Botanical Sciences 100 (Special Issue): S263-S89. 2022
DOI: 10.17129/botsci.3190
Received: May 22, 2022, Accepted: August 20, 2022
On line first: September 21, 2022

Roads traveled and roads ahead: the consolidation of Mexican ethnobotany in the new millennium. An essay

Caminos andados y caminos por recorrer: la consolidación de la etnobotánica mexicana en el nuevo milenio. Un ensayo

Heike Vibrans[1]* and Alejandro Casas[2]

[1] Posgrado de Botánica, Colegio de Postgraduados, Texcoco, Estado de México, Mexico
[2] Instituto de Investigaciones en Ecosistemas y Sustentabilidad, Universidad Nacional Autónoma de México, Morelia, Michoacán, Mexico
*Author for correspondence: heike@colpos.mx

Abstract
This work examines the development of ethnobotany, focusing on Mexico in this millennium. How has the discipline grown? What is the relative importance of Spanish? Are there inflection points? How did some select areas develop, and why? Numerical growth was analyzed mainly through Google Scholar queries. Other subjects were treated based on literature and experience of the authors. Spanish continues to be relevant, especially in Mexico. The discipline gained momentum from 2000 onwards because of the social context of the 1990s, the publication of several foundational works, methodological advances, and particularities of Mexican science. The trajectory of ethnobotany is congruent with a model derived from Kuhn's proposal of cyclical advancement of science: an initial defining stage was followed by a first synthesis, then fast growth of descriptive studies, with a notable recent turn to theory and framework construction. The causes for advances are discussed for three areas (medicinal plants, agriculture, and wild-growing resources). General interest, financing, the consolidation of research groups and the internal organization of institutions have played a role. We highlight important open questions. Ethnobotany is maturing from a descriptive to an analytical stage. However, careful descriptive studies continue to be valuable because the sources of information are in decline, and theory needs an empirical basis. Also, ethnobotany encourages the transmission of knowledge and biocultural memory. It is a key element for integrated sustainability science.
Keywords: scientific development, ethnobiology, sustainability science, theory, descriptive studies.

Resumen
Esta obra examina el desarrollo de la etnobotánica, centrándose en México en este milenio. ¿Cómo ha crecido la disciplina? ¿Cuál es la importancia relativa del español? ¿Existen puntos de inflexión? ¿Cómo se desarrollaron algunas áreas selectas, y por qué? El crecimiento numérico se analizó principalmente a través de consultas en Google Académico. Otros temas fueron tratados basados en la literatura y la experiencia de los autores. El español sigue siendo relevante, especialmente en México. La disciplina cobró impulso a partir del año 2000 debido al contexto social de la década de 1990, la publicación de varios trabajos fundacionales, avances metodológicos y particularidades de la ciencia mexicana. La trayectoria de la etnobotánica es congruente con un modelo derivado de la propuesta de Kuhn de avance cíclico de la ciencia: a una etapa inicial de definición le siguió una primera síntesis, luego un rápido crecimiento de estudios descriptivos, con un notable giro reciente hacia la construcción de teorías y marcos conceptuales. Las causas de los avances se discuten para tres áreas (plantas medicinales, agricultura y recursos silvestres). El interés general, el financiamiento, la consolidación de grupos de investigación y la organización interna de instituciones han desempeñado un papel. Destacamos importantes cuestiones abiertas. La etnobotánica está madurando desde una etapa descriptiva a una analítica. Sin embargo, los estudios descriptivos cuidadosos siguen valiosos porque las fuentes de información están decreciendo y la teoría requiere una base empírica. Además, la etnobotánica fomenta la transmisión de conocimientos y memoria biocultural. Es un elemento clave para la ciencia integrada de la sostenibilidad.
Palabras clave: desarrollo científico, etnobiología, ciencia de la sostenibilidad, teoría, estudios descriptivos.

This essay provides a view of the development of Mexican ethnobotany in the last twenty years. It complements a series of recent reflections on the state of ethnobotany in general and specifically in Mexico (*e.g.*, Camou-Guerrero *et al.* 2016, Gaoue et al. 2017, Albuquerque *et al*. 2020). In this contribution, we focus on a few pertinent aspects that are not sufficiently discussed in recent literature. It is not, as such, a literature review but rather a somewhat personal assessment of some features of the discipline and its development based on our experience from research practice.

Ethnobotany is the scientific research area that studies the relationships and interactions between plants and humans and is part of the broader context of ethnoecology and ethnosciences. First, we review some indicators of its numerical growth. Then, we identify factors that have influenced the main research topics. We also highlight some questions that have been addressed insufficiently as well as priorities for a research agenda. Ethnobotany in Mexico appears to have achieved remarkable consolidation, but there is still a deficit of theory-driven research, possibly inherent to its development phase. We explore and discuss this issue.

The growth of ethnobotany since the year 2000

This section discusses the following questions: How has ethnobotany grown worldwide in the last 21 years (2000-2021) compared to the previous 20 years (1980-1999)? Were there turning points? How does the growth of ethnobotany compare with related disciplines? How has the relative importance of language (Spanish and English) developed in the scientific literature of this research field? What was the role of Mexico?

To examine ethnobotany's development, we mainly used data on the number of documents found in response to search terms in Google Scholar, complemented with some data from Scopus. Google Scholar has some significant disadvantages: it contains much "junk", such as numerous duplicates and slight discrepancies between repeated searches. Nevertheless, these flaws are random and not systematic like the biases of the more widely used databases such as Web of Science (WoS) and Scopus (Harzing 2017). In fact, there are indications that Web of Science captures a decreasing proportion of scientific communication, which in recent years has partially shifted to more informal channels such as conference proceedings, prepublication archives, and others (Larsen & von Ins 2010). Google Scholar contains practically all documents listed in WoS and Scopus (Martín-Martín *et al.* 2018, 2021) but also includes other documents such as theses and government documents (scholar.google.com/intl/en/scholar/publishers.html). This inclusion of documents in Google Scholar is an advantage for our purposes, as the data reflect the more general usage frequency of a term. Also, it has another, decisive advantage: it treats texts in English and Spanish equally, in contrast to WoS and Scopus.

Numerical results of searches cannot be used as absolute values but as relative indicators. They correlate well with English terms in Scopus: the yearly number of mentions of the term 'ethnobotany' in Google Scholar and Scopus from 1980 onwards has an R^2 of 0.95 (see Supplementary Material 1, Sheet 2). This close relationship has been found in other domains and some combinations in English (Franceschet 2009). The same comparison cannot be made with 'etnobotánica' due to Scopus' low number of mentions. Thus, Google Scholar is better for comparing, for example, the relative frequency of word usage across languages.

Unfortunately, Google Scholar does not offer user-friendly tools to extract such statistics. We extracted them by hand, searching year by year. Supplementary Material 1 (Sheet 1) shows the search terms and data for the graphs below, which were retrieved on January 5, 2022. Citations were omitted from the searches, and the query was limited to documents in Spanish for the Spanish terms. When searching for 'botany,' the word 'bay' was excluded because results for Botany Bay in New Zealand distorted the results.

The following graphs (Figure 1) show the number of mentions of the word 'botany,' 'ethnobotany,' and their proportions in the last 40 years, and the same for the equivalent terms in Spanish.

Figure 1 shows two inflection points: one in the early 1990s and another in the first years of this millennium. However, the data also show an extraordinary growth of the discipline in the last 20 years: 'ethnobotany' and 'etnobotánica' had average growth rates above 10 % per year, doubling every 5 to 7 years (Supplementary data 1, sheet

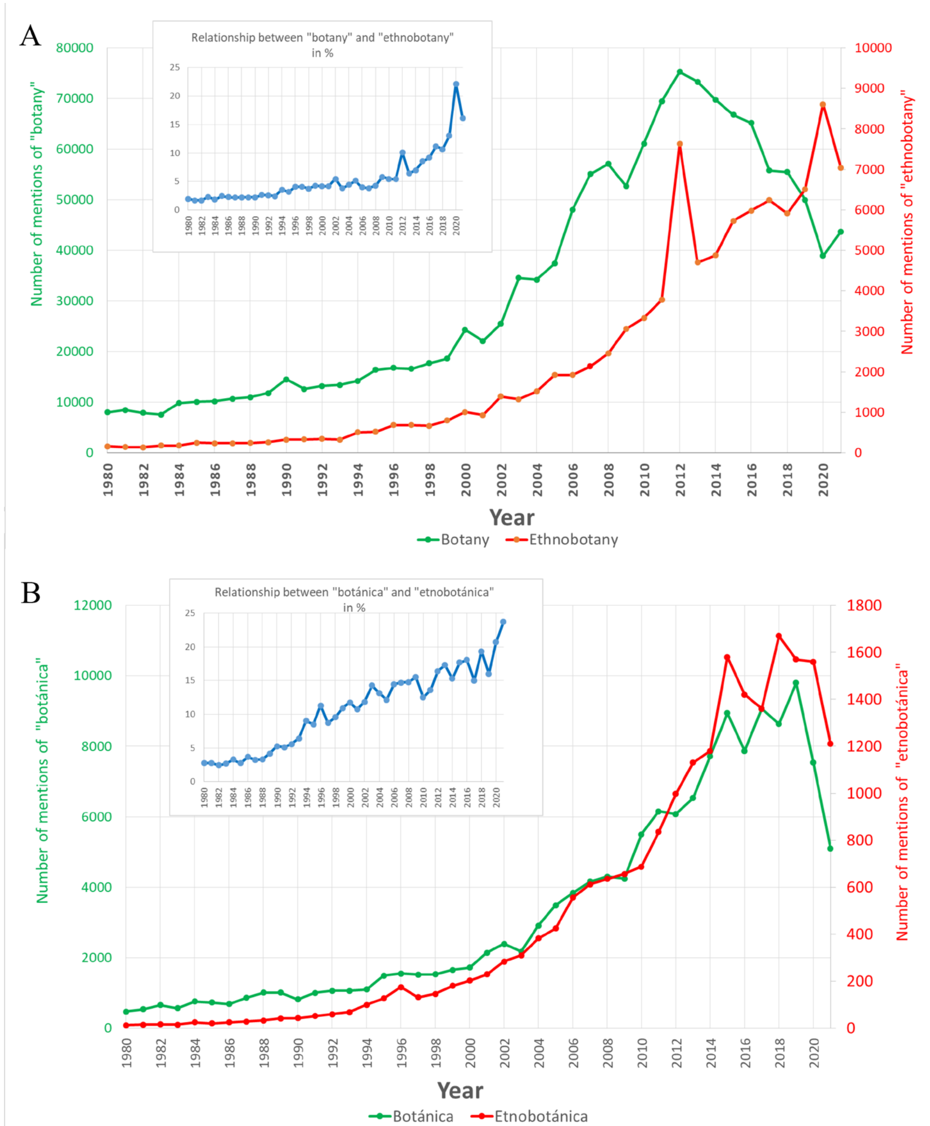

Figure 1. Number of mentions in Google Scholar of the words 'botany' and 'ethnobotany' (A), and 'botánica' and 'etnobotánica' (B), from 1980 to 2021, and their relative proportions. The main graphs have two scales to compare the relative increase; the drop in 2020/21 is due to still incomplete documentation.

1) The average growth rate of scientific publications in general was about 4 % per year (National Science Board, National Science Foundation 2019).

'Ethnobotany' has increased its relative importance compared to 'botany' worldwide and in the Spanish-language literature. Mentions of ethnobotany started below 5 % in the 1980s but are currently around 20 % of those of botany; the increase was more notable for publications in Spanish. This ratio increased even before the word 'botany' declined in English.

Figure 2 shows the relationship between the number of uses of 'ethnobotany' versus 'etnobotánica.' The proportion of texts on ethnobotany in Spanish grew until approximately 1995 and then stabilized at around 25 % of all texts recorded. A lag in the development of the discipline compared with other botanical disciplines, particularly in formal publications (scientific journals and books), can explain the low ratio at the beginning. The subsequent stabilization may confirm a tendency to continue publishing in regional languages, especially in social sciences, despite the worldwide trend toward English in the natural sciences (Liu 2017). Another possible explanation is the social commitment of many ethnobotanists and their desire to make their research results accessible to the studied communities, as well as the goal of cultural affirmation that has permeated the discipline since its beginning (Pardo de Santayana & Gómez Pellón 2002, Colunga-García-Marín & Zizumbo-Villareal 2009, Oses Gil 2010).

This tendency is even clearer if we focus the search on ethnobotanical documents that mention Mexico. The proportion of reports in Spanish increases continuously (Figure 3). The query for the Spanish terms was restricted to publications in Spanish. The numbers should not reflect use of these terms in abstracts of papers with the main text in English. This tendency may reflect the consolidation of the research community of the country.

In summary, the data show a shift in the discipline around the start of the new millennium. Before this date, ethnobotany was already well established in Mexico, but it took off in the last twenty years. It also developed institutionally (Pulido-Silva & Cuevas-Cardona 2021). The Mexican Society of Ethnobiology and Mexican and Latin American media publishing research in this field gained momentum and prestige. Other disciplines incorporated the study of ethnobotanical knowledge and research methods in their work. We suggest this surge was influenced by general trends towards interdisciplinary collaboration worldwide but also by situations specific to Mexican researchers. Also, Spanish continues to be an important language for exchanging information, especially for work conducted in Mexico.

Some likely factors influencing the transition around 2000

We suggest that the qualitative change around the year 2000 was mainly due to four factors: (1) increasing awareness of the fundamental role of plants in human livelihoods and planetary health, which influenced the social and scientific contexts and enhanced socio-ecological approaches in worldwide scientific agendas, particularly during the 1990s, (2) initial efforts of synthesis and theoretical reflections of the field, (3) methodological advances, and (4) some circumstances specific to Mexico.

The social and scientific context in the 1990s. The first influence or factor at the end of the previous century was the general political-social-scientific environment (Alexiades 2003). The threat of climate and other phenomena of global change (Vitousek 1994) attracted attention to life support systems and sustainability in its various meanings. The scientific community confirmed that social and ecological systems were intimately related and mutually influencing (Berkes *et al*. 1994). Concepts like social-ecological systems and biocultural diversity gained interest rapidly. Biological and cultural diversity was recognized as buffers against environmental risks (Khoury *et al.* 2021). Later, the widespread emphasis on nutrition and health fed back into central themes of ethnobotany (Mateos-Maces *et al.* 2020, Mulík & Ozuna 2020, Méndez-Flores *et al.* 2021, Ojeda-Linares *et al.* 2021).

Ethnobotanists found that the most marginalized human populations —those living in mountains, jungles, deserts, and cold regions— are the custodians of these life support systems (Toledo 2001). The massive disadvantages and costs (externalities) of industrial agriculture and food systems became much more apparent, as did the failure of the previously dominant development models, leading to a search for alternatives (Altieri 2004, Altieri & Toledo 2011). Participatory research increased and strengthened based on the interaction of researchers with local communities as groups of people with valuable knowledge and experience. This approach used formal research methods to solve problems identified as relevant by the communities and collaborated with them to develop innovations or local agreements and regulations. Scientific ethnobotany and various disciplines such as ecology, conservation biology and evolutionary ecology improved their interactions. They recognized the value of local knowledge in understanding and facing complex environmental problems. Of course, this change would have been impossible without the scientific and conceptual foundations built mainly in the second half of the 20th century.

Another important factor in science generally was a change in the evaluation methods for academic performance, especially the skyrocketing influence of "impact factors," for better or worse (impact factor refers to metrics for

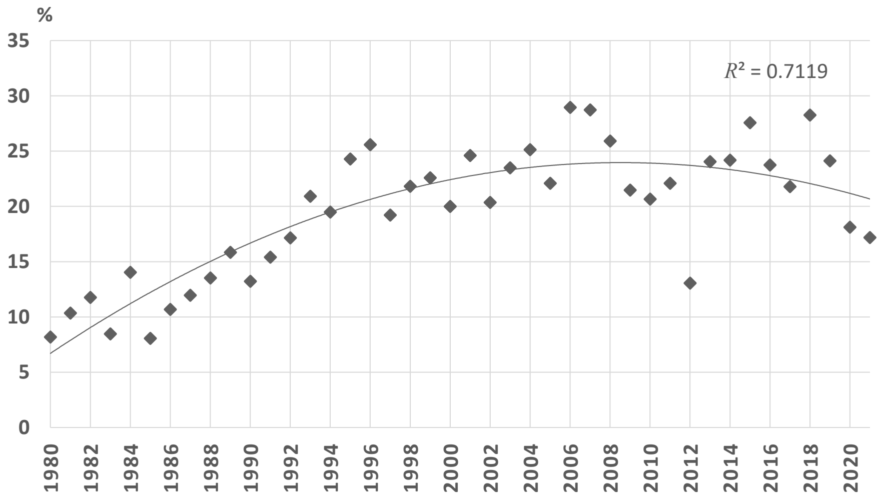

Figure 2. The proportion of mentions of 'ethnobotany' versus 'etnobotánica' per year in Google Scholar. The drop in numbers for 2020 and 2021 is probably due to still incomplete documentation.

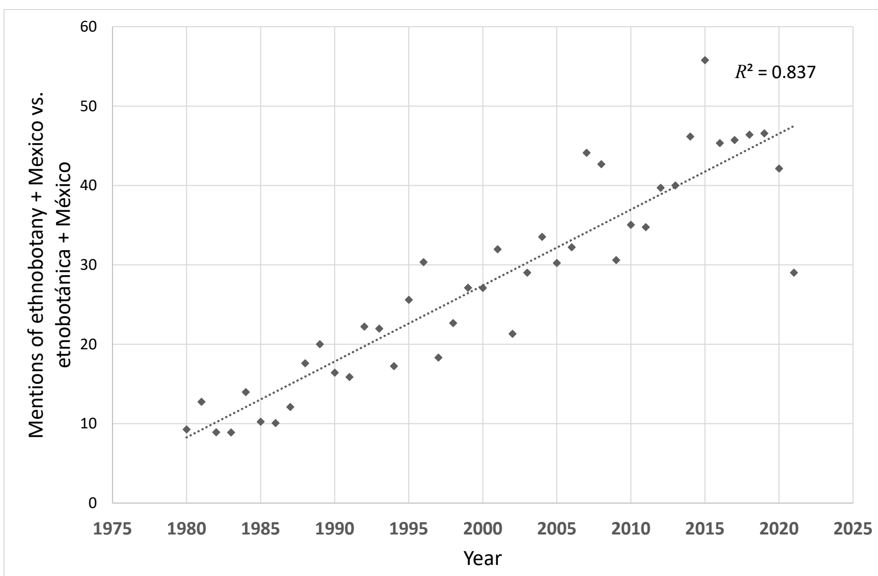

Figure 3. The proportion of documents with mentions of 'ethnobotany+Mexico' and 'etnobotánica+México' listed in Google Scholar.

research influence, mainly based on citations in other independent publications). Not only individual articles and researchers were evaluated with this criterion, but also institutions and journals. It stimulated the publication of work that previously remained in theses or as personal knowledge of researchers. Since reviews, on average, have more citations than an original article (Miranda & García-Carpintero 2018), they strengthened the incentives to summarize small or large areas of knowledge. This elevation of the influence of —controversial— impact factors for ranking and evaluation may have influenced the consolidation of ethnobotany in Mexico. The authors of this essay are conscious that the impact of research includes much more than these factors, for example, influence on public policies, education, actions, health, and nutritional programs. These aspects are difficult to evaluate but deserve special attention. Nevertheless, the influence of impact factors on the daily work of scientists is undeniable.

Finally, we observe a generational change, constructed on a broad base created by the founding generation and motivated by the factors mentioned above. Active researchers were moving more internationally, not only in the scientifically dominant countries but especially in Latin America. Examples are the scientific associations with their well-attended congresses and the exchange of information through group research, courses, and students.

A first synthesis. The second factor was the publication of several books with an initial synthesis and circumscription of the discipline between 1995 and 2005, both internationally and nationally. They were possibly stimulated by the Convention on Biological Diversity, first drafted in 1992 in Rio de Janeiro and legally adopted a year later, as well as the social forces that drove it, mentioned in the first section.

Internationally, Cotton (1996) published the first textbook on ethnobotany; in the same year, a book for the general public on plants, culture and people was also released (Balick & Cox 1996). Earlier, an influential review of the evolution of the discipline had already appeared (Schultes & von Reis 1995). This decade also saw the gradual spread of Ostrom's basic concepts of the governance of the commons (Ostrom 1990, Ostrom *et al.* 1999). Her work outlined alternatives to the "tragedy of the commons." This analysis did not surprise ethnobotanists already familiar with the modes of successful or unsuccessful internal regulation of indigenous communities. However, the findings modified a dominant paradigm of international science that had lasted for decades.

In Mexico, Anthony Challenger's monumental book integrated vegetation analysis with that of its management (Challenger 1998). It gave significant impulse to ethnobotany and conservation science, similar to the influence of Jerzy Rzedowski's *Vegetación de México* (*Vegetation of Mexico*; Rzedowski & Huerta 1978) twenty years earlier on the study of the country's vegetation cover. Unfortunately, this work is unavailable online, and as scientific activity has moved to digital format, it seems to fall into oblivion. Remedying this situation would be highly desirable.

In the same year, 1998, the Spanish translation of the book *Biological Diversity of Mexico* was published (Ramamoorthy *et al.* 1998) (the English version was from 1993). This work integrated many aspects of the relationship between humans and plants. Unfortunately, this seminal work is also not digitally available in its entirety. However, it inspired a whole series of similar works on states of the republic, several of which are readily accessible.

A particularly influential work of this period was the synthesis published by Victor Toledo in the *Ethnoecological Atlas of Mexico and Central America* (Toledo *et al.* 2001). The twelve volumes of the *Biblioteca de la Medicina Tradicional Mexicana* (*Library of Traditional Mexican Medicine*), discussed below, were published in 1994 (Argueta & Gallardo-Vázquez 1994). The cultural importance of medicinal plants and healer consensus was the subject of a highly cited article (Heinrich *et al.* 1998). Another on the role of ethnobotany in developing new medicinal compounds appeared in 2000 (Heinrich 2000).

These contributions encouraged teaching and stimulated the orientation of students towards ethnobotany. They underscored the importance of providing context to early, limited, and local studies.

Methodological advances. A third factor strengthening ethnobotany and ethnobiology was the publication of several works on methods, as well as methodological advances in other sciences.

The first generation of ethnobotanists in Mexico worked mainly with qualitative data based on observations and informal conversations, often together with documentation of useful plants. There were some basic quantifications, guided by the classic text by Hernández Xolocotzi (1971). This was necessary —the development of scientific knowledge requires qualitative data, especially during the first steps—, although qualitative data are valuable throughout the entire development of sciences like ethnobotany. From these, hypotheses emerge over time that can be tested with other methods, among them quantitative approaches.

Three influential publications around the turn of the millennium dealt specifically with research methods: *Ethnobotany: A Methods Manual* by Gary Martin (Martin 1995), with several subsequent editions and a Spanish translation, *Selected Guidelines for Ethnobotanical Research: A Field Manual* by Miguel Alexiades (Alexiades & Sheldon 1996), and a little later, *Applied Ethnobotany* with a detailed guide for applied work by Anthony Cunningham (Cunningham 2001). Also noteworthy was Begossi's (1996) article on ecological methods in ethnobotany. Earlier, methods had been mainly developed informally among researchers; now, the discipline had a systematic summary of the methods to be used for different purposes.

In subsequent years, several works were published on more specific methods in certain areas. However, methodological treatises from Mexico have been relatively scarce, with the exception of the text of Hersch-Martínez & González Chévez (1996) on participatory methods, though several unpublished manuals and informal tutorials circulated in the community.

Advances in methods of other sciences, applied to ethnobotanical problems, now allowed addressing previously difficult problems. Genomic sequencing, new methods for dating archaeological remains, and improved access to herbarium specimen databases have encouraged the study of domestication and related topics in evolutionary ecology. New methods of chemical analysis, particularly various chromatographic techniques combined with mass spectrometry, substantially improved the identification of new chemical compounds in medicinal and food plants. They also contributed to new insights into archaeoethnobotany. Advances in statistical methods, especially multivariate and multi-criteria methods, and geographic information systems promoted a deeper and more holistic analysis of the relationships between data and biological and social factors. In recent years, new, rigorous methods for qualitative analysis (Drury *et al*. 2011, Newing *et al.* 2011, Medeiros *et al.* 2014, Biggs *et al.* 2021) have been employed, particularly for subjects related to ethnobotanical and ethnozoological knowledge (Linares-Rosas *et al.* 2021, Zarazúa-Carbajal *et al.* 2022). The formal analysis of qualitative information continues to be central to ethnographic aspects of ethnobotany and other ethnobiological sciences. Additional investigations and quantitative analyses then address the new hypotheses derived from these insights.

Factors specific to Mexico. A fourth factor, and landmark event for ethnobotany, was the foundation in 1994 of CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad), the Mexican Biodiversity Commission, as an inter-secretarial government body. It was promoted by Dr. José Sarukhán, a plant ecologist with a broad vision that included the relationship between the human populations of Mesoamerica and their plant and animal environment. CONABIO has functioned as a bridge between academic knowledge, government institutions, and the general public on using and conserving wild and anthropogenic biological resources. It fulfilled this task outstandingly for decades and culminated in a series of publications under the name *Capital Natural de México* (*Natural Capital of Mexico*; Sarukhán 2008). In addition, it has supported numerous studies not only on wild flora and fauna but, more recently, on agrobiodiversity and the use of vegetation.

Some long-term regional studies also advanced ethnobotany in Mexico. Previous floristic, vegetation, ecological and archaeological studies laid the foundations for ethnobotanical research in some areas with highly diverse human populations. Examples are the Tehuacán-Cuicatlán Valley in Puebla and Oaxaca States, the Yucatán Peninsula, the Lake Pátzcuaro Basin, the Sierra Tarahumara, the Sierra Norte (Northern Sierra) of Puebla, the Highlands of Chiapas, the Northern Sierra of Oaxaca, the Huastec region, and several areas of the Balsas River Basin, among others. Building on this information, ethnobotanists examined the relationship between local, diverse people and their environment with detailed, continuous, and broad studies. The initial focus was on the use of wild vegetation but later included other types of management.

The concept of *in situ* domestication, that is, domestication based on *in situ* management and selection of weedy and wild-growing plant populations, was developed in several regions of Mexico. Several cases were investigated in the Tehuacán-Cuicatlán region based on some previous studies in El Bajío, the Yucatán Peninsula (Colunga-García-Marín *et al*. 1986) and the Balsas River region (Casas *et al.* 2007). Numerous studies explored the sustainability of various forms of collection, management, and agricultural systems. Lira *et al.* (2009) reported that more than 60 % of the plant species of the Tehuacán-Cuicatlán region have some use. Other regions that have been studied for a long time and by various disciplines and researchers and thus have produced a wider body of knowledge are the Northern Sierra of Puebla, the Yucatán Peninsula and some regions of Chiapas and Oaxaca.

The National University of Mexico (UNAM) has played an outstanding role in several of these long-term investigations. Many themes of contemporary ethnobotany, such as the sustainable use of forest resources, agricultural systems, or domestication, require the study of processes over long periods. The relative autonomy of researchers of this institution in terms of research subjects and the internal funding of projects has allowed its scientists to have life projects.

The stages of ethnobotany as a branch of science

The evolution of ethnobotany is consistent with a model proposed by Shneider (2009), based partly on the concept of cyclical advancement of science advanced by Thomas S. Kuhn (Kuhn 1970) (for a different classification, see Hunn 2007). According to Kuhn, the development of a scientific discipline has four main phases or stages. In the first stage, a new frame of reference or language is created, delimiting and defining the new field conceptually. It is based on initial observations and experiments, and several individuals or groups often work independently in a somewhat chaotic process. For ethnobotany in Mexico, this stage consists of most of its history, with an acceleration from 1970 onwards, until about 1995.

In a second stage, concepts and methods are refined, frequently through adaptation from other disciplines. Basic instruments are created, and some of the most highly cited papers are published. More intensive collaborations begin. For our area, this stage lasted roughly from 1995 to 2005.

In a third stage, these new instruments are combined with old and new problems to produce new answers and more questions. Novel phenomena are discovered, and new disciplines are sometimes born; more rigorous methods are developed and used in other disciplines. Most of the data and useful information are generated in this phase, and collaborations intensify. Separate bibliometric work supports the model: Citron & Way (2018) found that new fields evolve first in somewhat separate working groups and then mature into a densely linked network.

In the fourth stage, comprehensive and analytical reviews identify general rules and assess trends. The multitude of data generated in the third phase is organized, and future lines of research are identified. In this phase, a discipline has the tools to become at least partially predictive.

Under this model, we consider that Mexican and world ethnobotany are in stage three, with some initial elements of stage four. Recent years have seen several synthetic and theoretical publications (*e.g.,* de Albuquerque & Hanazaki 2009, Hurrell & de Albuquerque 2012, Moreno-Calles *et al.* 2013, 2014, Casas *et al.* 2016, Pickersgill 2016, Vibrans 2016, Gaoue *et al.* 2017, Mariaca Méndez *et al*. 2018, Albuquerque *et al.* 2019, Torres-García *et al.* 2019, Albuquerque *et al.* 2020, Clement *et al.* 2021, Gaoue *et al.* 2021, Leonti *et al.* 2020). Some topics, such as domestication and agroecology, derive at least partly from ethnobotany. They build on its methods but also incorporate tools of other disciplines and have taken directions of their own.

Advances of some selected themes of ethnobotany

The following sections briefly examine a selection of main subjects of ethnobotany to identify trends and challenges. These are examples and omit several other important areas of the discipline. It emphasizes factors that promote or constrain their development and identifies problems that deserve further attention and inclusion in a future research agenda.

Curing diseases: medicinal plants. Medicinal plants are among the most popular topics of ethnobotany; indeed, ethnobotany is often equated with knowledge about these plants. Supported early in Mexican science through the National Medical Institute (Méndez 2010, Sánchez Rosales 2012), Maximino Martínez compiled its results in a well-known and still popular book on Mexican medicinal plants (Martínez 1959). The field maintains popular support (Figure 4) and funding for scientific studies.

This history enabled the publication of the encyclopedic synopsis *Biblioteca de la Medicina Tradicional Mexicana* with its *Atlas* (1990-1994, with preparations from the 1980s onwards; Argueta & Gallardo-Vázquez 1994). It originally consisted of 12 volumes, with a dictionary of terms, several volumes on the traditional medicine of different ethnic groups, others on the medicinal flora, and a bibliography. First, this *magnum opus* was only available at a

Figure 4. Medicinal plants at the large wholesale market (Central de Abasto) of Mexico City (2011). From the upper left corner: *Tanacetum parthenium* (L.) Sch. Bip. (*Santa María*), *Ocimum basilicum* L. (*albahaca*), *Heterotheca inuloides* Cass. (árnica), hail-damaged avocado leaves (*Persea americana* Mill.), *Equisetum hyemale* L. (*cola de caballo*), *Calendula officinalis* L. (*mercadela*), *Zingiber officinale* Roscoe (*jengibre*) and *Citrus medica* L. (*acitrón, cidra*). The whitish material on the left are maize husks, used for tamales.

few institutional libraries. A 2009 digital version was taken down a few years later for technical reasons. Recently, the website has been renewed, and its content updated. It currently has its own maintenance team and is accessible through www.medicinatradicionalmexicana.unam.mx/index.html.

Besides this encyclopedia, revisions have focused mainly on species, taxonomic groups, and plants used for certain diseases. For example, there are several compilations and reviews on species used for gastrointestinal (Osuna Torres *et al.* 2005, Calzada & Bautista 2020) or respiratory illnesses, diabetes (Aguilar Contreras & Xolalpa Molina 2002, Alarcon-Aguilar & Roman-Ramos 2005), inflammation (Quiñonez-Bastidas & Navarrete 2021), nervous system ailments (Geck *et al.* 2021, Castañeda *et al.* 2022) or female reproductive health. There are also some regional compilations (*e.g.*, Cruz-Pérez *et al.* 2021 for Oaxaca).

However, more in-depth analyses are notably absent. Ethnobotanical research —often unintentionally— employs several assumptions that are not necessarily true. For example, the names of diseases in folk medicine and scientific medicine are regularly considered directly equivalent. However, this is frequently not the case and leads to serious misunderstandings. A well-known example is *cancer* —a neoplasm or unusual growth in scientific medicine, but a poorly healing wound or sore in the folk medicine of various regions of Mexico—, but there are many other cases, such as *resfriado* (García-Hernández *et al.* 2015).

Also common is the assumption that traditional physicians see a disease in the same way as a Western doctor and treat it with a specific substance or medicinal practice (Vargas & Casillas 1989). This is not necessarily so: traditional physicians first consider what they perceive as the cause, frequently unrelated to the cause identified by Western medicine. The cause may be related to aspects such as humoral systems, supernatural influences, one's own or other people's feelings, or taboo-breaking. Other ailments, called culture-bound syndromes in the literature, cannot be explained with the tools of Western medicine. In many places, the diseases considered natural are a small minority, often restricted to the after-effects of physical injury. Thus, the concepts of illness and health do not necessarily coincide. Many healers are also aware that faith, trust in the healer, rituals and prayers may promote healing and employ them. In addition, many treatments consist of certain practices (*e.g.*, a *temazcal* sweat bath) where plants are auxiliary (García-Hernández *et al.* 2015). Anthropologists have explored these issues extensively (Vargas & Casillas 1989). However, they are not regularly integrated into ethnobotanical studies, despite being fundamental to explaining the selection and use of plants as medicine.

Similarly, many publications assume that traditional practitioners experiment with plants and keep those that work, and this knowledge is passed down through generations. However, most diseases heal over time, with or without treatment, making it difficult for the healer to recognize effective plants (Tanaka *et al*. 2009). The few studies we have on the process of selecting plants indicate that experimentation exists, but many other factors influence the process. They involve taste and smell (Leonti *et al.* 2002, Geck *et al*. 2017), world view, perceived cause of illness, or external information (from other healers, books, or internet sources) (Leonti 2011). Perceptions also exist that are similar to the doctrine of signatures (Frei *et al*. 1998), which was very prominent in the Middle Ages in Europe but is known from other parts of the world and held that the shape of a plant indicated its medical function. Moreover, there are several ways to become a healer. One is family tradition, but supernatural signals, dreams, or the notion of "having the gift" may also direct the path toward becoming an empirical physician (Gallardo Arias 2004, Tafur *et al*. 2009).

Considering these mistaken assumptions, it is surprising that scientific research has often confirmed the usefulness and effectiveness of plants used in traditional medicine. The work of Waldstein & Adams (2006) discusses this topic extensively. The overlap is probably due to some selection criteria (*e.g*., species with a pleasant odor are employed for treating wounds, as aromatic oils often have antibiotic properties, or plants with astringent substances with their polyphenols for treating gastrointestinal complaints). Some healers do have a major advantage that can partially compensate for the difficulty of observing cures: the careful and long-term observation of their patients, who are relatives and neighbors, and knowledge of their personalities and social environment. Additionally, humans possibly have some instinctive response to healing plants, given that animals also employ plants as medicine (Shurkin 2014, Bos *et al.* 2015, Boukhdoud *et al.* 2021).

Thus, an important gap in descriptive ethnobotanical studies of medicinal plants is the link between the plants used and the folk nosology of the diseases. Medical anthropology has worked on this topic, but the interaction between diagnoses and treatments is rarely investigated. For example, in Mexico, many diseases are attributed to properties of things and phenomena called "hot" and "cold" (which are only partially or not related to temperature); the diagnosis directly determines the treatment. Numerous anthropologists have described the phenomenon in different regions and domains of knowledge. However, ethnobotanical research has largely omitted this fundamental factor for understanding the use of medicinal plants, with some honorable exceptions. We should also explore this and other beliefs related to health and illness to see if they have a background and to understand people's choices in everyday life. Only in the last decade have some studies answered questions on the relationship of the hot-cold system with the selection of medicinal plants and phytochemical or other characteristics (García-Hernández *et al.* 2015, 2021, Geck *et al.* 2017). This and similar lines of research on cultural factors deserve priority attention when constructing a study agenda. Ethnobotany should be strengthened by incorporating more aspects and methods of anthropology, pharmacology, and phytochemistry.

We also do not have many comparative regional analyses of the medicinal flora by both taxonomic and disease criteria. As Stepp (2018) indicated, we need to know which species are actually used, for what purpose and why, and the role of environmental variation on use and selection. His book was a first step in answering these questions for a Maya people. What plants were replaced by modern medicine, and why or which diseases are not treated with plants anymore? How do people value medicinal plants, and which factors influence the values of these plants? Does the number of plants used for diseases differ by climate, region or cultural group? For example, are there more plants for respiratory diseases in cold regions, gastrointestinal diseases in hot regions, and skin diseases in humid regions? Comparative work, even on a small scale, may uncover divergences between cultural groups: Choco *et al*. (2018) found commonalities but also significant differences between two Mayan groups in northern Belize —in the predominant gender of healers and the life form of the plants used (herbs vs. shrubs). Also, studies on the source habitat of medicinal plants are widely lacking. Recent evidence increasingly points to secondary vegetation and home gardens as the main suppliers of traditional medicines (Stepp 2004, Pérez-Nicolás *et al*. 2018, Voeks 2018). But which types of plants are obtained from these environments, and which from more natural vegetation? Are there differences between vegetation types? Theoretical ecology makes it likely that climate and vegetation types influence the number and category of medicinal plants.

Agrobiodiversity. Agrobiodiversity consists of the biological diversity associated with agroecosystems. It includes various organizational levels: the systems in agro-food landscapes, species (domesticated, weedy, and wild), and their genetic variation (Casas & Vallejo 2019). The vast majority of ethnobotanical agriculture studies in Mexico are focused on agrobiodiversity, by academics, the CONABIO and the efforts of the Ministry of Agriculture (especially the now-disappeared National System of Plant Genetic Resources for Food and Agriculture, SINAREFI, and the Ministry of Environment and Natural Resources, SEMARNAT), NGOs and other institutions and organizations.

The impetus for this approach derives from the increasing legislation on protection and restriction of the seeds trade. This tendency is due to a change in their legal status from a common good of humanity to patentable "inventions," the subsequent changes in legal attitudes and the accusations of biopiracy. This situation required inventories of native domesticated plants, especially of the landraces or native or creole breeds, and their wild relatives. Wild species may also be included, given their role in agroforestry systems (Moreno-Calles *et al.* 2013).

The progress in this field illustrates the role of public interest and international legal requirements due to Mexico's role as one of the main centers of domestication of the Americas and the world. This does not discredit the advances; on the contrary, it underscores the achievements possible in Mexico with the right conditions.

An example is knowledge on maize (Figure 5). After an early impulse (Wellhausen *et al.* 1951), a key element was the Global Native Maize Project, organized and funded by CONABIO from 2006 to 2010, in coordination with several ministries and organizations. Nearly 300 collaborators and 80 institutions participated. Apart from numerous individual publications by the participants, the main results were communicated attractively through a web page (www.biodiversidad.gob.mx/diversidad/proyectoMaices). We now have an illustrated catalog of the main maize variants and their wild relatives, maps, some information on their ecology and other characteristics. The book *Origen y Diversificación del Maíz, Una Revisión Analítica* (*Origin and Diversification of Maize, an Analytical Review*; Kato Yamakake *et al.* 2009) summarized the scientific results.

So, we now have better information on what and where, but more data are needed for practical purposes, especially on ecological and agronomic characteristics of the local varieties. We are still far from, for example, a catalog of germplasm resistant to various types of environments and diseases, or detailed information on the mechanisms of these adaptations. We do not know if, for instance, the extraordinary height of some tropical maize varieties is due to an environmental factor or selection for some secondary use of this biomass. Or why the population of some regions

Figure 5. Maize variety of the *cónico* group at an event in Ixtenco, Tlaxcala (2004).

of Jalisco selected the Jala variety with its extremely long ears. Or what mechanism allows some maize types from the Mixteca Alta, grown in *jollas* (terraces built in ravines, Figure 6; Rivas Guevara *et al*. 2008, Orozco-Ramírez *et al*. 2020), to withstand weeks of drought or flooding? Or why did the Mixe of a very humid region of the Northern Sierra of Oaxaca select weeping maize that self-fertilizes (Van Deynze *et al.* 2018), but their Nahua neighbors do not employ it? There are hundreds of similar questions, not only for maize but also for other crops. Answering them will deliver practical support for much more balanced and sustainable agriculture.

Besides the motivation from public interest, there are also other drivers. We find examples of notable advances driven by the interests of small groups of researchers over decades. In his early ethnobotanical studies in Mexico among the Tarahumara, Robert Bye was fascinated by the use of weeds as food. He wrote first about the use and incipient domestication of *Brassica rapa* (at that time known as *Brassica campestris*) in this region (Bye 1979) and then a much-cited article on *quelites* (edible herbs) (Bye 1981). Other authors have also worked on the subject. However, the decades-long constancy of the group around Bye that formed over the years, which includes Luz María Mera, Francisco Basurto and Cristina Mapes, led to several compilations and syntheses (*e.g.,* Mera Ovando *et al*. 2011). Also, Edelmira Linares and the outreach group of the UNAM Botanical Garden released numerous publications (*e.g.,* Mera-Ovando *et al.* 2003, Castro-Lara *et al.* 2014, Linares *et al.* 2017, and a special issue of La Jornada del Campo, November 18, 2017). It encouraged the formation of a *quelites* network at SINAREFI and the interest of numerous researchers from other institutions.

The group also organized culinary events, videos and talks to raise awareness of the topic with the general public. It made efforts to collaborate and transmit knowledge to a new generation of Mexican chefs; numerous Mexican restaurants now offer dishes incorporating these plants, particularly in the last decade. The well-known upscale restaurant Quintonil (named after *Amaranthus* greens) opened in 2012. With the boom of interest in healthy eating, *quelites* and their benefits increasingly entered urban popular culture, even with feedback to rural regions, where *quelites* had been discredited as food of the poor. Rural housewives viewed these plants with new appreciation after hearing positive references to *quelites* in talks on nutrition at a local clinic (Sánchez-Ramos *et al*. in press).

After concluding the maize study, the project Agrobiodiversity of Mexico initiated in 2018 by CONABIO again coordinated numerous researchers. It aimed to document and systematize information on agrobiodiversity broadly, including non-cultivated plants. This project should be continued. Detailed knowledge of which and where wild, weedy and domesticated species and varieties grow is the foundation for addressing multiple production problems and developing sustainable agriculture. The dominant approach has concentrated on species, their use and management, and various ecological and cultural attributes. However, processes (both in time and as action sequences) should receive more attention. Management techniques in agricultural and agroforestry systems may reflect the accumulated experience of thousands of years. Their documentation and systematization are major prerequisites for constructing sustainable management strategies.

Finally, apart from native crops, Mexico also harbors interesting non-native germplasm: old cereal or fruit cultivars brought at some point from Spain or the Philippines, which apparently are sometimes no longer found in their region of origin. Examples are barleys and wheats, plum trees (*Prunus*), apples and bananas, and some ornamentals. These, unfortunately, have not yet been studied with the attention they deserve, despite their long adaptation to Mexican conditions and, consequently, their value for plant breeders and niche markets. Programs of the extinct SINAREFI integrated a few, and agronomists have occasionally treated these plants. For example, Posadas-Herrera *et al.* (2018) found wide variation in fruit characteristics of apples from Zacatlán, Puebla.

Domestication. Another field with considerable progress is domestication, its processes and domesticate diversity. It has benefited from two driving forces. One is advances in methods: genetic sequencing, quantification of morphological characteristics and multivariate statistics, phytochemistry, reproductive biology and plant physiology, all of which provide indicators to evaluate and explain divergence between wild and domesticated plants, and the diversification associated with domestication. The other force was the interest of several research groups studying *in situ* and *ex situ* domestication for decades in different regions of Mexico, which resulted in deep knowledge of these processes.

Figure 6. A *jolla* (terrace in a ravine) in the Mixteca Alta of Oaxaca (2005).

The study of domestication and wild relatives transitioned from a niche of a few enthusiasts in the last century to a central field of genetics, botany, ecology, and agronomy. The current literature is so extensive that it can now be considered a field derived from ethnobotany with its own arsenal of language and methods. It has substantially enriched plant evolutionary theory (Hancock 2005) and been enriched by it.

The sequencing and better understanding of genes, regulation, transcription, modification of genomes, and the development of paleogenomics have played an outstanding role, improving understanding and allowing reconstruction of processes in the past. From some tentative archaeological hints on domestication locations and mechanisms, we have advanced to detailed and documented evidence of processes. For example, we know now that the domestication of maize included backcrosses with wild populations (*e.g.,* Wang *et al.* 2017) and that the crop had several waves of expansion, including reverse gene flow from South America to Mesoamerica (Kistler *et al.* 2020). Evidence is increasing that domestication began before the adoption of agriculture as a way of life (Clement *et al.* 2021). Researchers outside Mexico dominate the field, but there are important groups in the country studying various aspects of domestication in Mesoamerica and other regions of the Americas.

The research agenda in this field includes the need to document in greater depth why and how these processes operate. What are the different strategies of plant management by humans? What is the motivation for managing and domesticating some of them? Science has studied how the processes work in a few dozen species, whereas humans have domesticated an estimated 5,000 to 7,000 species (Khoshbakht and Hammer 2008). These are living processes, so they are functioning and can be studied in current contexts.

Selection mechanisms vary and have different intensity levels, depending on the plants' life cycle and reproductive biology. Knowing the general rules, the why and how these processes work can contribute substantially to deciphering archaeological findings. Interweaving and integrating ethnobotanical and archaeological studies is fundamental to the understanding of the processes.

Likewise, the outcomes of the process (the divergence between wild and human-managed populations) require a variety of strategies for investigating phenotypes and genotypes. Genomic approaches offer an extraordinary opportunity to understand human-driven evolutionary consequences and issues related to the origin and spread of domestication and production systems. A detailed understanding of these processes will surely change the notions about the centers of origin of cultivated plants proposed by Vavilov, Harlan and others. It seems increasingly clear that discrete areas of domestication will probably have to be revised. Also, growing evidence shows technical and genetic material exchanges from very early stages of domestication. These early events are a topic of great scientific interest and relevant for legislation on property rights of genetic resources.

Studies on domestication should also make greater efforts to connect processes at population and landscape scales. What happens in populations influences the configuration of species assemblages in communities and landscapes, and vice versa, the management of landscapes affects populations (Clement *et al*. 2021). These trans-scalar relationships should be investigated in greater detail, as they will have consequences for the path towards sustainable management of resources and ecosystems.

Traditional agriculture. There are numerous worthwhile aspects of traditional agriculture, apart from the agrobiodiversity mentioned above. Fortunately, some recent papers summarized and classified knowledge on the distribution and basic traits of some important traditional agroforestry systems in Mexico, partially based on the older work of Hernández Xolocotzi (Moreno-Calles *et al.* 2013, 2014). However, these descriptions need to be expanded and systematized, with the recent book by González Jácome (2022) as an excellent initial synthesis. Also, relevant systems in different regions and cultural groups in Mexico remain to be studied. More information is needed on processes and reasoning (the how and why).

We need to know more about the cognitive, technical, material, economic and practical processes in Mexico's highly varied environments and cultures, as well as the influence of the idiosyncrasies of each farmer. Few synthetic works analyze some aspect of the agricultural cycle comparatively and for larger regions, for example, sowing techniques, weed and pest control, harvesting or storage, and intercropping patterns and motivations for maintaining forest cover. This information is crucial as input for developing agroecological systems adapted to local conditions, which are highly diverse in Mexico. These systems contribute not only critical germplasm but also techniques and knowledge. This type of data is best obtained initially with robust qualitative research.

Although there are some descriptions of local agroecosystems, quantitative approaches are scarce. We need more data on the multiple products and alternatives in traditional agriculture and land use, including domestic and wild animals. They often have much higher productivity than that reflected in official statistics. The lack of data applies to individual land-use types such as a milpa and even more to entire agri-food systems and landscapes. This work is inherently complex, as it cannot be approached with interviews alone. It requires participant observation over long periods, repeated measurements, observations, and interviews, and can only be very local at the outset. Once farmers' decision-making processes, the components and the true productivity of their agroecosystems are understood, these very local qualitative and quantitative data can improve qualitative and quantitative research across larger regions.

There is one exception to the lack of information on systems: the milpa of the Mayan region (Terán & Rasmussen 1994, Moreno-Calles *et al.* 2014). The interdisciplinary and holistic research initiated by Efraím Hernández Xolocotzi with his project "La milpa en Yucatán" in the 1980s (Hernández Xolocotzi *et al*. 1995) is an excellent example of early studies and charismatic investigators that motivated a group of students and, through them, stimulated broad academic and knowledge production. In turn, many years later, these works also entered popular culture outside the academy, to the poin of their subjects becoming tourist attractions (Jouault *et al.* 2018). Recently, Ramón Mariaca and collaborators edited a book synthesizing different aspects of the milpa for the state of Chiapas (Mariaca Méndez *et al.* 2018).

In general, economic analyses of the traditional complex systems (Figure 7) are underdeveloped. An example is the role of the "shadow" or informal agricultural economy —which is not accounted for in official data and is often related to local preferences (Arslan & Taylor 2009). The vast majority of farmers —even those considered "subsistence" farmers— actually sell part of the production from their cultivated plots, home gardens or wild vegetation. However, they do so through informal channels, such as trade among neighbors and relatives or small-scale commerce at *tianguis* (weekly markets) (Lope-Alzina 2014). Today, a considerable part of the rural population is not or only partially engaged in agriculture; this local market has low marketing costs and appreciates local varieties and specialties. Bellon *et al.* (2021) found a considerable shadow market for maize in Mexico after assessing the area planted and comparing it with maize entering formal trade. Ethnobotanists must have notions of economic concepts, such as transaction costs, economies of scale, risk buffering and shadow prices. Understanding basic concepts helps build very useful and predictive models (Baker *et al.* 2017).

We also do not have comparative analyses of beliefs and world views associated with agriculture; the significant work of Ramón Mariaca (Mariaca Méndez 2003) on magical-religious beliefs related to agriculture has not found much echo. In other words, there is a persistent lack of syntheses linking the cosmos with the corpus and praxis, just as in the area of medicinal plants.

The use of wild resources with the example of copal. Copal resins are aromatic, hardened tree exudates employed in rituals to produce aromatic smoke, as medicinal products, adhesives, and waterproofing agents (Figure 8). Its role is similar to incense in the Old World. In both hemispheres, copal is mainly obtained from Burseraceae and some gymnosperms and legumes. It may be economically relevant among the non-timber products of tropical forests. Here, we use it as an example of the advancement of knowledge of this type of natural resource in the last twenty years.

Before the year 2000, anthropological and historical publications dominated the literature on copal. Medicinal or ritual use was referenced mainly in general studies on useful plants or archaeological artifacts, although there were scattered data on some resins' chemical compounds. Only one thesis of that period specifically addressed the ethnobotany of plant resins in the Maya region (Tripplett 1999). Ethnobotanists were aware of various types of copal resins available at local and regional markets, but there was no literature on identification or properties. A 2003 article comparing the chemical composition of three types of copal indicated only the "likely" species of origin (Case *et al.* 2003). This lack of information is surprising, given that resins may contribute about 20 % of the value of non-timber forest products (estimated with incomplete data in 2003) (Tapia-Tapia & Reyes-Chilpa 2008).

Figure 7. Field margins are underappreciated components of traditional agroecosystems. Here, in the mountains of northwestern Hidalgo (La Lagunita, Ixmiquilpan; 2017), there are pulque *agaves*, *Opuntia*, wild *Dahlia*, *Phaseolus coccineus* and apple trees.

Since the beginning of the millennium, there has been a surge of interest in this group of plant products in Mexico, perhaps triggered by Langenheim's monumental book (Langenheim 2003) on plant resins. The works of Cházaro-Basañez *et al.* (2010) on Mexican copals, Quiroz Carranza & Magaña Alejandro (2015) on natural resins, and Castillo Acal (2016) on copal use in Yucatán are useful summaries of uses.

Several papers have since examined the management of copal-producing trees, especially in Morelos, a center of diversity and collection. Copal harvesting is like many other gathering activities: the number of collectors varies, depending on the vagaries of the rural economy. However, it requires specialized knowledge about cutting and harvesting techniques, productive trees, and others (Cruz León *et al.* 2006). In this region, between 100 and 300 g per tree per season (autumn) are obtained. In 2004, it sold for around 200 pesos per kg and in 2017, for 300 (Blancas Vázquez *et al.* 2020). The Sierra de Huautla copal harvest had a much better economic return than local rural wages, but the three-month window made it only a seasonal activity (Cruz León *et al.* 2006).

Copaleros collect from wild trees, but they also select and manage them. The composition of aromatic substances apparently varies in wild populations (Cruz León *et al.* 2006). Managed trees produce more resin and aromatic substances (Abad-Fitz *et al.* 2020), thus suggesting that management likely increases the frequency of the best phenotypes in managed areas. This type of silvicultural intervention with consequences for the composition of populations has been documented in numerous other plant species (Parra *et al.* 2010, Aguirre-Dugua *et al.* 2012, Parra *et al.* 2012, Figueredo-Urbina *et al.* 2017).

Knowledge of chemical components has also improved. A comparative review of the different copal resins in Mexico is available (Gigliarelli *et al.* 2015). Most aromatic compounds are terpenes, with different compositions in different species (Gigliarelli *et al.* 2015, DeCarlo *et al.* 2019), and many have known medicinal effects. For example, copal from *Protium copal* calms rats, probably through the effects of amyrin on the GABA and endocannabinoid systems. This effect is undoubtedly desired in rituals (Merali *et al.* 2018). Anti-inflammatory properties also have scientific support, *e.g*., *Bursera copallifera* (Zúñiga *et al.* 2005, Romero-Estrada *et al.* 2016). With new methods, especially gas chromatography combined with mass spectrometry, archaeological copal can now be identified and assigned to species (*e.g*., Lucero-Gómez *et al.* 2014).

We also have other tools facilitating the identification of compounds and species of copal. The CONABIO page on copal resins (www.biodiversidad.gob.mx/diversidad/ceremonial-y-ritual/copales) and the manual on the use and management of aromatic copal trees (Purata Velarde 2008) are particularly useful. Recently, a book chapter synthesized recent advances (Blancas *et al.* 2021).

In summary, we now know which type of copal is obtained from which species and how, what active substances they contain, and what good management practices are. Several different researchers have contributed these data; in this case, no outstanding influence of any one group or institution can be identified. More regional data are still needed on managing the different species, the economics of this activity and the variation in chemical composition within species and populations.

Copal is but one example of several thousand forest species contributing valuable non-timber resources. Ethnobotany documents such resources, the current and potential economic aspects, and relevant ecological information, but the knowledge is still incomplete. Much information is part of the *campesino* experience, which is in decline. Thus, an essential task for ethnobotany is documenting management strategies and the socio-ecological basis for their sustainable use.

Some comments on theory and descriptive approaches in Mexico

In recent years, several authors have discussed theory in ethnobotany. They often conclude that many ethnobotanical publications lack a theoretical foundation (Gaoue *et al*. 2017). As discussed above, we consider ethnobotany is partially at the stage of gathering data and developing concrete hypotheses, but advances are variable in different areas of ethnobotany.

Figure 8. Copal for sale at the weekly market of Tlacolula, Oaxaca (2004).

However, there are other issues. Ethnobotany differs from other fields in several aspects. For one, its primary sources of information are declining. In most regions of Mexico, the rural population with deep knowledge has already died. Although the current older generation still retains some traditional knowledge, rapid cultural change, accelerating due to multiple and complex cultural and economic factors, limits the transmission of local knowledge, practices, and visions to the next generation (Saynes-Vasquez *et al*. 2016). The process is like that in developed countries about 100 years ago but much faster. There is little time left for detailed descriptions that are the basis for other work. For example, thorough documentation of botanical (and ecological) knowledge allows examination of cultural dynamics and the adaptation of humans to changing circumstances. The data can be compared between different time frames, thus probing important questions on the human condition. Understanding the dynamics of interactions between peoples and plants in a context of cultural and ecological change is undoubtedly one main challenge of ethnobotany.

Also, the discipline has practical functions. The knowledge of peoples with a traditional way of life needs to be documented for more reasons than "just" contributing data to science. The chain of generational learning has already been disrupted in many places, but interest continues in some young people, often for practical reasons (*e.g*., conversion to organic agriculture). Detailed, published descriptions of traditional knowledge —on agriculture, home gardens, traditional medicine— can conserve and transmit this knowledge to interested parties. So, it is crucial to maintain incentives for scientists to conduct well-documented descriptive studies —i.e., they should be able to publish in recognized media.

Descriptive studies are meaningful and contribute to understanding if enriched with the underlying data and detailed comparisons with previous work (Efraím Hernández X.: "There are always precedents"!). In this way, they contribute to the development of testable hypotheses. For example, almost all descriptive investigations contain statistics on the families of plants used, the type of use, the part of the plant used, and sometimes some indication of relative importance through an index. However, the conclusions are often variations of the statement "Farmers have a deep knowledge of their plants" or a similar generality. The search for patterns, comparing results from nearby places, the same vegetation type or the same (or other) ethnicity is scarce. Publishing the underlying data permits reanalysis and synthesis under other perspectives, as in other disciplines.

Mexico is particularly well suited for comparative studies, with its varied physiography and the mosaic of diverse human populations that intermingle in different combinations. For example, careful documentation and comparisons of medicinal plants can answer questions such as: Is it the type of vegetation or the cultural heritage that is more important for determining which species treat certain diseases? Which plants are cultivated, and which are collected? From what vegetation type? How does gathering influence plant populations and their genetics? Which plants are adopted from outside? Under what circumstances are names adopted from outside, and when are new ones created? What is the role of social networks (of people, not digital)? What is the importance of outstanding or influential people? What role do people's idiosyncrasies play? How and when, and how fast do innovations spread? And behind it all: why?

Final considerations

This paper briefly analyzed the trends in ethnobotany in the last two decades. The discipline has had remarkable growth compared to other disciplines and science in general. Despite the internationalization of science, a substantial part of the literature is written in Spanish and even more in publications referring to Mexico. We describe the influence of different factors on the progress of the discipline and some selected topics, and suggest it is on the verge of becoming an analytical and predictive science.

Hopefully, we will soon know who plants or collects what, when, where and why, who learns and why, or be able to explain and quantify human influence on the evolution and distribution of plants and vegetation types today (Gómez-Pompa 1971). Then, we will be able to answer the question, "Are there universal principles of plant-human interactions that apply across cultures?" (Bennett 2002).

However, there are additional considerations. Since the end of the last century, the rise of sustainability science as an integrated framework to face the massive problems associated with the contemporary environmental crisis has shifted paradigms and revolutionized scientific work. It approaches environmental problems based on the systemic consideration of processes, recognizing that these systems are socio-ecological and highly complex, with multiple components and subsystems in interaction and mutual interdefinability, with emergent properties and high uncertainty. Several theorists of this scientific approach emphasize the extraordinary importance of including different sectors of society in diagnoses and decisions. Ethnobotany is a significant contributor, and one of its functions on the road ahead is to become part of science for sustainability.

Acknowledgements

We are grateful for the comments of Xitlali Aguirre Dugua and Karina Yaredi García Hernández.

Literature cited

Abad-Fitz I, Maldonado-Almanza B, Aguilar-Dorantes KM, Sánchez-Méndez L, Gómez-Caudillo L, Casas A, Blancas J, García-Rodríguez YM, Beltrán-Rodríguez L, Sierra-Huelsz JA, Cristians S, Moreno-Calles AS, Torres-García I, Espinosa-García FJ. 2020. Consequences of traditional management in the production and quality of *copal* resin (*Bursera bipinnata* (Moc. & Sessé ex DC.) Engl.) in Mexico. *Forests* **11:** 991. DOI: https://doi.org/10.3390/f11090991

Aguilar Contreras A, Xolalpa Molina S. 2002. La herbolaria mexicana en el tratamiento de la diabetes. *Ciencia* **53**: 24-35.

Aguirre-Dugua X, Eguiarte LE, González-Rodríguez A, Casas A. 2012. Round and large: morphological and genetic consequences of artificial selection on the gourd tree *Crescentia cujete* by the Maya of the Yucatan Peninsula, Mexico. *Annals of Botany* **109:** 1297-1306. DOI: https://doi.org/10.1093/aob/mcs068

Alarcon-Aguilar FJ, Roman-Ramos R. 2006. *Antidiabetic plants in Mexico and Central America*. *In*: Soumyanath A, ed. *Traditional Medicines for Modern Times: Antidiabetic Plants*. Boca Raton: CRC Press, Taylor & Francis Group, pp. 179-193. ISBN: 0-415-33464-0

Albuquerque UP, Ludwig D, Feitosa IS, de Moura JMB, de Medeiros PM, Gonçalves PHS, da Silva RH, da Silva TC, Gonçalves-Souza T, Ferreira Júnior WS. 2020. Addressing social-ecological systems across temporal and spatial scales: a conceptual synthesis for ethnobiology. *Human Ecology* **48:** 557-571. DOI: https://doi.org/10.1007/s10745-020-00189-7

Albuquerque UP, Nascimento ALB, Soldati GT, Feitosa IS, Campos JLA, Hurrell JA, Hanazaki N, de Medeiros PM, da Silva RRV, Ludwinsky RH, Ferreira Júnior WS, Reyes-García V. 2019. Ten important questions/issues for ethnobotanical research. *Acta Botanica Brasilica* **33:** 376-385. DOI: http://dx.doi.org/10.1590/0102-33062018abb0331

Alexiades MN. 2003. Ethnobotany in the third millennium: expectations and unresolved issues. *Delpinoa* **45:** 15-28.

Alexiades MN, Sheldon JW, eds. 1996. *Selected Guidelines for Ethnobotanical Research: A Field Manual*. New York: New York Botanical Garden. ISBN: 978-0893274047

Altieri MA. 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in Ecology and the Environment* **2:** 35-42. DOI: https://doi.org/10.1890/1540-9295(2004)002[0035:LEATFI]2.0.CO;2

Altieri MA, Toledo VM. 2011. The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *The Journal of Peasant Studies* **38:** 587-612. DOI: https://doi.org/10.1080/03066150.2011.582947

Argueta A, Gallardo Vázquez MC, eds. 1994. *Atlas de las Plantas de la Medicina Tradicional Mexicana*. Mexico City: Instituto Nacional Indigenista. ISBN: 968-29-7323-6

Arslan A, Taylor JE. 2009. Farmers' subjective valuation of subsistence crops: the case of traditional maize in

Mexico. *American Journal of Agricultural Economics* **91:** 956-972. DOI: https://doi.org/10.1111/j.1467-8276.2009.01323.x

Baker K, Bull GQ, Baylis K, Barichello R. 2017. Towards a theoretical construct for modelling smallholders' forestland-use decisions: what can we learn from agriculture and forest economics? *Forests* **8:** 345. DOI: https://doi.org/10.3390/f8090345

Balick MJ, Cox PA. 1996. *Plants, People, and Culture: The Science of Ethnobotany*. New York: WH Freeman & Co. ISBN: 978-0716750611

Begossi A. 1996. Use of ecological methods in ethnobotany: Diversity indices. *Economic Botany* **50:** 280. DOI: https://doi.org/10.1007/BF02907333

Bellon MR, Mastretta-Yanes A, Ponce-Mendoza A, Ortiz-Santa María D, Oliveros-Galindo O, Perales H, Acevedo F, Sarukhán J. 2021. Beyond subsistence: the aggregate contribution of campesinos to the supply and conservation of native maize across Mexico. *Food Security* **13:** 39-53. DOI: https://doi.org/10.1007/s12571-020-01134-8

Bennett BC. 2002. Ethnobotany and Economic Botany: subjects in search of definitions. *In: Encyclopedia of Life Support Systems*. Paris: UNESCO, EOLSS Publishers.

Berkes F, Folke C, Gadgil M. 1994. Traditional ecological knowledge, biodiversity, resilience and sustainability. *In:* Perrings CA, Mäler K-G, Folke C, Holling CS, Jansson B-O, eds. *Ecology, Economy & Environment*. *Biodiversity Conservation: Problems and Policies*. Dordrecht: Springer Netherlands, pp. 269-287. DOI: https://doi.org/10.1007/978-94-011-0277-3_15

Biggs R, de Vos A, Preiser R, Clements H, Maciejewski K, Schlüter M (eds). 2021. *The Routledge Handbook of Research Methods for Social-Ecological Systems*. London: Routledge. DOI: https://doi.org/10.4324/9781003021339

Blancas J, Abad-Fitz I, Beltrán-Rodríguez L, Cristians S, Rangel-Landa S, Casas A, Torres-García I, Sierra-Huelsz JA. 2021. Chemistry, biological activities, and uses of copal resin (*Bursera* spp.) in Mexico. *In*: Murthy HN, ed. *Gums, Resins and Latexes of Plant Origin: Chemistry, Biological Activities and Uses*. Cham: Springer, pp. 1-14. DOI: http://dx.doi.org/10.1007/978-3-030-76523-1_21-1

Blancas Vázquez JJ, Beltran Rodríguez L, Maldonado Almanza B, Sierra Huelsz JA, Sánchez Méndez L, Mena Jiménez F, García Lara F, Abad Fitz I, Valdez-Hernández JI. 2020. Comercialización de especies arbóreas utilizadas en medicina tradicional y su impacto en poblaciones silvestres. *La Biodiversidad en Morelos. Estudio de Estado 2. Vol. III.* Mexico City: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, pp. 215-223. ISBN: 978-6078570423

Bos N, Sundström L, Fuchs S, Freitak D. 2015. Ants medicate to fight disease. *Evolution* **69:** 2979-2984. DOI: https://doi.org/10.1111/evo.12752

Boukhdoud L, Saliba C, Parker LD, McInerney NR, Kahale R, Saliba I, Maldonado JE, Kharrat MBD. 2021. Using DNA metabarcoding to decipher the diet plant component of mammals from the Eastern Mediterranean region. *Metabarcoding and Metagenomics* **5:** e70107. DOI: https://doi.org/10.3897/mbmg.5.70107

Bye Jr RA. 1979. Incipient domestication of mustards in northwest Mexico. *Kiva* **44:** 237-256. DOI: https://doi.org/10.1080/00231940.1979.11757919

Bye Jr RA. 1981. Quelites – ethnoecology of edible greens – past, present and future. *Journal of Ethnobiology* **1:** 109-123.

Calzada F, Bautista E. 2020. Plants used for the treatment of diarrhoea from Mexican flora with amoebicidal and giadicidal activity, and their phytochemical constituents. *Journal of Ethnopharmacology* **253:** 112676. DOI: https://doi.org/10.1016/j.jep.2020.112676

Camou-Guerrero A, Casas A, Moreno-Calles AI, Aguilera-Lara J, Garrido-Rojas D, Rangel-Landa S, Torres I, Pérez-Negrón E, Solís L, Blancas J, Guillén S, Parra F, Rivera-Lozoya E. 2016. Ethnobotany in Mexico: history, development, and perspectives. *In:* Lira R, Casas A, Blancas J, eds. *Ethnobotany of Mexico: Interactions of People and Plants in Mesoamerica*. New York: Springer, pp. 21-39. DOI: https://doi.org/10.1007/978-1-4614-6669-7_2

Casas A, Lira R, Torres I, Delgado A, Moreno-Calles AI, Rangel-Landa S, Blancas J, Larios C, Solís L, Pérez-Negrón E, Vallejo M, Parra F, Farfán-Heredia B, Arellanes Y, Campos N. 2016. Ethnobotany for sustainable ecosystem management: a regional perspective in the Tehuacán Valley. *In*: Lira R, Casas A, Blancas J, eds. *Ethnobotany of Mexico: Interactions of People and Plants in Mesoamerica*. New York: Springer, pp. 179-206. DOI: https://doi.org/10.1007/978-1-4614-6669-7_8

Casas A, Otero-Arnaiz A, Pérez-Negrón E, Valiente-Banuet A. 2007. *In situ* management and domestication of plants in Mesoamerica. *Annals of Botany* **100:** 1101-1115. DOI: https://doi.org/10.1093/aob/mcm126

Casas A, Vallejo M. 2019. Agroecología y agrobiodiversidad. *In:* Merino-Pérez L, ed. *Crisis ambiental en México. Ruta para el Cambio.* Mexico City: Universidad Nacional Autónoma de México, pp. 99-117. ISBN: 978-6073023337

Case RJ, Tucker AO, Maciarello MJ, Wheeler KA. 2003. Chemistry and ethnobotany of commercial incense copals copal blanco, copal oro, and copal negro, of North America. *Economic Botany* **57:** 189-202. DOI: https://doi.org/10.1663/0013-0001(2003)057[0189:CAEOCI]2.0.CO;2

Castañeda R, Cáceres A, Velásquez D, Rodríguez C, Morales D, Castillo A. 2022. Medicinal plants used in traditional Mayan medicine for the treatment of central nervous system disorders: An overview. *Journal of Ethnopharmacology* **283:** 114746. DOI: https://doi.org/10.1016/j.jep.2021.114746

Castillo Acal DA. 2016. El uso del copal en la Península de Yucatán, México. *Desde el Herbario CICY* **8:** 73-76.

Castro-Lara D, Bye-Boettler R, Basurto-Peña F, Mera-Ovando LM, Rodríguez-Servín J, Álvarez-Vega J, Morales de León J, Caballero-Roque A. 2014. Revalorización, conservación y promoción de quelites: una tarea conjunta. *AGROProductividad* **7:** 8-13.

Challenger A. 1998. *Utilización y Conservación de los Ecosistemas Terrestres de México: Pasado, Presente y Futuro*. Mexico City: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. ISBN: 970-9000-02-0

Cházaro Basáñez M, Mostul BL, García Lara F. 2010. Los copales mexicanos (*Bursera* spp.). *Bouteloua* **7:** 57-70.

Choco P, Blanco L, Thiagarajan T. 2018. A comparative analysis of ethnobotanical use of medicinal plants by Q'eqchi'Maya of Sothern Belize and the Yucatec Maya of Northern Belize. *International Journal of Herbal Medicine* **6:** 1-8.

Citron DT, Way SF. 2018. Network assembly of scientific communities of varying size and specificity. *Journal of Informetrics* **12:** 181-190. DOI: https://doi.org/10.1016/j.joi.2017.12.008

Clement CR, Casas A, Parra-Rondinel FA, Levis C, Peroni N, Hanazaki N, Cortés-Zárraga L, Rangel-Landa S, Alves RP, Ferreira MJ, Cassino MF, Coelho SD, Cruz-Soriano A, Pancorbo-Olivera M, Blancas J, Martínez-Ballesté A, Lemes G, Lotero-Velásquez E, Bertin VM, Mazzochini GG. 2021. Disentangling domestication from food production systems in the Neotropics. *Quaternary* **4:** 4. DOI: https://doi.org/10.3390/quat4010004

Colunga García-Marín P, Hernández Xolocotzi E, Castillo Morales A. 1986. Variación morfológica, manejo agrícola y grado de domesticación de *Opuntia* spp. en el Bajío guanajuatense. *Agrociencia* **65**: 7-44.

Colunga GarcíaMarín P, Zizumbo Villareal D. 2009. Efraím Hernández Xolocotzi. Pilar de la etnobotánica mexicana. *La Jornada, Suplemento 'La Jornada del Campo'*, 12-12-2009.

Cotton CM. 1996. *Ethnobotany: Principles and Applications.* Chichester: John Wiley & Sons. ISBN: 978-0471955375

Cruz León A, Salazar Martínez L, Campos Osorno M. 2006. Antecedentes y actualidad del aprovechamiento de copal en la Sierra de Huautla, Morelos. *Revista de Geografía Agrícola* **37:** 97-115.

Cruz-Pérez AL, Barrera-Ramos J, Bernal-Ramírez LA, Bravo-Avilez D, Rendón-Aguilar B. 2021. Actualized inventory of medicinal plants used in traditional medicine in Oaxaca, Mexico. *Journal of Ethnobiology and Ethnomedicine* **17:** 7. DOI: https://doi.org/10.1186/s13002-020-00431-y

Cunningham AB, ed. 2001. *Applied Ethnobotany: People, Wild Plant Use, and Conservation*. London: Routledge. DOI: https://doi.org/10.4324/9781849776073

DeCarlo A, Dosoky NS, Satyal P, Sorensen A, Setzer WN. 2019. The essential oils of the Burseraceae. *In*: Malik S, ed. *Essential Oil Research: Trends in Biosynthesis, Analytics, Industrial Applications and Biotechnological Production*. Cham: Springer, pp. 61-145. DOI: https://doi.org/10.1007/978-3-030-16546-8_4

de Albuquerque UP, Hanazaki N. 2009. Five problems in current ethnobotanical research—and some suggestions for strengthening them. *Human Ecology* **37:** 653-661. DOI: https://doi.org/10.1007/s10745-009-9259-9

Drury R, Homewood K, Randall S. 2011. Less is more: the potential of qualitative approaches in conservation research. *Animal Conservation* **14:** 18-24. DOI: https://doi.org/10.1111/j.1469-1795.2010.00375.x

Figueredo-Urbina CJ, Casas A, Torres-Garcia I. 2017. Morphological and genetic divergence between *Agave inaequidens*, *A. cupreata* and the domesticated *A. hookeri*. Analysis of their evolutionary relationships. *PloS ONE* **12:** e0187260. DOI: https://doi.org/10.1371/journal.pone.0187260

Franceschet M. 2009. A comparison of bibliometric indicators for computer science scholars and journals on Web of Science and Google Scholar. *Scientometrics* **83:** 243-258. DOI: https://doi.org/10.1007/s11192-009-0021-2

Frei B, Sticher O, ViescaT C, Heinrich M. 1998. Medicinal and food plants: Isthmus Sierra Zapotec criteria for selection. *Angewandte Botanik* **72**: 82-86.

Gallardo Arias P. 2004. Los especialistas de la curación. Curanderos teenek y nahuas de Aquismón. *Anales de Antropología* **38:** 179-200. DOI: http://dx.doi.org/10.22201/iia.24486221e.2004.1.16589

Gaoue OG, Coe MA, Bond M, Hart G, Seyler BC, McMillen H. 2017. Theories and major hypotheses in ethnobotany. *Economic Botany* **71:** 269-287. DOI: https://doi.org/10.1007/s12231-017-9389-8

Gaoue OG, Moutouama JK, Coe MA, Bond MO, Green E, Sero NB, Bezeng BS, Yessoufou K. 2021. Methodological advances for hypothesis-driven ethnobiology. *Biological Reviews* **96:** 2281-2303. DOI: https://doi.org/10.1111/brv.12752

García-Hernández KY, Vibrans H, Colunga-GarcíaMarín P, Vargas-Guadarrama LA, Soto-Hernández M, Katz E, Luna-Cavazos M. 2021. Climate and categories: Two key elements for understanding the Mesoamerican hot-cold classification of illnesses and medicinal plants. *Journal of Ethnopharmacology* **266:** 113419. DOI: https://doi.org/10.1016/j.jep.2020.113419

García-Hernández KY, Vibrans H, Rivas-Guevara M, Aguilar-Contreras A. 2015. This plant treats that illness? The hot–cold system and therapeutic procedures mediate medicinal plant use in San Miguel Tulancingo, Oaxaca, Mexico. *Journal of Ethnopharmacology* **163:** 12-30. DOI: https://doi.org/10.1016/j.jep.2015.01.001

Geck MS, Cabras S, Casu L, Reyes García AJ, Leonti M. 2017. The taste of heat: How humoral qualities act as a cultural filter for chemosensory properties guiding herbal medicine. *Journal of Ethnopharmacology* **198:** 499-515. DOI: https://doi.org/10.1016/j.jep.2017.01.027

Geck MS, Lecca D, Marchese G, Casu L, Leonti M. 2021. Ethnomedicine and neuropsychopharmacology in Mesoamerica. *Journal of Ethnopharmacology* **278:** 114243. DOI: https://doi.org/10.1016/j.jep.2021.114243

Gigliarelli G, Becerra JX, Curini M, Marcotullio MC. 2015. Chemical composition and biological activities of fragrant Mexican copal (*Bursera* spp.). *Molecules* **20:** 22383-22394. DOI: https://doi.org/10.3390/molecules201219849

Gómez-Pompa A. 1971. Posible papel de la vegetación secundaria en la evolución de la flora tropical. *Biotropica* **3:** 125-135. DOI: https://doi.org/10.2307/2989816

González Jácome A. 2022. *Traditional Mexican Agriculture. A Basis for Sustainable Agroecological Systems*. Boca Raton: CRC Press. DOI: https://doi.org/10.1201/9781003198833

Hancock JF. 2005. Contributions of domesticated plant studies to our understanding of plant evolution. *Annals of Botany* **96:** 953-963. DOI: https://doi.org/10.1093/aob/mci259

Harzing A-W. 2017. Google Scholar is a serious alternative to Web of Science. *LSE Review of Books*. https://blogs.lse.ac.uk/impactofsocialsciences/2017/03/16/google-scholar-is-a-serious-alternative-to-web-of-science/ (accessed December 1, 2021)

Heinrich M. 2000. Ethnobotany and its role in drug development. *Phytotherapy Research* **14:** 479-488. DOI: https://doi.org/10.1002/1099-1573(200011)14:7<479::AID-PTR958>3.0.CO;2-2

Heinrich M, Ankli A, Frei B, Weimann C, Sticher O. 1998. Medicinal plants in Mexico: healers' consensus and cultural importance. *Social Science & Medicine* **47:** 1859-1871. DOI: https://doi.org/10.1016/s0277-9536(98)00181-6

Hernández Xolocotzi E. 1971. *Apuntes sobre la Explotación Etnobotánica y su Metodología*. Texcoco: Colegio de Postgraduados.

Hernández Xolocotzi E, Bello Baltazar E, Levy Tacher SI, eds. 1995. *La Milpa en Yucatán: Un Sistema de Producción Agrícola Tradicional*. Texcoco: Colegio de Postgraduados. ISBN: 968-839-158-1

Hersch-Martínez P, González Chévez L. 1996. Investigación participativa en etnobotánica. Algunos procedimientos coadyuvantes en ella. *Dimensión Antropológica* **8:** 129-153.

Hunn E. 2007. Ethnobiology in four phases. *Journal of Ethnobiology* **27:** 1-10. DOI: https://doi.org/10.2993/0278-0771(2007)27[1:EIFP]2.0.CO;2

Hurrell JA, de Albuquerque UP. 2012. Is ethnobotany an ecological science? Steps towards a complex ethnobotany. *Ethnobiology and Conservation* **1:** 4. DOI: https://doi.org/10.15451/ec2012-8-1.4-1-16

Jouault S, Enseñat-Soberanis F, Balladares-Soberano C. 2018. La milpa maya en Yucatán: ¿una transición entre la patrimonialización y la turistificación? *Gremium* **5:** 9-24. DOI: https://doi.org/10.56039/rgn10a03

Kato Yamakake TA, Mapes Sánchez C, Mera Ovando LM, Serratos Hernández JA, Bye Boettler RA. 2009. *Origen y Diversificación del Maíz: Una Revisión Analítica*. Mexico City: Universidad Nacional Autónoma de México, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. ISBN: 978-607-02-0684-9

Khoury CK, Brush S, Costich DE, Curry HA, de Haan S, Engels JMM, Guarino L, Hoban S, Mercer KL, Miller AJ, Nabhan GP, Perales HR, Richards C, Riggins C, Thormann I. 2021. Crop genetic erosion: understanding and responding to loss of crop diversity. *New Phytologist* **233**: 84-118. DOI: https://doi.org/10.1111/nph.17733

Kistler L, Thakar HB, VanDerwarker AM, Domic A, Bergström A, George RJ, Harper TK, Allaby RG, Hirth K, Kennett DJ. 2020. Archaeological Central American maize genomes suggest ancient gene flow from South America. *Proceedings of the National Academy of Sciences of the United States of America* **117:** 33124-33129. DOI: https://doi.org/10.1073/pnas.2015560117

Khoshbakht K, Hammer K. 2008. How many plant species are cultivated? *Genetic Resources and Crop Evolution* **55**: 925-928. DOI: https://doi.org/10.1007/s10722-008-9368-0

Kuhn TS. 1970. *The Structure of Scientific Revolutions*, 2nd ed. Chicago: University of Chicago Press. ISBN: 0-226-45804-0

Langenheim JH. 2003. *Plant Resins: Chemistry, Evolution, Ecology, and Ethnobotany*. Portland: Timber Press. ISBN: 978-0881925746

Larsen PO, von Ins M. 2010. The rate of growth in scientific publication and the decline in coverage provided by Science Citation Index. *Scientometrics* **84:** 575-603. DOI: https://doi.org/10.1007/s11192-010-0202-z

Leonti M. 2011. The future is written: impact of scripts on the cognition, selection, knowledge and transmission of medicinal plant use and its implications for ethnobotany and ethnopharmacology. *Journal of Ethnopharmacology* **134**: 542-555. DOI: https://doi.org/10.1016/j.jep.2011.01.017

Leonti M, Casu L, Martins DTO, Rodrigues E, Benítez G. 2020. Ecological theories and major hypotheses in Ethnobotany: their relevance for Ethnopharmacology and Pharmacognosy in the context of historical data. *Revista Brasileira de Farmacognosia* **30:** 451-466. DOI: https://doi.org/10.1007/s43450-020-00074-w

Leonti M, Sticher O, Heinrich M. 2002. Medicinal plants of the Popoluca, México: organoleptic properties as indigenous selection criteria. *Journal of Ethnopharmacology* **81**: 307-315. DOI: https://doi.org/10.1016/S0378-8741(02)00078-8

Linares E, Bye R, Ortega N, Eloy Arce A. 2017. *Quelites: sabores y saberes del sureste del Estado de México*. Mexico City: Universidad Nacional Autónoma de México. ISBN: 978-6070297663

Linares-Rosas MI, Gómez B, Aldasoro-Maya EM, Casas A. 2021. Nahua biocultural richness: an ethnoherpetological perspective. *Journal of Ethnobiology and Ethnomedicine* **17:** 33. DOI: https://doi.org/10.1186/s13002-021-00460-1

Lira R, Casas A, Rosas-López R, Paredes-Flores M, Pérez-Negrón E, Rangel-Landa S, Solís L, Torres I, Dávila P. 2009. Traditional knowledge and useful plant richness in the Tehuacán–Cuicatlán Valley, Mexico. *Economic Botany* **63:** 271-287. DOI: https://doi.org/10.1007/s12231-009-9075-6

Liu W. 2017. The changing role of non-English papers in scholarly communication: Evidence from Web of Science's three journal citation indexes. *Learned Publishing* **30:** 115-123. DOI: https://doi.org/10.1002/leap.1089

Lope-Alzina DG. 2014. Una red comunal de acceso a alimentos: el huerto familiar como principal proveedor de productos para intercambio en una comunidad maya-yucateca. *Gaia Scientia* **8**: 199-215.

Lucero-Gómez P, Mathe C, Vieillescazes C, Bucio L, Belio I, Vega R. 2014. Analysis of Mexican reference standards for *Bursera* spp. resins by Gas Chromatography–Mass Spectrometry and application to archaeological objects. *Journal of Archaeological Science* **41:** 679-690. DOI: https://doi.org/10.1016/j.jas.2013.07.021

Mariaca Méndez R. 2003. Prácticas, decisiones y creencias agrícolas mágico-religiosas presentes en el sureste de México. *Etnobiología* **3**: 66-78.

Mariaca Méndez R, Elizondo C, Ruan Soto F, Bolom-Ton F, eds. 2018. *Etnobiología y Patrimonio Biocultural de Chiapas Tomo I*. San Cristóbal de las Casas: El Colegio de la Frontera Sur. ISBN: 978-607-8429-66-0

Martin GJ. 1995. *Ethnobotany: A Methods Manual (People and Plants' Conservation Manuals)*. London: Chapman & Hall. ISBN: 978-0412483707

Martín-Martín A, Orduna-Malea E, Thelwall M, Delgado López-Cózar E. 2018. Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *Journal of Informetrics* **12:** 1160-1177. DOI: https://doi.org/10.1016/j.joi.2018.09.002

Martín-Martín A, Thelwall M, Orduna-Malea E, Delgado López-Cózar E. 2021. Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations. *Scientometrics* **126:** 871-906. DOI: https://doi.org/10.1007/s11192-020-03690-4

Martínez M. 1959. *Las Plantas Medicinales de México*, 4th ed. Mexico City: Ediciones Botas. ISBN: 968-6334-07-6

Mateos-Maces L, Chávez-Servia JL, Vera-Guzmán AM, Aquino-Bolaños EN, Alba-Jiménez JE, Villagómez-González BB. 2020. Edible leafy plants from Mexico as sources of antioxidant compounds, and their nutritional, nutraceutical and antimicrobial potential: a review. *Antioxidants* **9:** 541. DOI: https://doi.org/10.3390/antiox9060541

Medeiros MFT, da Silva TC, de Silva Sousa R, Silva RRV. 2014. Oral history in ethnobiology and ethnoecology. *In:* Albuquerque UP, Cruz da Cunha LVF, de Lucena RFP, Alves RRN, eds. *Methods and Techniques in Ethnobiology and Ethnoecology.* New York, NY: Humana Press, pp. 59-73. DOI: https://doi.org/10.1007/978-1-4614-8636-7_4

Méndez A. 2010. El Instituto Médico Nacional y el desarrollo de la ciencia en México. *Inventio* **6:** 33-41.

Méndez-Flores OG, Ochoa-Díaz López H, Castro-Quezada I, Olivo-Vidal ZE, García-Miranda R, Rodríguez-Robles U, Irecta-Nájera CA, López-Ramírez G, Sánchez-Chino XM. 2021. The milpa as a supplier of bioactive compounds: a review. *Food Reviews International* (Online First): 1-18. DOI: https://doi.org/10.1080/87559129.2021.1934001

Merali Z, Cayer C, Kent P, Liu R, Cal V, Harris CS, Arnason JT. 2018. Sacred Maya incense, copal (*Protium copal* - Burseraceae), has antianxiety effects in animal models. *Journal of Ethnopharmacology* **216:** 63-70. DOI: https://doi.org/10.1016/j.jep.2018.01.027

Mera-Ovando LM, Alvarado-Flores R, Basurto-Peña F, Bye-Boettler R, Castro-Lara D, Evangelista V, Mapes-Sánchez C, Martínez-Alfaro MÄ, Molina N, Saldivar J. 2003. "De quelites me como un taco". Experiencia en educación nutricional. *Revista del Jardín Botánico Nacional* **24:** 45-49.

Mera Ovando LM, Castro Lara D, Bye Boettler R, eds. 2011. *Especies Vegetales Poco Valoradas: Una Alternativa para la Seguridad Alimentaria*. Mexico City: Universidad Nacional Autónoma de México. ISBN: 978-6070225895

Miranda R, García-Carpintero E. 2018. Overcitation and overrepresentation of review papers in the most cited papers. *Journal of Informetrics* **12:** 1015-1030. DOI: https://doi.org/10.1016/j.joi.2018.08.006

Moreno-Calles AI, Galicia-Luna VJ, Casas A, Toledo VM, Vallejo-Ramos M, Santos-Fita D, Camou-Guerrero A. 2014. La etnoagroforestería: El estudio de los sistemas agroforestales tradicionales de México. *Etnobiología* **12:** 1-16.

Moreno-Calles AI, Toledo VM, Casas A. 2013. Los sistemas agroforestales tradicionales de México: Una aproximación biocultural. *Botanical Sciences* **91:** 375-398. DOI: https://doi.org/10.17129/botsci.419

Mulík S, Ozuna C. 2020. Mexican edible flowers: Cultural background, traditional culinary uses, and potential health benefits. *International Journal of Gastronomy and Food Science* **21:** 100235. DOI: http://dx.doi.org/10.1016/j.ijgfs.2020.100235

National Science Board, National Science Foundation. 2019. *Publication Output: U.S. Trends and International Comparisons.* Science and Engineering Indicators 2020. NSB-2020-6. Alexandria: National Science Foundation.

Newing H, Eagle C, Puri RK, Watson CW. 2011. *Conducting Research in Conservation*. Oxfordshire: Routledge. ISBN: 978-0-415-45792-7

Ojeda-Linares C, Álvarez-Ríos GD, Figueredo-Urbina CJ, Islas LA, Lappe-Oliveras P, Nabhan GP, Torres-García I, Vallejo M, Casas A. 2021. Traditional fermented beverages of Mexico: a biocultural unseen foodscape. *Foods* **10:** 2390. DOI: https://doi.org/10.3390/foods10102390

Orozco-Ramírez Q, Bocco G, Solís-Castillo B. 2020. *Cajete* maize in the Mixteca Alta region of Oaxaca, Mexico: adaptation, transformation, and permanence. *Agroecology and Sustainable Food Systems* **44:** 1162-1184. DOI: https://doi.org/10.1080/21683565.2019.1646374

Oses Gil A. 2010. El lenguaje de la etnobotanica. *Boletín Antropológico* **28:** 159-175.

Ostrom E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press. DOI: https://doi.org/10.1017/CBO9780511807763

Ostrom E, Burger J, Field CB, Norgaard RB, Policansky D. 1999. Revisiting the commons: local lessons, global challenges. *Science* **284:** 278-282. DOI: https://doi.org/10.1126/science.284.5412.278

Osuna Torres L, Tapia Pérez ME, Aguilar Contreras A. 2005. *Plantas Medicinales de la Medicina Tradicional Mexicana para Tratar Afecciones Gastrointestinales: Estudio Etnobotánico, Fitoquímico y Farmacológico*. Barcelona: Publicacions i Edicions Universitat de Barcelona. ISBN: 978-84-475-2986-5

Pardo de Santayana M, Gómez Pellón E. 2002. Etnobotánica: aprovechamiento tradicional de plantas y patrimonio cultural. *Anales del Jardín Botánico de Madrid* **60:** 171-182.

Parra F, Blancas JJ, Casas A. 2012. Landscape management and domestication of *Stenocereus pruinosus* (Cactaceae) in the Tehuacán Valley: human guided selection and gene flow. *Journal of Ethnobiology and Ethnomedicine* **8:** 32. DOI: https://doi.org/10.1186/1746-4269-8-32

Parra F, Casas A, Peñaloza-Ramírez JM, Cortés-Palomec AC, Rocha-Ramírez V, González-Rodríguez A. 2010. Evolution under domestication: ongoing artificial selection and divergence of wild and managed *Stenocereus pruinosus* (Cactaceae) populations in the Tehuacán Valley, Mexico. *Annals of Botany* **106:** 483-496. DOI: https://doi.org/10.1093/aob/mcq143

Pérez-Nicolás M, Vibrans H, Romero-Manzanares A. 2018. Can the use of medicinal plants motivate forest conservation in the humid mountains of Northern Oaxaca, Mexico? *Botanical Sciences* **96:** 267-285. DOI: https://doi.org/10.17129/botsci.1862

Pickersgill B. 2016. Domestication of plants in Mesoamerica: an archaeological review with some ethnobotanical interpretations. *In:* Lira R, Casas A, Blancas J, eds. *Ethnobiology*. *Ethnobotany of Mexico: Interactions of People and Plants in Mesoamerica*. New York: Springer, pp. 207-231. DOI: https://doi.org/10.1007/978-1-4614-6669-7_9

Posadas-Herrera BM, López PA, Gutiérrez-Rangel N, Díaz-Cervantes R, Ibáñez-Martínez A. 2018. La diversidad fenotípica de manzano en Zacatlán, Puebla, México es amplia y es aportada principalmente por características de fruto. *Revista Fitotecnia Mexicana* **41:** 49-58.

Pulido-Silva MT, Cuevas-Cardona C. 2021. La etnobiología en México vista a la luz de las instituciones de investigación. *Etnobiología* **19:** 6-28.

Purata Velarde SE, ed. 2008. *Uso y Manejo de los Copales Aromáticos: Resinas y Aceites*. Mexico City: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Quiñonez-Bastidas GN, Navarrete A. 2021. Mexican plants and derivates compounds as alternative for inflammatory and neuropathic pain treatment—A review. *Plants* **10:** 865. DOI: https://doi.org/10.3390/plants10050865

Quiroz Carranza JA, Magaña Alejandro MA. 2015. Resinas naturales de especies vegetales mexicanas: usos actuales y potenciales. *Madera y Bosques* **21:** 171-183.

Ramamoorthy TP, Bye R, Lot A, Fa J, eds. 1998. *Diversidad Biológica de México*: *Orígenes y Distribución*. Mexico City: Universidad Nacional Autónoma de México. ISBN: 968-3665888

Rivas Guevara MR, Rodriguez Haros B, Palerm Viqueira J. 2008. El sistema de jollas una técnica de riego no convencional en la Mixteca. *Boletín del Archivo Histórico del Agua* **13:** 6-16.

Romero-Estrada A, Maldonado-Magaña A, González-Christen J, Bahena SM, Garduño-Ramírez ML, Rodríguez-López V, Alvarez L. 2016. Anti-inflammatory and antioxidative effects of six pentacyclic triterpenes isolated from the Mexican copal resin of *Bursera copallifera*. *BMC Complementary and Alternative Medicine* **16:** 422. https://doi.org/10.1186/s12906-016-1397-1

Rzedowski J, Huerta M L. 1978. *Vegetación de México*. Mexico City: Limusa. ISBN: 978-9681800024

Sánchez-Ramos C, Vibrans H., Rivas-Guevara M, Linares-Mazari E, García-Moya E, Saynes-Vásquez A. (in press). Preserving healthy eating habits - quelites in the food system of a Nahua mountain community, Mexico. *In:* Casas A, Blancas Vázquez JJ, eds. *Ethnobotany of the Mountain Regions of Mexico.* Cham: Springer.

Sánchez Rosales G. 2012. El Instituto Médico Nacional y los inicios de la investigación médico-científica. *Ciencia* **63:** 10-17.

Sarukhán J (coord.). 2008. *Capital Natural de México*. Mexico City: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. ISBN: 978-607-7607-02-1

Saynes-Vásquez A, Vibrans H, Vergara-Silva F, Caballero J. 2016. Intracultural differences in local botanical knowledge and knowledge loss among the Mexican Isthmus Zapotecs. *PLoS One* **11:** e0151693. DOI: https://doi.org/10.1371/journal.pone.0151693

Schultes RE, von Reis S, ed. 1995. *Ethnobotany. Evolution of a Discipline*. Portland: Dioscorides Press. ISBN 0-931146-28-3

Shneider AM. 2009. Four stages of a scientific discipline; four types of scientist. *Trends in Biochemical Sciences* **34:** 217-223. https://doi.org/10.1016/j.tibs.2009.02.002

Shurkin J. 2014. News feature: Animals that self-medicate. *Proceedings of the National Academy of Sciences of the United States of America* **111**: 17339-17341. DOI: https://doi.org/10.1073/pnas.1419966111

Stepp JR. 2004. The role of weeds as sources of pharmaceuticals. *Journal of Ethnopharmacology* **92:** 163-166. DOI: https://doi.org/10.1016/j.jep.2004.03.002

Stepp JR. 2018. *Ethnoecology and Medicinal Plants of the Highland Maya*. Cham: Springer. DOI: https://doi.org/10.1007/978-3-319-69315-6

Tafur MM, Crowe TK, Torres E. 2009. A review of *curanderismo* and healing practices among Mexicans and Mexican Americans. *Occupational Therapy International* **16:** 82-88. DOI: https://doi.org/10.1002/oti.265

Tanaka MM, Kendal JR, Laland KN. 2009. From traditional medicine to witchcraft: why medical treatments are not always efficacious. *Plos One* **4**: e5192. DOI: https://doi.org/10.1371/journal.pone.0005192

Tapia-Tapia E del C, Reyes-Chilpa R. 2008. Productos forestales no maderables en México: aspectos económicos para el desarrollo sustentable. *Madera y Bosques* **14:** 95-112. https://doi.org/10.21829/myb.2008.1431208

Terán S, Rasmussen CH. 1994. *La Milpa de los Mayas. La Agricultura de los Mayas Prehispánicos y Actuales en el Noreste de Yucatán.* Mérida: DANIDA. ISBN: 978-9686834208

Toledo VM. 2001. Indigenous peoples and biodiversity. *In:* Levin SA, ed. *Encyclopedia of Biodiversity*. San Diego: Academic Press, pp. 451-463. ISBN: 978-0-12-226865-6

Toledo VM, Alarcón-Chaires P, Moguel P, Olivo M, Cabrera A, Leyequien E, Rodríguez-Aldabe A. 2001. El atlas etnoecológico de México y Centroamérica: fundamentos, métodos y resultados. *Etnoecológica* **6:** 7-41.

Torres-García I, Rendón-Sandoval FJ, Blancas J, Moreno-Calles AI. 2019. The genus *Agave* in agroforestry systems of Mexico. *Botanical Sciences* **97:** 263-290. DOI: https://doi.org/10.17129/botsci.2202

Tripplett KJ. 1999. The ethnobotany of plant resins in the Maya cultural region of southern Mexico and Central America. PhD. Dissertation, University of Texas at Austin.

Van Deynze A, Zamora P, Delaux PM, Heitmann C, Jayaraman D, Rajasekar S, Graham D, Maeda J, Gibson D, Schwartz KD, Berry AM, Bhatnagar S, Jospin G, Darling A, Jeannotte R, Lopez J, Weimer BC, Eisen JA, Shapiro H-Y, Ané JM, Bennett AB. 2018. Nitrogen fixation in a landrace of maize is supported by a mucilage-associated diazotrophic microbiota. *PLoS Biology* **16:** e2006352. DOI: https://doi.org/10.1371/journal.pbio.2006352

Vargas LA, Casillas LE. 1989. Medical anthropology in Mexico. *Social Science & Medicine* **28**: 1343-1349. DOI: https://doi.org/10.1016/0277-9536(89)90354-7

Vibrans H. 2016. Ethnobotany of Mexican weeds. *In*: Lira R, Casas A, Blancas J, eds. *Ethnobotany of Mexico*. New York: Springer New York, pp. 287-317. DOI: https://doi.org/10.1007/978-1-4614-6669-7_12

Vitousek PM. 1994. Beyond global warming: ecology and global change. *Ecology* **75**: 1861-1876. DOI: https://doi.org/10.2307/1941591

Voeks RA. 2018. *The Ethnobotany of Eden: Rethinking the Jungle Medicine Narrative*. Chicago: University of Chicago Press. ISBN: 978-0226547718

Waldstein A, Adams C. 2006. The interface between medical anthropology and medical ethnobiology. *Journal of the Royal Anthropological Institute* **12:** S95-S118. DOI: https://doi.org/10.1111/j.1467-9655.2006.00275.x

Wang L, Beissinger TM, Lorant A, Ross-Ibarra C, Ross-Ibarra J, Hufford MB. 2017. The interplay of demography and selection during maize domestication and expansion. *Genome Biology* **18:** 215. DOI: https://doi.org/10.1186/s13059-017-1346-4

Wellhausen EJ, Roberts LM, Hernández X E, Mangelsdorf PC. 1951. *Razas de Maíz en México, su Origen, Características y Distribución.* Mexico City: Secretaría de Agrícultura y Ganadería.

Zarazúa-Carbajal M, Chávez-Gutiérrez M, Peña-Mondragón JL, Casas A. 2022. Ecological knowledge and management of fauna among the Mexicatl of the Sierra Negra, México: An interpretive approach. *Frontiers in Ecology and Evolution* **10:** 760805. DOI: https://doi.org/10.3389/fevo.2022.760805

Zúñiga B, Guevara-Fefer P, Herrera J, Contreras JL, Velasco L, Pérez FJ, Esquivel B. 2005. Chemical composition and anti-inflammatory activity of the volatile fractions from the bark of eight Mexican *Bursera* species. *Planta Medica* **71:** 825-828. DOI: https://doi.org/10.1055/s-2005-871293

Guest editors: Arturo de Nova, Jorge A. Meave, Ken Oyama, Victoria Sosa.
Author contributions: HV wrote the first version of the manuscript; AC contributed ideas, some text, and revised.