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PARA EL DESARROLLO INTEGRAL REGIONAL

UNIDAD OAXACA

Doctorado en Ciencias en Conservación y

Aprovechamiento de Recursos Naturales

Resiliencia ecológica-social de los paisajes forestales de la Mixteca Alta, Oaxaca, México

T E S I S

PARA OBTENER EL GRADO DE:

Doctor en Ciencias

Presenta: José Antonio Hernández Aguilar

Directores:

Dra. Elvira Durán Medina

Dr. José Alejandro Velázquez Montes

Santa Cruz Xoxocotlán, Oaxaca

SIP-13-BIS

INSTITUTO POLITÉCNICO NACIONAL
SECRETARIA DE INVESTIGACIÓN Y POSGRADO

ACTA DE REGISTRO DE TEMA DE TESIS Y DESIGNACIÓN DE DIRECTORES DE TESIS

México, D.F. a 24 de octubre del 2018

El Colegio de Profesores de Estudios de Posgrado e Investigación de CIIDIR-OAXACA en su sesión ORDINARIA No. 7° celebrada el día 13 del mes de AGOSTO conoció la solicitud presentada por el(la) alumno(a):

HERNÁNDEZ	**AGUILAR**	**JOSÉ ANTONIO**
Apellido paterno	Apellido materno	Nombre (s)

Con registro: | A | 1 | 7 | 0 | 3 | 0 | 3 |

Aspirante de: DOCTORADO EN CIENCIAS EN CONSERVACIÓN Y APROVECHAMIENTO DE RECURSOS NATURALES

1.- Se designa al aspirante el tema de tesis titulado:
Resiliencia ecológica-social de los paisajes forestales de la Mixteca Alta, Oaxaca, México.

De manera general el tema abarcará los siguientes aspectos:
Reconocer factores/indicadores clave que confieren resiliencia ecológica-social a las comunidades forestales que integran el paisaje de la Mixteca Alta.

2.- Se designan como Directores de Tesis a los Profesores:
DRA. ELVIRA DURÁN MEDINA Y DR. JOSÉ ALEJANDRO VELÁZQUEZ MONTES

3.- El trabajo de investigación base para el desarrollo de la tesina será elaborado por el alumno en: CENTRO INTERDISCIPLINARIO DE INVESTIGACIÓN PARA EL DESARROLLO INTEGRAL REGIONAL (CIIDIR OAXACA)

que cuenta con los recursos e infraestructura necesarios.

4.- El interesado deberá asistir a los seminarios desarrollados en el área de adscripción del trabajo desde la fecha en que se suscribe la presente hasta la aceptación de la tesis por la Comisión Revisora correspondiente:

Directores de Tesis

DRA. ELVIRA DURÁN MEDINA

DR. JOSÉ ALEJANDRO VELÁZQUEZ MONTES

ESTADOS UNIDOS MEXICANOS
CENTRO INTERDISCIPLINARIO DE INVESTIGACION PARA EL DESARROLLO INTEGRAL REGIONAL C.I.I.D.I.R. UNIDAD OAXACA I.P.N.

Aspirante

HERNÁNDEZ AGUILAR JOSÉ ANTONIO

Presidente del Colegio

DR. SALVADOR ISIDRO BELMONTE JIMÉNEZ

SIP-14
REP 2017

INSTITUTO POLITÉCNICO NACIONAL

SECRETARÍA DE INVESTIGACIÓN Y POSGRADO

ACTA DE REVISIÓN DE TESIS

En la Ciudad de Santa Cruz Xoxocotlán, Oax., siendo las 09:00 horas del día 09 del mes de Agosto del 2022 se reunieron los miembros de la Comisión Revisora de la Tesis, designada por el Colegio de profesores de posgrado del: Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, Unidad Oaxaca (CIIDIR UNIDAD OAXACA) para examinar la tesis titulada:

"Resiliencia ecológica-social de los paisajes forestales de la Mixteca Alta, Oaxaca, México"

del alumno:

Apellido Paterno:	Hernández	Apellido Materno:	Aguilar	Nombre (s):	José Antonio

Número de registro: A 1 7 0 3 0 3

Aspirante del Programa Académico de Posgrado: Doctorado en Ciencias en Conservación y Aprovechamiento de Recursos Naturales.

Una vez que se realizó un análisis de similitud de texto, utilizando el software antiplagio, se encontró que el trabajo de tesis tiene 18 % de similitud. **Se adjunta reporte de software utilizado**.

Después que esta Comisión revisó exhaustivamente el contenido, estructura, intención y ubicación de los textos de la tesis identificados como coincidentes con otros documentos, concluyó que en el presente trabajo **SI** ☐ **NO** ☒ **SE CONSTITUYE UN POSIBLE PLAGIO.**

JUSTIFICACIÓN DE LA CONCLUSIÓN: (Por ejemplo, el % de similitud se localiza en metodologías adecuadamente referidas a fuente original)

El porcentaje de similitud es de 18% porque en la tesis se incluyeron dos artículos publicados mismos son referidos en el reporte de turnitin en la sección de las referencias con coincidencias.

****Es responsabilidad del alumno como autor de la tesis la verificación antiplagio, y del Director o Directores de tesis el análisis del % de similitud para establecer el riesgo o la existencia de un posible plagio.**

Finalmente, y posterior a la lectura, revisión individual, así como el análisis e intercambio de opiniones, los miembros de la Comisión manifestaron **APROBAR** ☒ **SUSPENDER** ☐ **NO APROBAR** ☐ la tesis por **UNANIMIDAD** ☒ o **MAYORÍA** ☐ en virtud de los motivos siguientes:

La tesis cumple con los requisitos señalados por las disposiciones reglamentarias vigentes.

COMISIÓN REVISORA DE TESIS

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CARTA DE AUTORIZACIÓN DE USO DE OBRA PARA DIFUSIÓN

En la Ciudad de México el día 21 del mes de Noviembre del año 2022, el que suscribe, **Hernández Aguilar José Antonio**, alumno del programa **Doctorado en Ciencias en Conservación y Aprovechamiento de Recursos Naturales**, con número de registro **A170303**, adscrito al Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, Unidad Oaxaca manifiesta que es autor intelectual del presente trabajo de tesis bajo la dirección de la **Dra. Elvira Durán Medina y el Dr. José Alejandro Velázquez Montes** y cede los derechos del trabajo intitulado **"Resiliencia ecológica-social de los paisajes forestales de la Mixteca Alta, Oaxaca, México"**, al Instituto Politécnico Nacional, para su difusión con fines académicos y de investigación.

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UNIDAD OAXACA

Hernández Aguilar José Antonio

Contenido

Resumen

Los bosques templados proveen de servicios ecosistémicos que sostienen los medios de vida de las personas. Esta relación bosques-gente puede ser abordada desde los sistemas ecológicos-sociales (SES), dada la interrelación entre estas esferas. Históricamente, los ecosistemas forestales se han visto amenazados por la deforestación, la desertificación, las plagas forestales, la expansión urbana, entre otras problemáticas. De esta forma, el objetivo de esta tesis fue reconocer indicadores clave que confieren resiliencia ecológica-social a los paisajes forestales. Se eligió estudio de caso a la región Mixteca Alta de Oaxaca, una zona de vocación forestal pero que históricamente ha presentado procesos de alta degradación y deforestación. El estudio se base en métodos mixtos de recolección de datos que consistieron en análisis espacial en software especializado, recorridos de campo, mapeo participativo y entrevistas estructuradas. Los principales resultados fueron: a) el paisaje forestal de la Mixteca Alta es heterogéneo pues existen diferencias en biofísicas y sociales que pueden agruparse en cinco zonas, cada una con sus particularidades; b) la región ha experimentado en los últimas décadas una recuperación de cobertura forestal, particularmente las comunidades del Geoparque, donde dicha transición forestal local está relacionada con preocupaciones sobre servicios de provisión del bosque, normas comunitarias para regular la ganadería, acción colectiva para reforestar, entre otros elementos; y c) las políticas forestales deben considerar las particularidades de cada región forestal, que incluye factores ecológicos (reforestación con especies nativas) y sociales (conocimientos locales y aprendizajes sociales).

Abstract

Temperate forests provide ecosystem services that sustain people's livelihoods. This forest-people connection can be approached from ecological-social systems (ESS), given the interrelationship between these spheres. Historically, forest ecosystems have been threatened by deforestation, desertification, forest pests, urban expansion, among other problems. Thus, the objective of this thesis was to recognize key indicators that contribute to the ecological-social resilience of forest landscapes. A case study was chosen for the Mixteca Alta region of Oaxaca, an area with a forest potential but which has historically presented processes of high degradation and deforestation. The study was based on mixed methods of data collection that consisted of spatial analysis in specialized software, field trips, participatory mapping and structured interviews. The main findings were: a) the forest landscape of the Mixteca Alta is heterogeneous as there are biophysical and social differences that can be grouped into five zones, each with its particularities; b) the region has experienced in recent decades a recovery of forest cover, particularly the communities of the Geopark, where this local forest transition is related to concerns about forest provision services, community norms to regulate livestock, collective action to reforest, among other elements; c) forest policies should consider the particularities of each forest region, including ecological factors (reforestation with native species) and social factors (local knowledge and social learning).

CAPÍTULO I

Generalidades de la tesis

1.1 Introducción

Los bosques son ecosistemas de importancia para la gente, porque proveen distintos recursos maderables y no-maderables, albergan biodiversidad y son claves para asegurar la protección del suelo, el balance hidrológico y, actualmente se les reconoce su papel central en el almacenamiento y captura de carbono (MEA, 2003). De esta forma, es de relevancia su conservación y recuperación ante problemáticas ambientales tales como la desertificación, degradación, deforestación, escases de agua, entre otros.

Ante un escenario ambiental complejo, se requiere de mayores elementos teóricos y prácticos que ayuden a generar condiciones ecológicas y sociales favorables para los paisajes forestales, vistos como sistemas ecológicos-sociales (SES). En este sentido, la resiliencia ecológica-social es la capacidad de un SES para recuperarse, adaptarse o transformarse ante disturbios de tipo ecológicos u antrópicos (Folke et al., 2002; Folke, 2006; Walker et al., 2006; Lade et al., 2017). La resiliencia ecológica-social, al igual que los SES, interrelaciona procesos entre naturaleza y gente, lo cual es de relevancia para esta tesis considerando que existe evidencia de que la acción humana es determinante para revertir deforestación y degradación de ecosistemas forestales.

En México, donde existen cerca de 138 millones de hectáreas (ha) con vegetación forestal, que representa el 70% del territorio nacional (45% corresponde a bosques y selvas) (CONAFOR, 2012), es fundamental propiciar la resiliencia ecológica-social de estos ecosistemas. Asimismo, gran parte de dicha vegetación forestal se encuentra en tierras de propiedad social, donde sus dueños y poseedores interactúan con el recurso de manera estrecha (Bray 2020).

La presente tesis se enfocó en la región Mixteca Alta de Oaxaca, que cuenta con una importante masa forestal con bosques templados y donde la tenencia de la tierra corresponde a comunidades/ejidos. La Mixteca Alta destaca por aspectos negativos como el sobrepastoreo, la erosión y degradación de suelos y los conflictos agrarios, sin embargo, existen experiencias exitosas de manejo forestal comunitario dentro de la región (Hernández et al., 2017). Para determinar la resiliencia ecológica-social de la Mixteca Alta es necesario conocer algunos indicadores tales como el estado (recuperación/pérdida) de los bosques en las comunidades forestales, el capital social para el manejo del bosque y los reglamentos y ordenamientos territoriales. Gran parte de dichas condiciones han sido poco estudiadas y, prácticamente el potencial forestal de la Mixteca Alta es desconocido fuera de la región.

Por lo anterior, esta tesis pretende reconocer indicadores de resiliencia ecológica-social en los paisajes forestales de la Mixteca Alta. Para ello, en primer lugar, se analizaron los componentes del paisaje forestal de la Mixteca Alta. Posteriormente, examinó la dinámica de la cobertura forestal como un indicador de resiliencia ecológica-social en la porción con mayor degradación de la Mixteca Alta. Finalmente, se estudió la contribución de la acción colectiva, el capital social y la gobernanza con el proceso de construcción de resiliencia-ecológica de bosques comunitarios en la Mixteca Alta.

1.2 Marcos de referencia

1.2.1 Bosques comunitarios y manejo forestal comunitario en México

México cuenta con cerca de 64 millones de hectáreas de bosques y selvas (Chapela, 2009), que representa una tercera parte del territorio nacional (CONAFOR, 2012). De éstos, 51.7 por ciento corresponde a vegetación forestal de clima templado, y el resto, 48.3 por ciento, a bosques tropicales (Torres-Rojo y Amador, 2015). El 60.1 % por ciento de los bosques templados y 61.6 % de los bosques tropicales están en propiedad de núcleos agrarios (Torres-Rojo y Amador, 2015). Cerca de 9248 núcleos agrarios tienen como vegetación dominante bosques templados (Torres-Rojo y Amador, 2015). Estos núcleos agrarios con potencial forestal son conocidos como "comunidades forestales" (Bray y Merino 2004; Antinori y Bray, 2005; Macqueen, 2013).

El auge del manejo forestal comunitario en México se suscitó en la década de los ochentas y se profundizó en 1992 con la promulgación de la Ley Forestal y la reforma al Artículo 27 constitucional, que dio paso a la reapropiación de los bosques por parte de las comunidades originarias, que durante décadas lucharon por tener nuevamente el control de los recursos forestales (Merino y Segura, 2007). Por otro lado, el fin del reparto agrario en la década de los noventa abrió a las comunidades forestales la posibilidad de administrar sus bosques de acuerdo a sus intereses colectivos, generando el empoderamiento y fortalecimiento de las instituciones comunales en las localidades que poseen bosques comunitarios (Merino et al., 2013). El manejo forestal comunitario (MFC) se define como el uso doméstico o comercial de productos maderables, no maderables y servicios forestales hecho por comunidades indígenas o locales bajo reglas compartidas o derechos colectivos (Arnold, 1998; Cronkleton et al., 2011). El MFC ha sido documentado desde finales del siglo XX pues demuestra ser una estrategia para lograr metas medioambientales, económicas y sociales.

La “democratización de los recursos naturales” a partir de políticas agrarias llevadas a cabo hasta finales del siglo XX en México, ha generado el empoderamiento y fortalecimiento de las instituciones comunales en las localidades que poseen bosques comunitarios. Las políticas agrarias han dado lugar a plataformas de gobernanza comunitaria (basadas en usos y costumbres, que cuentan con reconocimiento legal) que fortalecen las relaciones entre las personas de la localidad, lo que se traduce en una mejor capacidad para la toma de decisiones con relación al manejo de los bosques de propiedad comunal (Bray, Antinori y Torres, 2006).

La gobernanza de los bosques en comunidades y ejidos tiene como componente fundamental el capital social. De acuerdo con Ostrom (2000), el capital social es el conocimiento compartido, acuerdos, normas, reglas, y expectativas que rigen las relaciones de un grupo de individuos en torno al manejo de bienes comunes (incluye los bosques). Agrega que instituciones para la gobernabilidad y la gestión de los recursos comunes son elementos fundamentales de este tipo de capital (Ostrom, 2001). Por “instituciones” hace referencia a las "reglas de uso" asumidas por los usuarios (Ostrom, 1991) para la gestión colectiva de un recurso común. Una gobernanza comunitaria poco efectiva puede contribuir a la destrucción de los recursos forestales (Ostrom, 1998), por lo tanto, el grado de organización de las comunidades define el grado de efectividad del manejo de los recursos naturales (Wright y Andersson, 2012).

1.2.2 Sistemas ecológico-sociales (SES)

El marco conceptual que brindan los sistemas ecológicos sociales (SES) ha tomado relevancia en el estudio del manejo de los recursos naturales pues reconocen al ser humano como un elemento del ecosistema. Un SES surge de la interacción interdependiente entre un sistema biológico y un sistema social. Cuando los sistemas sociales y ecológicos están tan vinculados, el SES general es un sistema complejo y adaptativo que involucra múltiples subsistemas (Anderies, 2004). Para Östrom (2009) un SES está integrado por unidades de recurso, un sistema de recurso (actividades de uso/aprovechamiento), un sistema de gobernanza (reglas/normas de uso del recurso) y usuarios.

El estudio de los bienes comunes, incluidos los bosques, se han abordado desde los SES a partir de estudios de caso donde se destaca la aportación de la gente en la conservación u aprovechamiento sostenible de recursos naturales (Berkes y Folke, 2000; Folke, 2007; Berkes et al., 2008; Ostrom, 2009). Para el caso de México, los SES sirven de marco de referencia para el manejo de los bosques comunitarios. Una comunidad/ejido forestal no se puede disociar los componentes físicos/biológicos de los recursos del bosque, de gran parte de lo que implica el contexto social, es que se puede decir que los núcleos agrarios operan como sistemas ecológico-sociales. El contexto social abarca aspectos de gobernanza e institucionales, culturales y económicos. La dimensión institucional está integrada por la gobernanza local, en la cual se lleva a cabo la toma de decisiones; además está ligada a entidades gubernamentales, empresas y organizaciones no gubernamentales, que fortalecen dicho proceso de gobernanza. Por su parte, el conjunto de creencias (cosmos) y conocimientos (corpus) son parte del sistema social (Toledo, 1992).

1.2.3 Resiliencia ecológica-social

La resiliencia es la capacidad de un sistema para absorber las perturbaciones y reorganizarse al mismo tiempo que experimenta un cambio para conservar esencialmente la misma función, estructura, identidad y retroalimentación (Walker et al., 2004; Folke at al., 2010). Bajo un enfoque de SES, la resiliencia se centra en tres aspectos: la resiliencia como persistencia, adaptabilidad y transformación (Folke et al., 2002; Folke, 2006; Walker et al., 2006; Lade et al., 2017). La adaptabilidad es la capacidad de un SES de ajustar sus respuestas a los cambios de los factores externos y los procesos internos y, por lo tanto, permitir el desarrollo dentro del dominio de estabilidad actual, a lo largo de la trayectoria actual (Janssen y Ostrom,2006). La transformación es la capacidad de crear nuevos dominios de estabilidad para el desarrollo, un nuevo panorama de estabilidad, y cruzar los umbrales hacia una nueva trayectoria de desarrollo (Janssen y Ostrom,2006).

El estudio de los SES no se enfoca solo al análisis de las partes que lo integran, pues por su naturaleza dinámica están sujetos a procesos de persistencia, adaptación y transformación (Lade et al., 2017). Dichas dinámicas dependerán del grado de resiliencia del SES. En la esfera ecológica, el término hace referencia a la capacidad de amortiguación o la capacidad de un sistema para absorber perturbaciones (Holling, 1996). Por otro lado, la resiliencia social es la capacidad de resistencia, recuperación y creatividad/innovación de una entidad social (por ejemplo, un grupo o comunidad) como respuesta ante algún tipo de adversidad o crisis (Adger, 2000; Adger et al., 2005; Maguire y Hagan, 2007).

A partir de estudios de caso, diversos autores han abordado indicadores clave que aportan resiliencia a un SES (Davidson-Hunt y Berkes, 2003; Berkes y Turner, 2006; Carpenter et al., 2011; Huber et al., 2012; Scheffer et al., 2015; Scherzer et al., 2019), los cuales se enlistan a continuación:

Indicador	*Esfera*	*Descripción*
Tasa de recuperación/Tiempo de recuperación	Ecológica	Capacidad de recuperación de un sistema ante perturbaciones naturales o antrópicas.
Grado de interacción	Ecológica/Social	Existencia de redes de información/comunicación que operan entre escalas.
Grado de integración	Social	Múltiples actores integrados a estructuras y procesos.
Aprendizaje social	Social	Transmisión de conocimiento entre grupos y entre generaciones
Identidad cultural	Social	Sentido de pertenencia a un lugar por razones históricas, étnicas, intereses comunes, entre otros.
Grado de gobernanza	Social	Existencia de una estructura institucional (reglas colectivas)

Sabiendo que México y particularmente Oaxaca cuentan con una gran diversidad biológica y social, el marco teórico de la resiliencia ecológica-social permite entender/analizar de manera integral la relación entre la naturaleza y la gente. Por lo antes expuesto, la resiliencia ecológica-social puede aplicarse para el análisis de sistemas complejos y las interacciones entre componentes sociales, económicos y biofísicos, considerando que existen precedentes de que en las comunidades forestal cuentan con capital social, esfuerzos institucionales locales y conciencia socio-ecológica.

1.2.4 El enfoque geográfico del paisaje

El enfoque de paisaje es un marco teórico-metodológico para el análisis de un territorio (Velázquez y Larrazabal, 2011). Esta aproximación reconoce que el paisaje está formado por componentes físicos, biológicos y sociales que interactúan entre ellos que determinan la función y estructura de un espacio (Zonneveld, 1989; Velázquez, 1993; Bocco, et al., 1998). Los componentes biológicos del paisaje son la vegetación y la fauna y estos ligados estrechamente a los componentes abióticos (el suelo, el relieve o el clima). El componente social representando por los usos de suelo (agricultura, forestería, asentamientos) es una importante fuerza modeladora del paisaje (Council of Europe, 2000; Green et al., 1996).

A diferencia de los sistemas ecológicos-sociales, el enfoque de paisaje existe en un espacio geográfica y se representa a múltiples escalas (vegetación, organización social, cultura e historia). El reconocimiento de paisajes a partir de este marco conceptual permite analizar los procesos de manejo y gobernanza de la escala local hacia una regional. El paisaje tiene una estructura jerárquica (de unidades de paisaje a mesositios) que permite analizar un territorio en diferentes escalas espaciales. La unidad de paisaje fundamental es el ecotopo que sirve para describir (espacial y funcionalmente) los sitios homogéneos de un espacio territorial en un momento dado (Velázquez, 1993). Un grupo de los ecotopos conforman tanto un micrositio como unidades de tierra (facetas de la tierra), que a su vez dan lugar a patrones espacialmente homogéneos o meso-sitios (sistemas de tierra). Un grupo de sistemas de la tierra conforman el paisaje real (Zonneveld, 1995). Para el caso de la Mixteca, es posible reconocer la estructura del paisaje a partir de establecer como unidades de paisaje a los núcleos agrarios. De esta forma, a partir de una serie de atributos físicos, biológicos y sociales se pueden conformar los diferentes niveles jerárquicos del paisaje.

1.2.5 Dinámica en paisajes forestales: deforestación, reforestación y transición forestal

Dada la importancia ecosistémica de los bosques, el análisis del cambio de la cobertura y uso de suelo se ha convertido en una importante herramienta para documentar y entender los procesos de deforestación, degradación, desertificación y disminución de la biodiversidad (CONAFOR, 2003; Velázquez et al., 2003). De igual forma, es importante considerar una serié de factores inmediatos y subyacentes que se asocian a las tendencias de cambio de cobertura forestal, es decir, variables que originan la pérdida o recuperación de bosques.

La deforestación según la FAO (2010), es la transformación del bosque en otro uso (que significa eliminarla por completo) de la tierra o reducción a largo plazo de la cubierta de copa por debajo del 10 por ciento. En un primer plano es causa la principal de la pérdida de protección del suelo y con ellos inician los diferentes procesos erosivos. A nivel regional esto conduce a la pérdida forestal, deterioro físico y químico del suelo, alteración del balance hídrico y desestabilización de cuencas. A escala planetaria esto altera el balance de agua atmosférica, afectando patrones, así como al calentamiento global. Otra de las consecuencias es la reducción del hábitat y/o su fragmentación, con la consecuentemente perdida de la biodiversidad y a la de variabilidad genética, de poblaciones y hasta de especies (Meli, 2003). Este proceso está asociado a diversos impactos ambientales, como al disturbio de los servicios ambientales, erosión, alteración de los regímenes hidrológicos, y el incremento de emisiones a la atmosfera de gases de efecto invernadero y por la descomposición del mantillo o por la alteración del régimen de aireación y humedad del suelo.

La deforestación se asocia con causas naturales tales como huracanes, incendios y plagas forestales, sin embargo, son las acciones del hombre las que más provocan la pérdida de bosques (FAO, 2010). De acuerdo con Geist y Lambin (2001) las causas de la deforestación se pueden clasificar en inmediatas y fundamentales (ambas interconectadas). Las primeras se refieren a todas aquellas acciones antropogénicas que impactan directamente en la cobertura forestal, las cuales se constituyen por expansión de las tierras agrícolas y de extracción maderable, así como el crecimiento de la infraestructura urbana (Geist y Lambin, 2001). Respecto a las causas subyacentes, son aquellas que derivan de procesos complejos y que sustentan a las causas inmediatas de la deforestación; pueden ser vistas como un conjunto de variables sociales, políticas, económicas, tecnológicas y culturales de naturaleza estructural (o sistémica) (Geist y Lambin, 2001).

El análisis de cambio en la cobertura forestal implica, de igual forma, conocer las causas que contribuyen a la recuperación del bosque. Un primer factor es la reforestación natural del bosque, la cual implica la no intervención directa del hombre en dicho proceso. Las causas directas de la reforestación se relacionan con una acción antrópica específica, en donde destacan las plantaciones con fines de aprovechamiento comercial o de repoblación y los sistemas agroforestales (Rudel, 2012). Asimismo, la reforestación puede ser producto de causas indirectas relacionadas con el hombre tales como políticas públicas, gobernanza comunitaria y factores socio-económicos, todas estas interconectadas. Rudel et al. (2009) ha documentado que en la última década existe la despoblación en las zonas altas de los bosques de América Latina y el Sureste Asiático, ha contribuido en la reforestación del bosque. De igual forma, el abandono de tierras agrícolas y ganaderas ha facilitado revegetación espontanea (Rudel, 2012). En México este abandono de tierras es asociado a la baja productividad y rentabilidad de la actividad agropecuaria (Rogé, et al., 2014) y que consecuentemente provoca una migración de tipo económica.

Tanto la deforestación y como la reforestación han sido relacionadas con cambios demográficos y socioeconómicos. Por ejemplo, dinámicas poblacionales, como la migración rural urbana, pueden estimular la recuperación del bosque, mientras que el aumento en la demanda mundial de alimentos puede promover la expansión agrícola (Aide et al., 2013). En el caso de la Mixteca, en diversas comunidades se ha registrado caso de abandono de parcelas y de la práctica de pastoreo a causa de la migración (Hernández-Aguilar et al., 2017) y de la baja rentabilidad de la actividad agrícola, lo cual podría significar que ciertas zonas de la región se encuentren en proceso de recuperación de cobertura forestal.

Existe una transición forestal cuando la ganancia de cobertura es mayor a la pérdida de esta (Mather, 1992; Martens y Rotmans, 2002). La mayoría de los estudios sobre transición forestal analizan la recuperación de los bosques a escala nacional o regional (Vaca et al., 2012; Oduro et al., 2015; Meli et al., 2017). Se han propuesto cinco vías principales relacionadas con dicho proceso: 1) el desarrollo económico, 2) la escasez de bosques, 3) las políticas gubernamentales, 4) la globalización, y 5) la intensificación del uso de la tierra por parte de los pequeños propietarios de árboles (Rudel, et al., 2005; Lambin & Meyfroidt, 2010). Pueden concurrir más de una vía en el mismo territorio y al mismo tiempo (He et al., 2014; Oliveira et al., 2017; Lorenzen et al., 2020), pero cada una con sus propias condiciones. Los impulsores de la transición forestal pueden ser exógenos -cuando son independientes del contexto analizado y siguen su propia dinámica- o endógenos -cuando forman parte del sistema analizado- (Lambin & Meyfroidt, 2010).

Cada vez son más los estudios que registran una disminución de la deforestación y la plantación local de árboles y la regeneración natural que da lugar a la recuperación de los bosques (Klooster, 2003; He et al., 2014; Meli et al., 2017; Lorenzen et al. 2020). Sin embargo, no se han analizado de fondo factores a escala local que influyen en la transición forestal tales como, el capital social, aprendizajes sociales, valores culturales, entre otros.

1.2.6 Teoría de la acción colectiva

La acción colectiva se refiere a situaciones en las que existe un grupo de individuos, un interés común entre ellos y una disyuntiva entre el interés común y los individuales (Olson, 1989; Ostrom y Ahn, 2009). Dicha condición puede ser espontánea, a partir de la interacción entre distintos individuos, o puede requerir la intervención de una institución centralizada, un gobierno, que suministre el bien colectivo (Miller Moya, 2004). La acción tiene objetivos e intereses comunes y que toman decisiones y actúan en conjunto para alcanzar beneficios para todos quienes forman parte de dicho grupo (Olson, 2009; Hardin, 2015; Ostrom, 1997). Sin embargo, este proceso no es estático ni espontáneo; se construye a través de relaciones sociales y dentro de un sistema de oportunidades y restricciones, donde los individuos del grupo crean una identidad colectiva a partir de tres orientaciones: los fines, los medios y el campo de acción (Melucci y Massalo, 1991).

En un contexto actual donde es necesaria la conservación y el aprovechamiento sustentable de los recursos naturales, la acción colectiva tiene un papel central en la consecución de objetivos ambientales. La acción colectiva puede llevar a formas de gobernanza y autogestión de recursos naturales (Ostrom, 2009) que permitan el uso racional del recurso a partir de reglas reconocidas por los miembros del grupo. En México, donde el 60% de los bosques son de propiedad social (comunidades/ejidos) (Madrid et al., 2009; Torres-Rojo et al., 2016), la acción colectiva en núcleos agrarios ha permitido que se lleven a cabo actividades relacionadas con la conservación y aprovechamiento sustentable del bosque tales como reforestaciones, combate de plagas e incendios, planes de manejo, áreas voluntarias de conservación, entre otras (Luis-Santiago y Durán, 2020; Hernández-Aguilar et al., 2021; Pacheco-Aquino y Durán, 2021,). Esta acción colectiva en bosques comunitarios (en mayor o menor grado dentro de las comunidades) se da a partir del reconocimiento que un buen cuidado y manejo del bosque genera beneficios ecológicos, económicos y sociales colectivos.

Se pueden destacar los siguientes aspectos de la acción colectiva aplicada a la conservación y al manejo de los bosques comunitarios:

1) *La base de la acción colectiva es la gente.* La participación de la gente de las comunidades se relaciona con sus condiciones económicas (actividades productivas y migración económica) y sociales (resolución de conflictos agrarios y políticos), lo cual influye con la disponibilidad de la mano de obra para tareas o actividades comunitarias.

2) *La acción colectiva implica el involucramiento de las partes interesadas (en inglés stakeholders) tanto locales como externas en la consecución de metas*. En caso de México, no siempre existen condiciones para que comunidades forestales y entidades públicas y privadas puedan realizar proyectos/planes conjuntos a favor del bosque (un ejemplo combate a incendios y plagas forestales), por ausencia de mecanismos de cooperación y gobernanza que marquen las pautas de acción de cada parte interesada.

3) *Es un proceso de construcción y aprendizaje social (con precedentes en la Revolución Mexicana) que está en constante cambio.* Las comunidades buscan adaptarse a nuevas condiciones ambientales, económicas y sociales tanto internas (plagas forestales, migración, etc.) o externas (cambio climático, presupuesto público, legislación, etc.), para aminorar estos shocks.

1.3 Área de estudio y su contexto

La Mixteca Alta se ubica a más de 1,500 msnm (Guerrero-Arenas et al., 2010); forma parte del llamado "Complejo Oaxaqueño" o "Nudo Mixteco" que es un sistema montañoso en el que convergen la Sierra Madre del Sur y la Sierra Madre Oriental o de Oaxaca. El relieve predominante es el de montañas, lomeríos, cañadas, valles de laderas tendidas, mesetas y cañones. Los climas prevalecientes con el semicálido subhúmedo, semifrío subhúmedo, semiseco semicálido, templado húmedo y templado subhúmedo (INEGI, 2010); mientras que la vegetación predomínate es de bosques templados con prevalencia de pinos, encinos y enebros (UMAFOR Mixteca Sur, 2009). Con el reparto agrario después de la Revolución Mexicana, cerca del 80% de la Mixteca Alta quedó seccionada en polígonos correspondientes a 142 núcleos agrarios (Fig. 1), cuya extensión oscila entre 77 ha (Ejido Cañada Santa María) a 53 mil ha (Tepelmeme Villa de Morelos).

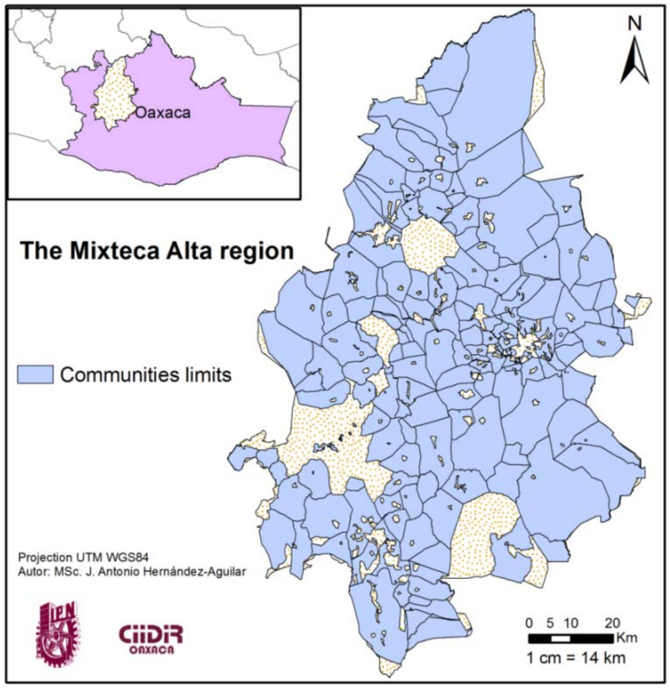

Figura 1. Localización de región Mixteca y núcleos agrarios pertenecientes al sitio de estudio

Las condiciones físicas, biológicas y sociales que actualmente se presentan en la Mixteca son el resultado de tres etapas:

- *Época prehispánica.* Modificación del paisaje forestal a causa de la creación de asentamientos humanos y la expansión agrícola a través del sistema de terrazas (*lamabordos*). De acuerdo con datos locales, se dice que en Yanhuitlán y zonas cercanas habitaron (Cerro Jazmín, Cerro Verde) cerca de 10 mil personas. Aunque el proceso de erosión del suelo es anterior a esta época, no hay datos exactos del impacto ecológico de la cultura mixteca durante este periodo (Guerrero-Arenas, 2010).

- *Época colonial y México Independiente (hasta finales del siglo XX).* En este tiempo, la Mixteca Alta comenzó a sufrir procesos intensivos de deforestación debido al sobrepastoreo del ganado caprino (Guerrero-Arenas, 2010). La presión de pastoreo, es decir la presión que el animal ejerce sobre el suelo, durante cinco siglos ha conducido al empobrecimiento del campo, aumentando la erosión y disminuyendo la cobertura vegetal.
- *Contemporánea (1980-Presente).* Para finales del siglo pasado, se puede destacar la creación de las primeras empresas forestales comunitarias, así como el surgimiento de los planes de reforestación. De igual forma, algunas comunidades de la región comienzan a establecer normas locales sobre la tala y el pastoreo. Desde el año 2000 a la fecha, se han expandido los programas de manejo maderable a otras comunidades y ha surgido otros de tipo no maderable (resina y agua de manantial) y de conservación (PSA y ecoturismo) (Hernández-Aguilar et al., 2017).

A pesar de que la Mixteca Alta destaca por aspectos negativos como el pastoreo excesivo, la erosión y degradación de suelos y los conflictos agrarios, existen experiencias exitosas de manejo forestal comunitario dentro de la región (Hernández et al., 2017). Un elemento positivo que no ha sido analizado es la capacidad organizativa de al menos 50 comunidades forestales que integran el Comité de Recursos Naturales de la Mixteca. Aproximadamente, la mitad de estos presentan experiencias previas de manejo forestal para aprovechamiento maderable y aunque no totalmente aprovechada, tienen una infraestructura instalada de aserraderos, caminos forestales y viveros

(Hernández-Aguilar et al., 2017). Estas comunidades forestales tienen capital social para el manejo del bosque, y mediante sus reglamentos y ordenamientos territoriales han logrado controlar el aprovechamiento del bosque, su conservación, hacer reforestaciones y saneamientos en áreas con afectaciones por plagas forestales. Lo anterior, en la literatura se reconocen como indicadores de resiliencia ecológica-social (Walker et al., 2002; Berkes y Folke, 2002), las cuales han sido poco estudiadas dentro de la región.

1.4 Planteamiento del problema y justificación

La deforestación y degradación forestal son problemáticas globales, que tiene múltiples consecuencias ecológicas y sociales. Sin embargo, se requiere ahondar en el análisis de los paisajes forestales para incorporar la dimensión espacial donde ocurren diferentes condiciones de resiliencia ecológica-social. Un factor central es reconocer los factores endógenos y exógenos que motivan acción colectiva para revertir deforestación y degradación. Hasta ahora el análisis académico de la transición forestal alude a factores económicos y la globalización (Rudel et al., 2009; Lambin y Meyfroidt, 2010), sin reconocer que la transición forestal a escala local puede tener sus bases fundamentales en factores culturales y sociales.

Durante décadas, la política forestal mexicana asume homogeneidad a nivel regional, aun en regiones altamente heterogéneas, en las cuales internamente se encuentran diferencias en vegetación, organización y acciones de manejo forestal. El análisis de la resiliencia del paisaje desde el punto de vista ecológico resulta insuficiente pues la acción antrópica es un fuerte elemento modelador (Green et al., 1996), por lo tanto, naturaleza-gente deben ser estudiados a la par. De esta forma, se necesitan de más estudios que analicen este binomio desde un punto de vista no solo funcional, como lo establece el marco de los sistemas ecológicos-sociales (Berkes y Folke, 1998; Bray 2020), sino también desde el ámbito espacial dada la naturaleza de los bosques comunitarios y la propiedad social. La escala de paisaje puede ayudar a comprender procesos y patrones en bosques comunitarios que van más allá de las fronteras administrativas.

En los últimos años, ha habido una tendencia hacia investigaciones que abordan tanto la resiliencia ecológica como la social (Plieninger y Bieling, 2012), cambiando el paradigma de que se inclinaba a la parte biológica de un sistema (Buma y Wessman, 2013; Reyer et al., 2015). Es de relevancia que se realicen estudios que aborden ambas esferas, dada las complejidades socioambientales de diversos lugares, pero sobre todo en espacios con condiciones biofísicas y sociales únicas, como es el caso de la Mixteca Alta, Oaxaca, sitio mundialmente reconocido por su alto grado de degradación y erosión de suelos y deforestación, además de ser una región históricamente marginada y con alta migración.

En el caso de la Mixteca, resulta impensable separar los procesos ecológicos con los procesos sociales, pues la condición actual de deforestación, degradación del bosque y erosión es una combinación de factores naturales y antrópicos. Con el análisis de la resiliencia ecológico-social de la Mixteca Alta es posible reconocer su complejidad, lo cual puede ser útil para el diseño de políticas públicas. De esta forma, un enfoque integral de las problemáticas socioambientales puede aportar a metas de sostenibilidad que difícilmente pueden ser abordadas desde una sola disciplina (Ruiz-Ballesteros, 2011; Masterson et al., 2017).

1.5 Preguntas de investigación y objetivos

Principal:

- ¿Son resilientes los paisajes forestales en la Mixteca Alta?

Secundarias:

- ¿Cuáles son las características (componentes ecológicos y sociales) del paisaje de la Mixteca Alta?

- ¿Qué cambios/procesos han ocurrido en la cobertura arbórea en las comunidades forestales en las últimas décadas y que factores inmediatos y subyacentes se relacionan con estos?

- ¿Qué indicadores de resiliencia ecológica-social en los SES forestales de la Mixteca Alta se pueden reconocer a partir de la condición actual de la cobertura y su dinámica social en las últimas décadas?

Objetivo general: Reconocer indicadores clave que confieren resiliencia ecológica-social a los paisajes forestales de la Mixteca Alta.

Objetivos particulares

a) Analizar el mosaico que conforma el paisaje forestal de la Mixteca Alta para reconocer el contexto actual de resiliencia ecológica-social

b) Analizar la dinámica de la cobertura forestal como un indicador de resiliencia ecológica-social en la porción con mayor degradación de la Mixteca Alta.

c) Identificar la contribución de la acción colectiva, el capital social y la gobernanza con el proceso de construcción de resiliencia-ecológica de bosques comunitarios en la Mixteca Alta.

El supuesto de esta tesis alude a que la Mixteca Alta, Oaxaca presentan resiliencia ecológica-social a partir de que en ella ocurren procesos intencionales de recuperación de cobertura, relacionados la seguridad en la tenencia de la tierra y distintos elementos sociales y culturales que favorecen la organización y la gobernanza para el manejo forestal.

1.6 Estructura de la tesis

La presente tesis esta estructura en cuatro capítulos: I. Generalidades; II. Enfoque de paisaje para el análisis del contexto actual de resiliencia ecológica-social en la Mixteca Alta, Oaxaca; III. Entendiendo los impulsores de la transición forestal local en los bosques comunitarios de la Mixteca Alta, Oaxaca, México; IV. Especies nativas para el manejo de la erosión de suelos en la región Mixteca Alta de Oaxaca; y V. Conclusiones generales.

En el Capítulo I se aborda la problemática, justificación, marco referencial, hipótesis, objetivos y metodología de la presente investigación. Los Capítulos II, III y IV se encuentran estructurados de forma independiente en la tesis ya que se escribieron en formato de artículo para su publicación en revistas acorde al tema. El Capítulo II describe el contexto socio-ecológico de los paisajes forestales de la Mixteca Alta. Por otro lado, los Capítulos III y IV identificaron indicadores de resiliencia ecológica-social en las comunidades del Geoparque de la Mixteca Alta, sitio reconocido por su alto grado de degradación y deforestación. Finalmente, el último capítulo abordó los principales hallazgos, contribuciones y aprendizajes de la tesis doctoral.

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CAPITULO II

Landscape approach for analyzing community-based forest management in Oaxaca, Mexico

ABSTRACT

Forestry landscape structure comprises a mosaic of natural and human-modified units, which well identified may help to planning and implement different public policies. However, commonly forest policies lacked to use some practical tools that considering the forestry social-ecological complex and help to scale-up result of programs along forestry territories. This paper provides a conceptual-methodological framework for zoning forestry territories in order to guide holistic forestry policies and promote collaborative forest development at the regional level, based on local practices. A case in a forestry region in Oaxaca, Mexico was analyzed. Based on biophysical, social and forest management criteria, a zoning was made and its potential to guide forestry policies and promote collaborative forest development regional was exhibited. The use of territorial zoning may take advantages of the current global agenda for forestry policies

Key Words: Community-based forest management, heterogeneity in Forest landscape units, Forest public policies.

1. INTRODUCTION

It has been demonstrated that community forest management (CFM) counterweights current forest loss and facilitates collective governance on forest resources (Velázquez et al., 2001; Gibson et al., 2000; Ostrom, 2005; Bray et al., 2003; Bray 2020). Many cases of successful community forest enterprises have been reported all around the world, where community members participate actively. However, the same achievements often do not extend to neighboring communities.

CFM needs diverse external institutions such as governments and NGOs, which provide technical advice and project financing. Simultaneously, some processes need to be addressed at the scale of groups of communities, such as watershed restoration, control of forest pests, synchronization of forestry activities, and access to markets.

On the other hand, external institutions should consider that forest management is commonly embedded in spatial contexts with high natural-anthropogenic heterogeneity, particularly for some countries with a considerable environmental and social variation. Hence, advanced forestry planning requires going beyond individual attention to each community and, at the same time, considering the significant heterogeneity of environmental and social conditions in which the communities are found within a region. An intermediate scale of intervention in relatively homogeneous areas between the region and the community is required.

This paper uses a landscape approach for identifying homogeneous areas in a heterogenous forested region to guide forestry strategies and promote collaborative development among local stakeholders. Its potential implementation is illustrated in the Mixteca Alta region in Oaxaca, Mexico.

The landscape approach

The conceptual framework of the landscape, which refers to an area shaped by both natural and sociopolitical elements and processes and that has a multifunctional and heterogeneous structure (Arts et al, 2017; Farina, 2000), could be useful for integrating processes and practices in complex environmental, socio-economic and institutional contexts (Reed, Deakin & Sunderland, 2015). Additionally, the landscape approach let to recognize the occurrence of mosaics of natural and human-modified areas (Farina, 2000; Zonneveld 2001; Scherr et al., 2013; Frost et al., 2016), which can be grouped in landscape units that represent homogeneous spaces with a unique physiognomy, structure, and physiography (Zonneveld, 1995).

Beyond Mexico, several studies have demonstrated the usefulness of the landscape approach in planning policies as a holistic theoretical-methodological model (Naveh, 2001; Buchecker et al., 2003; Görg, 2007; Nijnik et al., 2008; García-Martín et al., 2016). It has also been illustrated the potential of the standard conceptual and methodological framework for recognizing the still existent structure of the European cultural landscapes (Jongman, 2002).

The landscape approach can produce more efficient attention to subregional problems and point out those areas that require a particular type of intervention. The idea is to reduce spatial heterogeneity to more manageable (comprehensible) areas. The spatial recognition of more homogeneous subregional areas, called landscape units in this work, can guide public policies to incentivize and consolidate the CFM.

2. MATERIALS AND METHODS

2.1 Forests Context for Mexico

Mexico figure among forestry countries in the world (FAO,2020), with almost a third of the national territory, is forested areas (66 million of hectares) (CONAFOR, 2019). Common property and collective forest governance are prevalent, and currently, 21,095 communities in forested areas exist, referred to as the community forests of Mexico (Torres-Rojo & Amador, 2015; Bray, 2020). Numerous cases of community forests present an important fit with Elinor Ostrom´s design principles for common use resources and operate as community forest enterprises for both timber and non-timber forest products and services like environmental services market and ecotourism (Bray, 2020). Thus, in Mexico there are community forest consider icons for sustainable forest management, many of them (individually or in neighborhoods) need to improve their strategies. The community forest sector resulted from almost centennial shifts in public policies (agrarian and forestry; Table A), and for many decades government forest policies had supported forest communities, mainly focus on timber production, based on annual supports for individual community forests that request projects.

2.2 Study area

The Mixteca is an ethnic region of the state of Oaxaca, dominated by the *Mixtec* indigenous group. Based on cultural, productive, and environmental contrasts, the region has been divided into Mixteca Baja and Mixteca Alta (Leyva, 2009; Guerrero-Arenas, Jiménez-Hidalgo & Santiago-Romero, 2010), with neither geographical nor administrative delimitation, but clear cultural jurisdiction. We limited our study to the common property in Mixteca Alta defined as areas above 1800 meters in elevation, hereafter referred to as the Mixteca (Figure 1). The prevailing climates in the Mixteca are semi-cold sub-humid, warm humid and warm sub-humid (INEGI, 2010); and the potential and prevailing vegetation is of temperate pine, oak and juniper genera dominated forests (UMAFOR, 2009).

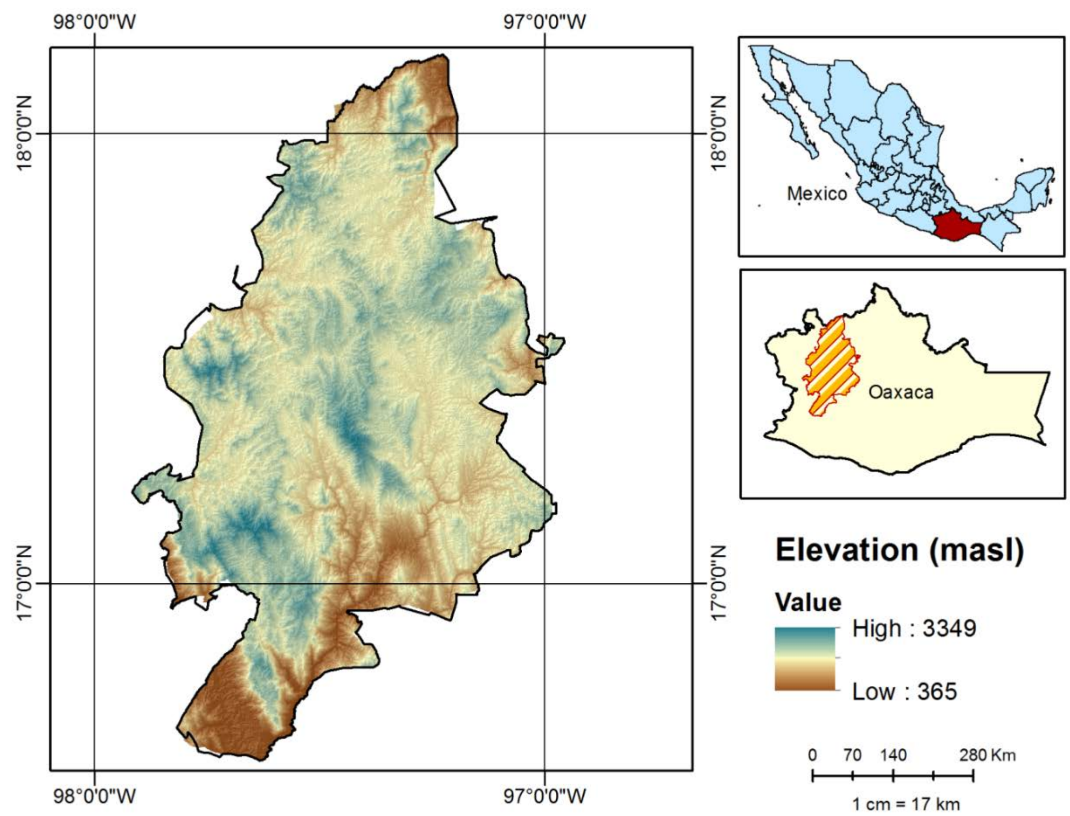

Figure 1. Localization of study area.

The Mixteca has a long history of forest use that can be divided in four periods: Pre-Hispanic, the Colonial, independent Mexico and present (post-revolutionary) (Guerrero-Arenas et al., 2010; Díaz-Núñez, 2006; García, 1996). With the introduction of livestock in the 16th century, forest cover loss was intensified (García, 2002). After four centuries of this practice, in some regions, deforestation and degradation are evident (García, 2002) (i.e., the municipalities of the Mixteca Alta Geopark). Currently, community forest management experiences (mainly timber extraction) emerged, as well as other forms of forest resource use (Hernández-Aguilar et al., 2017).

2.3 Landscape components and units in the Mixteca Alta

Data on physical attributes (basins and annual precipitation) were obtained from the National Institute of Statistics and Geography (INEGI) and field-verified by the authors. In addition, vegetation types were generated by classifying an image from the Landsat 8 satellite of the year 2017, relying on 80 locations of field verification. The social components such as localities, polygons of communities and infrastructure (roads and highways), were obtained from INEGI and the National Agrarian Register (RAN, 2017). In order to separate communities that have forest from those without forest, a filter was established. For this paper, a community forest was defined using the following criteria: 1) forest surface ≥ 400 ha, and 2) ≥ 5% forest cover. Additionally, six communities were included that do not satisfy the criteria but that have some sort of experience in CFM. Finally, forestry experiences in communities (reforestation, ecotourism, payment for environmental services, resin extraction, and timber logging) were registered through fieldwork and interviews (described in subsection 2.4).

The information was integrated into vectors with which six thematic maps were created: basins, precipitation, temperate forest distribution, settlements and roads, communities' forest, and forest management experiences.

The interviews information (see subsection 2.4) and data of thematic biophysical, infrastructure, and social maps were crossed, and forest communities that shared similarities in four or more attributes were grouped (Fig. 2). The data were integrated into a table composed by the attributes of (1) precipitation, (2) watershed, (3) percentage of forest surface, (4) experience CFM activity, and (5) inter-community collaboration. This table labeled the potential landscape units according to communities' similarities. Subsequently, the communities were located spatially through geographical information system software to zoning the study area.

2.4 Needs, challenges and strategies for improving the community forest management

To document the history, needs and challenges, and regional collaboration of the communities' forest in different landscape units of the Mixteca, a group of 30 Community Boards[1] (*Comisariados*) of them (of total 97) accepted participation in an interview. The interviews focused on the involvement of forestry potential, implementation of government programs, and inter-communal organization. Additionally, two government officials were interviewed – one from the Regional Office of the National Forest Commission (CONAFOR[2]) and one from the Ministry of the Environment and Natural Resources (SEMARNAT). Two members of regional

1 Legal representatives of a community elected by an Assembly.

2 All acronyms of Mexican organizations are according to their Spanish initials.

organizations were interviewed as well – one from the Southern Mixteca Natural Resources Regional Committee (CRRN Mixteca) which operate since 2006, and one from Project Mixteca (sponsored by the Global Environment Facility, the National Commission of Protected Natural Areas, and the Fund for the Environment of the United Nations since 2013).

The information was used to stablish a set of forestry strategies to promote CFM and regional collaboration. These recommendations were established based on the characteristics of landscape units and the analysis of community forest management development. Each recommendation was aimed at addressing problems and forestry potential in each area of the Mixteca Alta landscape.

3. RESULTS

3.1 Landscape components and landscape units of the Mixteca Alta

The landscape approach helped to identify patterns for the availability of forest resources and organizational processes for forest management. By identifying and characterizing forest landscape components, it is possible to locate landscape units with different forest potential based on specific biophysical and social attributes. The landscape of the Mixteca is a mosaic interconnected by topography, hydrology, natural vegetation. Additionally, the landscape presents interconnection towns and roads (Fig. 2d) and forestry needs and opportunities. Currently, common property represents around 78% of the Mixteca (722,732 ha) and comprises 142 community polygons (Fig. 2c). The extension of the communities ranged between 65 ha (San Andrés Andua) to 53,000 ha (Tepelmeme Villa de Morelos). The communities' polygons are included in three hydrographic basins: *Atoyac River*, *Verde River*, and *Papaloapam River*, which in turn include 23 micro-basins within the region (Figure 2a). It is estimated that temperate forest cover in the Mixteca is 297,058 ha (32% of the total surface), of which 83% are located in communities' common property (Figure 2c).

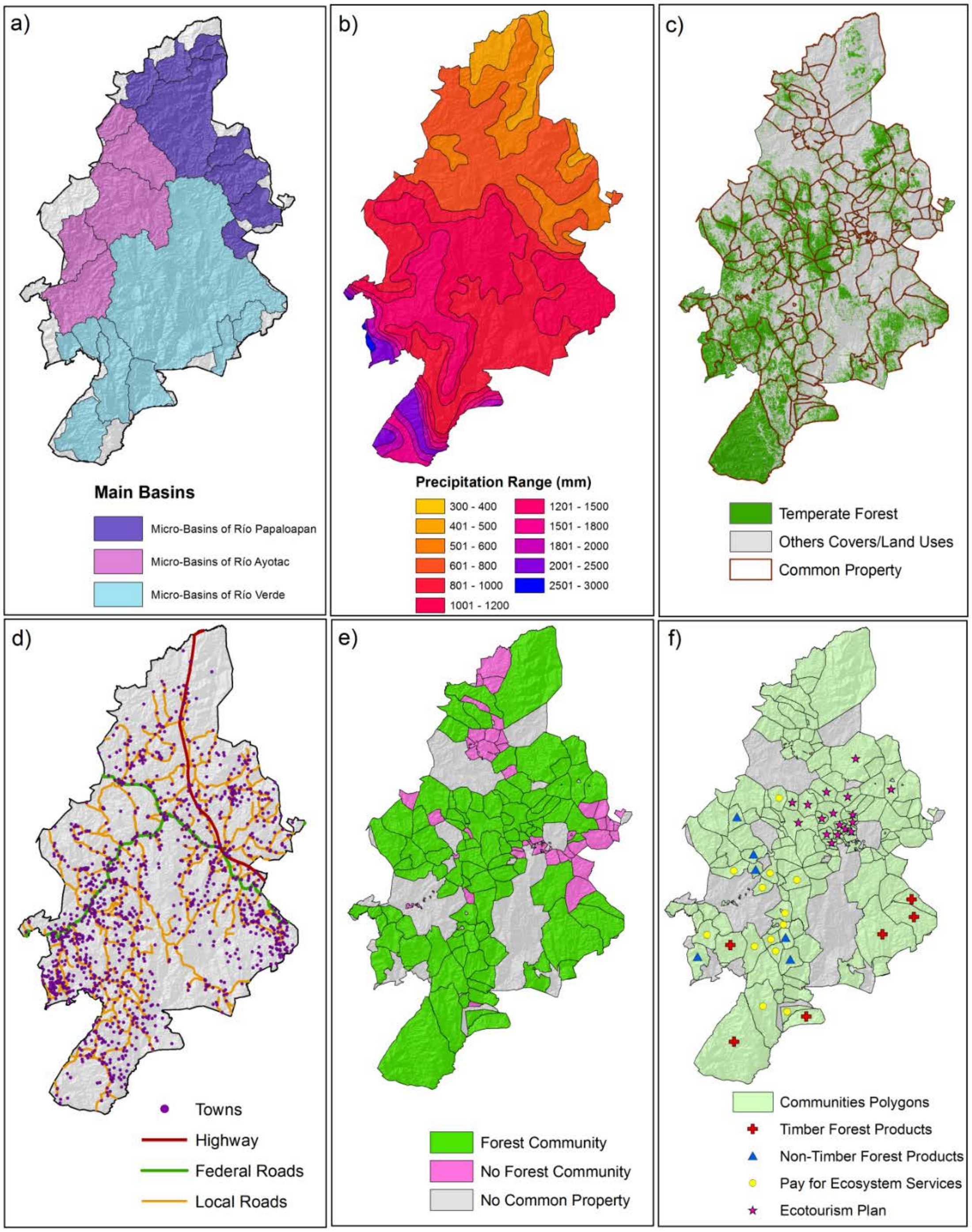

Figure 3. Biophysical and social landscape components in the Mixteca Alta. a) Basins in the Mixteca Alta, Oaxaca. b) Precipitation gradient in the Mixteca Alta, Oaxaca. c) Distribution of temperate forests in the Mixteca Alta, Oaxaca. d) Settlements and roads in the Mixteca Alta, Oaxaca. e) Forest Communities in the Mixteca Alta, Oaxaca. e) Experiences of CFM in the Mixteca Alta, Oaxaca.

Of the 142 communities present in the Mixteca Alta, 97 forest communities could be identified using the established criteria, including 98% of the surface of pine-oak forests in the common properties of the region (Figure 2e). In the Mixteca Alta, 43 forest communities (≈ 43% of the total area) were found to have experience in CFM for the commercial use of timber (6), water (2), resin (4), ecotourism (18), and payment for hydrological services (PES) (13) (Figure 2f).

The 97 forest communities identified in the Mixteca Alta have a basic set of documents that certify their legal existence (presidential resolution, registration of beneficiaries, and certified map of the community). All of them have communal statutes and carry out annual Assemblies (the maximum authority) to determine the use and management actions for forest resources in their territory. Those conditions have resulted in the majority of the forest communities in the Mixteca not having any conflicts over the boundaries of their territories. A rule established by the Community Assemblies that has contributed to the conservation of the forest is the prohibition of unregulated logging and livestock grazing for more than a decade. Moreover, more than half of the forest communities with degraded lands have carried out, at least every two years, reforestation activities. Grazing control was present in all interviewed communities through collective norms. These factors (reforestation and norms) have resulted in emerging vegetation in the Mixteca, and according to the community members, this vegetation has increased in the last years.

The analysis of the biophysical and social components has helped to identify trends and patterns into the Mixteca Alta. Despite the fact that forest communities were registered throughout the

Mixteca Alta, spatially, the northern part tends to be the driest and where there is less forest cover. On the other hand, the central and southern part of the study site has higher precipitation and forest availability. This configuration has led to differences in tree species within the Mixteca Alta. In the dry parts, remnants of pine-oak and shrub forests predominate, with species with low timber and non-timber potential. In contrast, the more humid parts have species suitable for timber and non-timber (resin extraction), such as Pinus *pseudostrobus*, Pinus *ayacahuite* and Pinus *oaxacana*. Given these conditions, cases of experience in CFM in the Mixteca Alta have arisen mainly in the more humid areas and with greater availability of species with commercial potential.

The components and patterns analyzed helped to identify the landscape units of the forest landscape of the Mixteca Alta, that it corresponded to five *quasi*-homogeneous areas (Table 2; Fig. 3). Zoning focused on the factors: precipitation, watershed, percentage of forest surface, experience CFM activity, and inter-community collaboration. These landscape units are described below:

- *Landscape unit I.* It encompasses forest communities that belong to the basin of *Papaloapam River*. This landscape unit registers the lowest precipitation, the lowest percentage of forest surface, few experiences in CFM, and null degree of inter-community collaboration, in comparison to the other sites.
- *Landscape unit II*. This landscape unit includes forest communities of the basin of *Papaloapam river*. The forest surface is of 14.5% and the precipitation are higher (800-1000 mm) than the Landscape unit I. The degree of collaboration in this area is high as

most of the communities have experience in ecotourism but collaboration among them is low.

- *Landscape unit III.* It is composed of forest communities within the watershed of the *Atoyac River*. Due to the high precipitation and high forest cover, this landscape unit has forest suitability, especially for non-timber forest products (NTFPs) production and PES program. The degree of inter-community collaboration is medium because around a third part of the communities participate in the CRRNN Mixteca

- *Landscape unit IV.* This landscape unit is composed of forest communities within the watershed of the *Verde River*. The biophysical conditions are similar to Landscape unit III. However, fewer communities participate in the CRRNN Mixteca.

- *Landscape unit V.* The landscape unit also includes forest communities in the *Verde River* watershed. This landscape unit has the highest annual average precipitation in the Mixteca Alta, and thus, there are good inventories of commercial timber species. These conditions have allowed six communities to operate a CFE since 1990. The degree of collaboration among them is high, which represents a participation of 60% by the communities in the CRRN Mixteca.

Table 3. Characteristics of the proposed landscape units in the Mixteca Alta region, Oaxaca

	Number of communities	**Precipitation**	**Watershed**	**Percentage of forest surface (%)**	**Experience CFM activity (#)**	**Inter-community collaboration***
Landscape unit I	14	300-800 mm	Papaloapam River	14.8	Ecotourism (2)	Null
Landscape unit II	16	800-1000 mm	Verde River	14.5	Ecotourism (13)	Low
Landscape unit III	30	800-1500 mm	Atoyac River	43.8	NTFP and PES (10)	Medium
Landscape unit IV	20	1000-1800 mm	Verde River	36.6	NTFP and PES (9)	Low
Landscape unit V	16	1500-2500 mm	Verde River	42.7	CFE (9)	High

* Participation in local organizations and regional committees (CRRN Mixteca and Mixteca Alta Geopark).

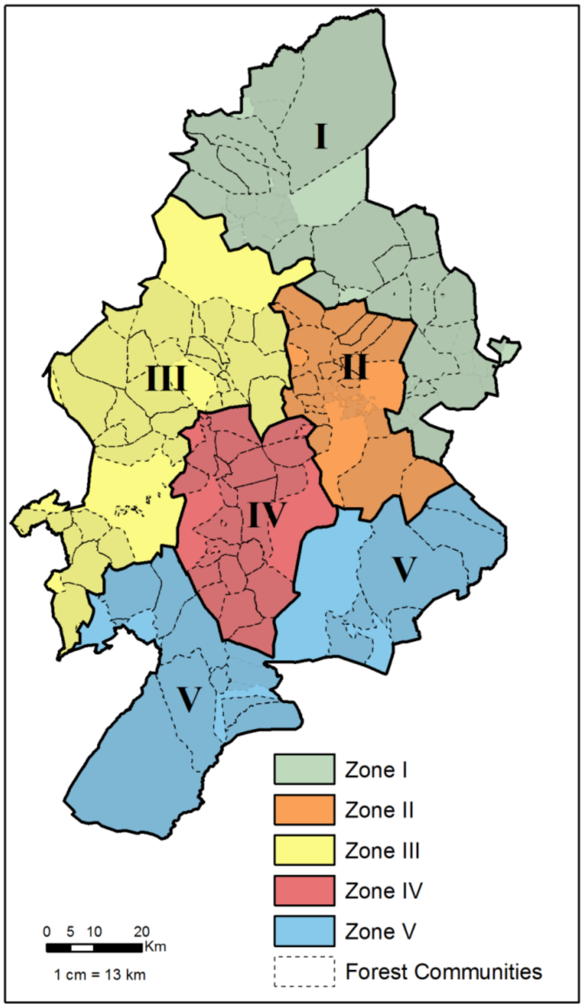

Figure 4. Five landscape units proposed for the landscape in the Mixteca Alta, Oaxaca

3.2 Needs and challenges of the CFM in the Mixteca Alta

Timber production in the Mixteca started in the *Landscape unit V* during forest concessions in the decades of the 1970s and 1980s. However, in the 1990s, 15 forest communities that had timber potential organized a community forest enterprise (CFE) and began commercially use their forests (Antinori & Bray, 2005). The communities of San Esteban Atatlahuca, Santo Domingo Nuxxa, San Juan Tamazola, San Andres Nuxiño, Santa Catarina Cuanana and Santa Cruz

Itundujía stood out. These CFEs started as small entrepreneurship with local financial resources, and they received government financial incentives until the early present century. Several of these CFEs have operated intermittently due to lack of investment or failure to renew forest management permits.

Since 1998, forest management of part of the landscape of the region has been organized around the CRRN Mixteca, which was promoted by the Community Forest Development Program (PROCYMAF). The CRRN Mixteca was consolidated in 2006 by obtaining legal register, and it adopted an organizational structure of a board of directors, which is composed of Community Boards (legal representatives) of 32 communities of *Landscape units III*, *IV* and *V*. Currently, it has permanent technical staff that helps coordinate the monthly reunions of the members and guides the procedures of the programs related with the forest sector. In the last ten years, the CRRN Mixteca has become a cross-sectional forum of communication and promotion where initiatives such as Project GEF Mixteca and federal agencies (mainly CONAFOR), have promoted programs and activities for non-timber forest products: resin extraction, spring water bottling, ecotourism, and the PES program.

These opportunities have been accepted in several forest communities of *Landscape unit III* and *Landscape unit IV* because they represent economic opportunities to improve CFM. The production of resin in forest communities of the Mixteca started in the year 2011, driven by a Mexican company (*Alen del Norte*). The number of resin tappers has increased due to promotion by Project Mixteca of the biological and economic benefits of the extraction. Likewise, this initiative brought funds for constructing greenhouses for the genetic improvement of seeds. The resources that PES offers have allowed several communities to undertake projects related to the promotion of tourist attractions present in the landscape, like waterfalls, rivers, archaeological sites, and Dominican temples. Additionally, two communities have initiated the sale of spring water through a bottling business.

The bark beetle pine disease is a threat present in several communities of *Landscape units III, IV,* and *V* (dozens of communities). This disease is not a new phenomenon in the Mixteca. Since 1995, some communities have tried to reach agreements for joint management of the forest landscape to control the plague. Currently, despite the efforts to achieve better management of the forests, the occurrence of the problem continues.

In the *Landscape unit II* exists another factor that contributes to the governance and management of the landscape in the region is the UNESCO Mixteca Geopark, operating since 2016 due to the impressive geological features and soil degradation. This project encompasses 41,500 ha, nine municipalities, and 13 communities. The Mixteca Geopark promotes the geological, biological, historical, and cultural richness of the region and, according to interviews with community members, has strengthened discussions about soil restoration, reforestation and helped ecotourism. The Mixteca Geopark tries to scale local management actions into a regional level. However, it does not have any formal structure (as the CRRN Mixteca has) that allows involving all the stakeholders. Although communities of *Landscape unit I* have similar biophysical and social conditions to those of *Landscape unit II,* they were not included in the Geopark project. However, several communities of *Landscape unit I* are a national and worldwide reference in reforestation activities, which they have carried out since the 80s.

3.3 Strategies for improving community forest management in the Mixteca Alta

Based on the characteristics, priorities, and needs of each landscape unit, strategies and actions are proposed that can be implemented by the governmental agencies and communities to enhance the CFM within each landscape unit.

Landscape unit I and *Landscape unit II.* Due to the state of degradation and deforestation of these areas, it is recommended to continue and expand restoration programs (forest and soil). These activities can be involved in jointly between communities. In the absence of information on the forest suitability, technical studies could help to communities to identify forest potential. Within *Landscape unit II*, technical advice and business skills development could help organize and promote ecotourism in the Geopark. On the other hand, communities should create a regional committee to jointly promote the activities in the Geopark.

Landscape unit III and Landscape unit IV. CONAFOR should be focused on generating new management plans for NTFP and strengthening existing ones; therefore, it is recommended for these *Landscape units* the implementations of technical studies, and the strengthening of supply, transformation, and marketing Processes. The forest health program should be a priority for those *Landscape units*, and its implementation should just be separately by communities but through a coordinated group of them. Additionally, communities should join the CRRN Mixteca to create cooperation, and this could help to coordinate logistics collaboration (storage, transport, and sale) of communities that produce NTFP.

Landscape unit V. The strengthening of supply, transformation, and marketing processes should be assigned to most communities of this *Landscape unit*. Additionally, the forest productive projects would help diversify activities in communities that extract timber. CFM in the *Landscape unit V* could be amplified if communities form a formal group or committee to obtain public and private financing to straighten timber production and diversify forest management (PES, resin extraction, and ecotourism). Joint forest sanitation between communities is recommended.

4. DISCUSSION

4.1 Practical use of the landscape approach

Land planning has become a central spatial component for different management fields that may to conduct to sustainable development (van der Zee & Zonneveld 2001; Metternicht 2018; Simensen et al. 2018). The landscape approach makes possible to distinguish the continuity/discontinuity of the territories with forest potential (Reed et al. 2017). The spatial recognition of contrasting landscape units could guide public policies to support, incentivize and consolidate the CFM through actions as technical guidance, projects and incentives. Thus, the spatial model of five landscape units for the Mixtec Alta (Figure 4), disentangled part of the spatial complexity using to attributes biophysical, social and forest management (Figure 3). This landscape analysis helped to recognize a spatial structure until now not documented, and the identified landscape units are useful for:

1) Contextualize forests and forestry lands within a connected biophysical-social space.
2) Integrate antecedents of community forest management.
3) Recognize natural connections among communities' polygons, like micro-watershed.
4) Recognize connections among communities that integrate organization and also critical areas with social conflicts or forests pest.

Also, five landscape units could be a spatial referent useful for recognize where specific needs and opportunities for forest management are located (Table 3), on the prevalent context of common property in the Mixteca Alta. Although this kind of property is the base for the current Mexican forest policy (CONAFOR 2019); unfortunately, the national intervention strategies from CONAFOR are still based on the spatial framework of geopolitical borders (states, geopolitical or biocultural regions and sub-regions), and for local scale basically are restricted for the community borders. For that, the achievements of forestry programs are reported on success cases, commonly reporting the individual or group of communities' performance, but they are failing to prospect systematically success that scaling up to the forestry landscape level (Figure 5).

The adoption of a landscape analysis based on a biophysical, social and forest management attributes differed from other spatial-political planning tools used in Mexico (Bray, 2020). One is the ecological land planning (Rosete 2006; Sanchez-Salazar et al. 2014), that is mandate by law, and exist for the national, states and municipalities. Second, is the mandatory forest management plans (a formal land use zoning needed for commercial harvest of forest products, established in the 2003 Forest Law), that demand landscape unit the entire community territories in: 1) conservation areas, 2) forest production areas, 3) forest restoration areas, and 4) other uses, mostly agriculture and village areas (Bray and Duran-Medina, 2014). Third, is the community land planning which emerged from the practice and was adopted by government for community forests, since the 90s decade (Lara and Chapela, 2006). It is a finer-grained and participatory land zoning into communities, focus on the "collective vision of their whole territory and prospected for a future based on taking advantage of their resources" (Bray 2020). For 2012, it was extended in almost a thousand of community forest, in at least 6.2 million ha (Anta Fonseca, 2015).

Mentioned land planning instruments have restrictions for forest-ecological and productive goals, because they use arbitrary borders (administrative and land tenure), instead natural or socio-ecological edges. The official ecological land planning has low potential because regional and municipality boundaries reduce possibilities for forest management across the landscapes (Meffe et al. 2002). While the forest management plans and community land planning are totally restricted in the community polygons, but anyone may overpass actions still when biophysical and functional contiguities happened. However, the landscape units recognized in the Mixtec Alta region could be inclusive of both natural and administrative borders, and still have flexibility for the current annual forest programs, which focused the grants for individual communities (local scale), and address both specific forest management goals and regional development. Thus, although reality is too complex to be captured with relatively few data (Figure 2), the results of the landscape analysis helped for recognized the spatial structure, which can be useful to introduce suitable programs (van der Zee & Zonneveld 2001; Siemmens et al. 2018).

Beyond Mexico, several studies that have demonstrated the usefulness of the landscape approach in planning policies as a holistic theoretical-methodological model (Naveh, 2001; Buchecker et al., 2003; Görg, 2007; Nijnik et al., 2008; García-Martín et al., 2016). Also, it has been illustrated the potential of the standard conceptual and methodological framework for recognized the still existent structure the European cultural landscapes (Jongman 2002).

4.2 Implications of landscape units' identification

The experiences of CFM in the Mixteca Alta have emerged in different periods of time and have developed at different intensity. Timber harvesting was predominant during the last century as a result of a forest policy without a diversification strategy (Table A; Bray, 2020). However, at the beginning of this century, like other forest regions in Mexico, additional types of forest harvesting and conservation programs have been included (Bray et al., 2005; Bray & Merino, 2007). This diversification in forest management activities could be linked to national strategies that have sought to promote the development of social forestry in the country (Torres-Rojo et al., 2016), although from a vision of individualized assistance.

In comparison with other regions of Oaxaca and Mexico, the Mixteca Alta is one of the low areas of contribution to national commercial production (Merino, 2004), despite the fact that it has a third of its surface area covered by forest and that it has had community forest enterprises operating for more than 20 years. The development of community forest management in the Mixteca has been slow because historically it has been considered by government entities as a region of high forest degradation and soil erosion. This conception of the Mixteca Alta has given a wrong perception that the entire region has no commercial potential and that only reforestation and soil restoration projects are needed. This work documented that the Mixteca Alta has biophysical and social conditions not only for timber production but also for products such as resin or bottled spring water, as well as for ecotourism activities.

The collective management and decisions regarding the forest, at the scale of communities, are the base to promote the structural and functional integrity (productive, cultural, organizational, etc.) of a forest landscape. In the Mixteca Alta, there are several individualized efforts to restore and conserve the forest, control the forest pests, and take advantage of forest products. However, collective actions among communities could trigger well-being in larger forest areas, as in the other regions of Oaxaca, such as “La Chinantla” (CORENCHI) and Sierra Juarez (Pueblos Mancomunados and UZACHI). A first attempt to scale up productive and organizational processes in forest communities in the Mixteca Alta has been the creation of the CRRN Mixteca. Although this committee was created to provide orientation to communities that belong to Forest Management Units (UMAFOR), the participation in this forum is not obligatory so membership is constantly changing. In order to understand the motivations of the communities for participating in the CRRN, it is necessary to carry out research at the local scale, although it has been identified that there are cultural factors in the region that influence the decision to harvest forest products for commercial purposes (Hernández-Aguilar et al., 2017). Administratively, the rest of the Mixteca Alta also has UMAFOR, but none of them has an assistance committee like the CRRN Mixteca, even though it has been demonstrated that forums that can promote collaboration between communities. Another collaborative scheme at the landscape level is the Mixteca Alta Geopark but like the CRRN Mixteca, participation is voluntary and limited to activities within the communities' jurisdictions and not on a regional scale. In this sense, the landscape units’ classification could help communities to understand the importance of regional collaboration through institutional mechanisms, while government agencies would be able to attend UMAFOR in a different way, considering that these are not homogeneous spaces. The communities of the Mixteca Alta could operate with relative synchronization if proximity and similarity between them is applied and landscape units are established to target policies and actions. Without a landscape focus has led to CFM in the region being focused on certain landscape units, causing uneven forest development in the Mixteca Alta.

Beyond Mexico, the European Landscape Commission illustrates the problem with tendencies for homogenization of landscapes, but the potential of the standard conceptual and methodological framework for recognized the still existent structure of the European cultural landscapes (Jongman 2002). Despite global influence in the rural landscape dynamics (Antrop, 2006), the relevance of public policies is that they may contribute to orient some future scenarios, in specific rural contexts (Min-Venditti et al., 2017).

4.3 Relevance in forest policy

The CONAFOR established the current national agenda focus on community forest, but use as reference administrative units (states, geopolitical/cultural regions, municipalities, and properties) and the strategic landscape units (priority areas for some purposes, indigenous, among others). Meanwhile, the mentioned strategy depends on each individual forestry community decision for applying to some programs, and each community decides, only for its property, based on their needs, problems, assembly agreements, information available, eligibility restrictions of the programs and, sometimes, based on the suggestion of the professional who advises them technically. The spatial axis has been included with different territorial planning instruments established in the Mexican Forest Law (2018), such as Forest Management Plan, Forest Management Units, and Forest Zoning, but these instruments generalize and simplify large regions and omit their internal complexity (Table B). In addition, Community Territorial Planning (OTC), a land zoning plan which is a participatory local delimitation into the community, lacks context (natural, social, productive) beyond each community's borders.

However, to channelize funds eligibility criteria lack recognition of the heterogeneity of the social-ecological complex spaces and a better-integrated landscape approach. For example, strategies for Oaxaca, southern Mexico, are focus on forestry areas into geopolitical regions and specifically, for the Mixteca Alta region, in areas where degradation was recognized as a socio-environmental problem, support prioritize reforestation and soil restoration (Plancarte, 2019), but in communities with potential for timber extraction forestry resources supports try to strengthen the community forest enterprises (Hernández et al., 2017).

In this context, the use of the landscape approach could help to plan forest management and conservation programs in the Mexican common property contexts (Velazquez et al., 2003, Bray 2020) and may allow addressing problems that occur at multiple levels. Likewise, this landscape approach provides a framework for negotiations between the stakeholders and helps to establish a flexible system to monitor and measure the impacts on a territory (World Bank, 2008; Angelstam et al., 2013). In addition, geographically synchronizing forest management actions in adjacent communities can up-scale organizational processes from the local level to the regional level.

5. CONCLUSION

This paper provides a conceptual-methodological framework for zoning forestry social-ecological complex territories in order to guide holistic forestry policies and promote collaborative forest development at the regional level. This framework conducts to recognized forest policies intervention landscape units in an spatial model. Its potential implementation was illustrated in the Mixteca Alta region, in Oaxaca, Mexico.

The landscape approach, with an emphasis on the potential for forest management, let to recognize the Mixteca region as a mosaic of landscape units, relatively homogeneous biophysical, social, and forestry management. Inside these landscape units, different forest social-ecological systems have the potential for improve different agendas related to forest management. This paper exhibited the advantages of this holistic approach for oriented public policies implementation and forest community collaboration oriented to impulse synchronically specific agendas in specific landscape units, which may scale-up results to improve management and practices for forest restoration and forest health, among others. This territorial zoning exhibits a different spatial and functional scenario for forestry policies for CONAFOR programs and forestry communities. Thus, the landscape analysis represents a tool for a new forest management paradigm, until now poorly explored in Mexico, where wide criteria (administrative or social) reduce the social-ecological complexity and fragment or ignore the real landscape structure.

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Table A. Contrast between forestry policy models in Mexico

	Historical Models			Holistic models	
Distinction	*Agrarian reform*	*Forestry cooperatives*	*Forestry concessions*	*Community forests*	*Landscape approach proposed in this paper*
Period	After the Mexican Revolution (1917) to 30s decade	1930-1940	1950-1970	1980-present	*Currently and for future*
Forestry National Policy	Property rights Transition	Forestry local cooperatives	Foreign forestry industry, national enterprises, forest bans, forest concessions	Community forest, community forest enterprises	Current and future climate change scenarios in forest social-ecological systems
Target	Define extent and ownership of forest areas	Local management of forest	Timber extraction	Forestry activities diversification	Forestry activities diversification based in sub-regional and regional needs
Spatial scale	Local to regional	Local to regional	Regional and macro-regional	Local scale (small and individual projects)	Local to subregional landscape scale (joint projects among communities and landowners)
Temporal scale	Short to medium term (1 to 5 years)	Short to medium term (1 to 5 years)	Medium term (3-5 years)	Short to medium term (1 to 5 years)	Long-term (over 5 years)
Policy approach	Uniformly applied top-down policy	Selective top-down policy	Uniformly applied top-down policy	Selective top-down policy	Multiple policy strategies (top-down and bottom-up)

Policy focus	Legal recognition to communities and landowners	Support for a single community or landowner	No support to communities and landowners	Support for a single community or landowner	Support for a multiple communities or landowners and larger program
Forest typology	None	Based on timber forest products	Based on timber forest products	Based on timber and non-timber forest products	Based on forest products and ecosystem services
Key actors & stakeholders	Government agencies, communities, and landowners	Government agencies, cooperatives, private enterprises, and landowners	Government agencies, communities, private enterprises, and landowners	Government agencies, local organizations, communities, and landowners	Multiple stakeholders (public, private, and social sectors/entities)

Table B. Instruments of land-use planning for forestry sector in Mexico

Instrument	Legal Frame	Scale	Delimitation criteria	Approach	Classification	Limits
Forest Management Plan	Forest Law	Local (only into forestry areas at the common or private property)	Biological (forest potential and restoration need) and economic (timber/non timber harvest rotation)	Technical Participatory	Classify social property according to forest commercial use.	-Only available for communities with forest potential. - Reduced spatial scale (restricted for the land tenure).
Territorial	LGEEPA	Local	Vegetation and other	Technical	Classify municipal area	-Low participatory

Ecological Planning		(municipalities)	land use cover		according to different land use covers.	process. -Opposite or duplicate of the OTC
Community Territorial Planning (OTC)	NO (CONAFOR technical rules)	Local (into polygon of common property)	Biological (forest potential) and social (local interests and perceptions)	Technical Participatory	Participatory zoning into social properties according to forest potential and local people needs (production, conservation, restoration, recreation, etc.).	- Reduced spatial scale (restricted for the land tenure). -Planning requires publics funds. -Instrument does not recognize the landscape needs and challenges.
Forested Management Units (UMAFOR)	Forest Law	Regional	Biophysics (basins) and political localization	Technical-Political	Classify municipalities according to basins and proximity to a political district	-The delimitated territorial unit is considered homogeneous- -Some UMAFOR includes different types of forests (for example, temperate forest and rainforest).
Territorial Ecological Planning	LGEEPA	Municipal and State Entities	Biological (vegetation), economic (productive activities) and social	Technical	Establishes Environmental Management Units to propose productive potential and identify	-Operation among administrative frontiers. -Sectorial approach does not recognize links

			(local conflicts and needs)		environmental challenges in a certain territory.	among areas or sectors.
Forest Zoning	Forest Law	National	Biophysics (soil, weather, edaphology, geology, hydrology, topography, and vegetation)	Technical	Classify national forests according to a specific vocation (production, conservation or restoration).	-Simplify forest ecosystems -Does not consider social aspects -Large space scale
Forestry Landscape Units	No	Local-Regional	Biophysics (Soil, Weather, Edaphology, Geology, Hydrology, Topography, And Vegetation) Land Tenure Forest	Technical Participatory	Spatial heterogeneous pattern of almost homogeneous Forestry Units	- Ignored by the current public policies focus on small spatial (private/ common land tenure polygons) and temporal (annual) scales

CAPÍTULO III

Understanding drivers of local forest transition in community forests in Mixteca Alta, Oaxaca, Mexico

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ABSTRACT

The Mixteca Alta region in Oaxaca, Mexico is characterized by its severely degraded landscapes. In the last three decades, the region has experienced a remarkable local forest transition. This paper reveals the drivers that favored local forest transition in five communities of Mixteca Alta. Three questions were addressed: how much forest cover was gained during the last three decades? What were the drivers triggering local forest transition? And what lesson can be derived for public policies aiming to restore forests? A cartographic analysis assessed forest recovery between 1990 and 2018. Community workshops, interviews, participant observation, and the review of historical sources helped reveal core drivers. During the period studied, forest cover increased by 71% (2,640 hectares), with an annual change of 2.73%. The increases are the result of reforestation and natural regeneration. Drivers of local forest transition include outmigration and new forest policies, as well as endogenous drivers, such as communities' social capital, local institutional efforts, and socio-ecological awareness. The prevalence of endogenous drivers suggests a strong community-based local forest transition pathway. Forest policies that promote local forest restoration need to recognize local land use land cover trajectories and

support those that encourage active and passive recovery pathways. Community-based local forest transition could be important for providing environmental benefits to local people, and it may also contribute to global environmental goals.

1. INTRODUCTION

Deforestation and forest degradation are a priority concern for global environmental agendas. They are primarily the result of human activities, like the conversion of forests for agriculture, illegal logging, and overgrazing (Penman et al., 2003; Schoene et al., 2007). The consequences of deforestation and forest degradation are the loss of livelihoods and ecosystem services important for local users (Simpson et al., 2001; Agnoletti, 2007), and for distant beneficiaries who are affected by changing weather patterns and the carbon emission caused (Griscom et al., 2017).

Persistent global deforestation has been offset by a forest cover increase in the regions of Asia, Europe, Latin America, and North America (Rudel et al., 2005; Meyfroidt et al., 2010; Vaca et al., 2012; Aide et al., 2013; Keenan et al., 2015; FAO, 2020), a process known as forest transition (FT) (Mather, 1992; Martens & Rotmans, 2002; DeFries et al., 2004). The replacement of old growth forest with planted and natural regenerating forests, however, does imply significant loss of biodiversity, and ecological functionality (Carnus et al. 2006). Most FT studies analyze forest recovery at national or regional scales (Vaca et al., 2012; Oduro et al., 2015; Meli et al., 2017). Theorists have proposed five main FT pathways: 1) economic development, 2) forest scarcity, 3) government policies, 4) globalization, and 5) smallholder tree-based land use intensification (Rudel, et al., 2005;

Lambin & Meyfroidt, 2010). More than one pathway can concur in the same territory at the same time (He et al., 2014; Oliveira et al., 2017; Lorenzen et al., 2020), but each has its own distinctive drivers, which are events or conditions that lead to land use and land cover changes. The FT drivers can be exogenous –when they are independent of the analyzed context and follow their own dynamics- or endogenous – when they are part of the analyzed system- (Lambin & Meyfroidt, 2010).

An increasing number of studies record a decline in deforestation and an increase in local tree planting and natural regeneration resulting in forest recovery. (Klooster, 2003; He et al., 2014; Meli et al., 2017; Lorenzen et al., 2020). Such local forest transition (LFT) is also known to result from a confluence of distinctive drivers (de Jong, 2010; Haines-Young & Potschin, 2010; Lambin & Meyfroidt, 2010; Minh et al., 2017; Rudel et al., 2019; Hultman et al., 2020; Lorenzen et al., 2020). The relevance and contribution of endogenous drivers to LFT has been less highlighted in the FT literature. For instance, in indigenous communities and other traditional societies, institutional and social capital may contribute to LFT (Chi et al., 2013; Bhagwat et al., 2014; Velasco-Murguía et al., 2014; Hartel et al., 2016). Where this happens, the theory of commons (Ostrom, 1990), the social capital framework (Coleman, 1988) and the socio-ecological systems theory (Berkes et al., 2008; Fischer, 2018) may help analyze and understand drivers of forest recovery. More empirical cases, however, are needed to improve the comprehension of endogenous drivers of LFT. Such better understanding has relevance for FT theory, and can also help improve the design of forest restoration policies.

This paper examines LFT in communities of the Mixteca Alta region, in Oaxaca, Mexico, where centuries of deforestation and forest degradation have taken place, but where since the late 1980s forest cover has increased. Three questions are answered: how much forest cover was gained during the last three decades? What drivers prompted the LFT? And what lesson can be learned to guide public policies that aim to restore forests in the context of local socio-ecological systems?

2. MATERIALS AND METHODS

2.1 Context of community forests of Mexico

The Mexican Revolution (1911-1917) led to extensive land distribution among farmers to whom land was granted under common property (Bray, 2013). Currently, in Mexico there are 31,837 (~51% of its territory) either agrarian communities or *ejidos* (both referred to as communities in this paper) with land under common property. A total of 21,095 communities are in forested areas and they are referred to as the community forests of Mexico (Torres-Rojo & Amador, 2015; Bray, 2020). The Agrarian Code (1942) and Mexican Agrarian Law (1992) established that the assembly of all legal members is the maximum authority to make decisions on communal territory and that each has a legal body of representation and leadership, the *Comisariado*, which is democratically-elected by the communal assembly. The assembly may establish different operational and use and management rules, a land-use plan (human settlements, agricultural areas, and common use areas), and regulate the harvest of natural resources, including those from forests. Common properties need to be governed by a community statute, a legally prescribed document. All community members have access to common use areas but are required to comply with assembly agreements. The community forests of Mexico present an important fit with Elinor Ostrom´s design principles for common use resources (Bray, 2020). Many communities, particularly those with indigenous roots, have strong social norms that facilitated the quick adaptation to official institutions and use and management rules (Bowles & Gintis, 1998) and represent empirical support of local governance (Andersson et al., 2013). For centuries, communities have carried out *tequios*, which are obligatory labor contributions to community activities without payment. These *tequios* have been recognized as a key condition for the conservation and restoration of forests in southern Mexico, where the State of Oaxaca is located (Bray, 2020). For many decades government forest policies have supported forest communities, but mainly to boost timber production. The National Forestry Commission (*Comisión Nacional Forestal*, CONAFOR, created in 2000), established a forestry agenda to promote reforestation (pine plantations) and other types of forest restoration in communities (CONAFOR, 2012). In the Mixteca Alta region in Oaxaca, where degradation was recognized as a socio-environmental problem, support was provided for reforestation and soil restoration, but only pine seedlings and modest financial support was provided and only a few communities received such support (Plancarte, 2019). CONAFOR has only been able to undertake short-term monitoring of the outcomes of the support provided.

2.2 Study area

The research leading to this paper was carried out in five communities of the Mixteca Alta region, in Oaxaca, Mexico: Tonaltepec, Yanhuitlán, Añañe, Suchixtlán, and Tiltepec (Fig. 1). The total area of the five communities studied is 16,969 ha.

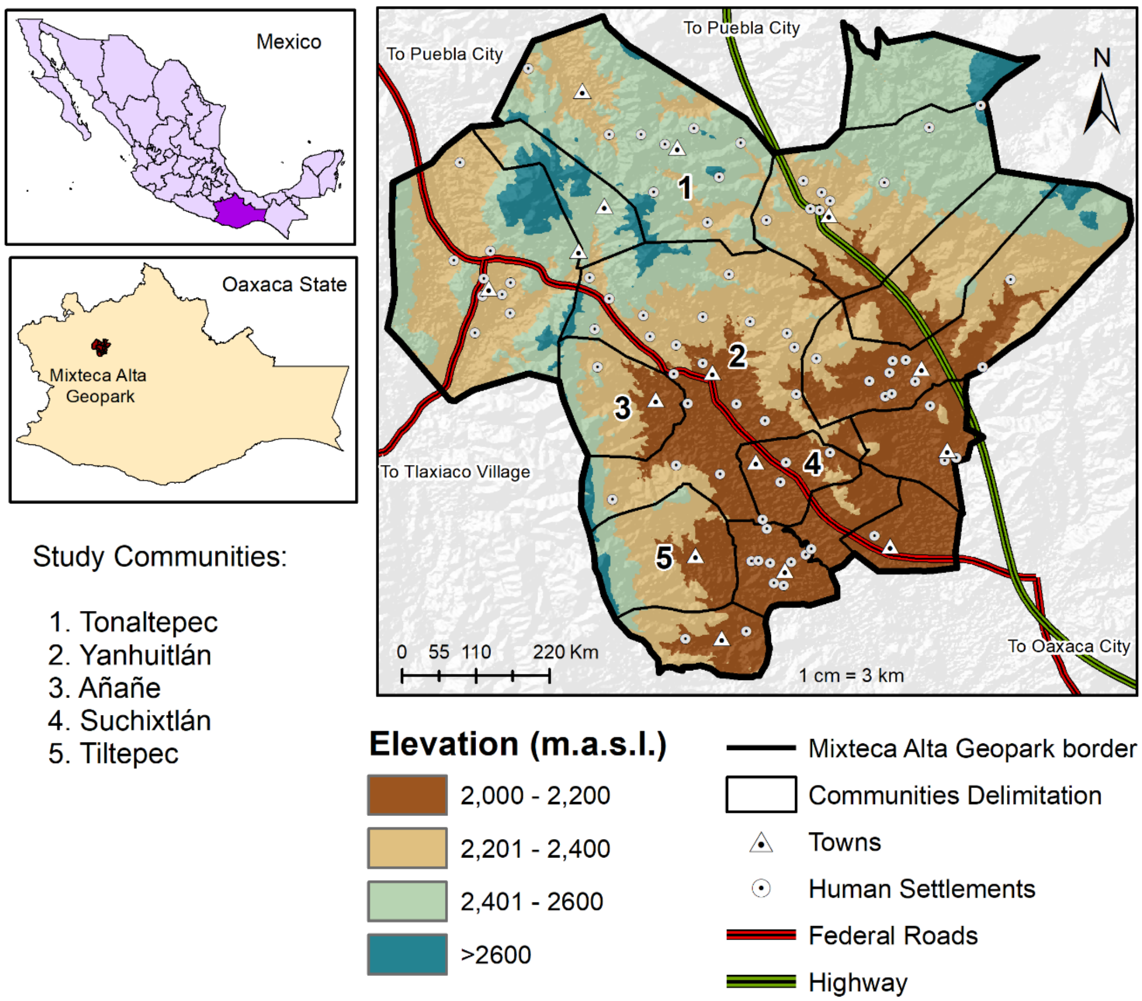

Figure 1. Location of study area

The communities studied have landscapes of sloping hills with an altitude between 2000 and 2800 m which are intersected by small streams, tributaries to the Papaloapan, Balsas, and Verde-Atoyac rivers. The study area is a mosaic of zones with severe soil erosion, and remnants of native temperate forest of pine (mainly *Pinus ayacahuite, Pinus pseudostrobus, Pinus montezumae;* Del Castillo et al., 2004), juniper (*Juniperus spp.*), and oak (Q*uercus spp.*) (See pictures in supplementary materials). This part of the Mixteca Alta region has a low potential for mechanized agriculture (INEGI, 2015a), but traditional agricultural plots are spread around human settlements (mainly maize and beans). Communities also traditionally maintained areas for grazing, mainly for goats. Those have been severely reduced and where they still exist, their use is strongly regulated by the communities themselves (Hernández-Aguilar et al., 2017). The landscape also shows remnants of prehispanic agricultural practices: like terraces constructed on slopes, and *lamabordos*, or sediment traps made of stones located in streams and runoff channels (Palacio-Prieto et al., 2019).

The communities studied are settlements that have their origin in pre-Hispanic times and belong to the same ethnic-cultural group: the Mixtecs. Many inhabitants still speak the native Mixtec language and 12.7% of adults are illiterate (see Table A in supplementary material). The main economic activity in the communities is traditional agriculture (maize and beans). The communities have a medium and high marginalization status (INEGI, 2010a) and experience ongoing outmigration (Cruz & López, 2009; Lorenzen et al., 2020).

All the communities studied are located in the Mixteca Alta Geopark, a polygon of 41,540 ha designed by UNESCO in 2017 (Rosado-González & Ramírez-Miguel, 2017), and their collective territory represents 41% of the park. The Mixteca Alta Geopark does not modify local rights, organization or governance arrangements established by the Mexican Agrarian Law or by communal assemblies. It is rather a symbolic designation by UNESCO and the communities participate voluntarily to coordinate geo-tourism activities, collaborate in scientific research, and promote their cultural heritage.

2.3 Antecedents of deforestation and forest degradation in the Mixteca Alta

The Mixteca Alta region has historically experienced severe forest degradation, soil erosion, and deforestation. The first sedentary farmers settled here around 4,000 BCE, but during the Postclassic Mesoamerican period (since 900 CE) the population grew and agriculture expanded (Spores & Balkansky, 2013; Borejsza & Joyce, 2016). During the colonial period (since 1521) and continuing into modern times (Fig. 4), deforestation increased and forest exploitation led to severe forest degradation, while the grazing of goats caused soil erosion whose effects are still evident today (García, 1996; García, 2002; Díaz-Núñez, 2006). Since the mid-20th-century, the outmigration of Mixtecs to other parts of Mexico and the United States reduced pressure on forests, and reduced goat herds and agriculture (Rivera-Salgado, 2005; Lorenzen et al., 2020). The abandoning of agriculture on slopes and along temporary streams, however, increased hydric erosion resulting in the distinctive *carcavas* or eroded slopes, which characterize a large part of the Mixteca Alta landscape (García-Barrios & García-Barrios, 1990; Velásquez, 2002; Lorenzen et al., 2020). Only in the last few decades, free grazing has been regulated by communities (Hernández-Aguilar et al., 2017).

2.3 Cartographic Analysis

During 2018 and 2019 five participatory mapping workshops were organized in the communities (one per community). A total of 57 *Comisariado* members selected by the assembly participated in these workshops, including women (19) and men (38). In each workshop between 10 and 13 *Comisariado* members took part. People were asked to identify on 1:50,000 topographic maps (INEGI, 2015b; RAN, 2017) the communal area and sites with remnants of native vegetative cover, reforested areas, sites restricted to free goat grazing, and areas with natural forest regeneration.

Based on the participatory mapping exercise ground-truthing was undertaken in each community with local guides and 275 GPS points were measured to confirm land cover, land use, reforestation and restoration sites identified during the workshops. The satellite images were used as working maps for guiding field transects as recommended by Pérez-Valladares et al. (2019). The first and most clear feature was to verify the borders of agricultural and polygons covered with natural vegetation. Landmarks recognized by the locals were crucial to define boundaries and these were recorded geographically using coordinates. Georeferenced data was used for a supervised classification of Landsat-4 satellite images (January 1990), Spot-5 images (year 2000), and Sentinel-II images (year 2018) in ArcMap 12.0 ®. Four categories of woody vegetation resulted from the classification, and those were used to create maps for 2003 and 2018. The 1990 map only distinguished areas with woody vegetation and without apparent woody vegetation. The land cover categories are the following:

a) Woody vegetation: mainly pine, oak, and juniper, as well as scrubland. Resolution of land cover data obtained from satellite imagery was not enough to discriminate between native and exotic tree species.

b) Mature forest: trees over 10 meters in height, principally pine, oak and juniper, including areas reforested over 15 years ago.

c) Secondary forest: trees from 5 to 10 meters in height, principally pine, oak and juniper, including areas reforested less than 15 years ago.

d) Scrubland: trees and shrubs 5 meters in height or less, consisting of pine, oak, juniper, and other arboreal species, including recently reforested areas (pine plantations).

e) No apparent woody vegetation: principally agricultural land, grassland, human settlements, water bodies, and eroded areas.

Preliminary forest cover maps were verified by selecting a sample by conglomerates (Mas et al., 2003) which consisted of 120 GPS points (30 for each class identified in the study area). The field data helped elaborate a simple confusion matrix to corroborate the supervised classification results (Aronoff, 1982), thus obtaining 89% of precision in the classes represented on the maps (mainly errors of commission). Forest cover maps were generated for the three dates analyzed and surface per each vegetation class was calculated.

The annual rate of change for the 2003-2018 period was estimated according to the following equation (FAO 1995):

$$q = \left(\frac{A2}{A1}\right)^{1/(t2-t1)} - 1$$

where A2 was forested area in 2018 (t1), A1 was forested area in 2003 (t2). The resulting value was multiplied by one hundred, to be expressed as a percentage.

To define the location of forest recovery during 2003-2018, the forest recovery layer was overlapped with the community agriculture plots and the common land uses layer (RAN, 2017), except for Tonaltepec for which it was not available. To recognize the percentage of forest recovery according to the three slope categories: moderate slope, moderate steep and steep (Tasbir & Dhillon, 1994), a digital terrain elevation model was used.

2.4 Community interviews and observations

Social data related to forest recovery processes in the communities studied came from a review of historical documents, official data from interviews held at the community participatory mapping workshops, and from observations during assemblies and reforestation events.

Informal interviews were held with at least five people in each community who were recognized for having knowledge of the territory or were involved in organizing forest recovery activities during the last 30 years. Additionally, a semi-structured group interview was carried out during each of the five participatory mapping workshops. These interviews inquired about four topics: 1. People’s motivations for forest recovery; 2. the influence and participation of migrants; 3. agreements and participation related to forest recovery efforts; and 4. local perceptions on forest cover changes and recovery. Information related to the impact of out-migration was calculated by inquiring about the number of goats in the community, percentage of abandoned agricultural plots, and percentage of families that use firewood materials.

When it corresponded, social information was organized by dates in a timeline of the process (Fig. 4) in order to recognize when community decisions happened and when they were engaging with activities. Information from interviews and different field notes (participant observations during the assembles and reforestation), were transcribed in a text processor, then using questions such as what drivers conducted forest recovery? what kind of motivations impulse community decisions? How do communities sustain collective engagements for years for forest recovery? Then, using content analysis (Hsieh & Shannon, 2005), information was organized to recognize exogenous and endogenous drivers of forest recovery (Table 3). We consider a driver, to these factors that directly or indirectly produce outcomes/activities/actions that in the short or medium-term result in vegetation growing in degraded zones. The interpretation about implications for each driver was directly expressed by local people or was inferred from the information provided. Finally, to locate areas with active and passive recovery, a thematic map of reforested areas and areas of natural revegetation was prepared.

3. RESULTS

3.1 Local forest transition: magnitude and location

Over the last three decades, forest cover increased from 3,717 ha in 1990 to 6,357 ha (71%) in 2018 in the five communities (Fig. 2). This represents a gain of 2,640 ha and an annual growth rate of 2.73%. The increase for the 2003-2018 period was 57%, and secondary forest expanded most with 1,442 ha (Table 1). Subsequently, mature forest and scrubland increased with 520 and 345 ha respectively (Table 1). Specified by vegetation category, between 2003 and 2018 secondary forest increased annually by 6.3%, mature forest by 2.0%, and scrublands by 1.3% (Table 1).

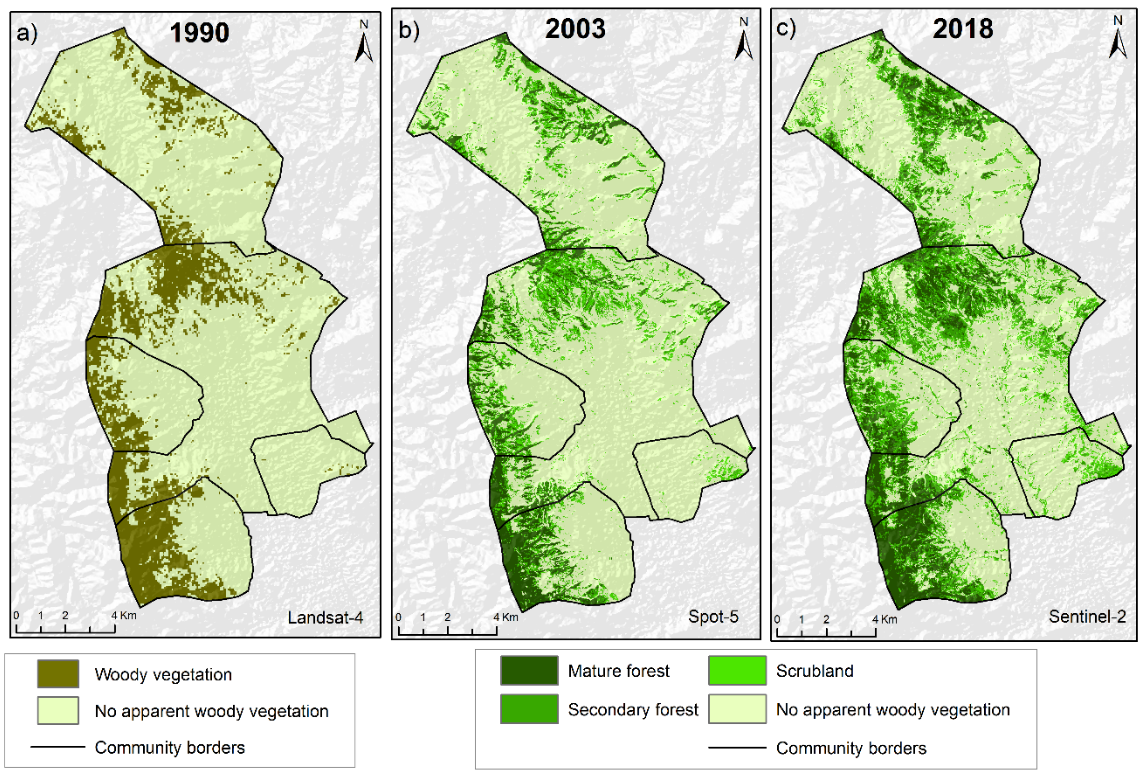

Figure 2. Forest transition in the last three decades in the study communities of the Mixteca Alta Geopark of Oaxaca, Mexico. Total area in 1990 for forest cover was 3,717 hectares

Table 1. Transition matrix and rates of change of different types of land cover for the 2003-2018 period in five study communities in the Mixteca Alta, Oaxaca, Mexico. Surface of each use is respectful to the total community area.

Land cover/ land use	2003		2018		Change from 2003 to 2018 in ha and %	Annual rate of change from 2003 to 2018 (%)
	Surface area (ha)	Percentage	Surface area (ha)	Percentage		
Mature forest	1,463.2	8.6	1,984.0	11.7	520.7 (35.6)	2.0
Secondary forest	958.8	5.7	2,401.7	14.2	1,442.9 (150.5)	6.3
Scrubland	1,625.8	9.6	1,971.4	11.6	345.6 (21.3)	1.3
Others (grassland, agriculture, no apparent cover, and human settlements)	12,921.2	76.1	10,611.9	62.5	- 2,309.4 (-17.8)	-1.3
Total	*16,969.0*	*100*	*16,969.0*	*100.0*	--	--

From 2003 to 2018, total forest cover increased by an average of 32% in the five study communities. Suchixtlán had the highest annual rate of change (7.7%; Table 2A), mainly in the scrubland and secondary forest categories, but this also represented the smallest reforested area of 4 ha. Yanhuitlán had an annual rate of change of 3.5% (Table 2A), a 64% of mature forest increase, and the largest area reforested (511 ha). Tonaltepec experienced the highest proportion of the total community territory reforested (0.145) (Table 2A).

Table 2. Magnitude and location of forestry recovery 2003-2018: A) Increase of forest cover and annual rate of change; B) location of forest recovery correlated with community land uses and slope categories

A)

Community	**Total surface area (ha)**	**Reforested surface area (ha)**	**Reforested surface / Total surface**	**Forest area**				**Annual rate of change in forested surface area (%)**
				2003		**2018**		
				Hectares	%	**Hectares**	%	
Yanhuitlán	7,007.7	511	0.073	1,646	23.5	2,763	39.4	3.5
Añañe	1,643.6	35	0.021	486	29.6	737	44.9	2.8
Suchixtlán	1,044.0	4	0.004	58	5.6	179	17.2	7.7
Tonaltepec	5,160.6	75	0.145	1,017	19.7	1,485	28.8	2.5
Tiltepec	2,112.3	81	0.038	834	39.5	1,186	56.1	2.3

B)

Community	Local Forest Transition (2003-2018)				
	Land use (%)		Slope category (%)		
	Agricultural plots	Common use area	Moderate slope (<10°)	Moderate steep (10°-20°)	Steep (>20° %)
Yanhuitlán	17.8	82.2	24.5	47.7	27.8
Añañe	5.6	94.4	18.0	41.6	40.5
Suchixtlán	13.8	86.2	52.8	42.7	4.5
Tonaltepec	No data	No data	26.4	47.5	26.1
Tiltepec	16.9	83.1	18.6	45.7	35.7

From 2,640 hectares recovered in three decades, 706 ha were through reforestation and 1,934 ha regenerated naturally. This forest recovery was located mainly in common use areas and on moderate steep and steep terrain, (Table 2B), close to forest remnants, in ravines and gullies–and in eroded areas. In Suchixtlán, almost half of the new forest (~ 50%) was located on moderate slopes (Table 2B) where subsistence agriculture and free goats grazing had been practiced before, but is now prohibited.

Satellite images revealed at least 30 sites of natural regeneration, each of approximately one ha, with evident secondary forest (Fig. 3). During field work, other smaller areas of forest recovery were recognized, for instance of riparian vegetation and in ravines. The patches of natural regenerated forest include seedlings and juvenile trees of native species such as pine juniper, oak, madroño (*Arbutus spp.*) and shrubs such as ramon (*Cercocarpus spp.*). Multiple herb species were identified in areas where natural regeneration had happened.

A total of 56 reforestation sites could be recognized totaling 706 ha of planted pine trees. Those were located on moderate slopes, near dirt roads and in abandoned terraces along seasonal streams (Fig. 3 see Fig. C in supplementary material). Reforestation mainly happened with two non-native species in the Mixteca Alta: *Pinus pseudostrobus* var *oaxacana* (native to the northern sierra of Oaxaca) and *Pinus greggii*. Both were provided by government agencies (CONAFOR, the Forest State Commission, the Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias –INIFAP-Mixteca). Direct observations showed that *Pinus greggi* exhibited slow growth and low survival rates. The first reforestation had been carried out in 1986, in Tiltepec. The area reforested from the late 1980s through the 1990s was relatively small (1-5 ha) in all communities. However, since 2000 Yanhuitlán and Tiltepec had undertaken numerous reforestation during the last thirty years (up to 10 ha) but in Suchixtlán reforestation events were less frequent (Table 2A).

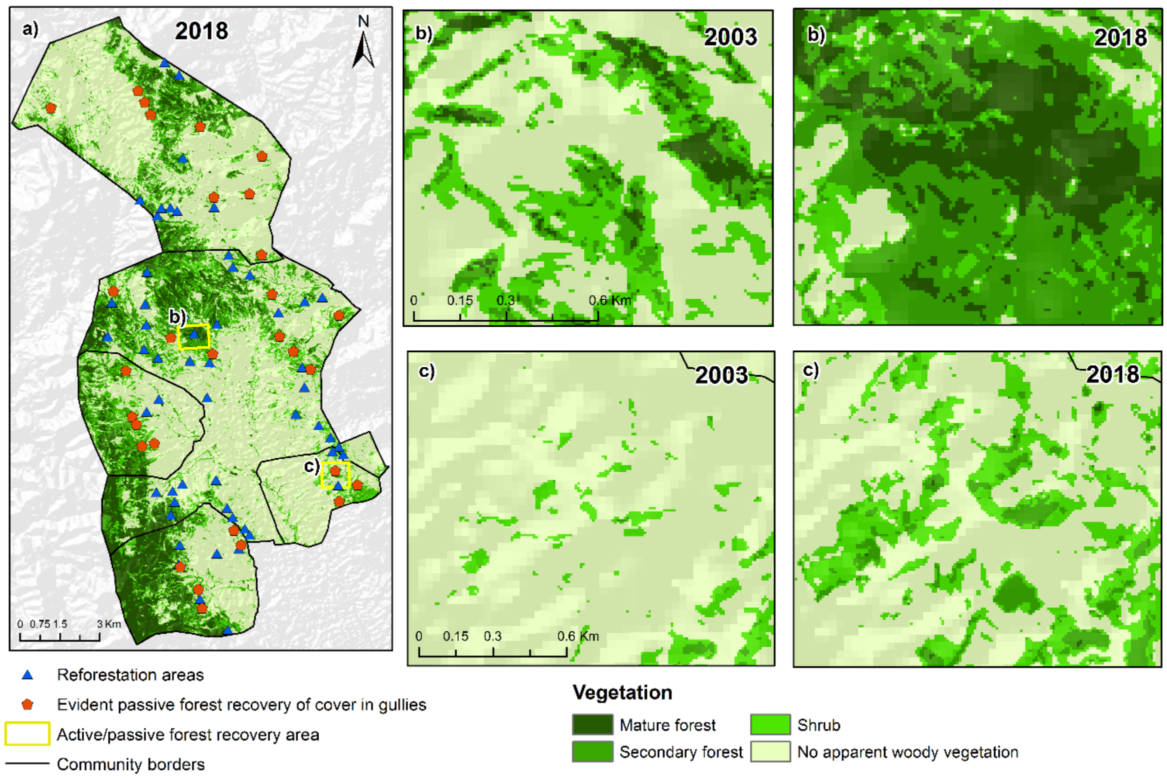

Figure 3. a) Reforested areas and passive forest recovery in study communities. b) Evidence of revegetation due to reforestation in Yanhuitlán from 2003 to 2018. c) Evidence of natural regeneration in Suchixtlán from 2003 to 2018.

3.2 What drivers prompted LFT?

The changing attitudes towards the prevailing forest degradation, which resulted in social changes that led to forest recovery, resulted from recurring assembly discussions for over one and two decades, before forest recovery took off (Fig. 4; Table 3). An intense dialogue within communal assemblies resulted in a new environmental culture with unprecedented rules and agreements. Different drivers converged to explain LFT in Mixteca Alta communities (Table 3), including two exogenous drivers: (1) outmigration and (2) forest policies, and six endogenous drivers: 1) community action, 2) self-organization capacity, 3) local leaderships, 4) cultural values, 5) environmental invest commitment, and 6) social learnings & feedbacks.

Outmigration began in the 1950s, when a new highway reached Mixteca Alta. It allowed poor Mixtec people, who traditionally had confined themselves to their remote villages, to travel to new destinations. As a result, permanent residents in all communities declined over the years. For example, in Tonaltepec, the local elementary school changed from almost 200 students in the late 1960s to 12 in 2018. Outmigration resulted in agriculture plots being abandoned, a decrease in goat herds, and a reduction of firewood and the harvesting of other forest products. Between 2003 and 2018, agricultural areas in all communities had decreased by 23.4%, the use of firewood had declined by 56.5%, and the number of goats by 60.5%. Because a high number of migrants return regularly and maintain communication with their relatives; thus, they also brought new points of view of landscape degradation and approval on the communities' efforts for forest recovery. National reforestation policies undertaken by CONAFOR, supported 21 from the total of 56 reforestation efforts, most of which happened in Yanhuitlán. Additional support for reforestation was advice provided by specialists of INIFAP-Mixteca, in Yanhuitlán and Tiltepec since the early 1990s. Also, the migrants who live in Mexico City organized in the

"Suchixtlán Countrymen Association", sent money in 1998 for support two reforestation initiatives.

These exogenous drivers, *per se*, could not have contributed to the success in LFT in the study communities if they were not converged in scenarios with endogenous drivers (Table 3). Despite the community assemblies not being enough themselves, the endogenous drivers resulted from processes influences by: 1) the historical and cultural antecedents related with indigenous roots, 2) the legal (assemblies & *Comisariados*) and institutional (*tequio*) frameworks for local governance into communities, 3) collective awareness emerged from discussions within the community assemblies about the relation among soil erosion, forest degradation, the lack of timber/firewood with poverty, outmigration and the loss of wellbeing, plus the commitments for environmental legacies for future generations. Besides, the feedback related to results in forest recovery. The process had the base on the official community assemblies which were held at least once a year; although it is a costume that the *Comisariado* team (~15 people) in each community attended issues regularly (every day or two times per week). While for those forest-related matters the *Comisariado* was fundamental during the rainy season, for the community self-organization (Table 3), in order to plan, organize, follow up on the development of reforestation, including the call for *tequios*. Also, the *Comisariado* members permanently conducted vigilance trips to ensure that there is no grazing in prohibited areas or verify incidences reported by the citizens about logging, grazing, or damages in recovery areas.

All actions and their monitoring were based on assembly agreements that prohibited logging and goat grazing, community rules for taking care of natural recovery, and sometimes on sanctions. Thus, it was necessary to establish damage repair (if it was possible), economic sanctions, and inclusive confiscation of livestock. According to interviews, at the beginning of the process, many people failed to attend to the rules, but gradually, in most of the communities there was an almost full completion of rules; although “there is always someone who is disobedient” . However, probably the main mechanisms of enforcement were probably based on culture, for example, the collective will to provide tools, trucks plants, and lunches during reforestation and currently, rarely communities apply a sanction.

Although each community had its own process (Fig. 2), those resulted in almost simultaneous community agreements in Mixteca Alta communities. Some of these agreements were inserted in community statutes and played an underlying role to trigger better local governance regarding forest as a common resource. Following these agreements, assemblies started to plan forest restoration based on two main practices: organize reforestation and regulate the free grazing and firewood harvesting (Table 3). Yanhuitlán and Tiltepec established mandatory annual tree planting events. Suchixtlán and Añañe also organized active tree planting events, but people also recognized that the control of goat grazing resulted in vegetation recovery with native species.

Each community, however, reserves its ways to enforce implementation of agreements. In addition to providing seedlings from governmental greenhouses, local people assisted in improving organizational capacity, provided financial support, tools, vehicles, gasoline, and lunch and drinks during tree planting activities. The *tequios* were fundamental in achieving communal forest restoration aspirations, as were the self-imposed restrictions and the collective willingness to invest in environmental improvements (Table 3). The role of local leaderships is illustrated by the case of a young biologist from Tonaltepec who organized his neighborhood to plant trees at the beginning of this century. Younger members of the *Comisariados* shared their environmental knowledge and awareness with other members and their communities. Only few community members did not abide by the assembly rules.

Successful forest recovery has improved availability of firewood and timber, resulting in soil recovery in ravines, and restored fauna and flora, like coyotes, birds and oaks. People also recognized that they have gained new knowledge by undertaking reforestation and natural regeneration. For example, people understand the importance of native species, like ramon (a shrub) to restore severely degraded gullies, and to plant seedlings in places with less soil erosion to improve their survival rate, or use *Leucaena spp* and *Lysiloma spp*. appropriate to be planted in dry, hot and eroded slopes.

Yanhuitlán, located along the highway, is the largest village of Mixteca Alta that functions as a center of socioeconomic activities, workshops and meetings related to the Geopark. It also has functioned as a center of inter-community exchange of environment related experiences, local knowledge and positive feedback.

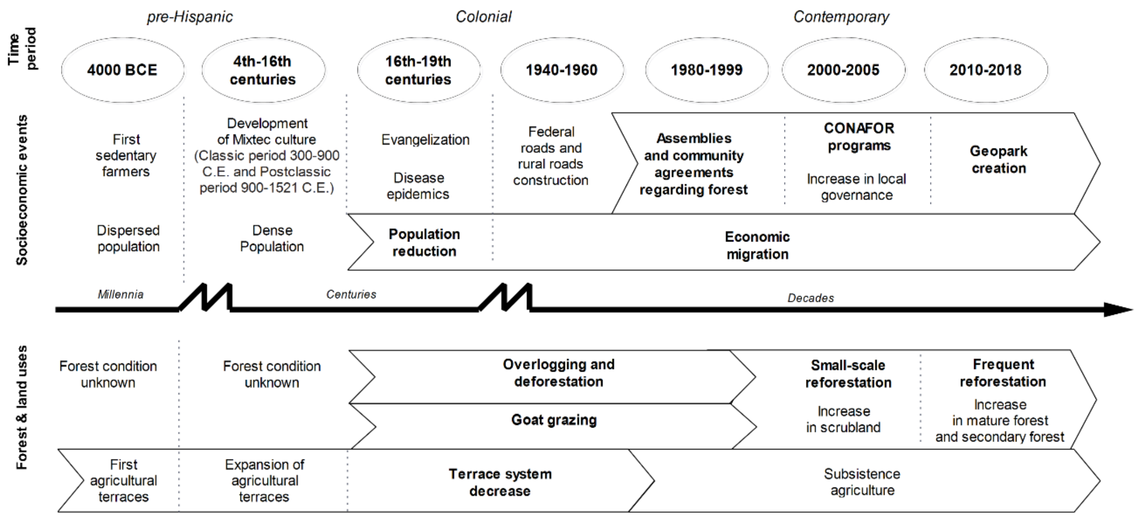

Figure 4. Timeline of principal socioeconomic processes and forest uses in the Mixteca Alta Global Geopark of Oaxaca, Mexico

4. DISCUSSION

4.1 Observed local forest transition

The average annual forest cover increase in the communities studied of 2.73% for the 1990-2018 period is similar to other areas of Mexico. Mexico, while experiencing a steady net forest cover decline since the 1990s, has vastly increased its area of planted forests since 2000 (FAO, 2020). Forest recovery takes place mainly in temperate forest regions (Gómez-Mendoza et al., 2006; Bonilla-Moheno & Aide., 2020). The Sierra Norte region of Oaxaca reduced deforestation and experienced an increase of its native pine and oak forests during the 1980-2000 period (Gómez-Mendoza et al., 2006) and similar trends were observed in some southern states (Vaca et al. 2012). Country-wise, deforestation declined in the past decades from over 600,000 hectares to about 250,000 hectares per year (Sanchez-Colón et al., 2008; Rosete Vergés et al. 2014). Forest trends are not taking place homogeneously nor equally in all ecosystems. Mountain temperate ecosystems have experienced recovery in central and southern Mexico (López-García et al., 2016). Bonilla-Moheno and Aide (2020) conducted a detailed analysis on the recovery trends and found similar patterns as well.

At the community level, in the Chinantec region in Oaxaca, Velasco-Murguía et al. (2014) estimated positive annual rates of change for tropical mountain forest, with rates between 0.07 and 1.01% for the 1990-2000 period and 0.14 to 1.37% for the 2000-2010 period. Other studies also suggested forest recover in Chihuahua, Durango, Michoacán, Guerrero, Oaxaca and Quintana Roo (Klooster, 2003; Bray & Klepeis, 2005; Bray, 2009; CONAFOR, 2009; Mendoza et al., 2011; Honey-Rosés et al., 2018; Pazos-Almada & Bray, 2018; Lorenzen et al. 2020).

Compared to other regions, the five communities reported here show substantially higher annual rates of forest recovery (Table 2A) suggesting that an unusual process has been happening in this centuries-long degraded landscape (Fig. 2). Slightly more than two thirds of the recovery was through natural regeneration, and only 26.7% resulted from active reforestation. Others attribute local forest recovery in the Mixteca Alta region and elsewhere to active reforestation (Lorenzen et al. 2020; López et al., 2011; Royero-Benavides et al., 2017; Plancarte, 2019). Of much relevance, the natural regeneration in the communities studied was intentional and the result of social efforts (Table 3). The almost two thousand hectares naturally regenerated forests are even more significant if one considers the difficult conditions of low annual precipitation of 800-1,000 mm (INEGI, 2010b), while only hundreds of hectares have been recovered during two decades in locations with tropical conditions (Velasco-Murguía et al., 2014), where the natural vegetation grows much faster. In contrast with cases reported by López et al. (2011) LFT in Mixteca Alta was not related to any type of soil but did prevail on moderate steep slopes (≥10°). The location of forest recovery intentionally targeted degraded common use areas, forests previously subjected to harvesting products and previous goat grazing areas, but rarely in abandoned agricultural plots. Forest recovery in other Mixtec communities (García Barrios & García Barrios, 1990; Lorenzen et al., 2020), and in other regions of Mexico (Klooster, 2003; Velasco-Murguía et al., 2014; Mendoza et al., 2011), mostly occurred on pervious agricultural land. Also, our case contrast with reports of LFT by the adoption of agroforestry practices (Aguilar-Støen et al., 2011), for cultural-religious purposes in India (Bhagwat et al. 2014) and for agriculture intensification reported in Chinese rural communities (He et al., 2014).

4.2 Local forest transition and its drivers

Drivers of FT have been one important focus in FT studies (Rudel et al., 2009; Lambin & Meyfroidt, 2010). In our study case, exogenous drivers are linked to global and national contexts, which interact with endogenous drivers (Table 3). Both can be linked, to the decades of local efforts of communities reversing centuries long landscape degradation, toward a process of forest recovery.

Outmigration and forest policies, as well as the endogenous drivers were fundamental to initiate the LFT, however, the endogenous drivers have been central for maintaining it. The economic development and national forest policy pathways mentioned by Lambin &

Meyfroidt (2010) do apply to the Mixteca LFT. Outmigration reduced pressure on forests, but also caused discussions within communities of the underlying problems causing outmigration. It also resulted in migrants supporting reforestation in their native communities. Rural migration has been mentioned as the main driver of LFT in some regions of Mexico (Velasco-Murguía et al., 2014; Mendoza et al., 2011), but in Mixteca Alta outmigration initially exacerbated degradation when erosion intensified in plots that were left uncultivated (Plancarte, 2019). With the assistance of national reforestation programs, communities had a regular supply of pine seedlings (CONAFOR, 2012; López et al., 2011; Plancarte, 2019, Lorenzen et al., 2020). In contrast with other areas in the Mixtec Alta region where CONAFOR had been very active, in our case communities it had a relatively limited role in explaining LFT except in Yanhuitlán. National policies to improve education in communities helped increase positive perception about forest restoration, which demonstrates the transformative power of education (Pavlova, 2013).

A major factor resulting in LFT in the study communities have been the discussions within community assemblies. These were in response to collective worries for the scarcity of water, soil for agriculture, firewood, but also for transgenerational environmental legacies. Important decisions were made based on consensus to address these concerns (Table 3). Control of widespread grazing and reduction of goat herds for instance, a century old cultural practice, should be regarded as an active process. A comparable process was found among six Chinantec indigenous communities which restrained ancient practices like wildlife hunting and the clearing of forests for agricultural crops, as part of their community-based conservation (Bray et al., 2012; Velasco-Murguía et al., 2014).

The six endogenous drivers documented in this paper are strongly related to the local governance, where local institutions are crucial for the effective conservation and management of forest resources. This coincides with drivers reported for communities in other regions of the Mixteca Alta region and beyond (Klooster 2003; Hernández-Aguilar et al., 2017). Other Mexican communities have been known to have gone through a process of intensive discussions before restraining or regulating timber and non-timber extraction or active forest conservation (Pazos-Almada & Bray 2018; Bray et al. 2012, Bray, 2020). In all these cases include factors such as local involvement, forest monitoring mechanisms, institutional rules, and active engagement, that correspond to the frameworks of the collective action theory (Ostrom, 1990) and the local governance forest (Andersson et al., 2013). Thus, we suggested calling this phenomenon a community-based LFT, because it could be a distinctive FT pathway which involves active forest recovery, but for reasons other than increasing economic gains. Similar collective action leading to FT is recognized in other regions in Mexico, Latin America and Asia (Klooster 2003; Seixas & Davy, 2008; Bhagwat et al., 2014; He et al., 2014; Wilson et al., 2019), we propose that FT theory pay more attention to contexts where endogenous drivers lead to forest recovery.

Table 3. Key drivers that converged to explain the current local forest transition (LFT) in the study communities.

	LFT Drivers	Effects	Outcomes/Activities/Actions
Exogenous	Outmigration →	- Social fluxes - Population decreases - Reduction of pressures on forests	- Migrants gave money for reforestation activities - Migrants brought new points of view of landscape degradation
	Forest policy →	- Governmental reforestation and forest restoration programs - Massive nursing of tree seedlings	- CONAFOR programs complemented community reforestations - Supply of tree seedlings
Endogenous	Community action → ↔	- Discussions in community assemblies - Collective rules and agreements - Adoption of forest recovery as a community' norm	- Boost collective exchange of ideas and perspectives - Sustained reforestations during the rainy season for a decade - All community members were involved in reforestation and regulation of free goat grazing
	Self-organization capacity → ↔	- Local governance that supports the local organization -Availability of resources and conditions needed for reforestation and restoration	- Coordination between agrarian (*Comisariado*) and administrative (municipality) authorities for rising funds, materials, and tree saplings -Involvement of inhabitants to participate with free labor (*tequio*)
	Leadership → ↔	- Individuals that encourage others - Stakeholders who promote new ideas/actions	- Convince and nourishing the collective enthusiasm
	Culture → ↔	- Use of ancient values and traditional knowledge - Indigenous culture influence attitude for change	- Boost collective contribution materials (trucks, tools and lunches) - Willingness to participate with free labor (*tequio*)
	Environmental investment commitment ↔	- Collective environmental awareness - Community concerns for the environmental legacies	- Collective awareness about the relationship among forest degradation, lack of forest products and local wellbeing - Local people were guests to participate in order to legate better environmental conditions to their descendants
	Social learnings & feedbacks ↔	- People may have noticed the LFT process - People understood that LFT result from their actions - Positive collective perceptions were expressed	- People started to use native plant species and regulated the goat grazing in order to protect reforestations and natural forest recover areas - The youth people were involved to increase their environmental knowledge and awareness - Forest cover increase and water availability stimulated communities to continue with reforestations and forest restoration strategies

Importance for: ⟶ starting forest recovery; ⟷ maintaining forest recovery. Source: participatory mapping workshops and interviews.

4.3 Forest policy implications

Reverting forest landscape degradation is increasingly recognized as a key strategy to address major sustainability challenges, including climate change (FAO, 2020). Until today, strategies for forest restoration in the Mixteca Alta region and Mexico, in general, have been successful (CONAFOR, 2009) and the increase in the area of planted forest since 2000 (FAO, 2020) corroborate this. However, we consider that government programs everywhere have important limitations for achieving recovered forest in degraded lands because overload the technical methods, unsuitable in their time frames and not openly inclusive of the human dimension in the context where they are operating. Thus, a better understanding of LFT processes and empirical evidence in the context of socio-ecological systems could be useful to formulate forest policies that encourage more local stakeholders' participation.

One of the goals of this study was to recognize those lessons for public policies in order to recover forest cover. Based on our findings in the case from Mixteca Alta, the relevance of the community collective action and local governance was evident for achieving an LFT successfully. Thus, we propose the need for a shift in forest policies in three ways:

1. That forest policy agendas embrace more holistic strategies for reforestation and restoration. It implies social involvement, wide landscape scenarios, vegetation recovery for multi-purposes, and medium/long-term goals for forest restoration.

2. That reforestation and restoration governmental programs, besides the technical criteria, explicitly include the human dimension (Boscolo et al., 2010; Ghazoul & Chazdon, 2017; de Jong et al., 2019; Meffe et al., 2012; Williams, 2011). Thus, projects may include social criteria like local organizational capacity and governance as potential success indicators. Also, they have the first phase for participatory planning, in which collective discussions take place and may include local knowledge, perceptions, values, and needs; thus, since the beginning, the social appropriation of a project could happen. Social involvement is ideal for forestry regions in the world, that operate as forest SES (Fischer, 2018), including Mexico (Bray, 2020).

3. Provide sustained support for at least one decade, particularly because a common rule is that land degradation and poverty are linked (Angelsen, & Kaimowitz, 1999; Geist & Lambin, 2003; Samii et al., 2014). It may imply the *ad hoc* design of public policy, for which it could be a necessary alignment of different governmental agencies besides CONAFOR –in the Mexican case-, and use opportunities like those offered by the REDD+ initiative and even appeal non-governmental contributions, such as the carbon voluntary market. However, in general, incentive and compensation of opportunity costs resulting from forest restoration are needed (Sims et al., 2014; Sims & Alix-García, 2017; Alix-García et al., 2019).

Contemporary environmental challenges, like climate change, and the new inclusive paradigms for habitat and biodiversity conservation are changing the current approaches for forest management (Bray, 2020). Thus, public policies for reforestation and forest restoration in Mexico, and beyond, should transit to a more integral forest restoration, which considers the human dimension, moreover from the technical bases for it. It is due to, where forest social-ecological system prevails (Fischer, 2018), the local governance is critical for the success of LFT; which was observed in communities from countries like China, Ecuador, Honduras and India, (Southworth & Tucker, 2009; Bhagwat et al., 2014; He et al. 2014; Wilson et al. 2019), who lack the Mexican institutionalized system. According to those studies, the base for collective action and conditions that conducted to LFT were local institutions and social capital. Consequently, although the policymakers tend to answer to the global agendas that demand national efforts for increasing the forest cover, simultaneously for implementing strategies at the local level they need to consider different instruments like incentives, information, advisory and education, among others, focused on strengthening local governance and social capital.

5. CONCLUSIONS

Our study analyzed drivers of LFT in five communities of the Mixteca Alta region, where reforestation, social capital and self-imposed restrictions resulted in sustained forest recovery. A forest recovery of 71% over the 1990-2018 period compares well with tendencies elsewhere in Mexico. However, LFT of the Mixteca Alta region led to forest recovery in severely eroded sites, after centuries of degradation and deforestation. We found that two exogenous and six endogenous drivers of LFT converged. Communities exhibited organizational capacity and mobilized taskforces to achieve forest recovery, which highlight the importance of collective action and local governance. This suggests that a novel community-based FT pathway should be recognized, because other similar cases have been documented for Mexico and elsewhere. Lessons for public policies in the context of local socio-ecological systems include paying attention to local land use land cover trajectories and support those where they contribute to forest restoration. At least for Mexican forest policies, forest restoration programs need to provide the right incentives to compensate opportunity cost in marginalized communities. Finally, it is important to emphasize that community-based FT, not only generates local environmental benefit, but also contributes to global environmental goals.

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CAPITULO IV

Especies nativas para el manejo de la erosión de suelos en la región Mixteca Alta, Oaxaca

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RESUMEN

La restauración de áreas degradadas y la erosión del suelo es un asunto de interés local, nacional y global, particularmente porque implican una dimensión social (servicios de provisión). Particularmente estos fenómenos se presentan en la región Mixteca Alta, en Oaxaca, donde por siglos han sido sometida a sobrepastoreo y deforestación. Para revertir esta situación se han llevado a cabo reforestaciones con especies inducidas de pinos. En este contexto, el objetivo del estudio fue analizar el potencial de las especies nativas para controlar y manejar la erosión en cinco comunidades de la Mixteca Alta. Se realizaron recorridos de campo y clasificación de imágenes satelitales para identificar los sitios con erosión y la distribución de cobertura forestal. Adicionalmente, se realizaron organizados cinco talleres y entrevistas semi-estructuradas con líderes y personas de la comunidad para documentar el estado de las reforestaciones y el conocimiento local sobre especies nativas con potencial para restaurar. Se encontró que el 37.5% del sitio de estudio cuenta con superficie forestal y que cerca del 10% registra algún grado de erosión. Ante este panorama, se identificaron una serie de especies arbustivas y arbóreas nativas no maderables (*Acacia* spp, *Arbutus* spp, Barkleyanthus spp, *Cercocarpus* spp, *Dodonaea* spp, *Juniperus* spp) que pueden ser útiles conforme el grado de erosión que presenten los terrenos a reforestar. Esta información será útil para futuros planes de restauración basados en propagación y reproducción de especies nativas en regiones degradadas.

Palabras clave: recuperación de áreas degradadas, reforestaciones, especies arbustivas, políticas forestales

ABSTRACT

The restoration of degraded areas and soil erosion is a matter of local, national and global interest, particularly because it involves a social dimension (provisioning services). These phenomena are particularly present in the Mixteca Alta region of Oaxaca, which for centuries has been subjected to overgrazing and deforestation. Reversing this situation has led to reforestation with induced pine species. In this context, the objective of the study was to analyze the potential of native species to control and manage erosion in five communities of the Mixteca Alta. Field surveys and satellite image classification were carried out to identify erosion sites and the distribution of forest cover. In addition, five workshops and semi-structured interviews were conducted with community leaders and individuals to document the status of reforestations and local knowledge about native species with restoration potential. It was found that 37.5% of the study site is forested and that about 10% shows some degree of erosion. Given this situation, a series of native non-timber shrub and tree species were identified (Acacia spp, Arbutus spp, Barkleyanthus spp, Cercocarpus spp, Dodonaea spp, Juniperus spp) that could be useful according to the type of erosion on the land to be reforested. This information will be useful for future restoration plans based on propagation and reproduction of native species in degraded regions.

Index words: degraded land recovery, reforestation, shrub species, forestry policies

1. INTRODUCCIÓN

Las estrategias contra la erosión y la desertificación es un asunto prioritario en la agenda medioambiental nacional y mundial (Paganos *et al.*, 2020). En el Simposio Mundial sobre la Erosión del Suelo señala que esta condición representa la mayor amenaza global para las funciones del suelo lo que pone en riesgo la seguridad alimentaria, la calidad del agua y la mitigación del cambio climático (FAO, 2019).

La erosión de suelo es el proceso de eliminación de la capa superior de la superficie terrestre (Pennock *et al*., 2015). Resultado de la interacción de factores ambientales, como el tipo de suelo (Martínez-Santiago *et al.*, 2015), la topografía, la escorrentía, el viento, y de factores humanos, como la deforestación, el sobrepastoreo y prácticas agrícolas inadecuadas (INEGI, 2014; Bolaños-González *et al.*, 2016). La erosión provoca pérdida de las propiedades físico-químicas y biológicas del suelo, que tiene implicaciones directas en la productividad agrícola y forestal (Pimentel *et al.*, 1995; Oldeman, 1998, Boardman *et al.*, 2003; Zhou *et al.*, 2008). En México, las principales pérdidas de suelo superficial se deben a la erosión hídrica (37%) y erosión eólica (14.9%), solo el 36% de la superficie se encuentra sin algún tipo de degradación. De acuerdo con datos reportados en la Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT) (2004), la degradación de suelo a nivel nacional es 30.9% moderada, 19.6% ligera, 12.6% severa y 0.9% extrema.

La degradación del paisaje es una condición que implica una reducción de la calidad de los atributos físicos, biológicos y sociales de un territorio. Este cambio negativo es causado principalmente por actividades humanas y en menor medida a factores naturales (Groves, 1998, Reynolds *et al.*, 2007; Prăvălie, 2021). En caso particular de áreas forestales degradadas no solo se ven afectados en sus componentes biológicos, sino también en elementos físicos como el suelo y el relieve. De la misma forma, la degradación a nivel de paisaje tiene implicaciones en la esfera social, lo que se traduce en menor productividad de tierras agrícolas y forestales y la disponibilidad de agua para consumo (Simpson *et al.*, 2001; Agnoletti. 2007; Sandoval-García *et al.*, 2021).

En la Mixteca Alta, se han hecho numerosos estudios que tienen que ver con reforestaciones de especies maderables principalmente como *Pinus greggii* Engelm. ex Parl., y *P. oaxacana* Mirov (López *et al.*, 2004; Ortiz-Mendoza *et al.*, 2021; Ramírez-López *et al.*, 2011). Estos estudios mostraron que la tasa de supervivencia de las especies inducidas es menor al 80% después de 10 años de ser plantadas. Sin embargo, dichos estudios no toman en cuenta el valor ecológico de la vegetación nativa, como un elemento clave no solo evitar la pérdida de suelo, sino también para promover la regeneración natural. Bajo este escenario, es pertinente la evaluación a nivel local y regional de la erosión del suelo con el objetivo de identificar y recomendar grupo de especies locales no maderables con potencial para la recuperación de áreas degradadas y suelos altamente erosionados en la Mixteca Alta, Oaxaca, México.

2. MATERIALES Y MÉTODOS

2.1 Sitio de estudio

El estudio se llevó acabo en el Geoparque “Mixteca Alta”, denominación otorgada en 2016 por la UNESCO por la peculiaridad geológica del sitio, reconocido mundialmente por su alto grado de degradación del suelo (Palacio-Prieto *et al.*, 2016). Se ubica al noroeste del Estado de Oaxaca, comprende 41 540 ha[3] que presenta un gradiente de elevación de 2000-2800 m y abarca 15 comunidades (Figura 1). La investigación se centró en cinco comunidades representativas (16 969 ha) conforme al gradiente de elevación del Geoparque: 1. Santo Domingo Tonaltepec, Santo Domingo Yanhuitlán, San Pedro Añañe, Santa María Suchixtlán y Santa María Tiltepec (Figura 1). En todas ellas se reconocen remanentes de bosque templado de pino-encino-enebro.

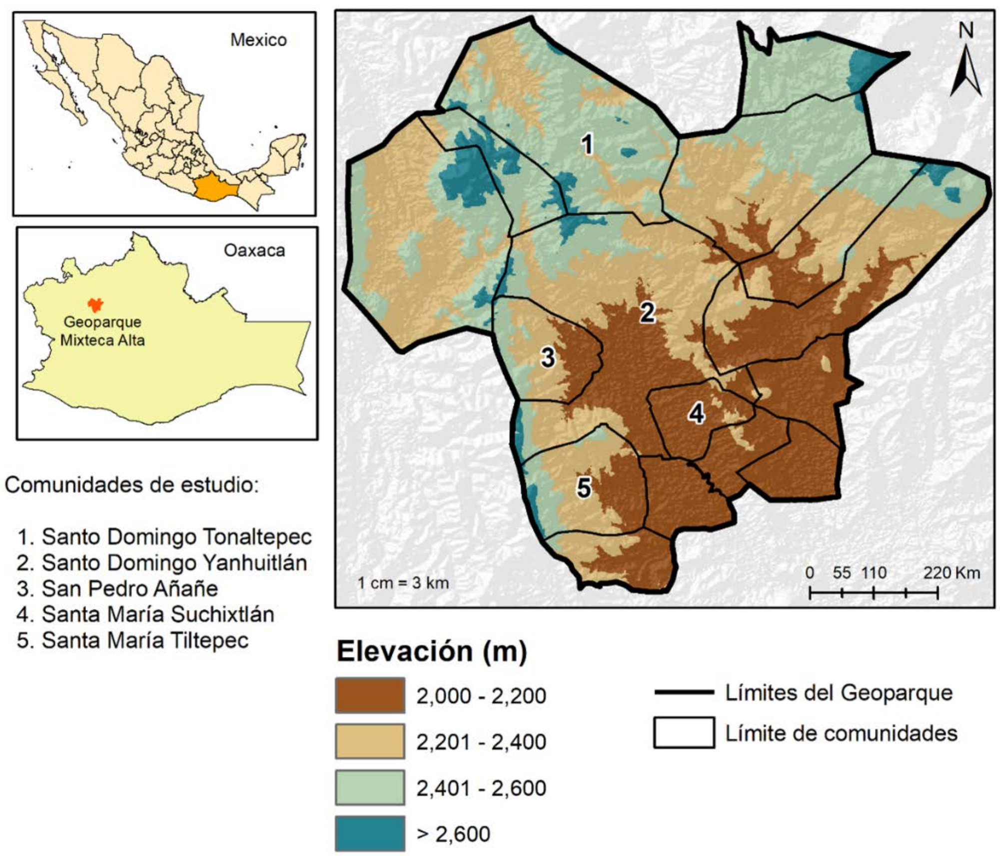

Figura 1. Localización del sitio de estudio

[3] Se simplifica hectáreas por 'ha'.

2.2 Análisis cartográfico

En cada comunidad se organizó un taller de mapeo participativo usando como referente el polígono del predio (RAN, 2017) y el mapa topográfico oficial (INEGI, 2015). Estuvieron presentes autoridades agrarias y municipales (±12 personas). A través de un mapeo participativo propuesto por Chambers (2006), los participantes identificaron sitios relacionados con sus recursos forestales, áreas de reforestación, parajes con diferentes tipos de erosión y sitios donde se reconoce recuperación natural. En recorridos de campo se obtuvo información georreferenciada de 275 puntos sobre coberturas forestales y usos de suelo.

Posteriormente, se analizaron imágenes satelitales (Sentinel-II de 2018) para identificar áreas vegetación y sin vegetación aparente con la información del mapeo participativo y la información georreferenciada. Se reconocieron a través de una clasificación supervisada con el software ArcMap 12.0 tres categorías que a continuación se describen.

a) Cobertura forestal. Comprende bosque maduro, vegetación secundaria arbórea y matorrales.

b) *Sin vegetación aparente*. Superficie que no cuenta con ningún tipo de vegetación leñosa. Comprende principalmente tierras agrícolas, asentamientos humanos y cuerpos de agua.

c) Áreas erosionadas. Superficie que presenta algún grado de erosión de suelo.

El mapa de coberturas fue verificado a través de la selección de una muestra por conglomerados (Mas *et al.*, 2003), que consistió en tomar 120 puntos con GPS (Garmin) (40 para cada clase) para corroborar que la cobertura representada coincidió con lo existente en campo, teniendo una precisión del 85% de las clases representadas en el mapa. Asimismo, la información de mapa de cobertura sirvió para elaborar un mapa de superficie forestal y superficie erosionada por comunidad.

2.3 Análisis de especies nativas no maderables

En cada comunidad se aplicaron entrevistas informales (± 6 personas) a habitantes locales, quienes narraron aspectos sobre reforestaciones y regeneración natural en los últimos 30 años. Adicionalmente, se organizaron cinco entrevistas semi-estructuradas grupales en talleres, donde participaron 35 informantes clave de las comunidades (líderes y autoridades mayores de 50 años), las cuales se centraron en tres elementos: I. Estado de las reforestaciones; II. Estado de la regeneración natural; y III. Especies nativas con potencial para restauración.

Con la información de las entrevistas y los recorridos de campo, se realizó un listado de las especies nativas dominantes y especies vegetales asociadas que se recomienda para programas de reforestación. Posteriormente, esta lista de especies locales se clasificó a través de un cuadro considerando tres grados de erosión. Para catalogar el grado de erosión se consideró la pérdida de suelo en las formaciones litológicas (Fernández de Castro-Martínez *et al.*, 2018). Se etiquetó como erosión severa a las cárcavas (formación Yanhuitlán), a la erosión de tipo laminar se le clasificó como moderada (toba “Llano de Lobos”) y a la erosión en surcos como baja (andesita “Yucudaac”).

3. RESULTADOS

3.1 Estado de la cobertura forestal y la erosión de suelo

El análisis de imágenes satelitales mostró que 37.5% de la superficie total del sitio cuenta cobertura forestal, que corresponde principalmente a bosque maduro, bosque secundario y matorrales (Figura 2). La comunidad con mayor superficie forestal fue Santa María Tiltepec (56.1%) y la que menor registró tuvo fue Santa María Suchixtlán (17.2%) (Tabla 1). Respecto al tipo de vegetación dominante por comunidad, se identificó que Santo Domingo Yanhuitlán y Santa María Tiltepec son las comunidades que registraron mayor superficie de bosques maduro. En Santa María Suchixtlán obtuvo el mayor registro de matorrales respecto al resto de las comunidades.

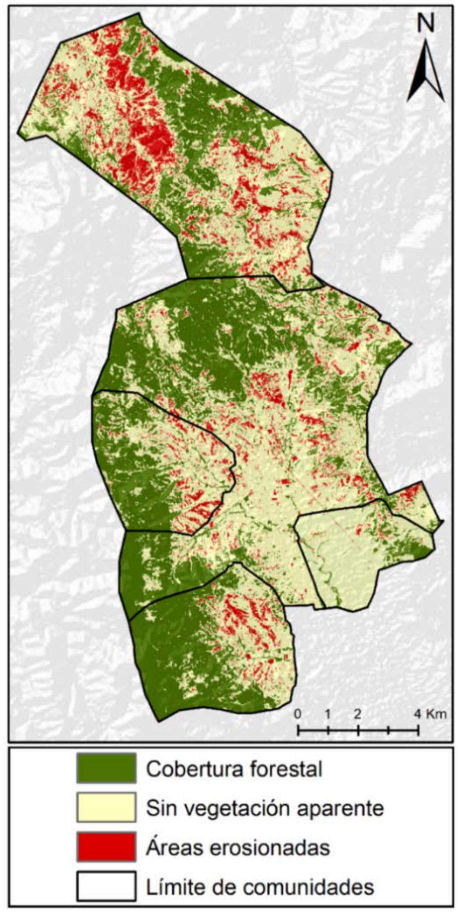

Figura 2. Cobertura forestal, cobertura sin vegetación aparente y áreas erosionadas en las comunidades del sitio de estudio. Fuente: elaboración propia

Se estimó que cerca de 10% (1 624.4 ha) de la superficie total de sitio de estudio presenta algún grado de erosión (Figura 2). Se observaron que los suelos erosionados se ubican principalmente en cárcavas, barrancas y lomeríos. Santo Domingo Tonaltepec es la comunidad con mayor erosión que presentó el 18% de la superficie total en esta condición (Cuadro 1).

Cuadro 1. Superficie forestal, vegetación dominante y superficie erosionada por comunidad

Comunidad	Superficie forestal ha	Tipo de vegetación dominante	Superficie erosionada ha
Santo Domingo Yanhuitlán	2 763 (39.4*)	Bosque maduro	399.1 (5.7*)
San Pedro Añañe	737 (44.9)	Bosque secundario	122.7 (7.5)
Santa María Suchixtlán	179 (17.2)	Matorrales	37.3 (3.6)
Santo Domingo Tonaltepec	1 485 (28.8)	Bosque secundario	929.8 (18.0)
Santa María Tiltepec	1 186 (56.1)	Bosque maduro	135.5 (6.4)

* Representa el porcentaje

La región Mixteca Alta históricamente ha presentado avanzados procesos de degradación forestal, erosión de suelos y deforestación. Con el establecimiento de los primeros agricultores sedentarios alrededor del año 4000 a.C., la región registró las primeras modificaciones antrópicas que consistieron en la remoción de vegetación y la construcción de *lama-bordos* (terrazas agrícolas) (Mueller *et al*., 2012).

Conforme la literatura, los bosques de la Mixteca podrían haber presentado notables modificaciones a partir del periodo prehispánico postclásico (900 d.C.) debido al crecimiento de la población y la ampliación del sistema de lama-bordos (Spores y Balkansky 2013; Borejsza y Joyce, 2016); sin embargo, se ha documentado que el sistema de terrazas agrícolas ayudó a la retención de suelo (Guerrero-Arenas *et al.*, 2010; Rodríguez y Anderson, 2013). La sobreexplotación forestal en la época colonial indujo a que los bosques experimentaran severa degradación y deforestación; mientras que, con la introducción del ganado caprino, el pastoreo propicio erosión del suelo (García, 1996;

Díaz-Núñez, 2006), evidente hasta ahora. En la época contemporánea, la migración económica de mixtecos que inició a mediados del siglo XX (Rivera-Salgado, 2005), redujo la actividad agrícola, lo que afectó negativamente al sistema tradicional de terrazas haciendo más propenso el suelo a la erosión hídrica (García-Barrio y García-Barrios, 1990; Velásquez, 2002). A inicios del presente siglo, tanto la migración económica y el pastoreo de ganado caprino todavía persisten en la mayoría de las comunidades de la Mixteca, aunque con diferente magnitud (Hernández-Aguilar *et al.*, 2017).

El análisis del estado de la cobertura forestal y de las áreas erosionadas puede ser útil para la toma de decisiones dentro de las comunidades de estudio, considerando que recientemente se ha reportado que la cobertura forestal ha incrementado en las últimas décadas en la zona del Geoparque de la Mixteca Alta (Lorenzen *et al.*, 2020; Hernández-Aguilar *et al.*, 2021). Tanto la regeneración natural como aquella que es inducida (reforestaciones), pueden ser benéficas para la conservación de suelos en la Mixteca Alta, sin embargo, ambas dependen de factores ambientales, sociales e institucionales para su éxito.

3.2 Situación de las acciones de conservación y restauración de suelos en la Mixteca Alta

De acuerdo con las autoridades agrarias locales, los programas de reforestaciones y conservación de suelos de la Comisión Nacional Forestal (CONAFOR) han sido la principal estrategia para frenar la erosión de suelos en la Mixteca Alta. Desde finales de la década de los noventa y principios del presente siglo, un gran número de comunidades del sitio de estudio y lugares cercanos han realizado campañas de reforestación bajo los términos o reglas de operación de las instituciones públicas. Generalmente, los programas de reforestación se han centrado en la siembra de árboles del género *Pinus*, principalmente con especies tales como *greggii* y *pseudostrobus (var. oaxacana)*, en parajes adyacentes a remanentes de bosques, parajes con tierras agrícolas abandonadas, y en áreas con algún grado de erosión de suelo.

La reforestación con pino presenta los siguientes problemas de acuerdo con la percepción de la gente: 1) el desarrollo de los árboles es lento por falta de materia orgánica en el suelo y obras de captación de agua (Figura 3); 2) la supervivencia de pinos es nula o escasa en terrenos con un grado de erosión severo (Figura 3); y 3) una parte de las plántulas de las especies de pino que otorga la CONAFOR no se adaptan a las condiciones biofísicas de las comunidades. Además de estas desventajas, las reforestaciones con una sola especie de árbol implican menor diversidad arbórea, que en términos ecológicos vuelve susceptible al bosque ante amenazas bióticas como lo es el escarabajo descortezador (Duran *et al.*, 2018).

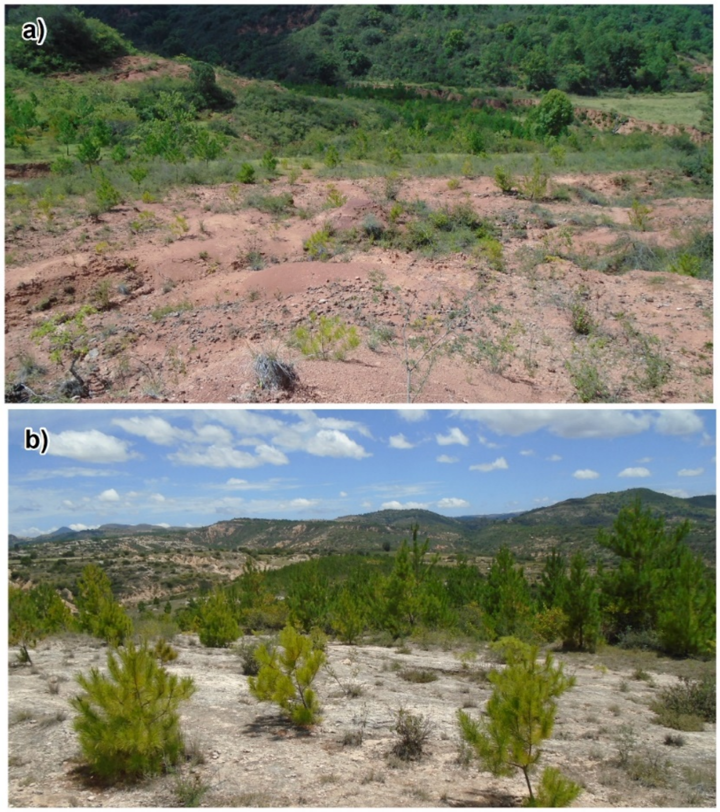

Figura 3. Reforestaciones en comunidades de Geoparque: a) sitios severamente erosionados y b) terrenos con erosión moderada. Fuente: elaboración propia

Los problemas en reforestaciones de programas gubernamentales en las comunidades de estudio coinciden con otros trabajos que revelaron que plantaciones forestales con especies inducidas en la Mixteca Alta no ha sido exitosa debido a factores como la precipitación media anual, la temperatura media anual, la altitud y el tipo del suelo (López *et al*., 2011; Plancarte, 2019). Por lo anterior, es necesaria una evaluación integral de los programas de reforestación de la CONAFOR, los cuales se han centrado en plantaciones comerciales con especies de pinos, principalmente no nativos (Burney *et al*., 2015), sin considerar el potencial especies nativas con fines de restauración forestal y de suelos. Asimismo, los actuales programas de reforestación aparentemente no fueron diseñados para comunidades/ejidos forestales que no buscan un aprovechamiento comercial del bosque, sino conservar/aprovechar otros servicios ecosistémicos como el ecoturismo, productos no maderables o fertilidad del suelo (Hernández-Aguilar et al., 2021).

3.3 Estrategia de reforestación con especies nativas

Conforme a la experiencia y observación de las personas entrevistadas, existen diversas especies nativas no maderables que pueden ser utilizadas de acuerdo con el grado de erosión en el que se encuentre el sitio a intervenir. Se identificaron asociaciones de especies arbóreas nativas que podrían ser utilizadas para los programas de reforestación; en función al tipo de terreno y al grado de erosión del sitio.

En sitios con erosión severa, como las cárcavas de formación Yanhuitlán, se observó que el "ramón" (*Cercocarpus* spp) se ha distribuido naturalmente en este tipo de suelos (Cuadro 2) (Figura 4), y se reporta en la literatura que esta especie nativa se distribuye naturalmente en todo tipo de terrenos (Villaseñor, 2016). Además, se desarrollan en terrenos con pendiente pronunciada, cualidad que difícilmente no se ha logrado observar en las reforestaciones con pino. La distribución de ramón comúnmente es acompañada de "pingüica" (*Arctostaphylos* spp) (Cuadro 2).

Cuadro 2. Especies nativas con potencial para manejo de la erosión de suelo

Grado de erosión	**Tipo de erosión**	**Número de sitios de muestra**	**Especies nativas dominantes**	**Especies vegetales asociadas**	**Estado de las reforestaciones**
Severa	Cárcavas	23	"ramón" o "ramonal" (Cercocarpus spp)	"pingüica" (A*rctostaphylos* spp.)	Nula o escaza supervivencia de plántulas

Moderada	Laminar	19	“ramón” (Cercocarpus spp), “Tepehuaje” (*Acacia acapulcensis*), “enebro” (*Juniperus* spp.)	“pingüica” (*Arctostaphylos* spp.), “madroño” (*aArbutus xalapensis*)	Lento crecimiento de árboles
Baja	Surcos	31	“ramón” (Cercocarpus spp), “tepehuaje” (*Acacia acapulcensis*), “enebro” (*Juniperus* spp.), “elite” (*Alnus acuminata*), “encino” (*Quercus spp.*) y pino (*Pinus spp.*)	“pingüica” (*Arctostaphylos* spp.), “madroño” (*Arbutus xalapensis*), “jarilla” (*Dodonaea viscosa*), “chamizo” (*Barkleyanthus salicifolius*),	Desarrollo normal de arboles

En sitios donde la pérdida de suelos es modera (formaciones litológicas como tobas y andesitas) (Fernández de Castro-Martínez *et al.*, 2018) es factible trabajos de reforestación con las especies arbóreas tales como “ramón” (*Cercocarpus spp.*), “enebro” (*Juniperus spp.*) y “tepehuaje” (*Acacia acapulcensis*) (Cuadro 2); esta última es resistente a sequias y su desarrollo no requiere suelos profundos (Pennington, 2005). En comunidades como Suchixtlán y San Pedro Añañe, se han presentado procesos de revegetación natural en terrenos con erosión, donde en un lapso de 10 a 15 años han transitado a matorrales y que cuenta con abundancia de especies arbóreas “ramón”, “enebro” y “tepehuaje” (Figura 4b) (Hernández-Aguilar et al., 2021). Esto demuestra que en terrenos donde la erosión de suelo es moderada y con poca pendiente el desarrollo de estas especies nativas es viable.

Los sitios con erosión baja pueden albergar una mayor diversidad de especies arbóreas debido a regularmente cuenta con una calidad de suelo adecuada. Además, árboles propuestos anteriormente (ramón, enebro y tejahuaje), es posible incluir en las reforestaciones especies de “elite” (*Alnus acuminata*), “encino” (*Quercus spp.*) y pino (*Pinus spp.*) (Cuadro 2). Otras especies vegetales, principalmente arbustivas, tales como “pingüica” (*Arctostaphylos* spp.), “madroño” (*Arbutus xalapensis*), “jarilla” (*Dodonaea* *viscosa*) y "chamizo" (*Barkleyanthus salicifolius*), también se adaptan exitosamente a terrenos con condiciones de erosión baja.

Figura 4. Especies nativas sitios: a) "ramón" (*Cercocarpus spp.*) y b) regeneración natural en cárcavas. Fuente: elaboración propia

Considerando que en la Mixteca Oaxaqueña el 80% de sus suelos se encuentra afectado por la erosión hídrica (Martínez-Peña, 1988; Martínez et al., 2006) y que cerca del 45% de las tierras presentan erosión alta, 38% erosión moderada y 17% signos de erosión severa, la propagación de especies nativas con potencial de conservación de suelos y manejo de la erosión en la Mixteca Alta requiere una revisión que las reglas de operación de CONAFOR para que sean considerados los conocimientos locales sobre especies nativas. Asimismo, es indispensable destinar recursos públicos y privados para el asesoramiento técnico y la creación de viveros comunitarios. Finalmente, las estrategias de restauración de áreas degradadas y erosionadas pueden ser exitosas si se apoyan en la base social de las comunidades, como caso es el Mixteca Alta donde por varias décadas ha operado el trabajo comunitario, las reglas de uso y acceso al bosque y el control del pastoreo (Hernández-Aguilar *et al.*, 2017, Hernández-Aguilar *et al.*, 2021).

4. CONCLUSIONES

Para mitigar la deforestación y la degradación y pérdida de suelos, es fundamental la diversificación de especies nativas para acciones de restauración de paisajes. Es necesario incluir en los programas de reforestación especies nativas locales, las cuales tienen mayor probabilidad de adaptación a las condiciones biofísicas de los diferentes sitios del territorio. El caso de la Mixteca Alta mostró que los actuales programas de reforestación basados en especies no nativas de pino no han sido totalmente exitosos, por lo que es recomendable dirigir los esfuerzos de restauración con especies arbóreas y arbustivas nativas.

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CAPITULO V

Consideraciones finales

5.1 Principales hallazgos y contribuciones

Los paisajes forestales mantienen diversos recursos naturales y son provisores de servicios ambientales que son clave para el bienestar social. La propiedad social (comunidad/ejido) prevalece en los paisajes forestales de México. Esto implica que el manejo de los bosques sea participativo y que los núcleos agrarios se comporten como sistemas ecológico-sociales, ya que tanto el bosque como los propietarios se interrelacionan. Es decir, toda vez que los dueños de un núcleo agrario deciden aprovechar, conservar o restaurar su bosque, puede beneficiarse sus recursos y adoptar una cultura asociada a las características del entorno.

El *Capítulo II* de la presente investigación destacó que la región Mixteca Alta puede ser analizada a partir del reconocimiento de unidades de paisaje, las cuales tienes diferentes contextos de resiliencia ecológicos-sociales. Además de esto, el estudio de nivel de unidades de paisaje da un marco conceptual y pragmático para analizar las implicaciones del manejo de los recursos forestales en regiones donde prevalece la propiedad social. Con el enfoque de paisaje fue posible entender el contexto socio-ecológico de la Mixteca Alta a raíz de poder responder preguntas tales como: ¿cómo es la tenencia de la tierra en microcuencas de paisajes forestales?, ¿cómo interactúan los núcleos agrarios en un continuo de bosque?, ¿dónde se ubican las áreas con alto potencial para aprovechamiento maderable y no maderable, conservación, ecoturismo, provisión de agua y con necesidad de restauración?, ¿ qué amenazas naturales y antrópicas existen para los bosques dentro de la región ?

Distinguiendo los elementos biofísicos y sociales del paisaje de la Mixteca Alta, Oaxaca, y del establecimiento de unidades de paisaje fue posible reconocer las conexiones entre núcleos agrarios para distintos tipos de manejo forestal o anticipar la necesidad de conexión (por ejemplo, para promover aprovechamiento forestal comercial, facilitar control de incendios o plagas forestales, entre otros). Asimismo, al sincronizar acciones de manejo del bosque entre grupos de núcleos agrarios colindantes, los resultados del cuidado o impacto del bosque a nivel local pueden escalar al nivel del paisaje.

El *Capítulo III* mostró que paisajes forestales altamente degradados y deforestados pueden transitar hacia recuperación de bosques en lapsos de tiempo cortos (décadas), como es el caso de la Mixteca Alta, Oaxaca, donde en los últimos 30 años ha habido un incremento de la cubierta forestal, donde el componente social ha jugado un papel primordial en tal proceso. El trabajo expuso que dicha recuperación de cubierta podría estar principalmente relacionada con factores directos e indirectas tales como las reforestaciones, tequios, asambleas, aprendizajes sociales y normas colectivas, que han operado espacialmente a nivel comunidad y temporalmente a largo plazo. Esta vía de transición forestal basada en la comunidad, no reconocida en la literatura, tuvo su origen en las motivaciones de la gente local para empezar a recuperar cobertura (activa o pasivamente), las cuales no son de tipo monetarias, sino se centran en la conservación de servicios ecosistémicos claves para su modo de vida: el mantenimiento de tierra fértil, la protección de nacimientos de agua y la disponibilidad de madera y leña. Dicho proceso no ha sido esporádico, sino que es una ruta que ha sido construida por la gente de las comunidades por varias décadas.

El *Capítulo IV* demostró que una serie de especies arbustivas y arbóreas nativas no maderables podrían tener potencial de restauración para zonas erosionadas dentro del Geoparque de la Mixteca Alta. Fue posible reconocer que estas especies se adaptan a las condiciones de los diversos tipos de erosión (laminar, surcos y cárcavas), además de ser resistentes a temporadas de secas. Esto tiene implicaciones en políticas forestales, considerando que las reforestaciones convencionales promovidas por la CONAFOR no han sido totalmente exitosas en diversos sitios de la Mixteca Alta. Con ello se puede dar paso a programas de reforestación basados en especies nativas con apoyo de personas de las comunidades, quienes han poseen el conocimiento sobre la reproducción y propagación de estas especies. La existencia de conocimiento locales adquiridos de forma empírica (manejo de especies arbóreas y arbustivas) dentro de las comunidades y la construcción de políticas de abajo hacia arriba podrían considerarse indicadores de resiliencia ecológica-social dentro del sitio de estudio.

El paisaje forestal de la Mixteca Alta podría estar transitando hacia un estado más favorable debido a la influencia principalmente de elementos sociales, lo que podría representar que existen factores que positivamente aportan resiliencia a los bosques comunitarios. El caso de la Mixteca Alta ilustró que hay elementos que confieren resiliencia al paisaje tales como: a) los procesos continuos de regeneración natural, b) los procesos recurrentes de revegetación inducida, c) las acciones colectivas para conservar y aprovechar el bosque, d) el sistema de gobernanza local, y e) los aprendizajes sociales. De esta forma, la presente tesis aportó elementos teóricos respecto a la resiliencia del paisaje, en el sentido de que la capacidad de recuperación, transformación o adaptación de un paisaje forestal no implica solamente el análisis la dimensión ecológica (estado del recurso) sino que también incluye el estudio de sus componentes sociales (actores locales, mecanismos de participación y gobernanza). Ambas dimensiones están interrelacionadas y son interdependientes, por lo que cualquier cambio positivo o negativo en una esfera tendría repercusiones dentro del SES (por ejemplo, un conflicto agrario). Finalmente, el análisis de la resiliencia ecológica-social de los paisajes forestales puede ser una vía para entender contextos socio-ecológicos complejos y para establecer políticas forestales integrales de largo plazo.

5.2 Oportunidades para futuras investigaciones

Más allá del grupo de comunidades estudiadas, se sabe que otros núcleos agrarios de la Mixteca Alta realizan actividades de restauración y de manejo forestal. Sin embargo, quizá aún no hay suficientes elementos para afirmar que en la Mixteca Alta se ha frenado la deforestación o que la región en su conjunto experimenta un proceso de transición forestal. Asimismo, es importante señalar que los factores de resiliencia ecológica-social puede variar dentro de las unidades de paisaje establecidas para la región Mixteca. Por ello, es necesario cartografiar y documentar la historia de la conservación, gobernanza local y manejo forestal en el resto de las comunidades forestales de esta región.

El caso de la Mixteca Alta puso de manifiesto la necesidad de revisar los programas forestales gubernamentales, los cuales se han enfocado en mayor medida en aumentar la producción de madera. Estos, aparentemente no fueron diseñados para comunidades/ejidos forestales que no buscan un aprovechamiento comercial del bosque, sino conservar/aprovechar otros servicios ecosistémicos como el ecoturismo, productos no maderables o la belleza escénica. Por otro lado, los programas forestales deberían considerar que los proyectos de conservación y manejo de bosques y el capital social (organización y gobernanza) de las comunidades puede verse afectado por amenazas de tipo social como la migración de comuneros y los conflictos agrarios, así como por aquellas biofísicas como la plaga del descortezador y los incendios forestales.