1018	649	63.8
Tierra Caliente de Michoacán[l]	2634	616	23.4
Average (%)			**38.9**
Mexico (native)	**23,314**	**9139**	
Mexico (native and introduced)	**30,000**	**11,760**	

[a]Based on Casas et al. (2017, updated in this study); [b]Santana-Michel and CONABIO (2021); [c]Benz et al. (1994); [d]Martínez-Alfaro et al. (1995); [e]Toledo et al. (1995); [f]CONANP/SEMARNAT (2006); [g]Flores (1999); [h]Casas et al. (1994); [i]Alcorn (1984); [j]De-Nova et al. (2019); [k]Blancas et al. (chapter "▶ Ethnobotanical Knowledge and the Patterns of Plant Use and Management in the Sierra de Huautla Biosphere Reserve and the Chichinautzin Biological Corridor in Morelos, Mexico"); [l]Rangel-Landa et al. (chapter "▶ Traditional Ecological Knowledge and Biodiversity Conservation in the Tierra Caliente Region of Michoacán").

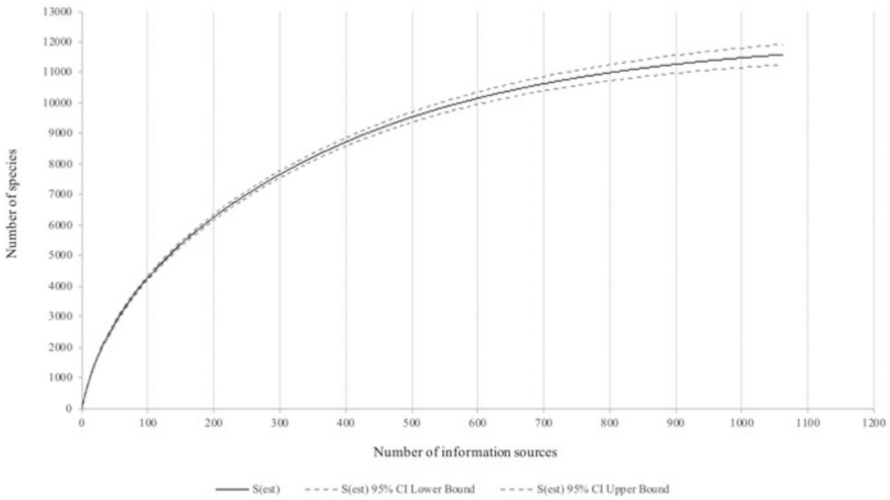

Fig. 9 Estimation of the useful flora of Mexico based on the cumulative records of information sources and its projection. (According to data from BADEPLAM)

and even at present, the rural communities continue practicing gathering and extraction of forest products, including gathering of plants, hunting, and fishing together with agriculture livestock and horticulture in homegardens and other systems. Gathering, according to Casas et al. (1996, 1997), González-Insuasti and Caballero (2007), Blancas et al. (2010), Rangel-Landa et al. (2016), and Farfán et al. (2018a, b) may vary in complexity in the management strategies, differential investment of energy, complexity of tools, social agreements, and involving human selection with different levels of intensity and other evolutionary forces associated to management. It may be systematic, circumstantial, at random or following a plan, manual or involving tools and machines, generalist, or selective. For all these reasons, gathering should be considered a form of management.

Currently, numerous plant resources are under management forms that are neither gathering nor agriculture, and that we have considered as "incipient" since they are less complex than agriculture (Casas et al. 1996, 1997, 2007, 2017; Clement et al. 2021). Among these management forms, the strategies of systematic, planned, and selective forms of gathering should be included, also, the tolerance of desirable plants when disturbing forests or when practicing weeding. It is also the case of induction or enhancement of abundance of desirable plants by sowing seeds, plating their vegetative propagules, or transplanting complete individuals, and also, the cases of plants protected through special ways to ensure their survival and reproduction as referred to above, including those from the wild, introduced deliberately to anthropogenic areas.

All these forms of management are under different levels of intensity, and such intensity is related to the balance between the cultural and/or economic value, on the one hand, and their availability, on the other, which is commonly influenced by distribution, abundance, seasonal availability of products, vulnerability before interannual climate changes, pests, and natural or human-caused catastrophes, among other ecological aspects (Blancas et al. 2010, 2013; Rangel-Landa et al. 2016, 2017; Farfán et al. 2018a, b). Also, these are related to the resilience of individuals, communities, and ecosystems affected by human actions to use their products, depending on the plant part used and other biological aspects of the plants related to life cycle duration, reproductive systems, among others. Considering all these variables, it is possible to appreciate that plants used and managed by humans are under a continuous gradient of cultural/economic motivation of use, and ecological/biological aspects determining risk to ensure the availability of their products. Therefore, the management intensity is also expected to have a continuous expression of states.

Through studies in different communities of the Tehuacán-Cuicatlán Valley (González-Insuasti and Caballero 2007; González-Insuasti et al. 2008, 2011; Blancas et al. 2013; Larios et al. 2013; Rangel-Landa et al. 2016, 2017), we analyzed the spectrum of forms and intensity of management of plants, mainly edible and ornamental plants in different rural communities. These studies show the broad spectrum of conditions of risk to ensure their availability, their relation to multiple ecological and social factors, and the responses to such risk. Likewise, the high relationship between risk conditions through the intensity of driving is highlighted.

Diversity of Domestication Processes

Domestication is a consequence of management. Not all plants managed are domesticated nor eventually become domesticated, but all domesticated plants involve management. Through domestication, humans adjust forms, functions, and behavior of organisms according to human context (material and immaterial needs, values, esthetic purposes, and curiosities). Among the most important needs are food, most domesticated plants are edible, and humans select favoring quantity (e.g., number, size) and quality (flavor, color, texture, general aspect, and qualities associated with preparation, among others) of the edible products. However, a number of medicinal, ornamental and aromatic plants have been domesticated in Mexico. Most commonly, humans select in favor of several attributes of one or several plant traits, the processes producing a high diversification of the domesticated species. In addition to selection, people may drive gene flow and manipulate the reproduction system of plants and determine contexts for the propitious action of other evolutionary forces like inbreeding and genetic drift in small populations, bottleneck, and founder effects. The mechanisms and criteria associated with domestication are profusely linked to human culture; therefore, domestication is a biocultural expression. It is therefore important to document in studies of domestication the diversity of life forms of organisms under domestication, the diversity of attributes that people distinguish and value, and the diversity of mechanisms through which phenotypes are favored or unfavored and the action of other evolutionary forces.

Domestication is an evolutionary process and therefore involves diversification. Darwin (1859) analyzed this process and adopted it in the first chapter of the “Origins of species” as a model to explain the origin of species in nature though developing the concept of natural selection. Domestication maintains and continually develops new varieties and in addition includes variation developed in different biocultural contexts through interchange of techniques, seeds and other propagules. It is a continuous process and therefore currently observable, which offers the possibility to document how it operates and provides to evolutionary biology and archaeology bases for interpreting what has happened in the natural evolutionary processes and ancient human-guided domestication. Through documenting domestication, it has been possible to describe and the broad spectrum of forms of plant management and ways through which human selection operates. This information is extraordinarily helpful to establish bases for sustainable management of genetic resources, particularly, to design strategies of in situ conservation.

We have hypothesized that higher management intensity has caused higher divergence between managed and unmanaged organisms. Therefore, the silvicultural management is expected to determine lower differentiation with respect to wild populations than horticultural or agricultural management. For testing such hypotheses, we conducted several case studies. In all cases, we documented how variation in populations is perceived by people, how they value the variations and if they manage it differently. Ethnobotanical studies make possible documenting these aspects, as well as the mechanisms through which such variation is managed. The next step is evaluating the divergences (morphological, physiological, reproductive, and genetic) and to test or reject the hypothesis. And we have analyzed all these aspects in annual plants, including some quelites like quintoniles *Amaranthus* spp. (Mapes et al. 1996, 1997), "alaches" (*Anoda cristata* (L.) Schltdl.), "chipiles" (*Crotalaria pumila* Ortega), some trees like "guajes" (*Leucaena esculenta* (Moc. & Sessé ex DC.) Benth; Casas et al. 1997, 2007; Casas and Caballero 1996; Zárate et al. 2005), tempesquistle (*Sideroxylon palmeri* (Rose) T.D.Penn.; González-Soberanis and Casas 2004), and *Ceiba aesculifolia* (Kunth) Britten & Baker f. (Avendaño et al. 2006, 2009; Arellanes et al. 2013, 2018), which are widely appreciated and commercialized in the Tehuacán Valley and Oaxaca. All these trees are important since remains of them were found by archaeologists associated with humans in strata from prehistoric times of the Tehuacán Valley (Smith 1967).

Other important trees that we have studied are the gourd trees *Crescentia alata* Kunth and *C. cujete* L. (Aguirre-Dugua et al. 2012, 2013, 2018) and the guava *Psidium guajava* L. (Arévalo-Marín et al. 2021). These and some columnar cacti species of the genus *Stenocereus* have allowed exploring questions related to the origin and diffusion of their domestication. We have found that *C. alata* appears to be native to Mexico, and its domestication has occurred in several areas of the territory. *C. cujete* has both native and introduced populations, but those with the clearest signs of domestication are genetically differentiated from the native populations, even where they coexist. We have not identified the area where these genotypes originated, but we have hypothesized that most probably such an area is in Central America, somewhere in Honduras or Nicaragua (Aguirre-Dugua et al. 2012, 2018; Moreira et al. 2017). The case of guava is a different story. Phylogenetic studies suggest that the genus *Psidium* originated and diversified in South America, and *Psidium guajava* is also from South America. It is a species with life history traits that make it able to spread and colonize wide areas. Arévalo-Marín et al. (2021) hypothesized several scenarios of its origin and diffusion, and one of the most probable is that the species arrived to Mexico thousands of years before the occupation of the territory by humans. However, the archaeological evidence indicates that the oldest remains are in South America, and its presence in Mesoamerica is relatively late. There are still several questions that are analyzed to clarify events of diffusion and domestications, and as in the cases of *Crescentia*, the phylogeographic approaches are particularly helpful. It is early to arrive at conclusions about this story, but the methodological approaches provided by molecular genetics, ecology, ethnohistory, and archaeology are keystones to reconstruct the natural and biocultural history of these species. The case of *Stenocereus* involved the analysis of a complex of related species grouped in the *Stenocereus griseus* (Haw.) Buxb. complex. Our study started exploring the origin and diffusion of S. *pruinosus* (Otto ex Pfeiff.) Buxb, a clearly domesticated species in central Mexico but with a wide distribution in Mexico. We soon found that what was identified as *Stenocereus pruinosus* were several species, including *S. griseus*. However, after a first step of our research we found that *S. griseus* is a South American species and that what was considered to be this species in Mexico was a well-differentiated new species, which was named *Stenocereus huastecorum* Alvarado-Sizzo, Arreola-Nava, and Terrazas (2018).

We have centered our attention in two additional systems: agaves and columnar cacti. In the case of agaves, we have documented the forest management of several wild populations (*Agave potatorum* Zucc., *A. cupreata* Trel. & A. Berger, and *A. inaequidens* K. Koch, *A. angustifolia* Haw.; Casarrubias-Hernández 2019; Delgado-Lemus et al. 2014; Illsley et al. 2018; Torres-García et al. 2013, 2015a, b, 2020) and states and changes associated to domestication in some of them and others (*Agave inaequidens*, *A. hookeri* Jacobi, *A. salmiana* Otto ex Salm-Dyck, *A. mapisaga* Trel., and *A. americana*; L. Colunga-GarcíaMarín et al. 2017; Figueredo-Urbina et al. 2017, 2018; Álvarez-Ríos et al. 2020).

Studies of forest management have included the documentation of current rates of extraction, the effect of demand on it, and the effect of it on population dynamics and population genetics. In all cases, we have identified that the increasing demand of mescal has caused the extirpation of numerous populations of the target species. The extraction of adult individuals occurs just before producing flowers which cancel the sexual reproduction, the only form of reproduction in part of the species studied (*A. potatorum*, *A. cupreata*, and *A. inaequidens*). This fact directly affects the recovering capacity of the populations, which become extirpated progressively as the remaining individuals reach the extraction stage (Torres-García et al. 2015a, 2019). Some individuals escape to the extraction, but there is an effect density-dependent influencing the visits of bats to flowers to cause pollination. Several studies have identified that at least 30% of individuals at reproductive stage should be maintained in a population to allow pollinators visiting flowers; below such threshold, bats rarely visit a population (Torres-García et al. 2013). Species that produce vegetative propagules are able to recover their populations but reducing genetic diversity and therefore increasing their vulnerability to several factors. Several demographic models developed by our research group have identified the stages whose maintenance and growth are crucial for ensuring an appropriate growth population rate. These aspects may vary from population to population and among species. But proposals for actions have been possible. In all cases, ensuring pollination is crucial for preventing loss of genetic diversity, and in some species like *Agave potatorum* facilitation interactions with some species of shrubs are equally important to ensure the establishing of seedlings (Rangel-Landa et al. 2015). Studies on domestication were conducted documenting morphological, genetic, and phytochemical (saponin content) divergence between wild and domesticated populations, as specified for the general research strategy. In the case of *Agave hookeri*, the wild relative is unknown, but we performed a comparison with wild and domesticated populations of *A. inaequidens*, which has been proposed to be the wild relative (Figueredo-Urbina et al. 2015, 2017, 2018). In the case of *A. americana*, the study is still in progress, the wild subspecies (*A. americana* subsp. *protoamericana*) is being compared with the domesticated subspecies (*A. americana* subsp. *americana*), and divergences between varieties of the latter subspecies are being analyzed. Something similar was performed with varieties of *A. salmiana*, *A. americana,* and *A. mapisaga* whose varieties are managed together, some of them possibly being hybrids (Álvarez-Ríos et al. 2020).

The system that has been studied with more detail is that of the columnar cacti, which are important plant resources in several regions of Mexico. This system allows analyzing in one region several species in a gradient of management intensity. We have characterized such intensity in relation to the energy invested in managing plant populations versus the productivity of the managed system. This balance is influenced by the viability of management, which is very much influenced by the growth rate of the plants and the viability of managing vegetative propagules. Species like *Escontria chiotilla* (F.A.C. Weber ex K. Schum.) Rose and *Polaskia chende* (Rol.-Goss) (A.C. Gibson & K.E. Horak) have slow growth and are difficult to cultivate; others like *Cephalocereus tetetzo* (F.A.C. Weber ex J.M. Coult.) Diguet and *Pachycereus weberi* (J.K. Coult.) (Backeb) produce tasty fruits, seeds, and flower buds very much appreciated by people, but their growth is even slower than *E. chiotilla*. These species are let standing, protected, or transplanted (young plants) in agroforestry systems. Other species like *Stenocereus pruinosus, S. stellatus* Riccob., *Lemaireocereus hollianus* (F.A.C. Weber ex J.M. Coult.), and Britton & Rose are intensively cultivated in homegardens, live fences, and borders of agricultural plots. These species grow faster, and selection is easier than in the other species mentioned, and they show clear signs of domestication (Casas et al. 2007; Parra et al. 2010; Rodríguez-Arévalo et al. 2006).

Studies of population genetics through neutral markers have showed that genetic differences among populations with different management are difficult to be visualized. Further studies with markers associated to traits could be more informative in this respect. For the moment, it has been found that silvicultural managed and cultivated populations have less genetic variation than wild populations, a pattern generally expected. However, in cultivated populations of *Stenocereus stellatus*, *S. pruinosus,* and in some cultivated agaves, we found higher genetic variation than in the wild. This is an interesting pattern that we have discussed considering the high gene flow among wild and managed populations, as well as the active movement of propagules from different communities and regions, carried out by people. To analyze this pattern, we have explored the provenance of materials from silvicultural managed and cultivated populations through interviews and molecular markers (Parra et al. 2010, 2012; Cruse-Sanders et al. 2013); this information allows identifying wild and managed populations that are sources of cultivated material within the territory of a community or among regions (the Tehuacan Valley and La Mixteca Baja region). These data illustrate the great capacity of traditional people to continually introduce and replace diversity in their management systems, and their crucial role in conserving and increasing the diversity these contain.

Perspectives

Our studies have documented different types of interactions between people and plants in Mexico. These interactions are motivated by the cultural value of the products used by people, as well as their ecological attributes and biological features that make viable or not their management. Use, management, and ecological knowledge are closely interconnected, and therefore their systematization is extraordinarily important to document the current state of biocultural diversity and for designing innovations based on what we currently know. In addition, these data and relations have high importance to construct and test hypotheses about the past processes that motivated people to manage plants.

Documenting and systematizing ethnobotanical knowledge continues to be an important task. This is especially necessary among human cultures and ecosystems poorly or not studied, as identified in this diagnosis. Field work efforts are important in relation to plant use, but studies of management require to be emphasized, especially in relation to factors motivating management, innovation techniques, and domestication. The current state of information allows visualizing that there are hundreds of case studies yet to be analyzed to understand the context and patterns of management and efforts to catalogue the management techniques.

It is important to mention that nowadays numerous scholars have worked in local or regional databases throughout the country, and the National Commission for the Knowledge and Use of Biodiversity (CONABIO) has enhanced an important project for systematizing the information on use and management of biodiversity. The effort by CONABIO dedicated to document and systematize information from a project on agrobiodiversity is outstanding. All these efforts spread throughout the country could be coordinated and shared. It requires leading institutions and clear rules to operate, but such a project is possible and necessary.

Analyzing ecological and evolutionary consequences of management is a relevant avenue of research, the first one to develop strategies of sustainable management of forest and agroforestry systems, the second to understand the evolution of managed plants, and both related with cultural and social changes associated with it. Morphometric, physiological, reproductive systems and population genetics are important tools to analyze them, and the new methods related to the genomic approaches are extraordinary opportunities to clarify the history of the processes. Now it is also relevant to consider the inter-scalar influence of domestication at population and landscape levels, and such influence should be studied in depth.

The collaboration of ethnobotanists using similar methods for studying different regions and cultural groups is relevant to produce comparable data to identify general biocultural patterns and contributing to construct theoretical frameworks. In addition, the complexity of the biocultural and social-ecological issues related to ethnobotany should enhance ethnobotanists to carry out interdisciplinary research, while the bridge that ethnobotanical research may construct between traditional ecological knowledge and the academy and other sectors indicates the extraordinary role ethnobotany may play to construct transdisciplinary approaches for constructing sustainability science.

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Appendix 1

Communities, regions, and cultural groups where our research groups have conducted studies, which are referred to in maps of Fig. 1.

Communities	Region	State	Municipality	Ethnic groups
Comondú	Baja California Península	Baja California Sur	Comondú	Mestizo
El Pescadero	Baja California Península	Baja California Sur	Los Cabos	Mestizo
La Purísima	Baja California Península	Baja California Sur	Comondú	Mestizo
Mulegé	Baja California Península	Baja California Sur	Mulegé	Mestizo
San Ignacio	Baja California Península	Baja California Sur	Mulegé	Mestizo
San Isidro	Baja California Península	Baja California Sur	Comondú	Mestizo
San Javier	Baja California Península	Baja California Sur	Comondú	Mestizo
Santa Gertrudis	Baja California Península	Baja California Sur	San Quintín	Mestizo
Todos Santos	Baja California Península	Baja California Sur	La Paz	Mestizo
Lacanjá Chansayab	Montes Azules	Chiapas	Bonampak	Lacandón
Tumbalá	North mountains	Chiapas	Tumbalá	Ch'ol
Ejido Cuiteco	Tarahumara mountains	Chihuahua	Urique	Raramuri
Antiguos Mineros del Norte	Cuatrociénegas Valley	Coahuila	Cuatrociénegas	Mestizo
Boquillas	Cuatrociénegas Valley	Coahuila	Cuatrociénegas	Mestizo
La Vega	Cuatrociénegas Valley	Coahuila	Cuatrociénegas	Mestizo
San Lorenzo	Cuatrociénegas Valley	Coahuila	Cuatrociénegas	Mestizo
Xichú	Sierra Gorda	Guanajuato	Xichú	Mestizo
Axaxacualco	Balsas basin	Guerrero	Eduardo Neri	Nahuatl

(continued)

Communities	Region	State	Municipality	Ethnic groups
San José Huitziltepec	Balsas basin	Guerrero	Eduardo Neri	Nahuatl
Acateyahualco	Mountain	Guerrero	Ahuacuotzingo	Náhuatl/ Mestizo
Agua Zarca	Mountain	Guerrero	Ahuacuotzingo	Náhuatl/ Mestizo
Alcozauca	Mountain	Guerrero	Alcozauca	Mixtec/Mestizo
Amapilca	Mountain	Guerrero	Alcozauca	Mixtec/Mestizo
Chilapa	Mountain	Guerrero	Chilapa	Náhuatl/ Mestizo
Copanatoyac	Mountain	Guerrero	Copanatoyac	Mixtec
Huamuxtitlán	Mountain	Guerrero	Huamuxtitlán	Náhuatl/ Mestizo
Ixcuinatoyac	Mountain	Guerrero	Alcozauca	Mixtec
Olinalá	Mountain	Guerrero	Olinalá	Náhuatl
San José Laguna	Mountain	Guerrero	Alcozauca	Mixtec
Tecolcuautla	Mountain	Guerrero	Ahuacuotzingo	Náhuatl
Tehuitzingo (Tlahuitzingo)	Mountain	Guerrero	Olinalá	Náhuatl
Tlapa	Mountain	Guerrero	Tlapa	Náhuatl, Mixtec, Tlapanec
Trapiche Viejo	Mountain	Guerrero	Chilapa	Náhuatl/ Mestizo
Xocoyolzintla	Mountain	Guerrero	Ahuacuotzingo	Náhuatl
San Miguel Xicalco	Southeast of Mexico City	Mexico city	Tlalpan	Mestizo
Cañada del Agua	Basin Cuitzeo	Michoacan	Indaparapeo	Mestizo
Pino Real	Basin Cuitzeo	Michoacan	Charo	Mestizo
Real de Otzumatlán	Basin Cuitzeo	Michoacan	Queréndaro	Mestizo
Rio de Parras	Basin Cuitzeo	Michoacan	Queréndaro	Mestizo
Cuanajo	Lake Patzcuaro region	Michoacan	Pátzcuaro	Purhepechas
Icuacato	Lake Patzcuaro region	Michoacan	Quiroga	Mestizo
Barranca del Aguacate	Lerma-Chapala region	Michoacan	Sahuayo	Mestizo
El Chocolate	Tierra Caliente region	Michoacan	Churumuco	Mestizo
Ichamio	Tierra Caliente region	Michoacan	La Huacana	Mestizo
Francisco Serrato	Zitacuaro region	Michoacan	Zitácuaro	Mazahua
Erongarícuaro	Lake Patzcuaro region	Michoacán	Erongarícuaro	Purhépecha
Zitácuaro	Monarca region	Michoacán	Zitácuaro	Mazahua/ Mestizo

(continued)

Communities	Region	State	Municipality	Ethnic groups
Undameo	Morelia	Michoacán	Morelia	Mestizo
Pichátaro	Purhépecha region	Michoacán	Pichátaro	Purhépecha
Infiernillo	Tierra Caliente region	Michoacán	Infiernillo	Mestizo
Pitirera	Tierra Caliente region	Michoacán	Infiernillo	Mestizo
Chalcatzingo	Balsas basin	Morelos	Jantetelco	Mestizo
Cuautla	Balsas basin	Morelos	Cuautla	Mestizo
Cuernavaca	Balsas basin	Morelos	Cuernavaca	Mestizo
Ejido Los Sauces	Balsas basin	Morelos	Tepalcingo	Mestizo
El Limón de Cuauhchichinola	Balsas basin	Morelos	Tepalcingo	Mestizo
El Zapote	Balsas basin	Morelos	Puente de Ixtla	Mestizo
Jojutla	Balsas basin	Morelos	Jojutla	Mestizo
Palpan de Baranda	Balsas basin	Morelos	Miacatlán	Mestizo
Tepalcingo	Balsas basin	Morelos	Tepalcingo	Mestizo
Tres Marías	Balsas basin	Morelos	Huitzilac	Nahuatl, Mestizo
Coajomulco	Highlands of the state of Morelos	Morelos	Huitzilac	Nahuatl, Mestizo
Huitzilac	Highlands of the state of Morelos	Morelos	Huitzilac	Nahuatl, Mestizo
Tepoztlán	Highlands of the state of Morelos	Morelos	Tepoztlán	Nahuatl, Mestizo
Tlayacapan	Highlands of the state of Morelos	Morelos	Tlayacapan	Nahuatl
Totolapan	Highlands of the state of Morelos	Morelos	Totolapan	Nahuatl
Cuilapam de Guerrero	Central Valleys of Oaxaca	Oaxaca	Cuilapam de Guerrero	Zapoteco-Mixteco-Mestizo
Coyula	Cuicatlán valley	Oaxaca	Cuicatlán	Cuicatec/ Mestizo
Cuicatlán	Cuicatlán valley	Oaxaca	Cuicatlán	Mestizo/ Cuicatec
Dominguillo	Cuicatlán valley	Oaxaca	Cuicatlán	Mestizo
Ixcatlán	Cuicatlán valley	Oaxaca	Ixcatlán	Ixcatec
Jocotipac	Cuicatlán valley	Oaxaca	Jocotipac	Mixtec
Nodón	Cuicatlán valley	Oaxaca	Cuicatlán	Mixtec
Quiotepec	Cuicatlán valley	Oaxaca	Cuicatlán	Mestizo/ Cuicatec
San Lorenzo Pápalo	Cuicatlán valley	Oaxaca	Cuicatlán	Cuicatec
Tecomavaca	Cuicatlán valley	Oaxaca	Tecomavaca	Nahuatl/ Mazatec/ Mestizo

(continued)

Communities	Region	State	Municipality	Ethnic groups
Santa Catalina Chinango	Low Mixteca	Oaxaca	Tequixtepec	Mixtec
Tequixtepec	Low Mixteca	Oaxaca	Tequixtepec	Mixtec
Tonaguia	Sierra de Juarez (north region)	Oaxaca	Santo Domingo Roayaga	Mixe
El Campanario	Sierra Sur	Oaxaca	Putla Villa de Guerrero	
San Juan de Los Cúes	Tehuacán valley	Oaxaca	Teotitlán	Nahuatl/ Mazatec/ Mestizo
Teotitlán del Camino	Tehuacán valley	Oaxaca	Teotitlán	Nahuatl/ Mazatec/ Mestizo
Chazumba	Low Mixteca	Puebla	Chazumba	Mixtec
Acateno	Northern sierra of Puebla	Puebla	Acateno	Nahuatl
Ahuacatlán	Northern sierra of Puebla	Puebla	Ahuacatlán	Nahuatl
Ayotoxco de Guerrero	Northern sierra of Puebla	Puebla	Ayotoxco de Guerrero	Nahuatl
Chignahuapan	Northern sierra of Puebla	Puebla	Chignahuapan	Nahuatl
Cuetzalan	Northern sierra of Puebla	Puebla	Cuetzalan	Nahuatl
Francisco Z. Mena	Northern sierra of Puebla	Puebla	Francisco Z. Mena	Nahuatl
Huachinango	Northern sierra of Puebla	Puebla	Huachinango	Nahuatl
Huehuetla	Northern sierra of Puebla	Puebla	Huehuetla	Nahuatl
Hueyapan	Northern sierra of Puebla	Puebla	Hueyapan	Nahuatl
Hueytamalco	Northern sierra of Puebla	Puebla	Hueytamalco	Nahuatl
Jonotla	Northern sierra of Puebla	Puebla	Jonotla	Nahuatl
Libres	Northern sierra of Puebla	Puebla	Libres	Nahuatl
Naupan	Northern sierra of Puebla	Puebla	Naupan	Nahuatl
Nauzontla	Northern sierra of Puebla	Puebla	Nauzontla	Nahuatl
Olintla	Northern sierra of Puebla	Puebla	Olintla	Nahuatl
Pahuatlan	Northern sierra of Puebla	Puebla	Pahuatlan	Nahuatl

(continued)

Communities	Region	State	Municipality	Ethnic groups
Tepecintla	Northern sierra of Puebla	Puebla	Tepecintla	Nahuatl
Teziutlan	Northern sierra of Puebla	Puebla	Teziutlan	Nahuatl
Tlatlauquitepec	Northern sierra of Puebla	Puebla	Tlatlauquitepec	Nahuatl
Tuzamapan de Galeana	Northern sierra of Puebla	Puebla	Tuzamapan de Galeana	Nahuatl
Tzinacapan	Northern sierra of Puebla	Puebla	Cuetzalan	Nahuatl
Venustianao Carranza	Northern sierra of Puebla	Puebla	Venustianao Carranza	Nahuatl
Xicotepec	Northern sierra of Puebla	Puebla	Xicotepec	Nahuatl
Xochitlán de Vicente Suárez	Northern sierra of Puebla	Puebla	Xochitlán de Vicente Suarez	Nahuatl
Zacapoaxtla	Northern sierra of Puebla	Puebla	Zacapoaxtla	Nahuatl
Zacatlán	Northern sierra of Puebla	Puebla	Zacatlán	Nahuatl
Zapotitlán de Méndez	Northern sierra of Puebla	Puebla	Zapotitlán de Méndez	Nahuatl
Zautla	Northern sierra of Puebla	Puebla	Zautla	Nahuatl
Zongoxotla	Northern sierra of Puebla	Puebla	Zongoxotla	Nahuatl
Zoquiapan	Northern sierra of Puebla	Puebla	Zoquiapan	Nahuatl
Caxalli	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Matlahuacala	Sierra Negra	Puebla	Coyomeapan	Nahuatl
San Gabriel Vista Hermosa	Sierra Negra	Puebla	Coyomeapan	Nahuatl
San Marcos Tlatlalkilotl	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Santa María Coyomeapan	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Xochitlalpa	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Ahuatla	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Ajalpan	Tehuacan valley	Puebla	Ajalpan	Nahuatl/ Mestizo
Aticpac	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Caltepec	Tehuacan valley	Puebla	Caltepec	Mestizo
Chilac	Tehuacan valley	Puebla	Tehuacán	Nahuatl/ Mestizo
Chimalhuaca	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Coatepec	Tehuacan valley	Puebla	Caltepec	Nahuatl/ Mestizo

(continued)

Communities	Region	State	Municipality	Ethnic groups
Coxcatlán	Tehuacan valley	Puebla	Coxcatlán	Nahuatl/ Mestizo
Guadalupe Victoria	Tehuacan valley	Puebla	Coxcatlán	Mestizo
Ixtacxochitla	Sierra Negra	Puebla	Zoquitlan	Nahuatl
Reyes Metzontla	Tehuacan valley	Puebla	Zapotitlán	Popoloca/ Mestizo
San Juan Raya	Tehuacan valley	Puebla	Zapotitlán	Mestizo
San Luis Atolotitlán	Tehuacan valley	Puebla	Caltepec	Mestizos
San Nicolás Tepoxtitlán	Tehuacan valley	Puebla	Atexcal	Mestizo/ Nahuatl
San Rafael	Tehuacan valley	Puebla	Tilapa	Mestizo
Santiago Tilapa	Tehuacan valley	Puebla	Tilapa	Nahuatl/ Mestizo
Tehuacán	Tehuacan valley	Puebla	Tehuacán	Mestizo
Yohuajca	Sierra Negra	Puebla	Coyomeapan	Nahuatl
Zapotitlán Salinas	Tehuacan valley	Puebla	Zapotitlán	Mixtec/ Popoloca/ Mestizo
Zinacatepec	Tehuacan valley	Puebla	Zinacatepec	Nahuatl/ Mestizo
Zoquitlán	Sierra Negra	Puebla	Zoquitlán	Nahuatl
Acaxochitlan	Northern sierra of Puebla	Puebla	Acaxochitlan	Nahuatl
Xkon Ha	Yucatan Península	Quintana Roo	Felipe Carrillo Puerto	Maya
Wirikuta (Las Margaritas ejido)	Altiplano region	San Luis Potosí	Real de Catorce	Mestizo, Wixarika
Aquismón	Huasteca	San Luis Potosí	Aquismón	Huastec
Tancuime	Huasteca	San Luis Potosí	Aquismón	Huastec
El Rosario	North region	Tlaxcala	Tlaxco	Mestizo
San Isidro Buen Suceso	South region	Tlaxcala	San Pablo del Monte	Nahua
Maxcanú	Yucatán Península	Yucatán	Maxcanú	Maya
Sucilá	Yucatán Península	Yucatán	Sucilá	Maya

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