Artículo

El monitoreo forestal por medio de Sitios Permanentes de Investigación Silvícola en Chihuahua, México
Forest monitoring by means of Permanent Plots for Forestry Research in Chihuahua, México

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Resumen

El monitoreo forestal es de gran interés para integrar bases de datos que permitan generar conocimiento y nuevas tecnologías para optimizar la producción, proteger los recursos y acrecentar el valor de los bosques, a través del manejo forestal sustentable. En el estado de Chihuahua, el monitoreo para el desarrollo de conocimiento científico relativo a estos ecosistemas se inició en 1950 con el establecimiento del primer Sitio Permanente, de Investigación Silvícola (SPIS), en el paraje conocido como "El Poleo", el cual se ubica en el norte del municipio Madera. En la década de 1980-1990 se establecieron 234 parcelas en el área experimental del INIFAP, localizada en la región sur del ejido El Largo; de 1990 a 2000, se implementaron 48 parcelas en el municipio Bocoyna y 16 en el municipio Guachochi, como parte del proyecto: Bosque Modelo. Finalmente, entre 1998 y 2001 se delimitaron 48 parcelas en el municipio Guadalupe y Calvo con el apoyo del Programa de Desarrollo Forestal (Prodefor). Las parcelas localizadas en El Poleo, Madera, Llano blanco, así como Guadalupe y Calvo tienen datos de remediciones periódicas; las cuales muestran incrementos medios anuales superiores a 4 m^3ha^{-1}, con registros de hasta 16 m^3ha^{-1} en el sur de la entidad. La información histórica y las bases de datos de los SPIS son un valioso antecedente para el seguimiento de los programas de monitoreo y el desarrollo de métodos silvícolas para el manejo sustentable de los bosques de la región.

Palabras clave: Ecosistemas forestales, inventarios forestales, manejo forestal, métodos silvícolas, monitoreo forestal, SPIS.

Abstract

Forest monitoring allows the generation of databases with valuable information, which are useful for developing knowledge and technology to make a better management of the natural resources. In the state of *Chihuahua*, Mexico, forest monitoring started in 1950. At that time, the first silvicultural monitoring in permanent plots (SPIS) was established in a forest known as "*El Poleo*", which is located in *Madera* municipality, *Chihuahua*. Later, from 1980 to 1990, a group of 234 permanent plots were established in the research station of INIFAP, which is located in the south of the same municipality. From 1990 to 2000, another 48 permanent plots were carried out in the *Bocoyna* municipality as a part of the International Model Forest Network, and 16 more in the *Guachochi* municipality. Finally, from 1998 to 2001 the Forest Development Program (Prodefor), in 2013 and 2014, 857 sites promoted by Conafor were established along different *ejidos* in the forest of *Chihuahua* contributed to set down another 48 permanent plots in the *Guadalupe y Calvo* municipality, located in the south of *Chihuahua* State. The sites of *El Poleo* in *Madera* and *Llano Blanco* in *Guadalupe y Calvo*, were resampled after their establishment. The records of these plots show an annual timber increment from 4 to 16 m^3ha^{-1}. Historical information and databases of the SPIS are a valuable precedent for the forest monitoring in the north of Mexico, as well as a contribution to generate better methods for a sustainable forest management in the region.

Kew words: forest ecosystem, forest inventories, sustainable forest management, silvicultural methods, forest monitoring, SPIS.

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Introduction

The area of temperate forests in the *Chihuahua* State is 7.4 million hectares, of which 86 % are for collective or *ejidal* use (Inegi, 2014). In these forests, the climax floristic composition is represented mainly, by species of the *Pinus* and *Quercus* genera (Martínez *et al.,* 2012). The timber harvest in the entity is 1.16 million m^3 average, which is equivalent to 18 % of the national production (Semarnat, 2017); these data highlight the socioeconomic and biological importance of these ecosystems, as well as the need to implement forest monitoring programs and design strategies for the sustainable management of natural resources (Kleinn and Morales, 2002).

Before reviewing the evolution of monitoring in the state, it is necessary to specify the differences between forestry and forest. The first refers to the collection of periodic information to assess the response of the forest to the application of management and harvesting treatments (Martínez *et al.,* 2012); while the second, in addition to including forestry, incorporates the measurement of indicators that address the complexity of ecosystems, considering the structure and functioning of populations, communities, landscapes and socio-economic and cultural indicators (Palmer, 2011).

Forest monitoring in the beginning focused on knowing the quantity and distribution of forests through indicators of ecosystem structure, such as forest area, botanical composition and timber stocks for forestry purposes (Päivinen *et al*., 1994; FAO, 2017). Subsequently, with the growing discussion about environmental chaos and the incorporation of theories on sustainability and climate change, the need to generate knowledge about ecosystem functions, such as carbon sequestration, water production, biodiversity conservation, productivity and degradation of soils were recognized (Bugmann and Solomon, 1995; Wulder *et al*., 2004; Saarinen *et al*., 2018). Currently, some variables related to social and cultural participation in forest management have been incorporated (FAO, 2017).

One of the first forest monitoring schemes implemented in *Chihuahua* was the "Model Forest" network (Besseau *et al.,* 2002). This system had an influence in Mexico through the establishment of monitoring plots in the forested areas of the state in 1995 (Martínez

et al., 2012). At the end of the 90's, the international audit process for certification was promoted Forestry of the Forest Stewardship Council (FSC) (Ismail *et al*., 2011) and recently, the Monitoring, Reporting, Verification (MRV) system as part of the mechanism of Reduction of Emissions of Effect Gases Greenhouse Caused by Deforestation and Forest Degradation (REDD +) (Palmer, 2011; Plugge and Köhl, 2012).

However, the history of forest monitoring in *Chihuahua* dates back to the middle of the last century, with the first Permanent Silvicultural Research Site (SPIS) known as "*El Poleo*", which was located in the municipality of *Madera*, in the year 1950 with the purpose of evaluating the effect of different cutting intensities on the timber increase (Mas and Pahua, 1989). This was followed by a series of monitoring sites described in this document, until 2002, which were established by forestry technicians, with support from different agencies (Tena, 2000; Meléndez, 2001a; Meléndez 2001b; Martínez *et al.,* 2012*;* Nava-Miranda *et al*., 2014).

It should be noted that, during the years 2007, 2013 and 2014, 3 669 permanent sites were delimited, in 14 states of the Mexican Republic, which include those of *Chihuahua*, in whose temperate forests 857 sites were located. This effort was developed by the National Forestry Commission (Conafor), with the support of the *Universidad Juárez del Estado de Durango (UJED)* for the storage of information online, using the system called *Monafor* (Nava-Miranda, 2014).

On the other hand, the influence of forest inventories in the monitoring of the forests of the *Chihuahua* State has also been important. The first inventory was carried out in the period 1961-1985, in which aerial photographs and field samples directed on the main wooded areas of the country were used as spatial references (SARH, 1992). This set the pattern for the National Forestry Inventory of Great Vision (SARH, 1992) to be implemented in 1991, in which for the first time the forest areas were captured on 1: 1 000 000 scale maps. In 1992, the National Inventory was initiated Periodic Forestry (SARH, 1994), and as of 2004 the National Forest and Soil Inventory (INFyS, for its acronym in Spanish), at a scale of 1: 250 000, replaced it (Conafor, 2009a).

This concluded in November 2007, at which time the periodic remeasurements began in 10 % of the INFyS conglomerates, nationwide (Conafor, 2009a).

Despite the local, regional and national interest in having optimal forest and forestry monitoring systems, there are few experiences that are considered well documented to form a reliable database that allows quantification of timber growths or increases, which is necessary to implement sustainable management systems in the local area of the forests of *Chihuahua* (Martínez *et al.,* 2012). This document shows a history of the SPIS established in the entity in the last 70 years. The information is useful for the development of projects that affect state ecological research, as well as historical evidence of silvicultural monitoring in the region.

Location of the SPIS

The history of forestry research monitoring in the *Chihuahua* State shows that between 1950 and 2004, 346 plots distributed in 16 Permanent Research Sites were established in different regions of the state (Table 1).

Table 1. Location of the SPIS in *Chihuahua* state.[*]

Name of the site	Location	Latitude	Longitude	Num. of plots
El Poleo	*Mesa del Negro*, municipality *Madera*	29º33'3.55"	108º 31'56.7"	9
Madera Experimental Area	*El Largo Madera*, South zone, *Madera*	29°06'45"	108°11'45''	225
San Ignacio de Arareco	*Ejido San Ignacio de Arareco, Bocoyna municipality, Chihuahua*	27º40'21.6"	107º32'17.8"	16
San Juanito	*Ejido San Juanito, Bocoyna municipality*	28º0 47.7"	107º35'44.9"	16
Cusarare	*Ejido Cusarare, Guachochi municipality*	27º34'49.7"	107º28'13.3"	16
Retiro y Gumeachi	*Ejido El Retiro y Gumeachi, Bocoyna municipality*	27º59'5.6"	107º40' 54.6"	16
Caseta de la Judicial	*Ejido Chinatú, Guadalupe y Calvo*	26º04'50.00"	106º45'15.00"	4
Rancho del Indio	*Ejido Chinatú, Guadalupe y Calvo*	26º01'15.00"	106º46'01.00"	4
Puerto El Sabinal	*Ejido Chinatú, Guadalupe y Calvo*	26º01'15.00"	106º47'55.00"	4
Llano Blanco	*Ejido Llano Blanco, Guadalupe y Calvo, Chihuahua*	26º03'34.0"	106º54'28.6"	12
El Zorrillo Air track	*Ejido El Pinito, Guadalupe y Calvo*	26º03'4.66"	106º58'42.51"	4
Las Cuevas	*Ejido El Pinito, Guadalupe y Calvo*	26º05'18"	107º00'24.4"	4
Regeneration area	*Ejido El Pinito, Guadalupe y Calvo*	26º05'38.5"	107º01'13.4"	4
Ojuelos o Aguaje	*Ejido Redondeados y anexos, Guadalupe y Calvo*	25º44'	106º51'	4
Junction at the Mesa de San Rafael	*Ejido Redondeados y anexos, Guadalupe y Calvo*	25º47'	106º47'	4
Regeneration area	*Ejido Redondeados y anexos, Guadalupe y Calvo*	25º05'	106º01'	4

[*] The location of 857 permanent plots established by Conafor (Nava-Miranda *et al.,* 2014) is not included, this information is protected by *Universidad Juárez del Estado de Durango* (UJED) on its page

http://forestales.ujed.mx/monafor/inicio/creditos.php

For the documentary integration of the SPIS, revisions of the Permanent Forestry Research Sites projects were carried out since 1950. Existing databases were consulted in the archives of the *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias,* as well as in the Forest Management Units of the *Madera* (0802), *San Juanito* (0805) and *Guadalupe y Calvo, Chihuahua* (0808) regions.

Figure 1 shows the spatial distribution of SPIS in the state, which includes the northern zone in the area of *Madera,* the center in the region of *Bocoyna* and *Guachochi* and the southern one in the municipality *Guadalupe y Calvo.* In the period from 2013 to 2014, 857 permanent plots were implemented in various state estates, with sizes ranging from 625 m^2 (25 × 25 m), 1 000, 1 500 or 2 500 m^2 in mixed masses (Nava-Miranda *et al.,* 2014).

Figure 1. Location of SPIS in *Chihuahua* State

Characteristics of SPIS in *Chihuahua* State

The SPIS are formed by experimental plots for the collection of information with multiple objectives, among which the interest to evaluate the productivity of the forests before different levels of density or ages of the trees stands out.

El Poleo Experimental Site

It was established in 1950; from then until 1980, the normal diameter, total height, height of the clean shaft and crown diameters of all trees were corrected every ten years, in nine plots of one hectare, each.

Initially *El Poleo* had two conditions: the so-called old growth, with mature structures, diameters greater than 30 cm with little presence of young trees; and the condition of young or second growth masses, with high densities per unit area. In both grow *Pinus durangensis* Martínez and *Pinus arizonica* Engelm., associated with different taxa of *Quercus* spp (Manzanilla, 1993; Tena, 2000).

The structure of the plots is square, with 300 m per side and an area of nine hectares. Each one divided into nine experimental units of one hectare (100 × 100 m). In these plots four intensities of cut (IC) were applied, with four repetitions, with the intention of evaluating the effect of residual density on the increase in volume (Figure 2). Also, the effect of density on a control was evaluated (treatment without intervention) (Mas and Pahua, 1989).
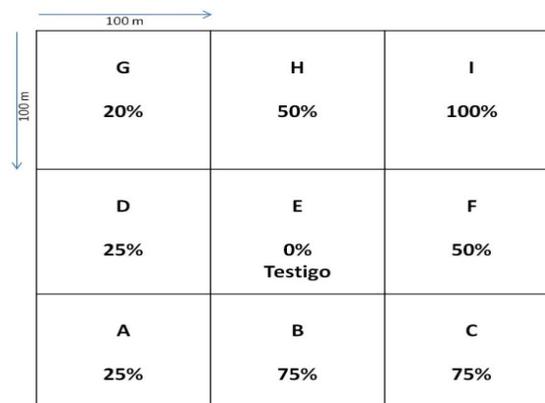

	100 m	
G 20%	H 50%	I 100%
D 25%	E 0% Testigo	F 50%
A 25%	B 75%	C 75%

Figure 2. Distribution of treatments at the *El Poleo* site.
(Modified from Manzanilla, 1993).

The volume and increment information for the 1950-1960 period shows evidence of the effect of residual density on the increases in the first ten years (Table 2). Higher annual values are observed in the control plots, 50 % and 75 % of cutting intensity, with 5.4, 5.2 and 4.2 m^3ha^{-1} of total tree volume (round), respectively; in the following decades, as well as in the average Annual Mean Increment (IMA, for its acronym in Spanish) evaluation, the treatments with less intensive cuttings (A, D, E and G) showed smaller increments compared to the treatments of greater intensity (B, H, I). The above is attributed to the effect of competition through density management, which considerably reduced the increase in biomass.

Table 2. Volume and increases in SPIS *El Poleo* for the period 1950-1980.

| Plot | IC % | VTA m^3ha^{-1} and IMA in the period | | | | | | | Average |
		1950	1960	IMA	1970	IMA	1980	IMA	IMA
A	25	217.8	225.6	0.8	254.0	2.8	278.0	2.4	2.0
B	75	57.7	86.7	2.9	163.9	7.7	218.4	5.5	5.4
C	75	61.4	103.1	4.2	144.3	4.1	173.6	2.9	3.7
D	25	108.9	139.7	3.1	180.6	4.1	194.6	1.4	2.9
E	0	178.8	232.4	5.4	265.7	3.3	288.7	2.3	3.7
F	50	104	118.6	1.5	130.8	1.2	162.7	3.2	2.0
G	20	148.2	172.3	2.4	230.3	5.8	233.6	0.3	2.8
H	50	112.1	163.6	5.2	205.0	4.1	251.3	4.6	4.6
I	100	16.3	17.7	0.1	81.7	6.4	144.2	6.3	4.3

VTA= Total Tree Volume; IC= Cutting intensity; IMA= Annual Mean Increment in m^3ha^{-1} VTA; average IMA = average IMA for the studied period.

Sites of *Madera* Experimental Area

During 1980 and 1981, a network of 100 permanent silvicultural research sites (SPIS) was implemented, of one hectare each in the INIFAP Experimental Area, located in the south of *ejido El Largo, Madera, Chihuahua*, whose aim was to determine the development of the regeneration of *P. arizonica* under different treatments of thinning

and Father trees; however, these were affected by fires in the period from 1991 to 1995 (Alanís *et al.,* 2000). Then, in 1985, 125 SPIS were established on a circular basis, of one tenth of a hectare as part of a monitoring system known as Continuous Forest Inventory (IFC, for its acronym in Spanish), which belongs to a monitoring system of the *ejido El Largo*.

SPIS in *Bocoyna* and *Guachochi, Chihuahua*

The network of forestry research sites in *Bocoyna* was part of the program "Integrated management of natural resources in a pilot program of Model Forest in the central region of the *Chihuahua* mountain range", which was carried out in collaboration with the International Forest Program Model, the Directorate of Rural Development of the Government of the State and INIFAP with the objective of keeping under constant monitoring the tree structures (normal diameter, total height, diameter of the crown, in addition to growth), with or without silvicultural treatment (Martínez *et al.,*2012).

Different forest productivity conditions were considered (Table 3) and 64 SPIS were established: 16 high productivity sites *in ejido San Juanito*, 16 medium productivity sites in *ejido San Ignacio de Arareco*, 16 low productivity sites in *ejido Cusarare*, and 16 of very high productivity in the *ejido Retiro* and *Gumeachi* (Chacón and Cano, 1998).

Table 3. Treatments applied in the forests of the *San Juanito-Creel, Chihuahua* region.

High, Medium and Low productivity	Very high productivity
60 %	50 %
40 %	40 %
30 %	70 %
0 %	0 %

Each treatment corresponds to the percentage of thinning applied in the plots by level of productivity.

The sites located in the *Bocoyna* municipality, like those of the *Madera* municipality, only have the information of the establishment, so it was not possible to make inferences regarding growth or growth attributes.

Guadalupe y Calvo, Chihuahua

In the *Guadalupe y Calvo* municipality, located in the south of *Chihuahua* State, SPIS were established between 1999 and 2000 in four *ejidos*, to assess the response of residual trees to different levels of density.

Chinatú ejido

In 1999, 12 plots were implemented in a forest between 30 and 60 years old, with the aim of evaluating the behavior of *P. arizonica* and its development dynamics (Tena, 2000; Meléndez, 2001a). The size of the plots was 625 m^2, they were established in three age classes (30, 45 and 60 years), with four replications per class. Each one was divided into four quadrants, and all trees larger than 7.5 cm in normal diameter were numbered, based on the methodology of Manzanilla, modified by Martínez *et al.* (2012).

The following year, another 12 experimental plots were added in order to know the growth response of *P. arizonica* in three site qualities (good, regular and bad), according to the conditions of soil depth and type, as well as on the slope; and qualified according to the experience of the forestry technician. Three woodland densities were considered. In this case, the ages fluctuated between 20 and 25 years. The plots had an area of 400 m^2, in which an experimental design of four treatments was installed, with different number of trees per hectare: 100, 900, 1 100, and a control with the number of trees in high density. Four replications corresponded to each treatment (Meléndez, 2001a). Up to date, there is no information on re-measurements.

Llano Blanco ejido

The objective of this SPIS was to assess the effect of densities on the increase in volume of *P. arizonica*. The design used was completely at random, with four treatments: Control, 1 100, 1 600, 2 500 trees ha^{-1}. Three replications per treatment were established. Plots were square (10 m x 10 m), with north-south orientation and a separation between sites of 5 to 10 m. Information was collected from trees with a normal diameter greater than 7.5 cm.

Table 4 shows the annual increases of more than 4 m^{3}ha^{-1} round, which assume high productivity in the region, compared to institutional data, since for the coniferous and broadleaved forests of Mexico, the National Forest Commission (Conafor) estimates an average annual increase of 1.35 m^{3}ha^{-1} vta (Conafor, 2018).

On the other hand, results show that for densities of 1 600 trees per hectare there are trends of increments of up to 16.3 m^{3}ha^{-1} vta. This data qualifies the region as one of the most productive areas of northern Mexico.

The increments recorded in the *Llano Blanco ejido* support the preliminary results of the network of permanent plots that houses the website of the *Universidad Juárez del Estado de Durango* (UJED), which include average growth for the *Durango* forests of: 6.36, 1.9, 0.47, and 1.51 m^{3}ha^{-1}, for the *Pinus, Quercus* genera, other broadleaves, and other conifers, respectively. In addition, the existence of regions where the increases could be three times higher is indicated (Nava-Miranda *et al.,* 2014).

Table 4. Volume and increments in Llano Blanco Experimental Site for the 2000-2004 period.

Treatment 32 (Trees ha^{-1})	Site number	DN1 (cm)	DN2 (cm)	A1 (m)	A2 (m)	VOL1 (m³ha^{-1})	VOL2 (m³ha^{-1})	IMA (VOL) (m³ha^{-1})
1 600	1	11.6	12.9	9.3	10.0	94.64	126.65	10.38
2 500	2	9.9	11.6	8.7	9.8	99.95	120.23	6.58
Control	3	8.7	9.5	8.2	8.8	200.57	215.86	4.96
1 600	4	8.7	10.5	7.9	8.5	44.09	50.73	2.16
Control	5	7.1	8.3	7.8	8.4	177.19	174.58	-0.85
1 100	6	10.5	12.2	8.3	9.0	46.86	63.17	5.29
2 500	7	6.5	7.6	4.9	5.7	24.37	12.38	-3.89
Control	8	8.3	9.3	8.1	8.9	150.70	122.01	-9.31
1 100	9	11.9	13.4	8.7	9.5	62.54	84.37	7.08
1 600	10	14.3	16.0	10.5	11.3	152.70	202.99	16.31
2 500	11	10.6	11.7	8.7	9.5	114.62	151.44	11.94
1 100	12	11.4	12.7	9.1	9.8	58.66	76.63	5.83

DN1, DN2 = Average Normal Diameters after the clearcuttings and in the re-measurement; A1 and A2 = Average total heights per site after the clearcuttings and in the re-measurement; VOL1 and VOL2 = Volumes per site after the clearcuttings and in the re-measurement (tree total volume (vta)); IMA = Annual Mean Increment (3.08 years).

El Pinito ejido

The SPIS were established in 2000, with the aim of knowing the growth and performance of three stands with different age classes (young, medium and mature): 15-25 years, 35-45 years and 45- 55, respectively; by applying different thinning densities. The plots were located in the places called: *El Zorrillo* Air Track, *Las Cuevas* and Regeneration Area (Meléndez, 2001b).

Three stands were chosen with dominance of *Pinus arizonica* and *P. duranguensis,* in association with *P. ayacahuite* Ehrenb. ex Schltdl. and *P. lumhotzii*, with the presence of some species of the *Quercus* spp., *Juniperus* spp., *Arbutus* spp. and *Alnus* spp. genera.

The young age class was located in *El Zorrillo*, with plots at densities of 32, 40 and 48 trees and a control with 91 individuals; the middle class in *Las Cuevas*, with plots of 20, 24, 28 trees and 38 trees as a control; while, the mature age class was established in the Regeneration Area, with

densities of 8, 12 and 16 trees and 42 trees in the control site. At present, there is only information about its establishment.

Redondeados ejido

In 2000, 12 experimental plots were implemented, with the objective of knowing the effect of density in young masses. The establishment of the SPIS was divided into three places known as *Ojuelos or Aguaje*, junction at the *Mesa de San Rafael* and *Rancho de Carlos*. In each one, four sites of 2 500 m^2 were located, in the form of 50 m by 50 m squares, in which four residual density treatments were applied: 20, 32, 42 trees and a control with 52 trees. Currently, this site is managed by technical personnel of the *ejido*, who continue the re-measurement processes.

The Permanent Forestry Research Sites in *Chihuahua* State are being retaken to continue the monitoring process. The information presented in this document shows an antecedent of additional forestry monitoring to that carried out by forestry professionals for the development of management programs for the purpose of exploitation, and to the efforts carried out by some units for specific conservation or protection purposes.

Discussion

The best decisions for the use, management and conservation of forest resources are based on the results of the analysis of reliable data series provided by forest monitoring, which bases its quality on the clear definition of its scale and aims; however, whatever these are, forest monitoring is usually an expensive process, especially because of the involvement of highly qualified scientific or technical personnel (Palmer, 2011).

The SPIS of *Chihuahua* represent a good reference for forest monitoring in northern Mexico. Nevertheless, it is clear that this system has partially met its objective, due to the interruption in the periodic collection of information, a situation that can be

related to the lack of financing, lack of operation of long-term projects and little involvement of local people or forest owners.

In recent years, efforts have been intensified for the establishment of Permanent Forestry Research Plots in Mexico, which including 857 plots in *Chihuahua*, as part of a monitoring strategy implemented by Conafor (Nava-Miranda *et al*., 2014). The information on the measurements and remeasure of these sites, established in the last decade, is stored in a database called: National Forest Monitoring (Monafor), which is hosted on the home page of the *Universidad Juárez del Estado de Durango* (http://forestales.ujed.mx/monafor/inicio/).

On the other hand, at the international level it has been suggested to approach the collection of information, based on the scheme called community-based/locally based monitoring or Community Local Monitoring (Danielsen *et al*., 2005; García and Lescuyer, 2008; Conafor, 2009b). This monitoring involves the participation of the owners and local users of the forests, with the participation of the inhabitants, both in the decision of which indicators to measure and in the periodic collection of the data (Danielsen *et al.,* 2009).

This type of local intervention has been widely accepted by the MRV system of the REDD + mechanism; It is also considered an essential part of environmental governance and as a safeguard for forest management (Palmer, 2011; Skutsch, 2011).

Local Community Monitoring has been implemented in the state of *Oaxaca*, in southern Mexico, through the system known as Community Forestry (Barton and Merino, 2005). However, in *Chihuahua*, it has been difficult to introduce, probably, by the forms of social organization and the interpretation of the rights and obligations of local populations in the use, management and conservation of natural resources.

In the national and international scopes there is a growing interest in the collection of information to generate strategies to curb the degradation of ecosystems, take care of biodiversity and sustain the production of goods and services, as well as to evaluate social participation in the management of Forests (FAO, 2017). These initiatives include the MRV System of the REDD + Mechanism (Plugge and Köhl, 2012) and the certification mechanisms, national or international

(Ismail *et al.,* 2011), which have promoted the establishment of monitoring sites with multiple objectives, which include variables not only environmental, but also social and economic.

With regard to the design of permanent plots of forest or forestry research in *Chihuahua* state, in the beginning, the establishment of Permanent Sites of Silvicultural Research was based mainly on the methodology proposed by Manzanilla in 1980. Such format has been used by some researchers, who have adapted the monitoring system to current forest conditions and new information needs (Corral-Rivas *et al.,* 2009). In addition, there is also the structure of the INFyS plots, with circular sites and subplots to measure the major and minor vegetation, regeneration, as well as the characteristics of the soil and fuels. This design involves a high value database for the knowledge of the forest ecosystems of Mexico (Conafor, 2018).

It should be noted that to refer to forest and forestry monitoring in northern Mexico it is advisable to consider the monitoring system established in the state of *Durango*, whose data can be consulted in the Monafor system. Based on this digital effort, a process of remedies has been initiated, which has allowed the identification of relevant information in relation to timber increases and that tools for forest management have been generated, such as density guides and growth equations of the structures of the trees, as well as the validation of planning systems for the management of forests in the region (von Gadow *et al.,* 2016; Corral-Rivas *et al*., 2019; Quiñonez-Barraza *et al.,* 2018).

On the other hand, the use of remote sensors, in the international arena, has become an easily accessible and reliable tool for monitoring forests (De León *et al.,* 2014; Saarinen *et al.,* 2018). Among the main possible variables to monitor through the use of remote sensors are loss of forest cover, forest fragmentation, carbon sequestration, forest fires and pests, as well as changes in land use (Banskota *et al.,* 2014).

Both local community monitoring, as well as the use of geospatial tools and remote sensors are elements that will allow the implementation of a modern and inclusive forest monitoring system, which will help society to have greater access to forest resources and develop more assertive tools for according to the biological, cultural and socioeconomic complexity of the silvicultural activity in the ecosystems.

Conclusions

Since 1950, efforts began to establish a silvicultural monitoring system in the *Chihuahua* State. In the period 1950-2002, 346 SPIS were implemented and in recent years (2013 and 2014), 857 more plots were located in various state estates. However, forestry policy and local decision-making has not been assertive in the process of remeasurement of these plots, since most of them only have information on their establishment, which frustrates the monitoring objectives.

The lack of uninterrupted financing can be an important factor to limit monitoring, so alternatives could be incorporated, such as community monitoring and the use of modern tools, remote sensors, to ensure the continuous collection of information.

For the *El Poleo* site, average increases of up to 5.4 m^3 ha^{-1} of total tree volume were estimated, while for the south of the state in the *ejido Llano Blanco* they were up to 16.3 m^3 ha^{-1} vta. These data have not been documented before, and show the high potential of timber increases in the state's forests.

The monitoring carried out in *Chihuahua* State in the period considered has focused on the evaluation of the increment and growth in tree biomass, depending on the application of harvest treatments; therefore, it is suggested to incorporate monitoring systems that involve indicators of ecosystem function, as well as socio-economic and cultural variables.

Acknowledgements

Conflict of interests

The authors declare that there is no conflict of interest in the investigation process that originated this document.

Contribution by author

Martín Martínez Salvador: coordination, analysis and writing of the document; Gabriel Sosa-Pérez: collection and digitalization of information, review and discussion; Juan Manuel Chacón-Sotelo: contribution of historical archives, information collection and revision of the manuscript; Alfredo Pinedo-Álvarez: analysis of information and writing of the document; Federico Villarrea-Guerrero: systematization of digital information, review and editing of the document; Jesús Alejandro Prieto-Amparan: collaboration in the discussion and editing of the document.

References

Alanís, M. H., M. Cano R., M. Tena V. y R. Armendáriz O. 2000. Efecto de los daños causados por incendios forestales en bosques de pino del Área Experimental Madera. INIFAP. Folleto Técnico Núm. 15. Chihuahua, Chih., México. 24 p.

Banskota, A., N. Kayastha, M. J. Falkowski, M. A. Wulder, R. E. Frose and J. C. White. 2014. Forest Monitoring Using Landsat Time Series Data: A review. Canadian Journal of Remote Sensing 40(5):362–384. Doi: 10.1080/07038992.2014.987376.

Barton, B. D. y P. Merino L. 2005. La experiencia de las comunidades forestales en México: veinticinco años de experiencia y construcción de empresas forestales comunitarias. Semarnat- Consejo Civil Mexicano. México, D. F., México. 273 p.

Bugmann, H. K. M. and M. Solomon A. 1995. The use of a European forest model in North America: a study of ecosystem response to climate gradients. Journal of Biogeography 22(2): 477-484. Doi: 10.2307/2845944.

Chacón, S. J.M. y M. Cano. 1998. Estructuras arbóreas de la región de San Juanito-Creel y su comportamiento. Folleto Científico Núm. 8. INIFAP. Chihuahua, Chih., México. 33 p.

Comisión Nacional Forestal (Conafor). 2009a. Inventario nacional forestal y de suelos: manual y procedimientos para el muestreo de campo. Semarnat-Conafor. Guadalajara, Jal., México. 133 p.

Comisión Nacional Forestal (Conafor). 2009b. Inventario Nacional Forestal y de Suelos México 2004-2009. Una herramienta que da certeza a la planeación, evaluación y el desarrollo forestal de México. Comisión Nacional Forestal. San Juan de Ocotán Zapopan, Jal., México. 22 p.

Comisión Nacional Forestal (Conafor). 2018. Inventario Nacional Forestal y de Suelos Informe de Resultados 2009-2014. Presidencia de la República. Zapopan, Jal, Méx. 200 p.

Corral-Rivas J., M. S. González-Elizondo, J. E Lujan-Soto and K. von-Gadow. 2019. Effects of density and structure on production in the communal forests of the Mexican Sierra Madre Occidental. Southern Forests: a Journal of Forest Science 81(1): 1-10. Doi: 10.2989/20702620.2018.1463152.

Corral-Rivas, J.J., B. Vargas L., C. Wehenkel, O. Aguirre C., G. Álvarez J.y A. Rojo A. 2009. Guía para el Establecimiento de Sitios de Investigación Forestal y de Suelos en Bosques del Estado de Durango. Editorial UJED. Durango, Dgo., México. 81p.

Danielsen, F., D. Burgess N. and A. Balmford. 2005. Monitoring matters: examining the potential of locally-based approaches. Biodiversity and Conservation 14(11): 2507–2542. Doi: 10.1007/s10531-005-8375-0.

Danielsen, F., D. Burgess N., A. Balmford, P. Donald, M. Funder, J. Jones P., P. Alviola, S. Balete D., T. Blomley, J. Brashares, B. Child, M. Enghoff, J. Fjeldså, S. Holt, H. Hübertz, E. Jensen A., M. Jensen P, J. Massao, M. Mendoza M, Y. Ngaga, K. Poulsen M., R. Rueda, M. Sam, T. Skielboe, G. Stuart-Hill, E. T opp-Jørgensen and D. Yonten. 2009. Local participation in natural resource monitoring: a characterization of approaches. Conservation Biology 23:31–42. Doi: 10.1111/j.1523-1739.2008.01063.x.

De León M., G. D., A. Pinedo A. y G. Martínez J. 2014. Aplicación de sensores remotos en el análisis de la fragmentación del paisaje en Cuchillas de la Zarca, México. Investigaciones Geográficas, Boletín del Instituto de Geografía, UNAM. 84 2014: 42-53. Doi: 10.14350/rig.36568.

Food and Agriculture Organization of the United Nations (FAO). 2017. Voluntary guidelines on national forest monitoring. Food and Agriculture Organization of the United Nations. Rome, Italy. 77 p.

Garcia, C. A. and G. Lescuyer. 2008. Monitoring, indicators and community based forest management in the tropics: pretext or red herrings? Biodiversity and Conservation 17(6): 1303–1317. Doi: 10.1007/s10531-008-9347-y.

Instituto Nacional de Estadística, Geografía e Informática (Inegi). 2014. Carta de Uso de Suelo y Vegetación del INEGI, Serie VI-2014 y Marco Geoestádistico 2010 versión 5.A. 1:250000. Aguascalientes, Ags., Mex. s/p.

Ismail, M., A. Rossi and N. Geiger. 2011. A Compilation of Bioenergy Sustainability Initiatives: Update. Food and Agriculture Organization of the UN (FAO). Rome, Italy. 24 p.

Kleinn, C. y D. Morales. 2002. Consideraciones metodológicas al establecer parcelas permanentes de observación en bosque natural o plantaciones forestales. Revista Forestal Centroamericana 39 (40): 6-12.

Manzanilla, B. H. 1993. Los sitios permanentes de investigación silvícola un sistema integrado para iniciarse en el cultivo de los ecosistemas forestales. Secretaría de Agricultura y Recursos Hidráulicos/Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP). México, D.F., México. 101 p.

Martínez, S. M., G. Sosa P., A. G. Valles G., J. A. López H., J. C. Monarrez G., R. Armendáriz O., J. M. Chacón S., A. Galván M. y C. Meléndez O. 2012. Estado actual del conocimiento de sitios permanentes de investigación silvícola (SPIS) en el estado de Chihuahua. INIFAP. Publicación especial Núm 4. Chihuahua, Chih., México. 125 p.

Mas, P. J. y A. G. Pahua. 1989. El sitio permanente de experimentación silvícola "La Nieve" a 27 años de su establecimiento. Ciencia Forestal 66(14):44-96.

Meléndez, O. C. 2001a. Respuesta de la calidad de sitio ante tres densidades de aclareo. Informe Final del proyecto en el Ejido Chinatú. Asociación de Productores y Responsables Técnicos de la Zona Sur del Estado de Chihuahua. Chihuahua,Chih., Méx. 97 p.

Meléndez, O. C. 2001b. Crecimiento de tres rodales de pino, con diferentes clases de edad y diferentes densidades de aclareo. Informe Final del proyecto en el Ejido El Pinito. Asociación de Productores y Responsables Técnicos de la Zona Sur del Estado de Chihuahua. Chihuahua, Chih., Méx. 110 p.

Nava-Miranda, M. G., H. L. Ávila-Márquez y J. J. Corral-Rivas. 2014. Una red de sitios permanentes de investigación forestal y de suelos (spifys) disponible en México. Innovación Forestal. https://www.conafor.gob.mx/innovacion_forestal/?p=2951 (17 de agosto de 2019).

Päivinen, R., H. G. y de L., S. Poso and T. Zawila-Niedzwiecki. 1994. IUFRO*: International Guidelines for Forest Monitoring. IUFRO World Series Vol. 5. IUFRO. Vienna, Italy. Doi: 10.13140/RG.2.1.4136.4568.

Palmer, F. B. 2011. Community forest monitoring in REDD+: the 'M' in MRV? Environmental Science and Policy 14 (2): 181-187. Doi: 10.1016/j.envsci.2010.12.004.

Peter B., D. Kafui and J. Frederick. 2002. The International Model Forest Network (IMFN): Elements of Success. The Forestry Chronicle 78(5):648-654. Doi: 10.5558/tfc78648-5.

Plugge, D. and M. Köhl. 2012. Estimating carbon emissions from forest degradation: implications of uncertainties and area sizes for a REDD+ MRV system. Canadian Journal of Forest Research 42(11):1996-2010. Doi: 10.1139/x2012-129.

Quiñonez-Barraza, G., J.C. Tamarit-Urias, M. Martínez-Salvador, X. García-Cuevas, H. M. De los Santos-Posadas and W. Santiago-García. 2018. Maximum density and density management diagram for mixed-species forests in Durango, Mexico. Revista Chapingo Serie Ciencias Forestales y del Ambiente 24(1): 73-90. Doi: 10.5154/r.rchscfa.2017.09.056.

Saarinen, N., J. C. White, M.A. Wulder, A. Kangas, S. Touminen, V. Kankare, M. Holopainen, J. Hyyppa and M. Vastaranta. 2018. Landsat archive holdings for Finland: opportunities for forest monitoring. Silva Fenica 52(3):1-11. Doi: 10.14214/sf.9986.

Secretaría de Agricultura y Recursos Hidráulicos (SARH). 1992. Inventario Nacional de Gran Visión, 1991-1992. Subsecretaría Forestal y de la Fauna Silvestre, SARH. Base de datos. México, D.F., México. http://www.conabio.gob.mx/informacion/metadata/gis/usv1m92gw.xml?_httpcache=yes&_xsl=/db/metadata/xsl/fgdc_html.xsl&_indent=no (18 de agosto de 2019).

Secretaría de Agricultura y Recursos Hidráulicos (SARH). 1994. Inventario Nacional Forestal Periódico, 1992-1994, Subsecretaría Forestal y de Fauna Silvestre, SARH. Base de datos. México, D.F., México. 141 p.

Secretaría del Medio Ambiente y recursos Naturales(Semarnat). 2017. Anuario estadístico de la producción forestal 2016. Dirección General de Gestión Forestal y de Suelos. Semarnat. México D.F., México. 228 p.

Skutsch, M. 2011. Community Forest Monitoring for the carbon market, opportunities under REDD. Earthscan. London, UK. 187 p.

Tena, V. M. 2000. Dinámica, desarrollo e impacto ecológico de los bosques del Estado de Chihuahua, en base a monitoreo de sitios permanentes de investigación silvícola. Informe final del proyecto. CONACYT-SIVILLA. Chihuahua, Chih., México. 59 p.

von-Gadow, K., X. H. Zhao, V. P. Tewari, C. Y. Zhang, A. Kumar, J. J. Corral-Rivas J. J. and R. Kumar. 2016. Forest observational studies: an alternative to designed experiments. European Journal of Forest Research 135(3): 417-431. Doi: 10.1007/s10342-016-0952-0.

Wulder, M. A., A. Werner K. and M. Gillis. 2004. National level forest monitoring and modeling in Canada. Progress in Planning 61(4):365-381. Doi: 10.1016/S0305-9006(03)00069-2.