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Classification and nomenclature of temperate forest types in Mexico

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Abstract

Aims: To analyze and synthesize the principal contributions to the creation of a classification of established forests in sub-humid, temperate climatic regions in Mexico. **Methods:** Documentary analysis and review of works on the classification of the vegetation of Mexico, with emphasis from 1950 to the present. To identify and analyze the terms frequently used to refer to these plant communities, the following was done: literature search, analysis of frequencies and co-occurrences of these terms that appeared in the titles of the documents. A list of associations of these communities was compiled through a documentary review. **Results:** Vegetation classification proposals, both nationally and internationally, tend towards the standardization of criteria and nested hierarchical integration at various levels based on physiognomic, climatic, phenological and floristic attributes. The two highest levels of organization in these proposals are based on major vegetation, defined by vegetation forms and climatic criteria as "temperate forests". Meanwhile lower levels, including the level of associations, are based on their floristic composition. The most frequently used term to refer to these plant communities, according to the documents used in the search, is "temperate forest", although other terms frequently used are "coniferous forest", "pine forest", and "oak forest". **Conclusions:** Knowledge about the classification of vegetation in Mexico dates back to pre-Hispanic times. However, it was not until the second half of the 20th century that solid proposals that are influential today were put forward. Given the high biological diversity of the country, it is still a pending task to characterize and make an inventory of the diversity at the level of associations that form this type of temperate forests.

Taxonomic reference: Villaseñor (2016).

Abbreviations: FVT = Trans-Mexican Volcanic Belt; SECLAVEMEX = Mexican Vegetation Classification System; SMO = Sierra Madre Oriental; SMOc = Sierra Madre Occidental; SMS = Sierra Madre del Sur (SMS).

Keywords

broadleaf forest, conifer forest, *Pinus* forest, *Quercus* forest, sub-humid temperate vegetation

Introduction

Classifying vegetation within a territory can be done from different approaches, come from different interests, and by using a wide range of criteria, allowing for many possibilities. One of the easiest and most practical ways is to separate natural vegetation from cultural vegetation. The first refers to the space where attributes regarding plant composition and structure in a community are determined by ecological processes that allow the evolutionary processes to continue their course, whereas in cultural

vegetation these attributes are determined by human activities (Küchler 1969). This form of classification facilitates the study and practical understanding of different plant formations and communities because it has implications for ecology as well as natural resource management. Hereinafter, natural vegetation types are addressed, specifically the forests that are distributed in sub-humid, temperate climatic conditions of Mexico.

In this sense, vegetation has been classified according to physiognomic-phytogeographic criteria and in association with climate in large environmental units, biomes, or their equivalent to large formations (Toledo and Ordóñez 1998). For the Mexican Republic, some authors have determined that there are between four or five different biomes (Velázquez et al. 2016) defined according to the dominant life form (Whittaker 1973): herbaceous, shrubs, and trees. Plant communities are the basic units that make up biomes, as vegetation types, also known as plant formations (Rzedowski 1978; De Cáceres et al. 2015).

The sub-humid temperate forest is a compound term that has a physiognomic connotation, that refers to the external characteristics of the set of dominant organisms that make it up, as well as a climatic connotation (Fosberg 1961). Meanwhile, "forest" refers to that group of plant organisms organized into populations and communities, where the dominant life form or biotope are trees, which presents the following as inherent attributes: woody stem, well-defined trunk, and a height greater than five meters (González-Medrano 2003; Velázquez et al. 2016). The term "temperate" comes from the classification of climates proposed by Köppen, in which its meteorological elements (temperature, pressure, wind, humidity, and precipitation) influence the distribution of biomes.

The knowledge and classification of vegetation in Mexico is not a new topic and dates back to pre-Hispanic times. According to González-Medrano (2003) and Velázquez et al. (2016), in earlier periods of time, the inhabitants of the Americas developed extensive knowledge about plants and vegetation in general, including their uses, properties, habitats, and classification. Vegetation was organized according to life forms, designating, and differentiating communities such as forests, grasslands, and pine forests, among others.

During the 16th and 19th centuries, knowledge about plants was focused on their medicinal properties, although authors such as Martin Sesse presented interesting, broader botanical works that were complemented by Humboldt's expeditions (1805). This is how, based on climatic and geographic data, Martens and Galeotti (1842), proposed a classification system of Mexico's vegetation in which they grouped the country according to climatic, topographic and latitudinal conditions. Grisebach (1872) in his work of the vegetation of the earth according to its climatic arrangement, discussed Mexico's mountainous regions and floristic diversity, and even differentiated oak from pine forests (González-Medrano 2003). These investigations contributed significantly to the knowledge that has led to an understanding of the country's vegetation.

In the 20th century, the most outstanding conceptual and methodological advances were developed (De Cáceres et al. 2015), which contributed to building proposals for the classification of vegetation around the world, including Mexico. Within the second half of the same century, several proposals for the taxonomic classification of vegetation were presented. These marked the beginning of a period of important and influential contributions that are still currently valid in both botany and in the field of taxonomic classification in the country. Nationally, authors such as Leopold (1950), Miranda and Hernández (1963), and Rzedowski (1978) have made the greatest contribution. Meanwhile, at international level, foundations were also laid for the theoretical and methodological framework that supported later proposed systems. From the beginning of the 21st century onwards, the most important works have been from Palacio-Prieto et al. (2000), Instituto Nacional de Estadística y Geografía (INEGI) (1999), González-Medrano (2003), and Velázquez et al. (2016).

According to Velázquez et al. (2010), harmonizing different levels of organization from subspecies to biomes is not a simple task because it implies incorporating both a conceptual and methodological framework. This has motivated the convergence of various disciplines in the effort towards harmonization, such as botany, geology, and geography, among others. Together with an increase in technological tools such as remote sensing and geographic information systems, this multidisciplinary approach has allowed filling in the gaps to create a more complete understanding, although a more complex one, yet still not free of ambiguities or confusions. The complexity of the biodiverse conditions that occur in the country, such as in temperate forests, where coniferous and broadleaf species converge and form a wide range of combinations between both taxonomic groups with different dominance, represent challenges when systematizing and classifying these communities.

This work analyzes the proposals and various ways of classifying forests distributed in the sub-humid temperate climate regions in Mexico from a diachronic standpoint. It also tries to identify the most frequently used names in literature to refer to these plant communities, and finally, to list some of the associations that have been described in these forests. This paper is structured into four main sections. The first presents the study area, the second section provides a detailed description of the methodological steps followed for the research. The third presents the results and includes a description of the distribution of temperate climate and its relationship with vegetation. The classification systems from the period 1950–1999 and from 2000 to the present are analyzed, concluding with a brief overview of the SECLAVEMEX classification system. The most frequently used names in academic literature to refer to this type of forest are presented. A list of some associations of these plant communities is provided, information that is further expanded upon in the Supplementary material. Finally, we conclude with a summary of the points discussed in this paper.

Study area

Mexico is geographically located in the northern part of the American continent and is characterized by a wide diversity of topographic forms as a product of past geological processes. These topographic forms have been designated for practical methodological purposes as physiographic provinces, in which four form the main mountain ranges: Sierra Madre Occidental (SMOc), Trans-Mexican Volcanic Belt (FVT), Sierra Madre Oriental (SMO), and Sierra Madre del Sur (SMS) (INEGI 2021), covering approximately 25% of the territory (González-Medrano 2003). It is in these regions where a temperate climate (Figure 1) predominates, and they are covered by extensive forested areas dominated by pine and oak species. These conditions, combined with components from the Nearctic, Northern, and Neotropical regions, have been fundamental factors that have given rise to the vast diversity of plant species that inhabit the country (Morrone 2005), currently considered megadiverse. It is estimated that there are a little over 23,000 species of vascular plants in the country, of which around 50% are endemic to Mexico (Rzedowski 1991; Villaseñor 2016). Additionally, it is considered a center of origin and diversification for a wide range of plant taxa. This diversification is represented at different levels of the classification of plant communities, from associations to biomes.

Methods

A review and documentary analysis of the main proposals for the classification of the vegetation in Mexico, which were proposed from 1950 onwards with emphasis on temperate forests, was carried out. This was followed by a search of literature to identify the most common terms used to designate these plant communities. Finally, we describe the steps that led to the creation of a list of associations that can be formed from these forests.

Documentary review of vegetation classification systems

Works considered in the analysis were divided into two time periods: 1950 to 1999 and 2000 to the present. Emphasis was placed on works that prioritize classification in the strict sense: Leopold (1950), Miranda and Hernández (1963), Rzedowski (1978), and some international references (UNESCO 1973). Approaches and main considerations of each one were synthesized, as well as the criteria they used, with a particular focus on temperate forests, through comparative tables and their respective analysis and discussion. Other works that have contributed to the development of this undertaking were reviewed, such as those from Gómez-Pompa (1965), Toledo and Ordóñez (1998), and INEGI (1999).

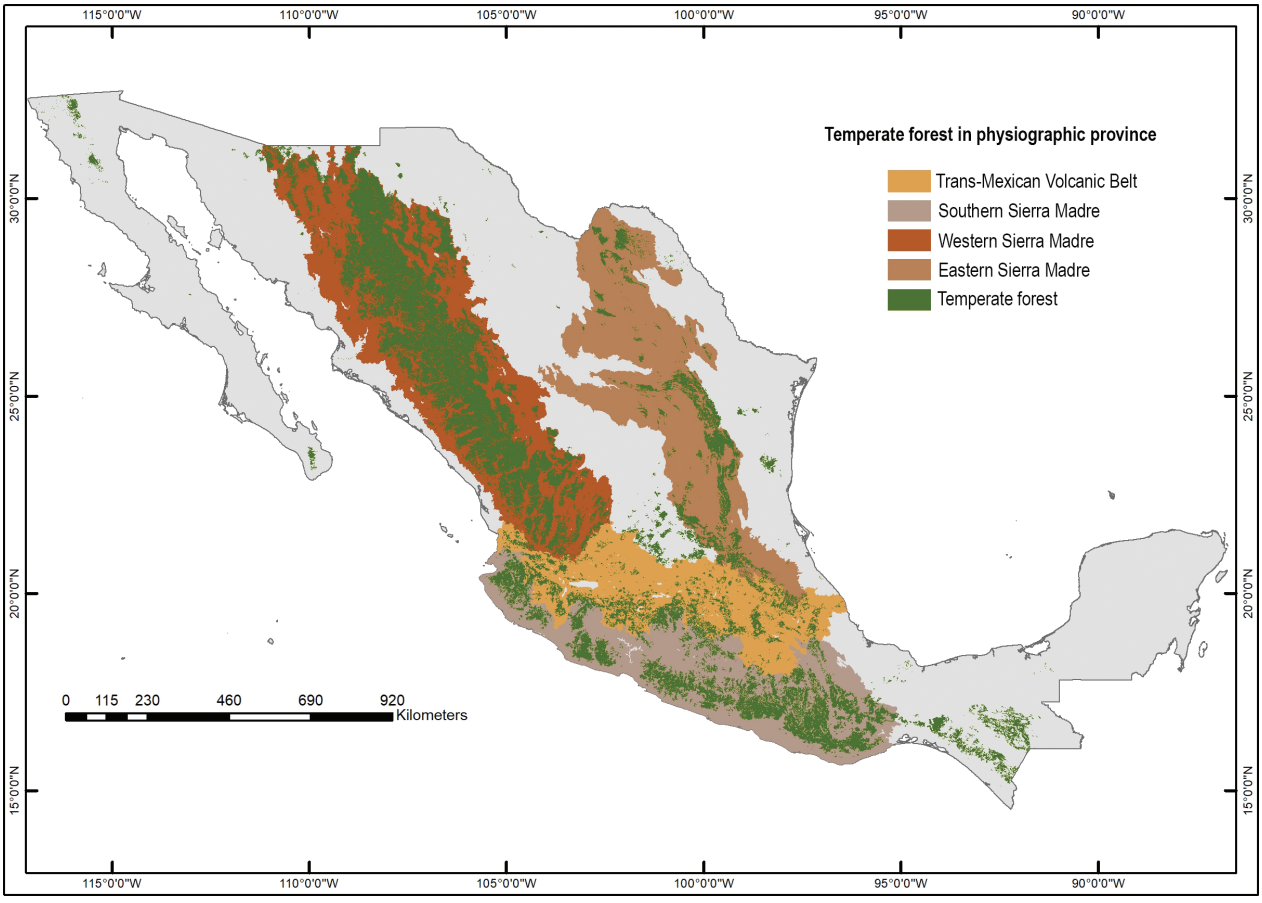

Figure 1. Distribution of temperate forests and sub-humid temperate climates in Mexico in the main physiographic provinces. Modified from INEGI (2021).

The analysis of the second period focused on the works of González-Medrano (2003) and Velázquez et al. (2016). In comparison with previous works, both contributions present important attributes, such as: compatibility with international classification systems and the use of physiognomic, climatic, phenological, and floristic criteria, which help to include and cover the high diversity of plant communities up to more detailed levels, such as associations. Other important publications, such as those from Palacio-Prieto et al. (2000), Velázquez et al. (2010), Villaseñor and Ortiz (2014), and the forest inventories carried out by the National Forestry Commission (CONAFOR) from 2004–2009 and 2017, contributed to enriching the analysis and discussion.

Documentary review to identify the use of names for these forests

To identify the most common names used in literature to refer to these forests, a review of document titles in academic literature was carried out. This began with a search in the Scopus database, entering as many terms as possible that have been used to designate these communities.

As inclusion criteria, the term "forest" was used in all search fields, in combination with other terms used to designate the type of forest, in such a way that the expected results were as broad and inclusive as possible. The terms used were: "temperate forest", "mix forest", "mixed forest", "pine forest", "oak forest", "fir forest", "pine-oak forest", "Pinus-Quercus forest", "Quercus-Pinus forest", "conifer forest", "coniferous forest", "Abies forest", "Abies religiosa forest", "Quercus forest", "Pinus forest", "broadleaf forest", and "Alnus forest". To include only works developed in Mexico, the term "mexic*" was added to find publications with any of the following terms in the title, abstract or keywords: Mexico, mexicano and mexicana. In addition, as a way of restricting the search to topics related to vegetation, the terms "vegetat*", "plant*", "flora", and "floristic" were entered in the search engine.

A table was constructed with the most frequent ways of naming these forests, which were integrated into a corresponding field according to the hierarchical levels of the most recent vegetation classification system used in Mexico. For the graphic visualization of these results, a frequency bar chart was created. In addition, a co-occurrence analysis was constructed in the VosViewer software to identify the way in which these terms are grouped based on keywords of the considered documents. Only these terms that presented a co-occurrence ≥2 were considered first, , subsequently excluding terms that were not associated with the theme of vegetation classification or the region or country of study, as well as those related to fauna or human actions. The co-occurrence map was constructed with a total of 78 items.

At the end, a list of associations identified in the literature for temperate subhumid forests of Mexico is presented. The International Code of Phytosociological Nomenclature (Theurillat et al. 2020) specifies that two is the maximum number of species to indicate an association; however, in the literature it is possible to find the use of two or three species. In this work, cases were identified with up to four, but this is not common. Therefore, an arbitrary criterion was established to have a maximum of three species to form an association and compile the list.

Results

The sub-humid temperate climate and vegetation in Mexico

The distribution of plant communities is largely influenced by meteorological elements such as temperature, pressure, wind, humidity, and precipitation – in other words, by climate. There are also other factors such as edaphic factors, topography, altitudinal gradients, and even evolution itself (Miranda and Hernández 1963; Rzedowski 1978; González-Medrano 2003). Five main climates have been identified around the world according to the system formulated by Wladimir Köppen, which are still used today (Peel et al. 2007); these are: tropical (A), warm (B), temperate (C), cold (D), and polar (E). However, in the Mexican Republic, according to modifications of the Köppen system proposed by García (2004), only A, B and C are present, which in turn are grouped into two large humid and arid groups, and five thermal categories.

Type C climate can be subdivided into sub-humid with summer rains (Cw), which occupies about 24% of the national territory (González-Medrano 2003), especially in mountains or plains with altitudes higher than 800 or 1000 meters. In Mexico, they are distributed particularly in the four physiographic provinces mentioned in the study area: SMOc, FVT, SMO, and SMS. These mountainous and climatic regions coincide with large forest areas of coniferous and broadleaf species (Figure 1).

As a consequence, proposals based on climate have been made to classify plant communities, such as those of Holdridge (1967), who proposed a diagram that represents the distribution of plant formations based on what he called "life zones". For the case of Mexico, Leopold (1950) grouped vegetation into temperate and tropical, and Gómez-Pompa (1965) into a) temperate or cold, b) arid or subarid climate, and c) warm climates.

Environmental features and habitat are factors that influence the way vegetation is named and classified. Thus, when the expression of large vegetation obeys climatic functions, it is considered zonal vegetation; and azonal when it depends on the conditions of the geological substrate and soil (González-Medrano 2003). Velázquez et al. (2016), for their part, apply a vegetation classification based on the climatic system according to García (2004), as well as the proposal of Holdridge (1967), considering only three climatic groups: temperate, tropical, and cold, in which they subdivide the temperate into dry and humid.

Other associated factors that stand out in the expression of vegetation at both local and regional levels are:

geological substrate, soil type, altitudinal gradient, orientation, and humidity (González-Medrano 2003; Sánchez-González and López Mata 2003). For example, in the case of soil, Rzedowski (1978) suggested that the predominance of oak forests over pine forests in the SMO is due to the tolerance of the former to soils approaching neutrality, as opposed to the soil conditions in the SMOc and FVT, where acidic soils predominate as a result of volcanic eruptions, which would favor the presence of pines.

Vegetation classification systems in Mexico

Period of 1950–1999

The period from 1950 to 1999 is characterized by the fruitful progress in creating knowledge around the vegetation of Mexico and its classification. The following sections present some of the most important contributions to this work, with emphasis on sub-humid temperate forests. At the international level, the UNESCO International Classification and Mapping of Vegetation (1973) is worth mentioning.

Leopold (1950), proposed 12 vegetation types in which the boreal forest and the pine-oak forest are located within the temperate zone; the first made up of three communities and the second of four, Table 1. The inclusion of a distribution map, the altitudinal range of its establishment, and the estimated area of each type of vegetation are outstanding attributes of this contribution; hence, it is considered one of the most relevant published from that time. In spite of this, the same author recognized certain arbitrary decisions in the inclusion of some categories; he even expressed that his objective was to divide the country into natural biogeographic units, and therefore, the task of critically defining plant communities would be assigned to specialists in flora ecology.

It was in this context a decade later that Miranda and Hernández (1963) proposed a classification system composed of 32 types of vegetation from a physiognomic approach, developed according to life forms and climatic criteria based on the Köppen system. Out of these 32, four are grouped within the temperate forests: 1) juniper forest, 2) pine forest, 3) holm oak forest, and 4) fir or oyamel forest. The first three are extended to other climatic expressions, while the last one is reduced to a single type in the mentioned system. An additional element of his work is a dichotomous key to determine these vegetation groups. Based on this contribution, Gómez-Pompa (1965) considered four types of vegetation formation for temperate climate: pine forests, oak forests, other associations and deciduous or deciduous forests.

During the years that followed, the work of Miranda and Hernández (1963) was widely used. However, in the opinion of Rzedowski (1978), it had its difficulties, which is why the latter presented his own proposal. In this proposal, he considered 10 types of vegetation

Table 1. Vegetation classification proposals for Mexico, period 1950–1999.

Authors	Climatic criteria	Types of vegetation or vegetation formation	Lower vegetation units
INEGI 1999	Forest	Conifers	Juniper forest
			Fir forest (includes spruce and cypress
			Pine forest
			Coniferous shrubs
		Conifers and broadleaves	Open lowland forest
			Pine-oak forest (includes oak-pine)
		Broadleaves	Oak forest
Toledo and Ordóñez 1998	Sub-humid temperate Cw	Pine forest	
		Oak forest	
		Mixed forest	
Rzedowski 1978	Temperate and semi-humid	*Quercus* forest	
		Coniferous forest	*Pinus* forest
			Pinus shrubs
			Abies forest
			Pseudotsuga and *Picea* forest
			Juniperus forest or shrubs
			Cupressus forest
Gómez-Pompa 1965	Temperate or cold climate	Pinares	
		Encinares	
		Other associations	
	Temperate or warm-humid transition	Deciduous forests	
Miranda and Hernández 1963	Cwb Cwa, Cwb	Enebro forest	
	Temperate (Cwb) and other climates Cwa, Cf	Pinares	
		Encinares	
Leopold 1950	Temperate	Boreal forest	Open pine forest
			Fir forest
			Pine-fir forest
		Pine-oak forest	Pine forest
			Open pine-oak forest
			Pinion-juniper woodland forest
			Oak shrubs

which, according to the same author, shared similarities with the work of Leopold (1950), given the number of classification categories.

The substantive points of Rzedowski's (1978) classification system included the exposition of a series of descriptive, ecological and distributional considerations for each category. Consequently, it is recognized by several authors as one of the most influential and outstanding works on Mexican vegetation and is still in use and commonly cited today, being used to estimate the surface area by vegetation type and in forest inventories. The *Quercus* forest and coniferous forest are two types of vegetation with a wide distribution in the country that prefer temperate and semi-humid climates, although are not limited to these climates. Another aspect to highlight is the use of the systematic name "*Quercus*" as the only vegetation type in which the genus name of the community's dominant species is used. In comparison, for coniferous forests he considers six subtypes which he names using the genus name.

Then at the end of the century, Toledo and Ordoñez (1998) considered three types of forests in regions with a sub-humid temperate climate, one of the six ecological zones into which the country is divided and which are also known as biomes or natural regions based on vegetation (Rzedowski 1978) and climate (García 1989). Although there were important contributions through proposals to organize plant community diversity during this period at the international level, some did so with little success, while others served mainly as a basis for continued refinement and improvement by including additional physiognomic, climatic, structural and floristic criteria over time.

These classification and nomenclature proposals influenced the naming of various vegetation types from associations to higher formations both in academic literature and for institutions responsible for natural resource management.

Period 2000-present

During this period, Mexico's vegetation classification was essentially addressed in two main works: that of González-Medrano (2003) and Velázquez et al. (2016), these are dealt with exclusively in the following section. In this period, INEGI (1999) also developed its own proposal for practical purposes intended for creating land use maps and vegetation charts in different series, as well as for the elaboration of forest inventories. It is worth mentioning that, both the classification in the strict sense and its practical version, are based on the work of Miranda and Hernández (1963) and Rzedowski (1978), although with an explicit tendency towards a hierarchical structure and with physiognomic, climatic, floristic, and even edaphological or disturbance criteria (Table 2).

González-Medrano (2003), for his part, considered that the physiographic, climatic and biotic characteristics of a country like Mexico, together with structural and phenological physiognomic features, provided the appropriate elements to differentiate and classify vegetation cover. Consequently, he proposed a system based on five criteria: 1) life form: tree, shrub, herbaceous, lianas; 2) function: foliage conditions, phenology; 3) size of life form: high, medium, low; 4) texture and consistency of leaves and stems; and 5) coverage. These criteria are incorporated into one of two climatic zones – zonal or azonal – which in the case of the former, corresponds to the product of climatic conditions, and in the latter to local and regional conditions such as soil and substrate. In a higher hierarchy, there are three major climatic zones: a) tropical, b) temperate, and c) arid and semi-arid.

There are other works that did not necessarily aim to classify vegetation yet made their contributions to the topic from their own particular objectives and interests. Such

Table 2. Types of biomes or plant formations and types of vegetation in temperate climates.

Authors	Major formation	Types of temperate vegetation, formations	Lower vegetation units
CONAFOR 2017	Conifers	Spruce forest	
		Cypress forest	
		Fir forest	
		Pine forest	
		Juniper forest	
		Coniferous shrubs	
	Conifers and broadleaves	Oak-pine forest	
		Pine-oak forest	
	Broadleaves	Oak forest	
		Gallery forest	
González-Medrano 2003	Biome Temperate forests	High temperate *linearifolio* forest (Cwb)	
		Medium temperate *acicudurifolio* forest (Cf, Cw, Cwa)	
		Medium temperate *duriaciuclifolio* forest (Cwa, Cwb)	
		Medium temperate *durifolio* forest (Cf, Cwa, Cwb)	
		Lowland temperate *escuamifolio* forest (Cwa, Cwb)	
		Medium temperate *caducifolio* forest (Cfb, Cwb)	
		Lowland temperate *escuamiaciculifolios* forest (Cwa, Cwb)	
		Lowland temperate *duriescuamifolios* forest (Cwa, Cwb)	
Palacio-Prieto et al. 2000	Biome Formation: forests	Conifers	Juniper forest
			Fir forest (includes spruce and cypress)
			Pine forest and coniferous shrubs
		Conifers and broadleaves	Open lowland forest
			Pine-oak forest (includes oak-pine)
		Broadleaves	Oak forest

is the case of Villaseñor and Ortiz (2014), whose work based on that of Rzedowski (1978) grouped vegetation into five major biomes. One of them, the temperate forest, included four types of vegetation: *Abies* forest, oak forest, pine-oak forest, and *Pinus* forest. This work brought together the important characteristics of classifying vegetation, while estimating the number of Magnoliophyta species in each biome and their vegetation type and endemism. Recently, Loidi et al. (2022) proposed a global classification system with nine major biotic units or biomes defined based on climatic criteria, that also includes Mexican temperate forests.

Palacio-Prieto et al. (2000), grouped vegetation in a hierarchical system, and with biological criteria: phenological, floristic, and dasometric. Here the minimum unit or level would be represented by stands, and the highest level by biomes; in each level they highlight the defining criteria, as well as the approximate scale for its cartographic representation. However, they only focused on three main levels: 1) formation, 8 groups; 2) type of vegetation and soil, 16 types; and 3) community and other coverages, 46. In forest formations, it considered the following forests: coniferous, coniferous-broadleaf, and broadleaf, and within these, seven plant communities (Table 2).

Moving forward, its use has stood out for its practicality, and is the basis for INEGI in quantifying the uses of soil and vegetation throughout the country. However, CONAFOR also applied this system as a reference together with INEGI's modifications, to elaborate the national and soil inventories for the years of 2004–2009 and 2017. However, for Palacio-Prieto et al. (2000) vegetation types were formed by six communities that included the fir forest and within that the spruce and cypress forest. Taking a different approach in their most recent forest inventory, CONAFOR (2017) divided these communities into 10 categories, but now they designate them as types of vegetation.

Vegetation of sub-humid temperate climate based on SECLAVEMEX

The contributions of different international classification systems as well as those developed in Mexico, combined with the development in research on vegetation given the biodiverse nature of the country, have resulted in the Mexican Vegetation Classification System (SECLAVEMEX), a proposal by Velázquez et al. (2016). This system is hierarchically structured in eight nested levels. Levels I to III are based on physiognomic and environmental criteria, while IV to VI are botanical and floristic in nature. The last two levels, sub-association and facies, are established by edaphic and substrate characteristics in that order, considering the degree of disturbance or ecological succession of the community.

Some of the qualities of this system include recognition, versatility, and reorganization, which involve harmonizing and comparing classification proposals, particularly those of Miranda and Hernández (1963), Rzedowski (1978), Technical Consultative Commission for the Definition of Grazing Coefficients (COTECOCA 1994), and González-Medrano (2003). This is further complemented by compatibility with global systems, such as the European phytosociological approach and the North American EcoVeg approach (Faber-Langendoen et al. 2014, 2016; Velázquez et al. 2016) (Table 3). In addition, it seeks to satisfy both technical and academic needs, as well as those of practical use, such as for institutions responsible for natural resource management, including field data collectors. In addition, it foresees adaptations that may arise due to the dynamism of vegetation, such as changes from natural to cultural. Finally, it considers the presence of exceptions as a product of the evolutionary history of vegetation and the biogeographic history in Mexico.

Table 3. Levels of classification for the Mexican Vegetation System and other systems.

Levels	SECLAVEMEX	Phytosociological	EcoVeg
I	Biome	Class	Class formation
II	Major formation	Subclass	Subclass formation
III	Formation		Formation
IV	Subformation	Order	Division
V	Series of associations	Alliance	Macrogroup
VI	Association	Association	Group
VII	Subassociation	Subassociation	Alliance
VIII	Facie	Facies	Association

In the case of temperate forests, this system would only include up to level VI Associations. As mentioned, levels VII and VIII depend on edaphic and substrate conditions, attributes that are not considered at this level. Table 3 shows the levels in which temperate forests are integrated in this classification system, and Table 4 shows the criteria for the vegetation types of these forests.

The eight levels that make up this system are designed with the purpose of grouping or naming all plant communities, although not all levels use all the criteria to define a particular type of community.

Level I Biome. The highest level encompasses all lower levels; it is defined by physiognomic criteria (forest, shrubland, herbaceous), which is a function of the dominant life form. Level II Major formation. Defined by climatic criteria, based on García (2004) and Holdridge (1967). Level III Formation. This is a function of phenological criteria, i.e. the fall or permanence of foliage (deciduous, sub-deciduous, evergreen, sub evergreen), a condition that depends on the amount or percentage of the fall or permanence of foliage.

Level IV Subformation. Depends on phenological and floristic criteria, such as leaf characteristics, presence of thorns or leaf succulence. In the particular case of humid and sub-humid temperate forests, these are characterized by the absence of dominant species with thorns or succulence, so only the characteristics of leaves, their shape and anatomy are considered. Level V Series of Associations. Part of the floristic criterion, in which two hierarchical criteria are used: family level, or dominant genera. Level VI Association. Finally, for the association level, the floristic criterion is taken into consideration, although unlike level V, it uses one to three or more dominant species as a reference.

Table 4. Hierarchical levels of SECLAVEMEX for temperate forests in Mexico.

Hierarchical levels				
I	**II**	**III**	**IV**	**V**
SECLAVEMEX category				
Biome	Major formation	Formation	Subformation	Series of associations
Definition criterio				
Physiognomic	Type of climate	Foliage phenology	Morphology of leaves	Genus dominance
		Stratum height		
Forest	Temperate	Evergreen	Linea leaved	*Abies*
				Pseudotsuga and *Picea*
			Needle leaves	*Pinus*
			Scale-leaves	*Cupressus*
			Needle leaves, scale- linearifolius	*Juniperus*
				Pinus and *Juniperus*
			Broadleaves and needle leaves	*Pinus* and *Abies*
				Pinus and *Quercus*
				Quercus
		Sub-evergreen, sub-deciduous	Broadleaves	*Quercus*
		Deciduous	Broadleaves	*Alnus*
				Quercus

Use of terms for naming temperate forests in the academic literature

The document search process yielded a total of 360 documents, of which 92 were considered for analysis. From a review of these, the use of 18 terms to refer to this type of plant communities was identified (Table 5). The most commonly used term was "temperate forest", which appears in 34 titles of these documents, followed by the terms "oak forest" and "pine-oak forest", with 14 and 10 appearances respectively. These three together account for 63% of terms used.

Table 5. Terms used to name temperate forests in academic literature.

Terms in title	**Documents**	**SECLAVEMEX level**
Temperate forest	34	Major formation
Conifers	6	Subformation
Mixed conifers	5	
Conifers and broadleaves	1	
Conifers and *Quercus*	1	
Oak	14	Series of associations
Pine-oak	10	
Pine	4	
Mixed	1	
Oak-pine	2	
Quercus	1	
Pinus-Quercus-Abies	1	
Quercus-Pinus	1	
Secondary mixed pine-oak	1	
Abies religiosa	4	Associations
Fir	4	
Pinus pinceana	1	
Pinus ponderosa	1	

The term temperate forest has been used in a conventional way to refer to these formations, from the work of Leopold (1950) to Velázquez et al. (2016), as analyzed in both periods in previous sections. It is frequently used in classification systems as a reference to plant communities established in this type of climatic conditions – both in those proposed worldwide and in those of Mexico, Velázquez et al. (2016). According to the SECLAVEMEX system, this term is included within the major formation level (Level II), given that in this hierarchical system the two highest levels are integrated with floristic and climatic criteria. The other two terms, pine forest and oak-pine forest, would be included within the series level of associations of the aforementioned system.

This suggests that the vegetation classification proposals that have had an important influence on the use of one or another denomination come from the works of Rzedowski (1978), Miranda and Hernández (1963), or INEGI (1999), and to be more specific, names of well-marked plant associations such as *Abies* and fir forest are often used.

Coniferous, mixed coniferous, coniferous and broadleaved, and coniferous and Quercus forests are located within the Subformation level, which total 13 documents. The term conifers is based strictly on physiognomic criteria, given that the external physical appearance of the taxa grouped within is cone-shaped, which is represented in 11 titles of the documents found. It appears formally in Rzedowski's classification system (1978) and was taken up by Palacio-Prieto et al. (2000) to designate a type of vegetation within forest formation, which is also used in CONAFOR's forest inventories and in INEGI's land use and vegetation inventories.

At the association series level, there are 35 documents that use the terms oak forest, pine-oak forest, pine forest and other variants, such as *Quercus-Pinus* and mixed. In this context, Rzedowski (1978) used the term *Quercus* to refer to oak forests, which is the technical name that groups all oak species and although it is uncommon to use it in the titles of academic documents, the term persists, suggesting the author's influence. On the other hand, Miranda and Hernández (1963), used the term *encinares*, which was no longer used in later classification systems and was not even found in the titles of these revised documents. However, for practical uses, like in forest inventories and wherever the term oak forests is used, it can specifically refer to oak forests or to pine-oak forests.

According to the results on the level of associations of different terms, the presence of these in document titles refer to *Abies religiosa* or *oyamel* forests, which are used

indistinctly and with the same number of appearances (4). The other two identified are for *Pinus ponderosa* and *Pinus pinceana* forests (1 each; Miranda and Hernández 1963).

The terms with a high co-occurrence of keywords are: "*Quercus*", "temperate forest", "coniferous forest", "*Abies religiosa*", with 22, 15, 11 and 10 respectively, and present the highest number of interactions with other terms (Figure 2). This would suggest that "*Quercus*" is an alternative term widely used to indicate that the titles of academic documents would refer to a type of vegetation community composed of oak forest or mixed pine-oak forest (Figure 3). Similarly, the other keywords with a high number of co-occurrences such as "coniferous forest" or "temperate forest" indicate that they are either a community with a predominance of some of the coniferous species, or any forest related to temperate climate in general.

Temperate Forest Associations and Associations Series

As previously mentioned, in sub-humid temperate forests, predominantly conifer and broadleaf communities are established, either independently or forming associations between one another, along with mixed conifer and broadleaf forests. The conifer group in Mexico is represented by four families (Pinaceae, Cupressaceae, Podocarpaceae and Taxaceae), 94 species, and 10 genera (Gernandt and Pérez-de la Rosa 2014). The genera *Pinus*, *Abies*, *Pseudotsuga*, and *Cupressus* mainly form the Series of Associations: *Pinus-Pinus*, *Pinus-Abies* or *Cupressus-Pseudotsuga*, among others. These, in turn, are integrated in Associations either with the dominance of one, two or more species (Braun-Blanquet 1974) – for example, *Pinus hartwegii* or *Abies religiosa*, *Pinus pseudostrobus*, or associations between species of the same genus, two or more genera as shown in Table 6, which expands on what is presented in Suppl. material 1.

The Subformation of mixed coniferous and broadleaf forests is a combination of coniferous and broadleaf species, in their various proportions. The most common are Series of Associations such as *Pinus-Quercus* and *Quercus-Pinus*, and to a lesser extent *Abies-Quercus*, *Quercus-Cupressus*, and *Pseudotsuga-Quercus-Cupressus*, Table 6 and Suppl. material 2.

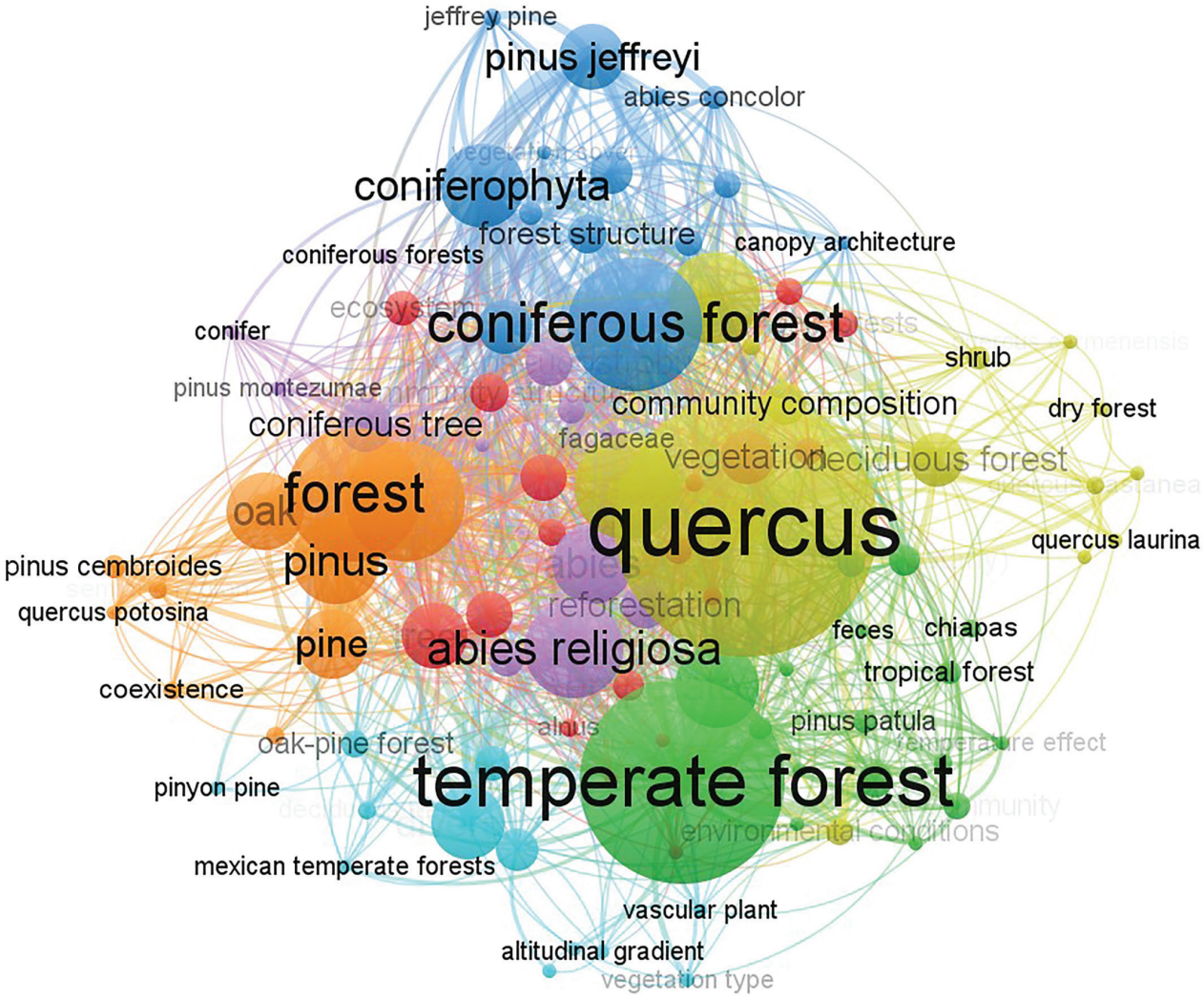

Figure 2. Map of co-occurrence of terms for sub-humid temperate climate plant communities.

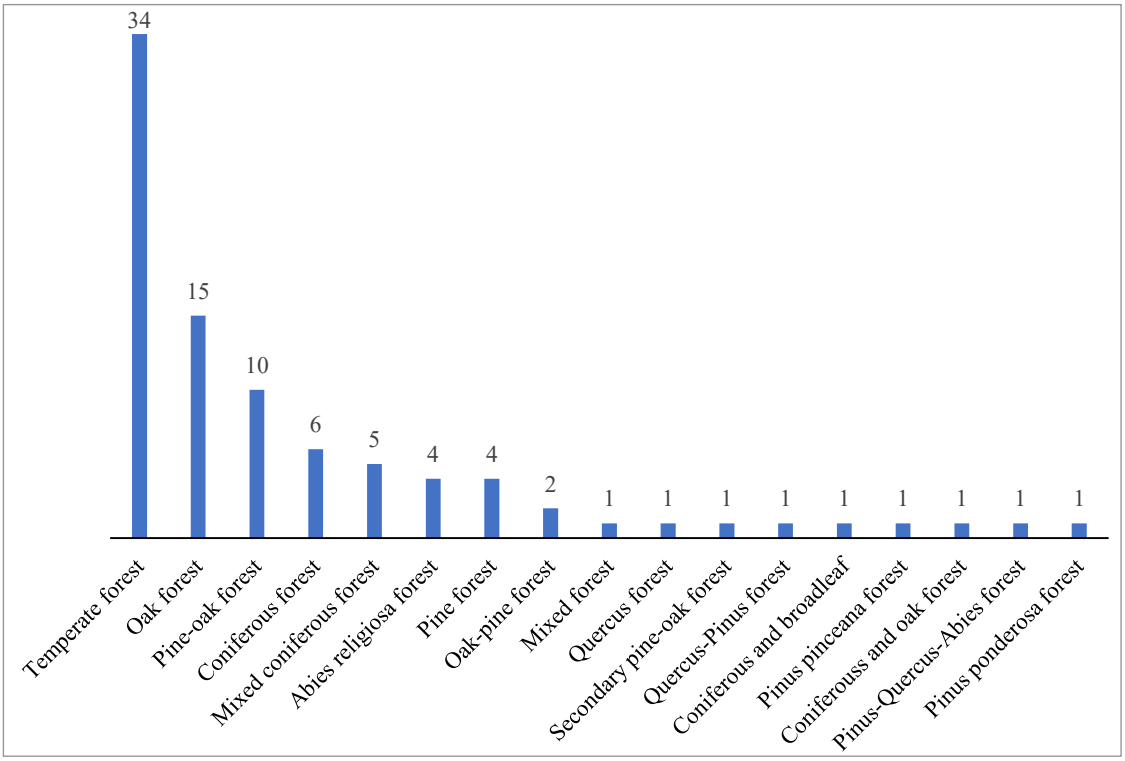

Figure 3. Frequency of the most common terms of temperate forests.

Table 6. Associations and series of associations of the subformations of sub-humid temperate forest.

Subformation	Series of Associations	Association	Reference
Mixed conifers	*Pinus-Pinus*	*Pinus durangensis-Pinus teocote*	Graciano-Ávila et al. (2020)
	Pinus-Abies	*Pinus durangensis-Abies durangensis*	Valenzuela-Núñez and Granados-Sánchez (2009)
	Pinus-Cupressus	*Pinus patula-Cupressus lusitanica*	Almeida-Leñero et al. (2007), Velázquez et al. (2010)
	Abies-Pinus	*Abies durangensis-P. ayacahuite*	Holguín-Estrada et al. (2021)
	Pinus-Abies-Pseudotsuga	*Pinus durangensis-Abies durangensis-Pseudotsuga menziesii*	Valenzuela-Núñez and Granados-Sánchez (2009)
	Cupressus-Pseudotsuga	*Cupressus lusitanica-Pseudotsuga menziesii*	García-Arévalo (2008)
Conifers and broadleaves	*Pinus-Quercus*	*Pinus durangensis-Q sideroxyla*	Graciano-Ávila et al. (2020)
	Quercus-Pinus	*Quercus canbyi-P. teocote*	Estrada-Castillón et al. (2015)
	Quercus-Abies	*Abies religiosa-Q. laurina*	Almeida-Leñero et al. (2007), Velázquez et al. (2010)
	Pinus-Acacia	*Pinus cembroides-Acacia schaffnerii*	Valenzuela-Núñez and Granados-Sánchez (2009)
	Juniperus-Quercus	*Juniperus flaccida-Quercus potosina*	Siqueiros-Delgado et al. (2016)
	Cupressus-Quercus	*Cupressus lusitanica-Quercus rugosa*	Siqueiros-Delgado et al. (2016)
	Quercus-Cupressus-Alnus	*Q. crassifolia-C. lusitanica-Alnus oblongifolia*	Holguín-Estrada et al. (2021)
	Pinus-Quercus-Pinus	*Pinus durangensis-Q. sideroxyla-P. ayacahuite*	Holguín-Estrada et al. (2021)
	Abies-Quercus	*Abies religiosa-Q. laurina*	Almeida-Leñero et al. (2007)
Broadleaves	*Quercus-Quercus*	*Q. laurina-Q. rugosa*	Almeida-Leñero et al. (2007), Martínez-Cruz et al. (2009)
	Quercus-Arctostaphylos	*Quercus potosina-Arctostaphylos pungens*	Martínez-Calderón et al. (2021)
	Quercus-Quercus-Quercus	*Quercus chihuahuensis-Q. praeco-Q. laeta*	Siqueiros-Delgado et al. (2016)

In the broadleaf Subformation, species belonging to the *Quercus* genus dominate, although they are also associated with other genera such as *Alnus* and even *Arctostaphylos*. The Series of Associations that these form are: *Quercus-Quercus*, *Quercus-Alnus*, and less frequently *Quercus-Arctostaphylos*. Similar to what happens with *Pinus* associations, where a single species usually dominates, in the case of broadleaved trees, these are frequently *Quercus rugosa* and *Quercus deserticola*, among others. In other cases, they are usually formed by two or more *Quercus* species such as: *Quercus rugosa-Quercus laurina*, Table 6 and Suppl. material 3.

Conclusions

Grouping and classifying the diversity of plant communities distributed throughout the Mexican territory has been a complex task, despite the various efforts made. This complexity is accentuated by the diverse physical and biotic attributes present in a country like Mexico, among which the climatic and physiographic factors stand out, as well as those of biodiversity in all its expressions. Therefore, this work is a continuous process of construction, evolution and refinement.

Some of these classification systems proposed over time have been influential and have transcended both

academia and practical use, while others are no longer in use. Nevertheless, these proposed systems contributed to the construction of more refined classification systems, thus reducing the confusion and ambiguities once present. The most recent proposals have allowed for a greater inclusion and integration of a wide diversity of plant communities, as well as compatibility with global systems.

The sub-humid temperate forests are a clear example of terrestrial biomes that present the peculiarities mentioned in previous paragraphs. In this sense, a wide variety of names and forms have been identified to refer to these plant communities, which arose as a result of some of the classification systems. The term temperate forest has been the term most widely used. Others of note are: coniferous forest, mixed forest, *Abies religiosa* forest or oyamel forest, and oak forest.

Despite the fact that the most recent classification and characterization systems are increasingly sophisticated and include more detailed levels, challenges still remain. Given the high diversity of conifer and broadleaf species that inhabit Mexico, combined with the diversity of associations that form both groups, one outstanding challenge involves identifying and creating an inventory of the associations that form these types of communities, as well as establishing criteria regarding the maximum number of dominant species to designate an association.

Data availability

A list of the data used for this publication is provided as Suppl. material 4.

Author contributions

VAA planned the research and translated the paper into English, RRE conducted the documentary review, statistical analysis and wrote part of the paper in Spanish, TGM helped in the analysis of information and the writing of the paper, BPG and DSG helped with the compilation and review of the information. All authors critically revised the manuscript.

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Supplementary material

Supplementary material 1
Mixed coniferous forest associations
Link: https://doi.org/10.3897/VCS.100796.suppl1

Supplementary material 2
Mixed coniferous and broadleaf forest associations
Link: https://doi.org/10.3897/VCS.100796.suppl2

Supplementary material 3
List of oak forest associations
Link: https://doi.org/10.3897/VCS.100796.suppl3

Supplementary material 4
References to identify most frequently used terms for temperate subhumid forests in Mexico
Link: https://doi.org/10.3897/VCS.100796.suppl4