ECOSUR

El Colegio de la Frontera Sur

Incorporación de herbáceas nativas en plantaciones de árboles forrajeros para resolver problemas de pérdida de biodiversidad y establecimiento.

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Dedicatoria

A mi familia, cuya fortaleza me inspira para encontrar la mía.

Siempre que siento que no hay mucha esperanza, recuerdo las tibulaciones de aquellos cuyo día a día realmente es una lucha por sobrevivir dignamente

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CONTENIDO

Resumen

En el primer capítulo de esta tesis se determinó qué tanto del paisaje en las fronteras forestales dentro de una Reserva de la Biósfera puede ser considerado como un recurso silvopastoril. Los resultados ponen en perspectiva la utilidad de los sistemas silvopastoriles en estos sitios. El análisis deja claro que las fronteras forestales *ya son como sistemas silvopastoriles*: hay una gran cantidad de plantas que las vacas ramonean ¿No es esto acaso lo que quisiéramos en un sistema silvopastoril "ideal"? ¿No es esto acaso lo que se busca en la agroecología? ¿Inspirarse en los sistemas ecológicos; aprovechar al máximo la partición de recursos de tal modo que haya mucha diversidad de plantas con usos? (Liere, Jha y Philpott, 2017). El bosque ya hace esto para el ganado. Esta diversidad de plantas ramoneadas es mucho más alta de lo que registros anteriores mostraban, tanto de evaluaciones anteriores del mismo paisaje según el conocimiento campesino (Trujillo-Vázquez y Hernández-Ramírez, 2011), como de otros trabajos en paisajes comparables, hechos por académicos (*e.g.* Pinto-Ruiz *et al*., 2010). Esto nos hace considerar porqué a algunos campesinos en fronteras forestales es difícil convencerlos de sembrar más árboles. Para una persona que vive en la frontera forestal, *el sistema silvopastoril ya está ahí*. Es natural entonces que ellos dediquen el tiempo a otros tipos de intensificación de la producción, sembrando pastos mejorados, por ejemplo. Esta exploración del paisaje fue la primera pregunta que entendimos que había que resolver antes que dar un solo paso más en otra dirección: examinar a detalle cómo es la matriz ecológica forestal en la que está inmersa la producción ganadera.

Sin embargo, esta primera sección no es pesimista ni su conclusión pretende descartar los sistemas silvopastoriles. Precisamente porque hay una enorme cantidad de diversidad, esto abre un mundo de posibilidades, donde podemos pensar en aprovechar estos recursos y, haciendo auténtico uso de nuestra imaginación, concebir paisajes genuinamente forestales y silvopastoriles. Non interesamos por los paisajes de bosques manejados, donde la mayoría de las plantas sean de uso ganadero. En el segundo capítulo de la tesis se detalla una propuesta de cómo hacer esto, aprovechando una parcela experimental que se volvió un claro ejemplo de algunas contradicciones entre conservación y producción que representan los sistemas silvopastoriles.

Se concluye que el bosque tiene una clara y muy importante función desde el punto de vista ganadero y es un elemento crucial para esta actividad en las fronteras forestales, lo que motiva su conservación y también su uso razonable. Además, aunque los sistemas silvopastoriles pudieran resultar redundantes desde el punto de vista de los productores tal y como se promueven actualmente, siguen siendo absolutamente necesarios para tratar de conciliar la producción y la conservación, aunque quizá debería cambiar el enfoque de su promoción: en lugar de sembrar árboles *per se*, quizá lo mejor sería adoptar un esquema donde se cerquen pequeñas porciones de terreno y se permita y dirija la sucesión del bosque seleccionando paulatinamente aquellas plantas con usos silvopastoriles, además de reconocer y permitir cierto ramoneo dentro de las fronteras en las zonas de amortiguamiento.

Palabras claves: Sistemas silvopastoriles, ramoneo, reserva de la biósfera, lógica difusa, sistemas agroforestales, *Tithonia diversifolia, Gliricidia sepium*, claros de dosel.

CAPITULO I

1. Introducción

1.1 Conservación y ganadería en Reservas de la Biósfera

Las Reservas de la Biósfera son un claro ejemplo del problema de cómo crear un esquema en donde se respete el ambiente y donde asimismo se permita el desarrollo de las poblaciones humanas (Batisse, 1997). La expansión territorial humana y su economía afecta directamente la biodiversidad y la capacidad de un paisaje de proveer de servicios ecosistémicos (García-Barrios *et al*., 2009). Dentro de los cambios que los seres humanos hacen a su ambiente se incluye tácitamente una alteración del paisaje debido a las actividades agrícolas y ganaderas. Estas modificaciones del paisaje dependen directamente del estado de la economía, local y global (Ahnström *et al*., 2009), que impacta la capacidad del campesino de hacer o no agricultura y hacerse parte activa del comercio de los productos que cultiva, o quedarse en un nivel más local, de auto-abasto. En un mundo económicamente globalizado, los vaivenes del mercado afectan directamente el paisaje de las fronteras forestales (Angelsen and Kaimowitz, 1999). En ningún caso se hace esto más evidente que en el caso de las actividades ganaderas. En Chiapas, esto se observa claramente en la Reserva de la Biósfera de La Sepultura (REBISE), donde la implementación del TLC y la importación de maíz subsecuente afectó a los productores drásticamente, provocando el aumento de las actividades ganaderas (Valdivieso-Pérez *et al*., 2012).

Este crecimiento provocó cambios en el paisaje y afectó la composición del suelo, entre otros efectos. A pesar de todo, la historia de la reserva de la biósfera de la Sepultura incluye un elemento de aprovechamiento ganadero que ha sido más o menos constante por lo menos desde hace 100 años (Lillo *et al*., 1999). Esta actividad tenía y tiene un papel importante para la subsistencia de los habitantes sin que esto fuera un problema relativamente grande hasta ahora, cuando el aumento poblacional y la expansión territorial y económica (sumado a los vaivenes del mercado), ha llevado a un aumento como nunca antes de la ganadería. Esta actividad es además diferente actualmente. Algunos campesinos que tenían unas pocas vacas (mayoritariamente como reserva económica) se han transformado en rancheros solventes económicamente, que han masificado e intensificado su producción. Que esta intensificación reduzca la presión en las fronteras forestales es incierto (Garret *et al*., 2018; Kreidenweis *et al*., 2018; Alvarado *et al*., 2018; Kaimowitz y Angelsen, 2008), pero esto no es el tema principal de esta tesis. Más relevante es el papel de los pequeños productores que, teniendo relativos pocos recursos para mantener a sus vacas, aprovechan continuamente los recursos del paisaje. Estos son los campesinos que por practicar la ganadería extensiva ocasionan más deforestación, al sustituir el bosque por pasturas, pero al mismo tiempo, son los que más aprovechan las fronteras forestales como un recurso (Sanfiorenzo-Barnhard *et al*., 2009).

Si bien el campesino remueve el bosque, también valora y necesita del bosque. Esta necesidad parte muchas veces de la carencia de recursos para aportar suplementos alimenticios a las vacas además de pastura; algo que es requerido por el ganado para el crecimiento, desarrollar músculos y producir leche. En el tipo de clima en el cual la REBISE está inmersa, que es estacionalmente seco, la necesidad impuesta por la carencia de agua durante la temporada de estiaje también empuja a muchos campesinos a dejar que su ganado se interne a las fronteras forestales (la interfase entre los terriotrios humanos y las zonas arboladas) para que ramonee lo que pueda y así subsista durante este periodo (Rosabal-Ayan, 2015). Los bosques de la zona coexisten de esta manera con el ganado, excepto en aquellas partes donde los dueños de los animales cortan los árboles para hacer espacio para pasturas.

Parece ser posible entonces concebir un manejo del ganado que sea compatible con la cobertura forestal. Este es (en parte) el enfoque de los sistemas silvopastoriles (Murguieitio, 2000; Mahecha, 2009 Milera, 2013). Usar los árboles como complementos en los potreros, para aprovechar los servicios directos que éstos dan, como aprovisionar follaje rico en proteína y proveer de sombra y además beneficiarse de los servicios ecosistémicos que éstos proveen (Ibrahim *et al*., 2010). Este tipo de manejo ganadero ha sido promovido para resolver los inconvenientes que tiene el manejo extensivo tradicional del ganado. El objetivo es conciliar la producción ganadera con la conservación de la cobertura forestal (Crespo, 2008; Solorio *et al*., 2016).

Sin embargo, hay problemas asociados a su implementación en la REBISE. Uno principal es la dificultad de su establecimiento, pues la competencia provocada por pastos exóticos como la “Jaragua” *Hypharrenia rufa* (Parsons, 1972; D'Antonio y Vitousek, 1992) provoca una elevada mortalidad de las plántulas de árboles en etapas iniciales de su establecimiento (Trujillo-Vàzquez, 2010). Además de esto, hay un tiempo de espera para que las plantas crezcan lo suficiente y toleren el ramoneo por las vacas, lo que implica que los terrenos donde se ubican no pueden ser destinados a la alimentación del ganado hasta ese momento (Clavero y Suárez, 2006). Otro problema se da cuando los árboles alcanzan un tamaño que impide su ramoneo o su manejo por corte y acarreo (Toral e Iglesias, 2007), además de que en plantaciones densas el exceso de sombra impide el crecimiento del pasto debajo de los árboles (e.g. Obispo *et al*., 2008). Adicionalmente a estos problemas, que son ecológicos (parten del comportamiento de las plantas y sus interacciones), están los problemas de índole social y económico. Los costos en recursos económicos y de tiempo de implementar un sistema silvopastoril muchas veces son prohibitivos para los campesinos de recursos más bajos; el ganado requiere a su vez de un proceso de aclimatación a los nuevos piensos y prácticas. Este es un fuerte cuello de botella que restringe la aplicación de estas prácticas (Dagang y Nair 2003).

1.2 El bosque como un recurso silvopastoril. ¿Llevar la vaca al bosque o llevar el bosque al ganado?

Inmerso en este escenario de sistemas silvopastoriles, el bosque está y seguirá presente como un recurso para los productores. Es esto lo que llevò a hacer la pregunta ¿Qué acaso el bosque en sí mismo no es ya el sistema silvopastoril que tanto se anhela para complementar la producción? ¿No se deberían de enfocar mayoritariamente los esfuerzos en conservar el bosque por un lado, e intensificar las prácticas ganaderas por el otro, de tal modo que se reduzca la cantidad de tierra convertida en pastizales por la ganadería? Dentro de esta doble visión de conservación y manejo del bosque se podría integrar el ramoneo de una manera mesurada, concibiendo efectivamente las fronteras entre territorios humanos y el bosque como los sistemas silvopastoriles.

Pero es incierto cuánto del bosque es exactamente un recurso en este sentido. Parecería que no se han aprovechado todo lo que ofrecen las fronteras forestales, ya que la prevalencia de la práctica de ramoneo implica que debe haber abundantes recursos silvopastoriles dentro de estas zonas, más allá de las especies “clásicas” como *Gliricidia sepium* y *Guazuma ulmifolia*, que son las que más se señalan y usan (Mendoza *et al*., 2011; Simmons y Stewards, 1994) ¿Qué hay de las hierbas y arbustos que ramonean las vacas? ¿Por qué estas especies no son reconocidas explícitamente como elementos silvopastoriles? Es casi seguro que debe haber especies que el ganado ramonea que no han sido plenamente reconocidas, las cuales podrían ayudarnos a mejorar los sistemas silvopastoriles ya existentes, debido a su rápido crecimiento, tolerancia a la sombra, u otras características útiles. Fue sorprendente reconocer que no había una buena descripción de la vegetación en estos territorios a pesar del alto potencial para ser considerada como un recurso silvopastoril.

También fue necesario una propuesta de manejo y un experimento simultáneos, que tuvo como objetivo aprovechar una parcela silvopastoril previamente existente. Esta fue resultado de un experimento previo de sobrevivencia y desarrollo de *G. sepium* en un pastizal bajo condiciones de siembra de semilla o trasplante (Morales Díaz, 2011). Como resultado de este experimento, quedó en pie una parcela de árboles que continuaron creciendo hasta resultar en un tamaño de > 6 m. Esta parcela estaba semi-abandonada cuando el trabajo inició. Al visitarla, se reveló que este pedazo de terreno representaba un claro ejemplo de algunas contradicciones del paradigma silvopastoril, pero que al mismo tiempo era una gran oportunidad de investigación.

Primero ¿por qué contradicción? Si bien el terreno y el experimento fueron exitosos y además esta fue una porción de terreno “recuperada” de la especie exótica *Hypharrenia rufa* (Parsons, 1972), el terreno perdió (en palabras propias de un productor de la zona) su valor ganadero, volviéndose un paraje más o menos inútil. ¿Por qué está percepción tan negativa? Primero que nada, debido al tamaño que los árboles alcanzaron. Si bien las vacas ramonean los árboles pequeños durante los primeros años de establecimiento, una vez que éstos superan cierto tamaño el ganado no alcanza el follaje. Una alternativa es la producción de bloques nutricionales a partir de las hojas (Cruz-Morales *et al*., 2011; Bunham y García-Barrios, 2014), pero esto es algo que requiere considerable esfuerzo y tiempo para hacerse. Por lo tanto, una vez que los árboles crecen, efectivamente la parcela deja de ser útil. Es fácil darse cuenta como esto es paradójico: los árboles de la plantación se volvieron aquello que la hace improductiva. Normalmente, el curso de acción que los productores toman es mantener a las vacas ramoneando los árboles, o podarlos, lo que impide que crezcan. Pero hacer esto implica que los árboles nunca crezcan a una altura cercana a un árbol adulto. ¿Dónde queda entonces lo silvopastoril? Parecería que el prefijo –*silvo* es engañoso en este sentido porque en realidad no se están promoviendo la siembra de árboles y la reforestación; en realidad se promueve el uso de forrajes alternativos que vienen de árboles, pero las acciones que se llevan a cabo para recuperar explícitamente cobertura forestal en realidad son escasas. Esto nos lleva a preguntarnos si en realidad es posible un manejo auténticamente silvopastoril; de una forma ideal: paisajes relativamente extensos, con árboles maduros, en donde aún así el ganado encuentre recursos. Aunque esta posibilidad es extremadamente atractiva en la imaginación, es incierto si esto es posible a gran escala. En todo caso, indudablemente requeriría un plan complejo y una cantidad apreciable de recursos para ser implementado.

Hasta aquí, todo parecería ser una descripción de las dificultades. Sin embargo, al mismo tiempo que esta parcela fue un ejemplo de los problemas que surgen con el manejo silvopastoril, fue una fuente de inspiración para tratar de probar ideas nuevas. Así, imaginamos y enmarcamos su uso dentro de un tipo de manejo diferente. Este tipo de manejo estaría dominado por un aspecto sucesional. Reconociendo la cantidad de plantas comestibles para el ganado que hay en la reserva, en lugar de dedicar tiempo y esfuerzo a la siembra constante de árboles, quizás sería mejor designar áreas de terreno estratégicas para ser cercadas por un tiempo. El manejo consistiría entonces en limpiar estos terrenos cada cierto tiempo (y posiblemente dispersar algunas semillas de árboles forrajeros en sitios estratégicos); removiendo aquellas plantas que no contribuyan a la alimentación del ganado, dejando sólo las reconocidas como útiles. Introduciendo ganado a partir de cierta etapa o manejando su estancia en estos lugares, sería posible aprovechar cierto aporte de ramoneo de estos sitios, mientras pasan los años y se permite a la cobertura forestal crecer.

Ahora bien, sería necesario diseñar una forma en la que los estratos vegetales que se estuvieran desarrollando fueran accesibles y además que crecieran de forma óptima. No se puede dejar que el estrato arbóreo siga creciendo indiscriminadamente, ya que, como se mencionó, esto provoca por fuerza que los estratos más bajos disminuyan su productividad por la falta de luz (Obispo *et al*., 2008; Fernández *et al*., 2002; Lin *et al*., 1998) además de que las vacas no alcanzan los estratos superiores. Una primera posibilidad para lograr esto sería provocar un disturbio de forma artificial durante el manejo sucesional, que permitiera una adecuada distribución de la biomasa vegetal en los estratos arbóreos y del sotobosque. Al final el resultado serían parcelas con diferentes niveles de vegetación comestible (figura 1a) y el paisaje en total consistiría en una matriz de estos parches forestales (figura 1b).

Como una segunda posibilidad, si de alguna manera pudiéramos identificar aquellas plantas que verdaderamente tuviesen una alta tolerancia a la sombra y fueran nutritivas, podríamos sembrarlas, de modo que se evitara completamente la necesidad de remover árboles. De hecho, la observación que detonó originalmente estas ideas fue que bajo el dosel de esta plantación creció de forma extremadamente abundante una especie herbácea (Figura 1c). Teniendo la parcela disponible, fue claro que habría que intentar aprovechar de algún modo la presencia de plantas en el sotobosque para el ramoneo por parte del ganado, tratando de incorporarlas de alguna forma en la parcela.

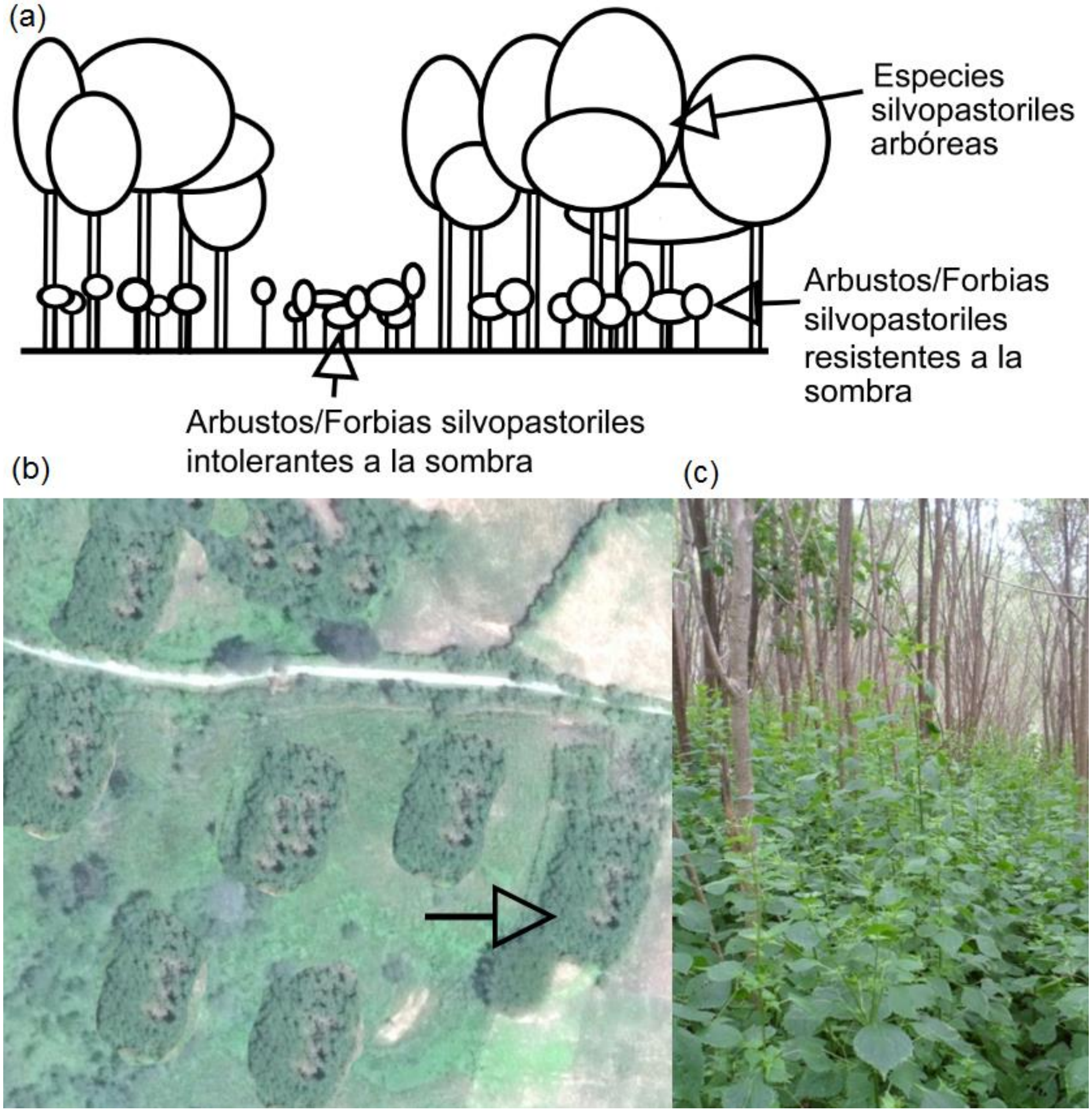

Figura 1. (a) Esquema sencillo de la estructura vertical de un hipotético sistema silvopastoril enriquecido con arbustos y forbias en el sotobosque. Dentro del dosel de árboles silvopastoriles se seleccionarían aquellas especies con potencial silvopastoril que resistieran la sombra, mientras que en los espacios abiertos se dejarían especies intolerantes a la sombra. (b)Visualización hipotética de cómo se podría enriquecer un paisaje silvopastoril sembrando pequeñas plantaciones silvopastoriles en las que después se cortarían huecos al interior. La parcela real en donde se llevó a cabo el experimento de

siembra en claros aparece en el extremo derecho, marcada por una flecha. Con la ayuda de un programa de edición de imágenes, se repitió porción de imagen donde aparece la plantación, para sugerir imaginativamente cómo podría apreciarse un paisaje manejado de esta forma. (c) Foto real del sotobosque en la parcela de *G. sepium* durante la temporada húmeda de 2014, mostrando que ciertas plantas pueden exhibir un abundante crecimiento aún bajo condiciones sombreadas. Esto nos sugirió que un sotobosque relativamente sombreado es compatible con la producción silvopastoril (se determinó que la especie que aparece en la foto pertenece al género *Hyptis*).

Una dosis de realismo impidió que la segunda posibilidad fuera el curso de acción. Pareciò extremadamente difícil conseguir reproducir una especie relativamente desconocida con verdadera a la sombra y con la capacidad de ser ramoneada. Esto debido a diferentes razones tales como que al inicio se desconocía cuáles especies del sotobosque eran ramoneadas, que era incierto cuándo conseguir sus semillas y cómo propagarlas, y también era dudoso si sobrevivirían suficientes plantas en un experimento piloto. Se realizaron entonces pruebas preliminares de propagación vegetativa con algunas especies de aquellas identificadas (lo que se detalla en el capítulo II), tratando además de sembrar algunas como *Acalypha leptopoda* y *Montanoa tomentosa* directamente dentro de la parcela (esto no está reportado en ninguno de los artículos realizados). La sobrevivencia fue baja y esto nos llevó a reflexionar en que se ignoraban los factores ya mencionados que incidirían negativamente en un intento de propagación de especies de sotobosque. Si el objetivo del manejo es producir algo de forraje, se decidió que había que proceder por la primera posibilidad e idear algún sistema que involucrara disturbio, alterando el estrato arbóreo, para así dar cabida a alguna especie medianamente tolerante a la sombra y fácil de establecer dentro del espacio liberado por ese disturbio. También se decidió entonces usar alguna planta presente en las fronteras forestales inmediatas de la que tuviéramos un conocimiento previo de su uso silvopastoril, para maximizar la posibilidad de tener buenos resultados.

Un ejemplo es *Tithonia diversifolia*. *Tithonia diversifolia* (Hemsl.) A. Gray, (Asteraceae) es una planta muy usada para manejo silvopastoril recientemente, por su alto contenido de proteína (24.31 %), aminoácidos esenciales como ácido aspártico, acido glutámico y leucina; y una tolerancia a suelos pobres, además de que se propaga fácilmente por estacas (Gallego-Castro *et al*., 2014; Osuga, *et al*., 2012; Fasuyi, & Ibitayo, 2011). Tiene la capacidad de almacenar fósforo en sus tejidos, y sus hojas y tallos se pueden usar como fito-fertilizante para este nutriente (Jorge-Mustonen, *et al*., 2013; Phiri, et al., 2003; Wishnie, *et al*., 2007). Tiene una alta tasa de crecimiento, y posee efectos alelopáticos sobre otras plantas en ciertas condiciones (Ademiluyi, 2012; Miranda, *et al*., 2015). Esta planta se localiza creciendo naturalmente en las fronteras forestales de la REBISE (y en varias partes de México y Centroamérica) y estaba disponible en poblaciones cercanas a la parcela.

Recapitulando, esta investigación se erige en dos preguntas principales ¿Qué obtiene exactamente el ganado del bosque? Para apuntalar los planes mencionados de manejo silvopastoril sucesional, sería necesario contar con listas no ambiguas de cuáles plantas podrían ser aprovechadas y cuáles no (para removerlas), reconociendo diversas características, como su abundancia, aquellas con alta incidencia de ramoneo, etcétera. La segunda pregunta es: ¿Qué de nuevo se puede traer del bosque para las plantaciones silvopastoriles?). Se hizo entonces un experimento piloto donde se investigó la posibilidad del manejo mediante claros del dosel de la vegetación más alguna planta forrajera herbácea sembrada en éstos. Esta idea también provino de previa experiencia con claros de dosel en el bosque tropical seco (Dechnik-Vázquez *et al.*, 2016) en la que se observaron que los claros del dosel eran punto focal de establecimiento de herbáceas de crecimiento rápido. Intentar enriquecer esta parcela de *G. sepium,* con elementos silvopastoriles encontrados en las fronteras forestales corresponde entonces a un pequeño ensayo de cómo se podrían ir transformando los pastizales en pequeñas plantaciones o “bosques” silvopastoriles dispersos, conectando estos entonces en el manejo sucesional ya mencionado.

No hay forma en que ningún plan de reforestación/aprovechamiento silvopastoril sustentable de las fronteras forestales se haga en el corto plazo. Incluso esta pequeña plantación tardó casi 10 años en llegar a su estado actual, e involucró el trabajo de dos tesistas y muchos pobladores en llegar a lo que es ahora. Cualquier plan serio de este tipo tendrá por fuerza que involucrar pasos discretos que involucren la recuperación progresiva de pequeños pedazos de terreno y su aprovechamiento tendrá que ser planeado para que, en cada etapa, el productor tenga la posibilidad de usar de alguna manera el terreno. Recuperar el terreno de esta manera, reconociendo las etapas de regeneración natural por las que pasa el bosque, es una forma de restauración que no ha sido plenamente reconocida y podría ser fructífera (Chazdon, 2017)

1.3 Zona de estudio

Este estudio se realizó específicamente en los ejidos de Los Ángeles y Ricardo Flores Magòn, dentro de la Cuenca Alta del Río el Tablón, ubicada al interior de la Reserva de la Biósfera de La Sepultura (CART-REBISE), situada a su vez dentro de la porción occidental de la Sierra Madre de Chiapas entre las coordenadas 16°16′40” − 16°12′40“ norte y 93°37′10” − 93°32′55“ oeste. El clima en la región es estacionalmente seco, con temperaturas promedio entre 25 y 28°C y 2003 ± 484 mm de precipitación anual en promedio. La vegetación se compone principalmente de selva baja caducifolia y bosques de pino-encino. Los suelos de la zona son principalmente arenosos. La reserva está dividida en zonas núcleo de conservación, zonas de amortiguamiento y territorios con poblaciones humanas. Esta Reserva de La Biósfera se declaró formalmente en 1995, lo que llevó a cambios importantes en las principales actividades económicas realizadas ahí: de ser una zona con principal vocación de producción de maíz, pasó a tener un fuerte componente ganadero. Actualmente, las actividades económicas están diversificadas, siendo las principales la agricultura (cultivo de maíz, frijol y café) y la ganadería

Objetivo

Determinar cuánta de la biodiversidad del paisaje de fronteras forestales en la Reserva de la Biósfera de La Sepultura puede ser considerada como un recurso silvopastoril (¿Qué obtiene el ganado al ir al bosque?) y cuántas de estas plantas son potencialmente nuevos y útiles elementos de sistemas silvopastoriles; evaluando además la posibilidad de crear una variante de un sistema silvopastoril dentro de una parcela de *Gliricidia sepium*. Esto mediante la siembra de alguna especie de sotobosque en claros de dosel abiertos dentro de la misma (¿Qué de nuevo se puede traer del bosque para las parcelas silvopastoriles, y cómo usarlo?).

Objetivos específicos

(1) Determinar mediante un muestreo de vegetación qué proporción total de plantas y de qué tipos dentro de las fronteras forestales son ramoneadas por el ganado.

(2) Muestrear y determinar el contenido nutricional de estas plantas comestibles, con el fin de establecer si su calidad nutricional las hace opciones realistas para ser nuevas especies de sistemas silvopastoriles. Esto nos permite además estimar cuánto de sus nutrimentos obtiene el ganado al realizar el ramoneo.

(3) Mediante encuestas, evaluar cuántas de estas plantas son reconocidas por ganaderos locales expertos, para sumar el saber local al conocimiento científico de las preferencias del ganado.

(4) Experimentar con la siembra de *Tithonia diversifolia* (presente en la frontera forestal) dentro de una parcela de árboles de *Gliricidia sepium*, para evaluar la posibilidad de obtener forraje en el estrato del sotobosque. Esto como incentivo indirecto para conservar árboles adultos dentro de parcelas silvopastoriles.

Hipótesis

La diversidad de plantas ramoneadas en las fronteras forestales de la Reserva de la Biósfera de La Sepultura es mucho más alta que lo reconocido por campesinos y científicos, haciendo de la vegetación en estos sitios un recurso silvopastoril más amplio de lo reconocido actualmente. Dentro de estos ensambles vegetales con varias especies con potencial forrajero, existen algunas que tienen potencial para ser cultivadas en sistemas silvopastoriles.

Organización de la tesis

En el **capítulo I** se detalla el marco teórico de este proyecto de investigación, que se gestó a partir de explorar las fronteras forestales y de observar el estado de la parcela de *G. sepium* y las opiniones de algunos productores y los dueños acerca de la misma. El proyecto silvopastoril en la Cuenca Alta del Río el Tablón en La Reserva de la Biósfera de la Sepultura ha tenido períodos anteriores de mucha actividad, pero actualmente no es el enfoque principal de las investigaciones. En este contexto, pareció importante realizar dos trabajos esenciales para dar seguimiento a esta línea de investigación; por un lado reconocer adecuadamente el potencial silvopastoril de las fronteras forestales, apuntalando un cimiento de conocimiento que hasta ahora no se había hecho a profundidad; y por otro lado, para tratar de continuar con las propuestas de manejo, proponer algún tipo de uso para una parcela de *G. sepium*. Esto considerando que el esfuerzo que fue necesario para establecer y mantener esta parcela no debería de ser en vano, si no que debería de ser enmarcada en algún plan a futuro.

El **capítulo II** expone la realización de la evaluación de las fronteras forestales como sistemas silvopastoriles. Se describió el paisaje haciendo un muestreo botánico, observando las marcas de ramoneo de las plantas, y se seleccionaron algunas especies para obtener más información de éstas de acuerdo a criterios nutricionales y la opinión de algunos productores acerca de las mismas. Se utilizó un sistema experto basado en lógica difusa para hacer la clasificación de acuerdo a estos criterios. Encontramos muchas más especies de plantas ramoneadas y con potencial uso silvopastoril que las comúnmente descritas en otros estudios.

El **capítulo III** detalla la realización de un experimento de siembra de *Tithonia diversifolia* en claros de dosel dentro de una plantación con árboles jóvenes de *Gliricidia sepium*. Se explica a detalle qué variables físicas medimos (humedad del suelo; radiación solar incidente), cómo medimos el crecimiento de las plantas y cómo fue realizado el análisis de éstos datos. Concluimos que el manejo de claros de dosel es una alternativa viable para enriquecer plantaciones silvopastoriles con árboles adultos en regiones tropicales estacionales.

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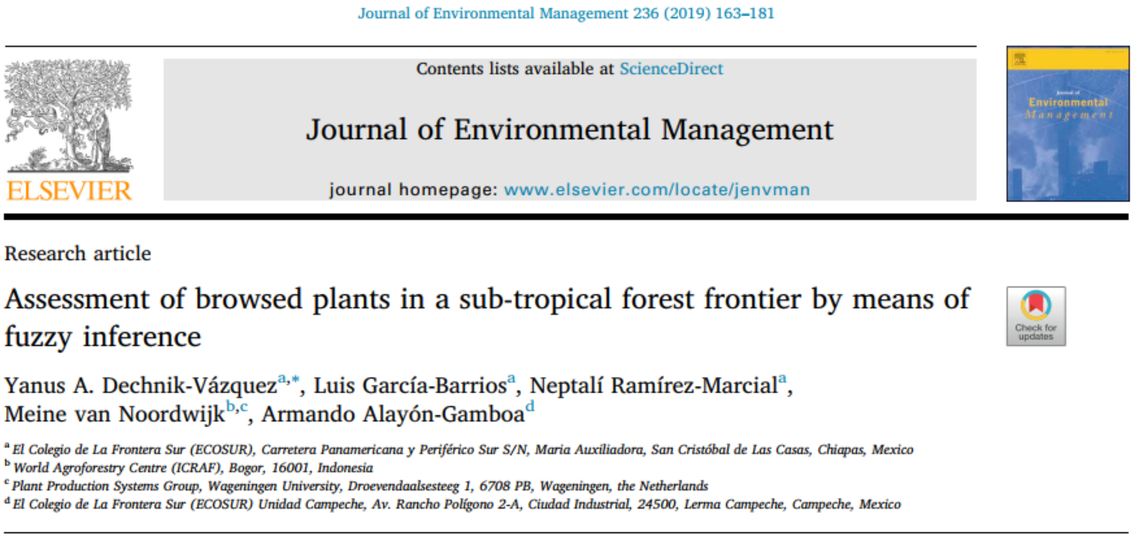
CAPITULO II

ASSESSMENT OF BROWSED PLANTS IN A SUB-TROPICAL FOREST FRONTIER BY MEANS OF FUZZY INFERENCE



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Research article

Assessment of browsed plants in a sub-tropical forest frontier by means of fuzzy inference

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Assessment of browsed plants in a sub-tropical forest frontier by means of fuzzy inference

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ABSTRACT

Browsing of forest frontiers by cattle in sub-tropical landscapes is detrimental to ecosystem health, but essential to smallholder livelihoods. We described a silvopastoral landscape, searching for browsed plants to assess how much of the forest is actually used for this end, and also searching for potential new useful species for silvopastoral purposes. The first objective was accomplished through a floristic description, making observations of individuals with browsing marks. Information from interviews, bromatological analyses and vegetative propagation tests further complemented this information to achieve the second objective. We classified the results using Fuzzy Inference Systems (FISs). A great variety of nutritious browsed plants was found, distributed across various types of vegetation, growth habits and taxonomic groups: forest frontiers already are like silvopastoral systems. Various plants like *Acalypha leptopoda*, *Montanoa tomentosa* and *Verbesina perymenioides* are interesting prospects for further intensification of silvopastoral systems

Keywords: *Agroforestry, Browsing, Cattle, Fuzzy Inference, Silvopastoral Systems.*

1. INTRODUCTION

At the forest frontier of sub-tropical Man and the Biosphere Reserves such as La Sepultura Biosphere Reserve in Chiapas, Mexico, where cattle ranching is very important to inhabitants, external actors promote fodder tree plantations as a land-use intensification strategy to reduce pressure on forests (García-Barrios and González-Espinosa, 2017). These plantations often fall short on their purpose to fulfill production, livelihood and conservation goals. Most of these producers continue to let their cattle roam in the forest frontiers during both dry and wet seasons and browse freely the understory of these forest communities. This suggests that the diversity and abundance of browsed plants is high in the different landscapes of this reserve and calls for a description and an assessment of their silvopastoral potential, also opening the possibility that fodder tree plantations could harbor some of these under-appreciated species.

Livestock ranching is widespread in the world, and a great proportion of it consists of smallholders with farm sizes < 3 ha (McDermott *et al*., 2010; Wright *et al*., 2012; Thornton, 2010; Robinson *et al*., 2014). The modest assets of smallholders in rural regions are linked to low efficiency of production of cattle and cattle related products (Rao *et al*., 2014, McDermott *et al*., 2010). Silvopastoral systems have been promoted as a solution to these problems (Solorio *et al*., 2017). Trying to preserve diversity in tropical cattle production is important because this activity is expected to grow further as the global demand for livestock products increases (Wright *et al*., 2012).

The vegetation in which the areas for cattle ranching are immersed helps sustain this production because plants found there supplement the diet of animals (*e.g.* Schoenbaum *et al*., 2017; Wangchuk *et al*., 2015). In Latin American countries, browsing/grazing of the forest by cattle is prevalent (Marquardt *et al*., 2009; Blackhall, Raffaele and Veblen, 2008; Stern, Quesada and Stoner, 2002; Montero-Solís *et al*. 2006, Sosa *et al*., 2000). From the point of view of conservation, browsing is discouraged since it is a major source of disturbance, reducing the number of seedlings and saplings and the species richness (Stern, Quesada and Stoner, 2002; Dufour-Dror, 2007). Nevertheless, this is a fundamental activity in the context of low intensity, extensive cattle ranching: forest frontiers are resources for smallholders. A better assessment of browsing helps us understand the role of forest frontiers in smallholder cattle management. It also allows for gauging the actual impact of cattle in vegetation. It is also an opportunity to discover new plants that might be useful for silvopastoral uses (Murgueitio *et al*., 2011). The search and identification of plants different from grasses that can provide high quality food for cattle has been extensive in Africa and Latin America (Pinto-Ruiz *et al*., 2010). Indeed, from the latter originate some of the most used plants for silvopastoral purposes such as *Leucaena leucocephala* (Zarate, 1999) and *Tithonia diversifolia* (Pérez *et al*., 2009).

Distinguishing the most useful species for browsing and then those best for potential domestication requires evaluating various factors, some more subjective like palatability in the field and others more straightforward like content of crude protein (CP) and high content of minerals (Minson, 2012a; Minson, 2012b). Another important aspect is a cultural one: do ranchers recognize the fodder potential of a species? Challenges to the adoption of silvopastoral systems are often of this kind (Dubeux *et al*., 2015, Atangana *et al*., 2014a). Biological and ecological characteristics like capacity for propagation, competitive ability and fast growth rate are also important (Jose, 2005).

Given this need to evaluate technical, ecological and social information in an efficient, intuitive way, as is often needed in ecological research (e.g. Du Toit, 2000; Meli *et al*., 2014), we used fuzzy logic (Papageorgiou, Kokkinos and Dikopolou, 2016), specifically, Fuzzy Controllers (Kickert and Mamdani, 1978.), also called Fuzzy Inference Systems (FISs; Castellano, Fanelli and Mencar, 2003; De Barros, Bassanezi and Lodwick, 2016). Fuzzy logic has the ability to deal with complex concepts that intertwine in complicated ways, and is a useful tool for systematizing local and indigenous knowledge (Berkes and Berkes, 2009). The essence of this approach can be summarized as using an expert system to conduct an assessment at the landscape level (*e.g.* Papadimitrou, 2012). In forested areas, fuzzy logic has been used for tasks such as area classification and timber harvesting (Brown, 1998; Boyland et al., 2006).

Many observations of what cattle and wild animals eat (Owen-Smith and Cooper, 1987) and farmer knowledge and nutritional composition (Carranza-Montaño *et al.*, 2003) of native fodder plants in Mexico and other parts of the world are available (Bayer, 1990; Roothaert and Franzel, 2001; Jiménez-Ferrer *et al*., 2007) but to our knowledge, no study has ever been made that groups or orders plant species according to more than two variables at once. In this study we aimed to characterize the main types of vegetation of the silvopastoral landscape (Tropical Dry Forest: TDF, Oak Forest: OAK, and Riparian Vegetation: RIP), in order to assess the status of forest frontiers as silvopastoral resources, to discuss the role of browsing compared to that of silvopastoral systems: why exactly smallholders bring the cow to the forest in subtropical ecosystems? Answering this question contributes to understanding the smallholder-forest relationship in forest frontiers of subtropical regions around the world. We also set to investigate what species have the most potential as new crops for silvopastoral plantations; “bringing the forest to the cow”. Are there new plants with interesting characteristics that could render them useful as new fodder crops?

2. MATERIALS AND METHODS

2.1 *STUDY AREA*

The study was carried out in La Sepultura Biosphere Reserve, established in 1995, in the southern Mexican state of Chiapas, at the west end of the Sierra Madre de Chiapas mountain range (16°16′40” − 16°12′40“N and 93°37′10” − 93°32′55“W; Figure 1). Climate is seasonally dry, with mean temperatures between 25 and 28 °C. Precipitation (2003 ± 484 mm annually) occurs mainly from May to October (CONAGUA, 2016).

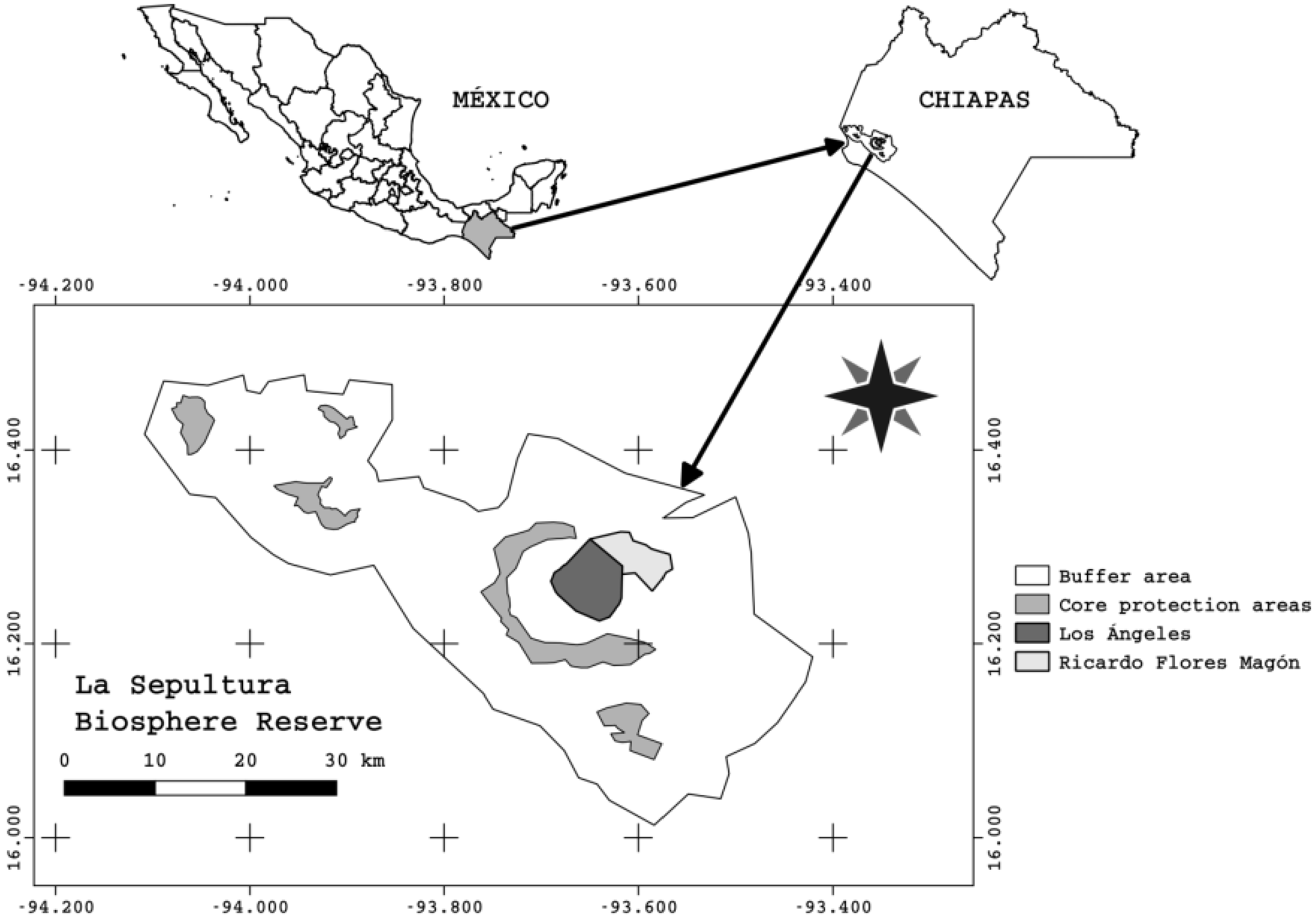

Figure 1. Location of the *ejidos* Los Ángeles and Ricardo Flores Magón in La Sepultura Biosphere Reserve of Chiapas, México.

The reserve is managed according to a governmental plan (Lillo *et al.*, 1999) that divides the territory into core zones and buffer zones, managed by the local inhabitants. We did our field work in two *ejidos* (communally owned lands) named Los Ángeles and Ricardo Flores Magón (figure 1). Maize agriculture was the principal economic activity of both ejidos before NAFTA took effect in 1994. Since then, extensive cattle ranching has become a main source of monetary income.

Silvopastoral approaches are supported nowadays by governmental institutions (García-Barrios and González-Espinosa, 2017). Main vegetation types are TDF in the lower zones, and oak and pine forested zones in the mid zones. The core zone is still dominated by montane cloud forest. Within the *ejidos* studied, vegetation is mainly TDF interspersed with OAK. We surveyed the study area in October 2015 with the aid of two local ranchers who walked us through various silvopastoral landscapes, identifying plants they recognized as eaten by cattle. The ranchers acknowledged that TDF, RIP and OAK are the main vegetation types.

2.2 PLANT COMMUNITY SAMPLING

We surveyed vegetation systematically along 16, 2-m x 35-m linear transects through the three vegetation types (TDF, RIP and OAK). The transects were next to or inside forested areas where we saw signs of cattle browsing, and could confirm that cattle had indeed browsed the vegetation. We sampled all plants shorter than 6 m, and whose foliage reached down to 2 m. The linear shape of transects minimized oversampling of monospecific patches. Variables measured for each plant were maximum height, crown cover (two perpendicular diameters), and diameters of the stem or stems at either the 50-cm height or (for plants shorter than 1 m) half the plant’s height. Sampled stems were examined carefully to determine which ones had been browsed by cattle rather than by other animals: cows are not very selective of the material they ingest, often eating branches as well as leaves, while deer and other wild animals usually eat only tender tissues such as leaves in the tips of branches, causing less damage to individual plants.

We searched for clear signs of browsing by cows such as multiple broken branches and marked absence of leaves (Figure 2b, c). Samples of individual plants were collected for later taxonomic identification, to the level of species, in the herbarium of *El Colegio de La Frontera Sur*, aided by the collection curator.

From measurements made during transects, we calculated descriptive statistics of height, cover, diameter and number of stems. The exponential of Shannon’s index, effective diversity (Magurran, 2013) was calculated as a measure of diversity. Bray – Curtis and Jaccard distance matrices were also calculated between sites, and dendograms were drawn (1) to determine whether the sampled transects follow the classification that ranchers told us (TDF, OAK and RIP sites), or whether composition is more a mixture of these types; and (2) to establish whether plants with browsing importance are exclusive to one vegetation type, or shared among them. Data were analyzed with the “vegan” library (Oksanen *et al*., 2018) of the R programming language (R Development Core Team, 2008).

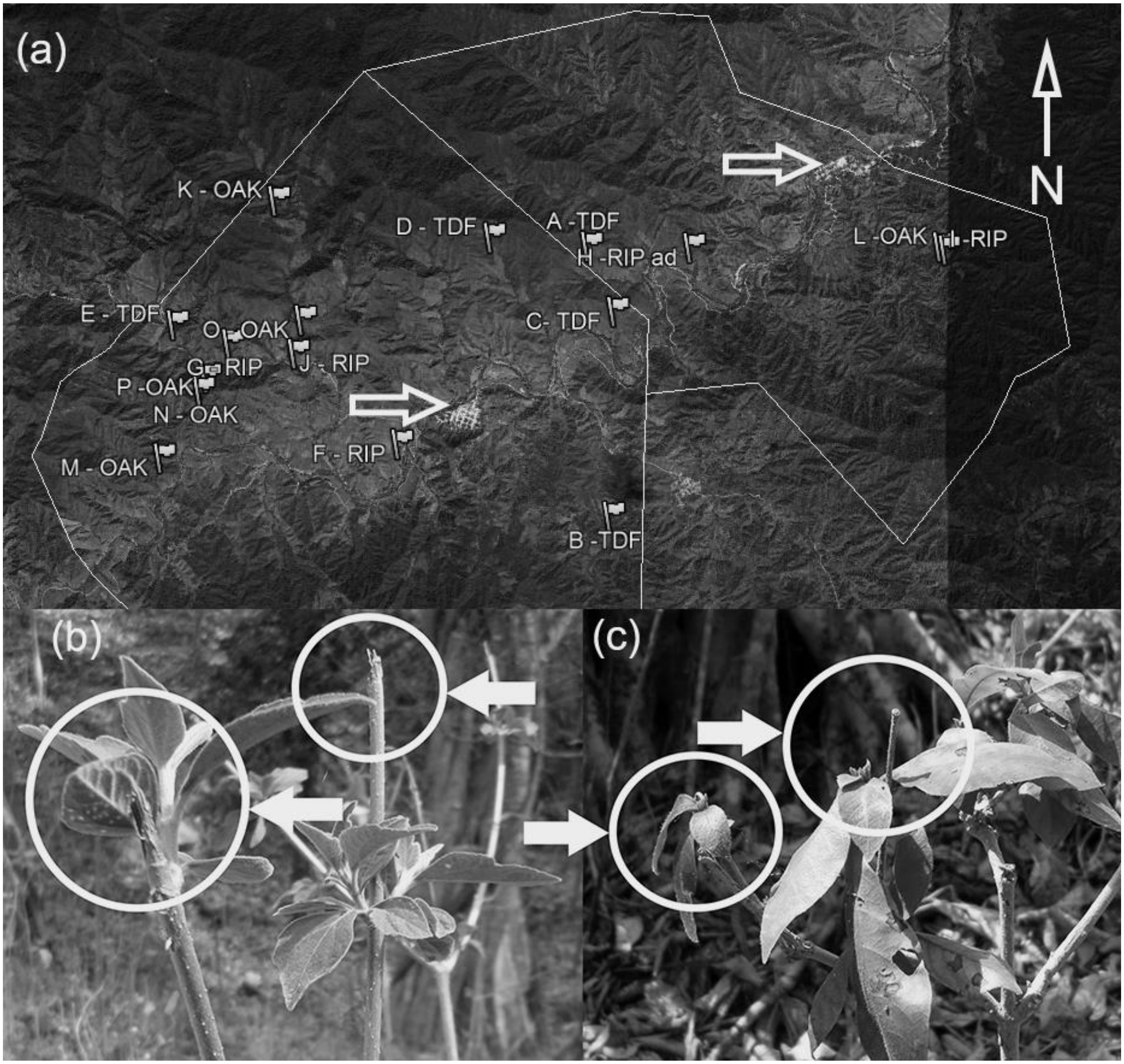

Figure 2. (a) Location of the sampling sites within the *ejidos*. Hollow arrows indicate locations of the main population centers. (b) and (c), show examples of what was considered to be evidence of browsing by cattle. Inside the circles are stems bitten or chewed by cattle.

2.2.1 VEGETATIVE PROPAGATION TESTS

To further solidify the conclusions about the best candidates for silvopastoral domestication, simple tests were made for checking whether some species could be easily propagated. Our reasons for testing vegetative propagation (rather than propagation by seeds) were practical ones: some species do not reproduce by seeds, and the flowering and seed-production seasons of other species are not well known. In contrast, vegetative material of local plants is always available to ranchers and researchers.

Following the intuition that plants found growing in clusters are the most likely to be ones that reproduce vegetatively, we chose for our tests eight species that grew abundantly in clusters within heavily grazed secondary vegetation: *Machaerium chiapense, Montanoa tomentosa, Acalypha leptopoda*, *Verbesina perymenioides*, *Sida rhombifolia*, *Acalypha villosa*, *Croton pseudoniveus* and *Desmodium cinereum*. Approximately 60 stakes between 30 and 40 cm long were cut from stems, and planted in half-gallon bags containing soil taken from a home garden in the *ejido* Los Ángeles. We added a commercial auxin-containing root-growth enhancer (Raizal®, Arysta LifeScience) to the soil following the manufacturer's instructions (10 g/ L). We allowed four months for sprouting and growth.

2.3 INTERVIEWS

We interviewed seven local ranchers, all of them *ejido* residents with extensive field knowledge and at least 20 years of experience with livestock management as their main economic activity. We sought more ranchers for interviews, but few individuals met those criteria. The interviews were designed to elicit ranchers' recognition and evaluations of 42 plant species, most of which were selected based on rancher advice during the first walks through the reserve. We selected other species based upon our own observations.

During the interviews, we presented ranchers with specimens of each species, attached to a cardboard rectangle and accompanied by photos of live specimens in the field. We asked four closed questions, and three open ones. The closed questions were asked: (1) Do you recognize this plant?; (2) Do you perceive it as abundant, or scarce?; (3) Do cows eat this plant?; and (4) If so, do cows like it? Do they search for it actively? Our open questions were: (1) Which vegetation type (TDF, RIP or OAK) is the best for browsing?; (2) What effect (beneficial or detrimental) does browsing have on cattle?; and (3) how important is browsing for their cattle?

2.4 BROMATOLOGICAL ANALYSES

Knowing how nutritious and/or toxic a plant can be is crucial for screening new forages. Samples of forage were collected following suggestions in Lashley *et al*. (2014). For each species, 1 kg of fresh, above-ground biomass was collected, oven-dried at 50 °C and pulverized, then analyzed at *El Colegio de la Frontera Sur* to determine contents of common nutritional and anti-nutritional compounds that are regarded as important for animal nutrition: (1) Ashes or total mineral content (incineration at 100 ºC and 550 ºC, Official Mexican Norm, 1978a); (2) Neutral detergent fiber (NDF) and acid detergent fiber (ADF; according to Van Soest, (1966); (3) Fat content (extracted with ether, Official Mexican Norm, 1978b); (4) Crude fiber (by digesting the sample in acid and alkaline solutions, Official Mexican Norm, 1978c); (5) Non-structural carbohydrate content (NSC: glucose, fructose, sucrose and others, determined by adding the percentage of ashes + CP + fat + crude fiber and subtracting this number from 100, Tejeda, 1983); (6) Crude protein (CP, by digesting the samples, distilling with boric acid, and performing titration curves, Official Mexican Norm, 1980); (7) Concentration of condensable tannins (through methanol extraction and spectrophotometer analysis, Hagerman, 2002); and (8) Presence of saponins (extraction with distilled water, García, 2004), cyanogenic glycosides (picric acid reaction, García, 2004) and alkaloids (Wagner, Dragendorff and Mayer reactions, García, 2004). Tannin concentrations were measured for only eight species.

2.5 DEVELOPMENT OF FUZZY INFERENCE SYSTEMS (FISs) FOR CLASSIFICATION AND DUMMY CRISP INDEXES FOR COMPARISONS

FIS’s were done using the library “sets” (Meyer, Hornik and Buchta, 2017) of the R programming language (R Development Core Team, 2008). We constructed FISs from browsing data; from rancher interviews; and from bromatological analyses. We used Mamdani type-1 ((Zarandi, Gamasaee and Castillo, 2016) FIS’s because of their simplicity and transparency (Castellano, Fanelli and Mencar, 2003; De Barros, Bassanezi and Lodwick, 2016). Previous formulas for evaluating silvopastoral potential didn't exist; only for nutritional information there were linear models (and others) made to predict fermentation rates and other qualities (*e.g.* Albores-Moreno *et al*., 2018). It's complicated to define *a priori* what makes a plant a solution for foraging, since this is related to a myriad of factors like producers habits, physiology and digestion dynamics of cows. Therefore the fuzzy approach allows to generate proxies based on limited information. Fuzzy logic is useful as a heuristic tool: fuzzy controllers/inference systems are often compared to crisp formulas as alternatives for approximating solutions to various problems and end up making closer or even superior predictions (*e.g.* Leal-Ramírez *et al*., 2011; Echavarria-Heras *et al*., 2018; Pulido, Melin y Prado-Arechiga, 2018).

We took a different approach: we first made FIS's and then we made example dummy crisp indexes. We considered fuzzy inference valid in itself for reaching an approximate solution to the problem. Various linear and non-linear combinations of the factors were tried, to assess how complicated a mathematical function would have to be in order to reproduce precisely the fuzzy results. We chose the ones that resembled these more closely and allowed insightful comparisons. We applied fuzzy and crisp approaches to both real data and also to computer –generated results forged in R. This was done to evaluate the adequacy of indexes applied to a full range of simulations of input values. 300, 100 and 100 replica results were created for botanical, interview and bromatological evidence respectively.

3. RESULTS

3.1 CHARACTERIZATION OF SITES

The least diverse site (N-OAK) had 24 species; the most diverse (B-TDF) had 67. The lowest mean height of plants was 33.3 ± 41.2 cm (G-RIP), while the highest was P-OAK (106.4 ± 106.9 cm. While high species diversity could be found in all three vegetation types, the site with the most species and the highest effective diversity (*S* = 67, Effective diversity = 37.7) was in TDF vegetation. The second and third most diverse sites were L – OAK and I – RIP. A hilltop site in a zone dominated by OAK and nearby secondary TDF vegetation was the least diverse (site N-OAK, with 24 species from 10 families). All of the least-diverse sites were in OAK vegetation far from streams.

Diversity was not significantly greater in less-browsed sites, nor did we find any correlation between browsing and abundance, height, or any community-structure variable. Effective diversity had a small correlation with browsing (p-value = 0.077, R^2 = -0.45). We also found a correlation was found between the effective diversity of herbs and the amount of grazing (p-value = 0.024, R^2 = -0.55).

3.2 ANALYSIS BY TYPE OF PLANT COMMUNITY

TDF and RIP sites did not cluster flawlessly, and only OAK sites formed a well-defined group (Figure 3). RIP sites were the richest plant communities overall, with 163 recorded species, followed by TDF (152) and OAK (122). Diversity indexes indicated a higher diversity in the RIP transects, followed by TDF transects. RIP sites also had the highest absolute number of grazed species (88), though the highest percentage of browsed species was in OAK, with 71 grazed species that constitute 58% of all OAK species. TDF sites had 72 grazed species (47%). OAK sites contained more individuals (1661), but TDF sites had higher densities of individuals (330 inds. / transect for TDF, versus 277 inds. / transect for OAK). Table 1 summarizes the main traits of each plant vegetation type.

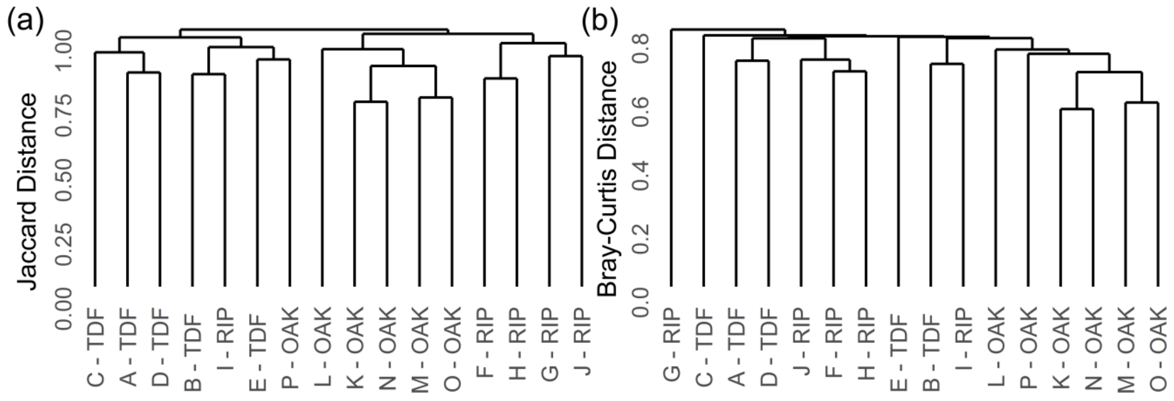

Figure 3. Dendograms of the sampled sites: (a) with Jaccard distance and complete-link clustering method; (b) with Bray-Curtis distance and single-link clustering method.

3.3 CHARACTERIZATION BY INDIVIDUAL, SPECIES AND FAMILY TRAITS.

The 4633 individual plants that we sampled belonged to 78 families and 268 morphospecies. Cattle had browsed 1521 of the plants, from 47 (65%) of the families and 161 (60%) of the morphospecies. The most-abundant species was *Calea ternifolia* (414 individuals recorded), which was dominant in the understory of OAK sites, followed by *Malpighia hintonii* (136 registers) and *Siphonoglossa sessilis* (134 registers), both of them abundant in TDF sites. All three species were browsed (42% of the *Calea ternifolia* plants, 69% of the *Malpighia hintonii*, and 42% of the *Siphonoglossa sessilis*). *Acacia pennatula* appeared in the most transects (13), followed by *Lysiloma acapulcense* (12 observations), *Vernonia leiocarpa* and *Calea ternifolia* (11 each), and *Apoplanesia paniculata* and *Mimosa albida* (10 each). Fifty-six species appeared only once. Various low-abundance species (<5 recorded individuals) always appeared grazed. The most-browsed species with abundance > 50 were *Siphonoglossa sessilis* (69%), *Calea ternifolia* (59%) and *Acalypha leptopoda* (55%). The most-represented families were Asteraceae (83 species), Fabaceae (59 species) and Acanthaceae (43 species). Families for which we observed > 10 species (many of them browsed) were Acanthaceae (50% browsed) Asteraceae (47%), Euphorbiaceae (46%) and Fabaceae (44%). Seventy-seven percent of all species had ≤ 5 stems. Plants with at least ten browsing observations and > 15 stems included *Verbesina* sp. *Trixis inula*, *Acalypha villosa*, *Tithonia diversifolia*, *Acalypha leptopoda*, *Chusquea simplicifolia* and *Desmodium cinereum*.

Table 1. Descriptive characteristics of the sampled transects grouped according to plant community type.

Vegetation type	Mean abundance (N. inds. / N. sites)	# Species	# Families	Mean plant height (± 1 s.d.) cm	Mean plant diameter (± 1 s.d.) mm	Mean plant cover (± 1 s.d.) m^2	# Stems sampled	% Grazed inds.	% Grazed species	Effective diversity	Most abundant families
TDF	330	152	53	70 ± 74.9	6.79 ± 10.4	1.11± 6.1	3139	40%	47%	57.39	Acanthaceae, Fabaceae, Euphorbiaceae,
OAK	277	122	37	74.9 ± 64.4	5.34 ± 4.97	0.91 ± 2.87	3500	30%	58%	38.86	Asteraceae, Fabaceae, Fagaceae,
RIP	264	163	55	42.9 ± 60.1	5.6 ± 5.59	0.85 ± 3.53	2308	32%	54%	78.25	Asteraceae, Fabaceae, Euphorbiaceae, Malpighiaceae

Of the growth forms that were present, trees had the greatest diversity (86 species), followed by shrubs (76), herbs (63), climbers (46), graminoids (4), and creepers (3). We also found one columnar cactus (*Stenocereus pruinosus*) and two agave species (rosettes). The most-grazed growth forms were the shrubs (87 %), and the trees (72 %). Proportions were much lower for herbs (36% browsed) and climbers (32%). The three creepers and two graminoids (*Lasiacis ruscifolia* and *Oplismenus hirtellus*) were found to be browsed; the cactus and the agave plants were not. Growth forms appear to be equally distributed among vegetation types, with RIP harboring more herbs and trees (Figure 4).

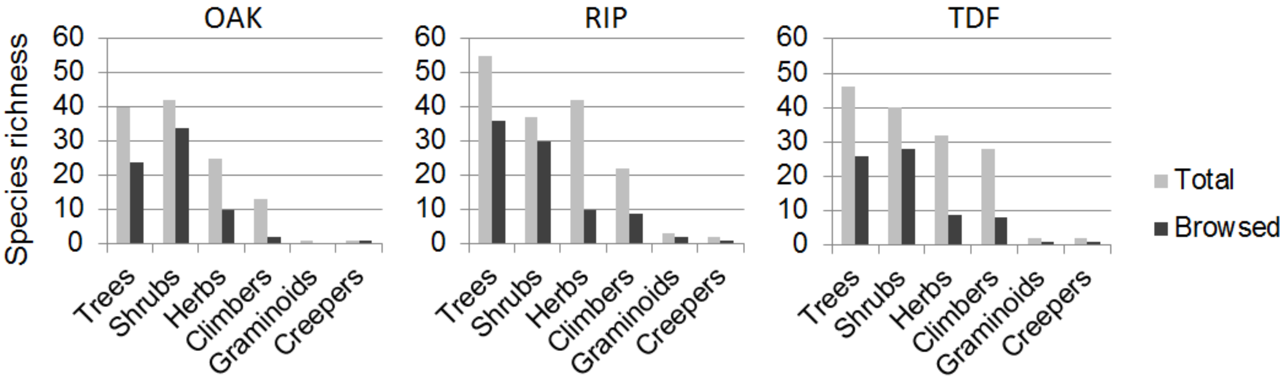

Figure 4. Distribution of growth habits and browsed fractions across all species in the most-representative plant community types of the *ejidos*.

3.4. GRAZING FIS RESULTS

About half of the species (165 of 268, belonging to 62 families) had poor values of the Grazing Usefulness Index (GUI = 0.2) because of low browsing or very low abundance. Families which appeared only in this group include Solanaceae, Urticaceae, Vitaceae, Papaveraceae, Orchidaceae, Ranunculaceae, Aspleniaceae and Boraginaceae. Most of the climbers (39 of the 46 species) belong to this group; only one climber had GUI > 0.45. Although as many as 50% of individual plants from species in the next group (0.24 < GUI < 0.35) had been browsed, these species had only middling GUI scores because of low abundance, low distribution, small plant size, or a low number of stems. One species in this group, *Liabum andreuxii*, was highlighted by a single rancher as a good plant for browsing. The 24 species in the group GUI = 0.35 were much browsed in the field, but had low relative abundances. Among these species were the known fodder plants *Tithonia diversifolia* and *Psidium guajava*. Using GUI = 0.2 as the lower limit, the FIS identified 103 useful browsing plants. That number fell to 96 when GUI = 0.35 was used as the lower limit.

The "medium GUI" group (GUI=0.5) contained 20 species, including *Eupatorium collinum* (Asteraceae), *Acalypha schlechtendaliana* and *Acalypha tricholoba* (Euphorbiaceae). The succeeding transition group between 0.5 and 0.7 had nine species. Finally, 21 species had GUI => 0.7: 10 trees, 9 shrubs and 2 herbs. Among these, *Guazuma ulmifolia* and *Inga edulis*. Euphorbiaceae (five species) and Fabaceae (seven species) were the most common families. Because of its high abundance in OAK sites, *Calea ternifolia* had the highest GUI value, followed by *Malpighia hintonii*, *Acalypha leptopoda, Inga edulis* and *Guazuma ulmifolia*. Table 2 presents the results of the highest-rated 30 species.

Table 2. Main descriptive characteristics of the highest rated 30 species found during the vegetation sampling. Eat. = Proportion of times a species appeared browsed. Regs. = number of observations of the species; Dist. = Distribution value (result of a mathematical function, see Appendix); Hght. = Mean height of the species (m., ± 1 S.D.); Cov. = Mean cover (m^2 ± 1 S.D.); GUI = Grazing Usefulness Index.

Species	Eat.	Regs.	Dist.	# Sites	# Stem	Max Stem	Mean Stem	Hght.	Cover	GUI
Liabum caducifolium	0.6	5	10.74	3	6	2	1.2	234 ± 122.19	2.64 ± 2.68	0.5
Luehea candida	0.8	5	2.87	2	8	3	1.6	46.6 ± 16.89	0.3 ± 0.32	0.5
Critonia sp.	0.36	14	10.6	5	23	3	1.64	108.5 ± 69	1.04 ± 1.32	0.5
Coccoloba barbadensis	0.31	16	6.44	3	34	14	2.13	105.19 ± 71.69	2.77 ± 4.22	0.5

Eupatorium collinum	0.35	20	10.41	7	48	7	2.4	146.25 ± 118.16	2.38 ± 4.86	0.5
Heliocarpus reticulatus	0.39	23	10.9	9	31	6	1.35	128.7 ± 115.41	1.45 ± 3.16	0.5
Lysiloma acapulcense	0.31	29	12.73	12	35	5	1.21	112.66 ± 128.5	2.65 ± 6.79	0.5
Lasianthea fruticosa	0.33	55	7.02	4	207	14	3.76	115.62 ± 66.65	1.27 ± 1.6	0.5
Inga edulis	0.6	15	5.62	5	19	4	1.27	35.8 ± 29.87	0.33 ± 0.44	0.5
Celtis iguanaea	0.42	12	7.02	4	31	7	2.58	99.83 ± 160.75	2.3 ± 3.97	0.54
Desmodium cinereum	0.44	25	7.02	4	77	15	3.08	66.6 ± 53.65	0.74 ± 1.65	0.57
Calliandra houstoniana	0.48	33	8.52	7	47	5	1.42	94.45 ± 72.43	1.02 ± 1.53	0.59
Mimosa albida	0.5	26	11.4	10	57	7	2.19	50.81 ± 33.02	1.76 ± 6.03	0.6
Trixis inula	0.51	47	10.9	9	105	22	2.23	78.81 ± 45.2	1.08 ± 1.77	0.6
Montanoa tomentosa	0.51	47	10.8	4	83	9	1.77	98.72 ± 101.22	1.12 ± 1.83	0.6
Machaerium chiapense	0.53	40	7.97	6	65	4	1.63	114.2 ± 122.66	1.71 ± 3.74	0.605
Siphonoglossa sessilis	0.69	134	5.48	2	158	4	1.18	20.57 ± 10.47	0.1 ± 0.13	0.69
Croton alamosanum	0.83	12	3.86	3	20	5	1.67	71.83 ± 48.6	0.59 ± 1.02	0.7
Coursetia mexicana	0.64	14	6.44	3	19	3	1.36	47.86 ± 27.3	0.26 ± 0.32	0.7

Crusea setosa	0.76	21	6.44	3	35	6	1.67	42.1 ± 21.38	0.2 ± 0.5	0.7
Acalypha schiedeana	0.75	24	10.43	6	30	3	1.25	65.62 ± 79.74	0.92 ± 3.51	0.7
Guazuma ulmifolia	0.68	25	10.43	6	32	3	1.28	74.28 ± 51.38	0.91 ± 1.41	0.7
Quercus peduncularis	0.89	27	2.87	2	40	4	1.48	59.44 ± 70.36	0.77 ± 3.03	0.7
Verbesina perymenioides	0.86	35	7.49	5	74	7	2.11	185.26 ± 120.87	2.73 ± 3.57	0.7
Croton pseudoniveus	0.8	35	10.6	5	51	4	1.46	66.23 ± 48.67	0.5 ± 0.98	0.7
Acalypha villosa	0.72	65	8.52	7	194	21	2.98	86.38 ± 77.21	1.13 ± 1.77	0.7
Malpighia hintonii	0.43	136	10.57	8	292	9	2.15	75 ± 63.22	1.11 ± 2.55	0.77
Acalypha leptopoda	0.55	110	10.43	6	325	16	2.95	75.12 ± 47.68	0.94 ± 1.58	0.80
Calea ternifolia	0.59	414	12.01	11	1051	13	2.54	84.75 ± 57.3	0.85 ± 2.6	0.835

3.5 INTERVIEW RESULTS AND INTERVIEW FIS

Most species (33 of 42) were recognized by all cattle ranchers, while the rest were recognized by at least five. Species that weren´t fully recognized include *Trixis inula* and *Swietenia humilis*. Species' perceived abundance values were not correlated with the species' abundances in the field (p-value = 0.75, R^2 = 0.064). Thirty-two species were recognized by at least five producers as eaten by cows; 22 of these species had a perceived palatability of ≥ 3. Half of the species have browsing value in the eyes of producers, a result similar to that from the grazing

FIS. Four species (*Acalypha leptopoda*, *Lasiacis ruscifolia*, *Chusquea simplicifolia* and *Acalypha schiedeana*) had a LKI of 1. Sixteen species had LKI values between 0.8 and 0.94, and 13 species were between 0.29 and 0.73. Ten species had LKI = 0.2 (Table 3). In answer to our open questions, ranchers replied that browsing is a valuable complement to cattle's diet, with OAK being the least-important vegetation type for browsing, and RIP and TDF more or less equal.

3.6 BROMATOLOGICAL AND NUTRITIONAL RESULTS AND FIS RESULTS

CP contents were generally high: 15 species had > 15% and seven had > 20%. *Salix humboldtiana* had the lowest content (1.5%); three species (*A. villosa*, *E. collinum*, *P. berlandieri*) had > 24%, a very high content. The highest NDF and ADF contents were found in *Inga edulis* (78% and 64.6%).

Most species (22 of 27) had some sort of nutritional value, being rated medium to high (≥ 0.5; Table 3). Only *Thouinidium decandrum*, *Inga edulis*, *Machaerium chiapense* and *Senecio salignus* scored badly, because they had medium NSC contents, low levels of ashes and CP, and ~45 % ADF. Even so, these species were eagerly browsed. Among the species ranked as "medium" we found *Acalypha leptopoda* and *Calea ternifolia*, which were abundant*. Salix humboldtiana* is ranked as medium because it's very high level of NSCs compensates for its other nutritional deficiencies. In general, plants appeared to either have CP or NSCs (contributing to nutrition either way), but not both. Indeed, contents of both CP and ash were negatively correlated with NSC content (R^2 =-0.76, p<0.001 and R^2 = -0.62, p=0.0008, respectively).

Twenty-six of the 27 analyzed species tested positive for alkaloids. Nine of them tested positive with all three reagents (Dragendorff, Meyer and Wagner). These results imply that alkaloids are very common in the vegetation of the studied area. Saponins were found in fewer than half of the species (12 of 27). Only two (*Verbesina perymenioides and Thouinidium decandrum*) had higher concentrations. Five species contained tannins: *Critonia* sp. (0.15 %): *Thouinidium decandrum* (0.26%), *Salix humboldtiana* (0.27%), *Inga edulis* (0.31%) and

Acalypha schiedeana (with the highest content: 23.26%). Cyanogenic glycosides were not detected in any of the 27 species. (See Table A.2 in the Appendix.)

Table 3. Interview and bromatological results, and FIS's results. *Rec* = Recognized; *P. Abun* = Perceived Abundance; *E* = Eaten; *P. Palat* = Perceived Palatability; LKI = Local Knowledge Index; CP = Crude protein content; NSC = Non-Structural Carbohydrates content; ADF = Acid Detergent Fiber Content; NI = Nutritional Index.

Species	*Rec*	*P. Abun*	*E*	*P. Palat*	**LKI**	Ashes %	CP %	NSC %	% ADF	**NI**
Siphonoglossa sessilis	0.71	2.8	0.9	2.67	**0.2**	16.06	23.84	37.75	28.9	**0.7**
Swietenia humilis	0.79	2.6	0.3	3	**0.2**	9.18	16.65	43.48	35.59	**0.5**
Piper berlandieri	1	3.14	0.43	2	**0.3**	15.36	24.76	36.7	30.89	**0.7**
Calea ternifolia	1	3.29	0.43	2	**0.3**	10.48	13.16	50.25	30.61	**0.5**
Thouinidium decandrum	1	2.57	0.43	2.33	**0.3**	6.29	2.21	53.33	46.95	**0.375**
Eupatorium collinum	1	3	0.71	2.4	**0.54**	8.78	25.21	49.78	39.86	**0.7**
Critonia sp.	1	2.86	0.71	2.8	**0.54**	11.83	14.26	39.81	23.22	**0.5**
Sida rhombifolia	1	3.86	0.71	3	**0.55**	10.48	16.52	44.53	35.95	**0.5**
Salix humboldtiana	1	3.71	1	2.14	**0.56**	5.19	1.49	73.78	36.95	**0.5**
Senecio salignus	1	2.71	0.86	2.2	**0.64**	9.95	2.58	65.05	43.26	**0.375**
Mimosa albida	1	3.71	0.86	2.33	**0.8**	5.52	15.69	47.54	39.15	**0.5**
Calliandra houstoniana	1	2.86	0.86	2.67	**0.8**	5.43	15.63	51.79	41.61	**0.5**
Machaerium chiapense	1	3.57	0.86	2.83	**0.8**	4.26	4.06	58.65	39.91	**0.375**
Inga edulis	1	4.29	0.86	2.83	**0.8**	5.76	3.42	57.6	64.66	**0.375**
Verbesina auriculata	1	2.43	0.86	3.17	**0.8**	14.51	14.53	49.82	27.15	**0.5**

Verbesina perymenioides	1	3.86	0.86	3.17	**0.8**	21.06	18.01	41.3	27.23	**0.7**
Croton pseudoniveus	0.93	3	1	3.33	**0.8**	9.62	23.14	45.06	26.91	**0.7**
Desmodium sp. 1	1	3.14	0.86	3.5	**0.8**					
Montanoa tomentosa	1	3.71	1	3.57	**0.84**	15.54	20.2	39.27	40.3	**0.7**
Acalypha villosa	1	4	1	3.6	**0.85**	18.69	26.11	33.45	24.81	**0.6**
Centrosema molle	1	3.43	0.86	3.67	**0.87**	14.44	18.48	33.38	45.61	**0.6**
Desmodium barbatum	0.8	3.75	0.88	3.67	**0.88**	7.15	19.08	47.15	38.06	**0.7**
Chusquea simplicifolia	1	4.43	1	4	**1**	21.4	12.02	34.48	50.48	**0.58**
Acalypha leptopoda	1	4	1	4.14	**1**	14.61	14.87	48.83	28.91	**0.5**
Lasiacis ruscifolia	0.86	3.33	0.83	4.2	**1**	9.39	20.58	41.5	32.16	**0.7**
Acalypha schiedeana	1	3.29	0.86	4.33	**1**	13.23	13.44	49.85	37.17	**0.5**
Desmodium cinereum						6.04	18.52	37.84	42.87	**0.7**

3.7 COMPARISON OF FUZZY AND DUMMY CRISP INDEXES

All fuzzy indexes resulted in stepwise functions (Figure 5). The two GUI crisp indexes found to more closely reproduce the behavior of the fuzzy index were:

$$\text{GUI crisp index 1: } Et + Ab + Dst + Sz + Mt \qquad \textbf{[1]}$$

$$\text{GUI crisp index 2: } \log(Et + 1) \times \left(\left(\frac{Ab+Dst}{1+Sz}\right) + \sqrt{Mt}\right) \qquad \textbf{[2]}$$

Where Et = Eaten; Ab = Abundance; Dst = Distribution; Sz = Size; Mt = Multistem. All values were plugged after normalization. Both dummy crisp indexes had low fit values, index 1 having a lot of variation in comparison to the fuzzy. Crisp index 2 reproduced low values similarly to the fuzzy GUI but higher values were over-dispersed index (Figure 5a). Models adjusted to simulated data showed the same pattern (Figure 5d).

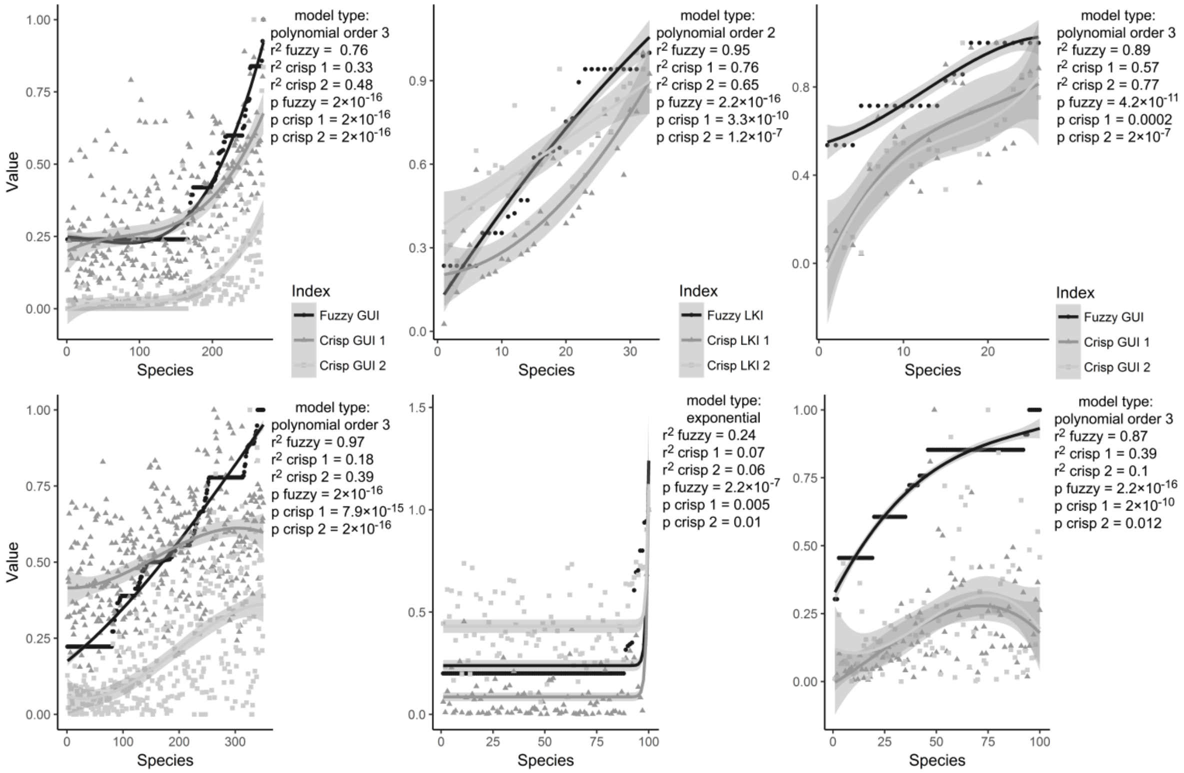

Figure 5. Comparisons between fuzzy and crisp indexes for each evidence set. In (a), (b) and (c) real data is plotted for the GUI, LKI and NI respectively, while (d), (e) and (f) are plots for simulated data. Points were arranged from minimum to maximum according to fuzzy indexes. Crisp indexes appear overlaid with the same order. Statistical models were fit to each point cloud, with its respective error measure (± 1 S.E.) in gray. The type and order of fit models as well as their r^2 and p-values appear to the right of each graph.

For the interviews, the following dummy crisp indexes were similar to the fuzzy index:

LKI crisp index 1: $Rc \times Pab \times Pet \times Ppb$ **[3]**

LKI crisp index 2: $(Rc \times Pab) \times (Pet^{Ppb})$ **[4]**

Where *Rc* = Recognized; *Pab* = Perceived abundance; *Pet* = Is it eaten?; *Ppb* = Perceived palatability. Models adjusted to real data had relatively high fits, LKI crisp index 1 having less dispersed values (Figure 5b). Fits of models were very low for forged data though, since the lower part of the fuzzy LKI consisted on a straight line for lower values, giving the results an exponential shape, while crisp indexes were much dispersed for this part of the curve (Figure 5e). For bromatological information, suitable dummy crisp indexes were found to be:

$$\text{NI crisp Index 1:} Ash \times CP \times Nsc \times FDA \qquad \textbf{[5]}$$

$$\text{NI crisp index 2: } (((Ash + Nsc) \times (1 - FDA)) \times CP)^{1+CP} \qquad \textbf{[6]}$$

Where *Ash* = Ash content; *CP* = Crude protein; *Nsc* = Non-structural carbohydrates *FDA* = Acid detergent fiber. Fit values compared to fuzzy values were higher for NI crisp index 2 than index 1 (Figure 5c), but this was reversed with simulated data (Figure 5f). Closer examination revealed crisp indexes favored CP content more than the fuzzy index, causing some points along the middle to have the highest values and provoking the fit statistical models to have a hump in the middle.

3.8 *COMBINED FIS RESULTS*

Several species had good combinations of diverse traits. The FIS's summarize this information via three indexes (Figure 6). Among the best-rated plants were *Acalypha leptopoda, Montanoa tomentosa, Acalypha schiedeana* and *Verbesina perymenioides.* No significant correlations between indexes appeared.

In tests of clonal propagation by stakes, three species had very low rates of germination (*Sida rhombifolia,* 0.02%*; Machaerium chiapense,* 0.027%*;* and *Desmodium cinereum*, 0.04%). *Croton pseudoniveus* had 0.11% germination, and four species had ≥ 0.2% germination (*Montanoa tomentosa,* 0.2%; *Acalypha villosa,* 0.42%; *Acalypha leptopoda*, 0.51%; *Verbesina perymenioides,* 0.61%).

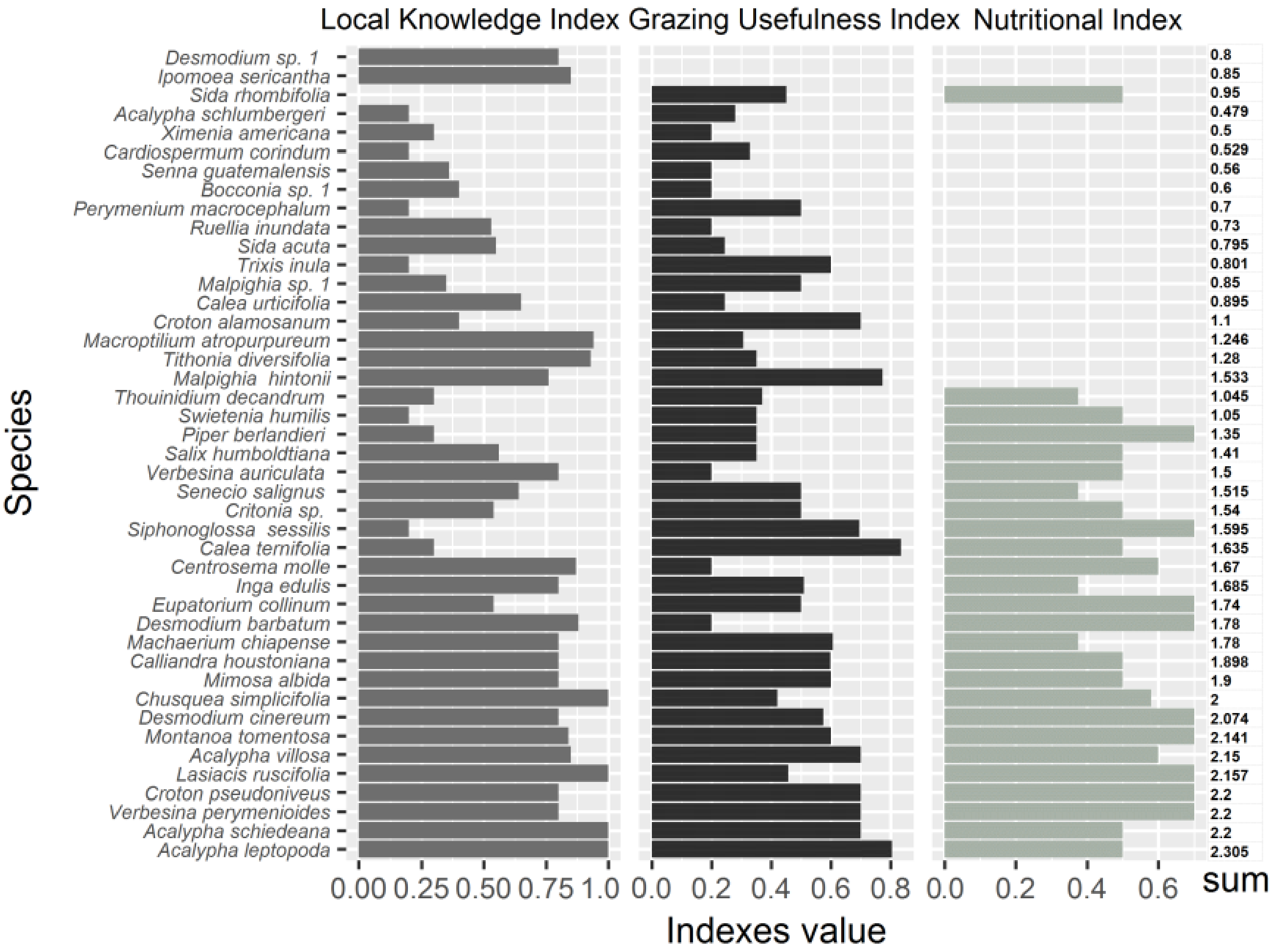

Figure 6. Species FIS outputs for each type of evidence. The sum of available indexes is presented to the right. Results are ordered by total sum.

4. DISCUSSION

4.1 USEFULNESS OF THE FUZZY CLASSIFICATION APPROACH

Fuzzy outputs ordered as step-wise functions, meaning resulting values tended to aggregate with smooth transitions between groups. This is useful if we are to convey management decisions to ranchers. Definite groups, *e.g.* “useful”, “more-or-less useful”, “not-useful” are clearer than comparing species within a continuous gradient. Crisp GUI 1, a simple sum, and Crisp GUI 2, a complicated function, were the best indexes that resembled the GUI, and yet dispersion was quite high, suggesting that it’s difficult to adequately ensemble a mathematical function (not a black-box model) to reproduce what was easy to convey with the FIS.

It was easier to find high model fits to the LKI applied to real data. Here, a multiplication was the closest model to the results. In stark contrast, for simulated data, models varied wildly in comparison. The fuzzy index strictly filtered inputs where the *recognized* input was *no*, while crisp indexes had a myriad of values for the same cases. FIS's can be easily fine-adjusted whenever a source of information needs to be stringently cut.

For the NI, dispersion of crisp models was also quite high. In the fuzzy NI, the OR operators in the fuzzy rules favor either high content of CP, sugars or minerals for a high score. This desired property of the model, in fact a non-linearity, was straightforward to incorporate in the fuzzy model. This wasn't easy to do with a mathematical function, were in contrast we could assign more importance to CP through a manipulation such as the operation of exponentiation by 1-CP. This suggests interactions between factors are easier to be interwoven with a FIS's than with a crisp index. Such property of type-1 fuzzy inference can be useful for those who want to develop indexes but lack advanced mathematical skills. All things considered, fuzzy indexes appear very well suited as a heuristic first approach to problems that involve quick systematization of local knowledge for land-management purposes. Using the shape of the ordered fuzzy results as a guide, we can search for suitable mathematical functions that resemble these patterns.

4.2 BRINGING THE COW TO THE FOREST: FOREST FRONTIERS AS SILVOPASTORAL LANDSCAPES

We found that cattle had browsed plants belonging to a great variety of families. Thus, cows appear to be generalists. No family stood out as being grazed more than others: the most abundant families both in browsed and non-browsed sets were Asteraceae, Euphorbiaceae, and Fabaceae, which are some of the most abundant in Mexico and Chiapas (Villaseñor, 2004; Rocha-Loredo, Ramírez-Marcial and González-Espinosa, 2010). These three families appear to contribute the most to browsing in sub-tropical silvopastoral landscapes. Browsed shrubs and herbs were abundant, indicating clearly that we should focus not only on trees when seeking new plants for silvopastoral purposes. The sheer number of browsed plants in the area of study indicates that vegetation in forest frontiers is not a mere garnish for cattle's main feed sources; instead, it appears to be more important than has been recognized. Cattle were moderately detrimental to the plant-community structures of all three vegetation types. Effective diversity and the quantity of herbs declined as the amount of browsing marks increased. Heavy browsing appears to affect small, non-woody plants, while dense, multi-stemmed, woody shrubs like *Calea ternifolia*, found in OAK sites, seem more resistant.

Of the genera found in the study area, *Acalypha* (Euphorbiaceae) had the most species with high rankings. It has been reported as useful for feeding cattle and as a very important component of the diet of deer (Roothaert and Franzel, 2001, Benavides, 1999, Mandujano *et al*., 1997). *A. leptopoda* stands out as a plant that ranchers recognize very valuable for cattle and wildlife because it is nutritious, abundant, widely distributed, and sustains leaf growth when browsed. It also propagates clonally from stakes. *A. schiedeana* and *A. leptopoda* had the highest values across all three indexes, but *A.leptopoda* has a slightly higher GUI because it is much more abundant and widely distributed: a result that might be expected given that *A. leptopoda* is a woody perennial shrub, and therefore more resistant to browsing and other disturbances than *A. schiedeana* (an annual herb)Various plants highlighted by the browsing FIS appear in the literature as fodder; e.g. *Guazuma ulmifolia* (Atangana et al., 2014b; *Verbesina perymenioides* (Nahed *et al*., 1997)*, Lantana camara (*Roothaert and Franzel, 2001; Atangana et al., 2014b*), Senecio salignus* (Benavides, 1999), *Lasiacis ruscifolia (*Maldonado, 1997*)*; *Trixis inula (*Fulbright, 1999) and *Macroptilium atropurpureum* (Walker, 1977). This last species showed promise as a plant for forage, but fell into disuse because it propagates with difficulty (Jones, 2014). That same difficulty may account for its low GUI, which was due precisely to its comparatively low abundance and distribution. Various Fabaceae genera with high GUI have been previously described as having potential for livestock production, like *Senna* (Bazill, 1987; Toral, Navarro y Reino, 2015) and *Desmodium* (Bazill, 1987; Toral, Navarro y Reino, 2015). The GUI also signaled species that have no previous reported silvopastoral, such as *Croton pseudoniveus*, *Acalypha leptopoda*, *Calea ternifolia*, and *Montanoa tomentosa*. These results highlight the usefulness of fuzzy techniques for unraveling new practical biodiversity knowledge. We must mention one pitfall though: *Centrosema molle,* a useful tropical forage (Bazill, 1987; Addison, 2003, Cook *et al*., 2005; and Oquendo *et al*., 2006), had a low GUI because its low proportion of browsed individuals (0.11) placed it firmly in the “NO” category.

Every rancher told us that OAK is the worst vegetation for browsing, and that TDF and RIP are the best. Our data suggests those rankings have objective according to the qualities (e.g., abundance, diversity, and fractions browsed) of species present in each vegetation type. Thus, ranchers are capable of distinguishing the usefulness of the particular types of local vegetation.

4.3 BRINGING THE FOREST TO THE COW: PLANTS WITH POTENTIAL FOR DOMESTICATION IN SILVOPASTORAL SYSTEMS.

Among the species with the highest LKI values were the grasses *Chusquea simplicifolia* and *Lasiacis ruscifolia*. Those values (which reflect local knowledge and opinions of species) may reflect a pervasive, ingrained preference for grasses among cattle ranchers in Latin America (Casasola *et al*., 2013; Villanueva *et al*., 2008). The other two species belonged to the genus *Acalypha* (Euphorbiaceae).

Ranchers’ perceptions of the benefits of browsing seem justified, given the high nutritional values of many local plants. PSM were also widespread. Although several plants with high GUI are reported to have physiological effects, like *Calea ternifolia* (Mayagoitia, Díaz and Contreras, 1986), *Montanoa tomentosa* (Robles-Zepeda *et al*., 2006) and *Eupatorium collinum* (Moreno-Salazar, Robles-Zepeda and Johnson, 2008), the presence of those plants doesn´t seem to deter browsing. This observation implies that cows adapt to eating some level of PSM. The large-scale use of *Tithonia diversifolia* as forage (Ruiz *et al*., 2014; Rivera *et al*., 2015) demonstrates that even of a plant with alkaloids (John-Dewole and Oni, 2013), reported physiological effects (Owoyele *et al*., 2004; Adedire and Akinneye, 2004), and bitter taste can be valuable. Therefore, PSMs may not be strong predictors of a plant’s suitability for silvopastoral use. Nevertheless, care is needed: one interviewed rancher blamed *Macroptilium atropurpureum* for the death of a calf. In sum, browsing in forest frontiers probably requires a process of adaptation of cattle.

Although the eight species selected for vegetative propagation tests were abundant, and some have clear resprouting abilities (e.g. *Sida rhombifolia*), few appeared capable of clonal propagation, even when stimulated with auxins. This finding agrees with previous results which show that ability to resprout is not correlated with ability to grow from stakes in TDF trees (Vieira, Coutinho and da Rocha, 2013, but see Itoh *et al*., 2002). On the positive side, species that did reproduce clonally were among those with the highest FIS scores (*Montanoa tomentosa*, *Verbesina perymenioides* and *Acalypha leptopoda*). During our four-month vegetative-propagation tests, *V. perymenioides* and *A. leptopoda* sprouts grew to > 1 m. Because both species grow in shaded areas, they are cultivated at present in closed-canopy conditions. We sampled few members of the Poaceae family, but some of its species are strong candidates for intensification: *Lasiacis ruscifolia* grew abundantly beneath the canopy, and *Chusquea simplificifolia* was also found in TDF beneath a dense canopy. The task remains of propagating these species, but at least one study addresses the possibility of sowing *Chusquea* sp. vegetatively (Insuasty-Torres *et al*., 2011).

Verbesina perymenioides stands out as probably the most promising new option for silvopastoral intensification. Abundant and much-browsed in both open and shaded areas, it reproduced from stakes, then grew very rapidly. It contains high levels of protein, carbohydrates and minerals. When collected, its foliage decayed exceptionally rapidly-a possible indication of very high digestibility. It had no tannins, a somewhat high level of alkaloids, and some saponins, which could be useful. It is an important fodder in other zones of the Chiapas (Nahed *et al*., 1997), but its CP content in our area of study was much higher (18% versus 11.8%). Being a medium-sized tree found normally as a multi-stemmed shrub (probably due to browsing), it has seemingly perfect characteristics for being cultivated as a high-yield cultivar in silvopastoral systems, as is *T. diversifolia*.

Interestingly, *Verbesina perymenioides* and *Eupatorium collinum* grow naturally beneath the canopy of the study area's dedicated *Gliricidia sepium* silvopastoral plantations. This observation leads us to propose that natural dispersion, combined with weeding, could do a better job of establishing a productive understory beneath trees: a simpler strategy of selecting these plants during the succession of silvopastoral plots, as opposed to actively planting them.

4.4 PERSPECTIVES ON SILVOPASTORAL MANAGEMENT IN FOREST FRONTIERS

Forest frontiers can be conceived as high-quality silvopastoral systems; thus providing a clear motive for conserving them even within the focus of cattle ranching. The forest should be kept as a silvopastoral resource as it is, thus balancing and reducing the need to clear more land for cattle fodder. However, this measure implies a conflict with conservation inside the forest. We don't recommend excessive intensification of browsing inside the forest, because: (1) recovery periods for the forest are probably too long for sustained productivity; and (2) wild ruminants in Mexico's TDF eat plants like *Acalypha* sp. and *Croton pseudoniveus* (Mandujano *et al*., 1997), and the impact of cattle upon their food sources in sub-tropical forests can be considerable (Madhusudan, 2004). Future work will be needed to establish which level of browsing is compatible with forest conservation.

Composition of RIP sites, where both TDF and OAK species appear, suggests that these places act as reservoirs of diversity, and should be a priority for conservation. However, from a smallholder's perspective, these terrains are often the most useful because of sustained plant growth and year-round availability of drinking water. Also, the TDF was consistently mentioned as the best landscape for browsing (along with RIP), perhaps due to the higher density and the second-highest diversity of plants. However, this is a most threatened vegetation type in the zone and the world (Portillo-Quintero and Sánchez-Azofeifa, 2010). These contradictions show how coexistence between conservation and production is difficult in sub-tropical forest frontiers, and will require studies to unravel what frequency of browsing/grazing is sustainable in different landscapes.

It was clear that the expert rancher's ability to differentiate important species for browsing is not infallible. Ranchers and scientists alike appear to underestimate the number of useful species for browsing present in forest frontiers in sub-tropical landscapes. Surveys for new plant choices for silvopastoral intensification are still needed. From questioning producers, we can assert that they are very realistic in their perceptions about browsing and what they expect from it: they know the activity is beneficial, but lack a continued use for it, given the dry season and the pressures of production and stringent markets they face (where people often buy the cheapest option). Some kind of incentive is probably needed to promote planting of dedicated multi-layered silvopastoral patches in forest frontiers; we recommend that future policies consider this element as essential.

Paradoxically, the richness of browse could also be discouraging silvopastoral practices, as the forest frontier is already a source of rich fodder. This paradox could partly explain why smallholders most choose to concentrate their efforts on sowing fast-growing, easily manageable crops like *Pennisetum purpureum*. We need to re-think strategies for promoting silvopastoral systems in forest frontiers. As we mentioned before, exclusion and selective weeding may prove more successful in establishing silvopastoral plots in the long term than direct tree cultivation. We should consider orderly, cyclical exclusion of cattle from various terrains, where the succession of the forest is influenced by cattle.

We think that future progress will come: (1) from further experimentation with novel fodder plants and long-term exclusion-and-weeding experiments for establishing successional silvopastoral plots; (2) from devising practices in which cows roam the forest with low or very low intensity: though apparently contrary to conservation goals, some level of browsing that does not damage the forest is probably feasible. This practice could be added to others found in holistic cattle ranching in Chiapas like controlled grazing or diversified forage (Ferguson et al., 2013); and finally (3) from recognizing the diversity of properties novel plants have and harnessing the positive effects, such as reduction in methane emissions (Goel and Makkar, 2012) and stimulation of the immune system (Cheeke, 2000) by ingestion of saponins.

5. CONCLUSIONS

In the forest frontier of sub-tropical Man and The Biosphere Reserves is revealed a high diversity and abundance of nutritious plants that represent options for growing as fodder. Plant communities contain many unrecognized browsed species that increase possibilities for improving silvopastoral systems. The abundance and diversity of nourishing plants explains the positive perception that ranchers have of browsing, and suggests that forest frontiers in tropical and sub-tropical regions of the world are actually like high-quality silvopastoral systems. Therefore, silvopastoral systems could be redundant in the eyes of smallholders, given that natural landscapes provide similar resources. This policy and practice conflict needs to be recognized when promoting silvopastoral systems in forest frontiers in sub-tropical regions around the world. The abundance of browsed species also suggests that impact of cattle on vegetation can be considerable. Incorporating moderate grazing of forest frontiers and multi-layered silvopastoral plantations that mimic the forest will probably be crucial for improving production conditions and avoiding clearance of further land for pastures. Regarding the method, the fuzzy approach is a quick alternative for devising indexes for evaluation of natural resources, and its results can serve as templates for development of other measures. Future venues or research include comparing the suitability of fuzzy indexes in predicting the palatability and digestibility of plants; augmenting the fuzzy algorithm with parameter optimization, and extending the interviews and further comparing the assessment of ranchers in comparison to fuzzy inference.

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APPENDIX

A1. EXPLANATION OF MAMDANI FUZZY INFERENCE

Mamdani FIS's are an application of fuzzy sets designed to conduct classification and controller tasks, resulting in an answer in response to supplied values (Sabri *et al*., 2013). We define from the start a collection of x in relation to each output value y.The collection of input values is denoted by:

$$X = \{x_1, x_2, x_3, \dots, x_n\} \qquad \textbf{[A1]}$$

And the output variable is denoted by:

$$Y = \{y(x_1, x_2, x_3, \dots, x_n)\} \qquad \textbf{[A2]}$$

With these sets, then proceeds *fuzzification*, which implies associating a set of membership functions $\mu_i(x_j)$ to each x, such that:

$$\mu(x) = \{\mu_{A,B,\dots,N}(x_1), \mu_{A,B,\dots,N}(x_2), \dots, \mu_{A,B,\dots,N}(x_N)\} \qquad \textbf{[A3]}$$

Thus, for a set X we have a set $\mu(x)$. For the output variable Y, the same procedure applies; hence we also have a set μ_y, associated to a collection of membership functions in relation to both y and x:

$$\mu(y) = \{\mu(y(x_1, \dots, x_n))\} \qquad \textbf{[A4]}$$

For each membership function $\mu_{A,B,\dots,N}\left(x_{1,\dots,n}\right)$, there's also an associated linguistic value $A_{ik}(\mu)$. For each membership function $\mu(y(x_1, \dots, x_n))$ there is an associated linguistic value $B_{jk}(\mu)$

For each conjunction of values x and its associated set of membership functions $\mu(x)$ and set of linguistic expressions, $A_{ik}(\mu)$ we consider R_i rules that associate each antecedent A_{ik} to a consequent B_{jk}. A collection of linguistic statements of the inputs is mapped to a collection of statements of the output:

$$R_i\!: if\ x_1\ is\ A_{i1}(\mu), x_2\ is\ A_{i2}(\mu), \dots, x_n\ is\ A_{in}(\mu) \qquad \textbf{[A5]}$$

$$then\ y(x_1, x_2, x_3, \dots, x_n)\ is\ B_{jk}\big(\mu(y)\big)$$

Rules of union (AND) or intersection (OR) determine the shape of $\mu(y)$ associated to $B_{jk}\big(\mu(y)\big)$, also called the firing strength of the rules. The AND operator corresponds to finding the minimal point of the membership functions; $\min(\mu_A(x_i), \mu_B(x_i), \dots, \mu_N(x_i))$, also denoted by the symbol ∧ (see equation A6 next); while the OR operator corresponds to finding the maximum point of the membership functions $\max(\mu_A(x_i), \mu_B(x_i), \dots, \mu_N(x_i))$, also denoted by ∨. These operations, in the context of fuzzy logic, belong respectively to a class of mathematical operators called *t-norm* and *t-conorm* operators (Zarandi, Gamasaee and Castillo, 2016). For Mamdani fuzzy inference, where the minimum and maximum operations are used, the name *min-max* also appears in the literature (Jang and Sun, 1995). Whenever there is more than one rule invoked, the result is the union of fuzzy membership functions that are activated by each R_i. The fuzzy inference is then a non-linear mapping $X \rightarrow Y$ through the rules. Formally:

$$\mu(y) = \vee_{i=1}^{R}\Big(A_{ik}(\mu) \wedge B_{jk}\big(\mu(y)\big)\Big) \qquad \textbf{[A6]}$$

A *defuzzification* operation then associates a crisp value y_i to $\mu(y)$. This defuzzification is important because we seek a crisp value as a result. Defuzzification was carried out with the fast method of *centroid* or *center of gravity* (Bai and Wang, 2006):

$$y_i = \frac{\sum y\mu(y)}{\sum \mu(y)} \qquad \textbf{[A7]}$$

To further explain this, we shall use an example from the interview-evidence FIS. We named the four measured variables *recognized, perceived abundance*, *eaten* and *perceived palatability*. First we assign membership functions (Figure A1).

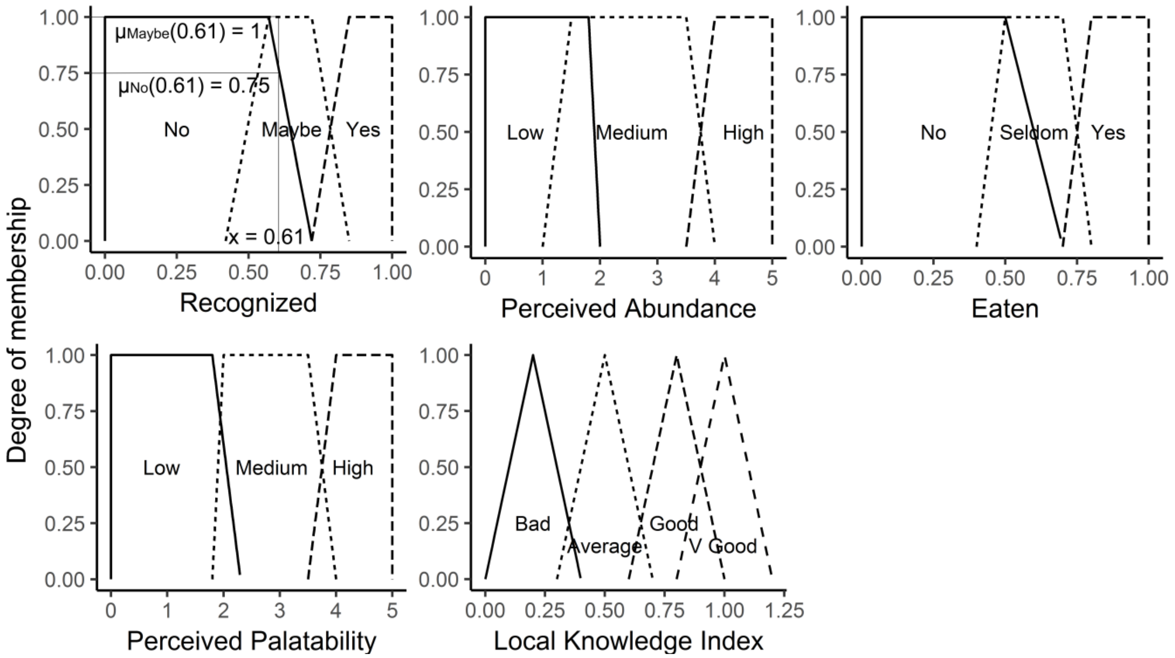

Figure A1. Fuzzy membership degree functions of the interview FIS. The Local Knowledge Index (LKI) is the output variable. Notice in the first panel how for x = 0.61 in *Recognized*, there are two corresponding fuzzy membership functions μ(x).

Consider the following input variables for *Eupatorium collinum*: *recognized* = 1, *perceived abundance* = 3, *eaten* = 0.71 and *perceived palatability* = 2.4 (Figure A2). The value 1 for *recognized* belongs to the fuzzy subset *yes*, with membership value 1. "*Perceived abundance* = 3" belongs to the fuzzy subset *medium*, with value 1. *Eaten* belongs to both *seldom* and *yes*, with values of 0.875 and 0.125 respectively, and *perceived palatability* belongs to *medium*, with value 1. These combinations (*yes-medium-seldom-medium* and *yes-medium-yes-medium*) fall under Rules 14 and 16:

-Rule 14**:** if *recognized* is **YES** AND *perceived abundance* is **MEDIUM** AND *eaten* is **SELDOM** AND *perceived palatability* is **MEDIUM**, *local knowledge index* is **AVERAGE**

-Rule 16**:** if *recognized* is **YES** AND *perceived abundance* is **MEDIUM** AND *eaten* is **YES** AND *perceived palatability* is **MEDIUM**, *local knowledge index* is **GOOD.**

Graphically, this means the values of the membership degrees of the input variables are mapped to the corresponding output membership function (Figure

A2). Following the rules for AND operators, we find that the output for *Eupatorium collinum* is equal to the smallest of the values of the input variables. If two or more rules are invoked, as (again) in the case of *Eupatorium collinum*, then the final output distribution is the union of the output distributions for each rule. Finally, from this final output distribution a single number is obtained with the defuzzification. Remember, we applied the *center of gravity* procedure, widely used because it is reliable (De Barros, Bassanezi and Lodwick, 2016) and yields the most intuitive results of all the defuzzification methods included in the "*sets"* R library. The final result (0.544) means that this plant is rated as average, but some producers have favorable opinions of it. This complete process is outlined in Figure A2.

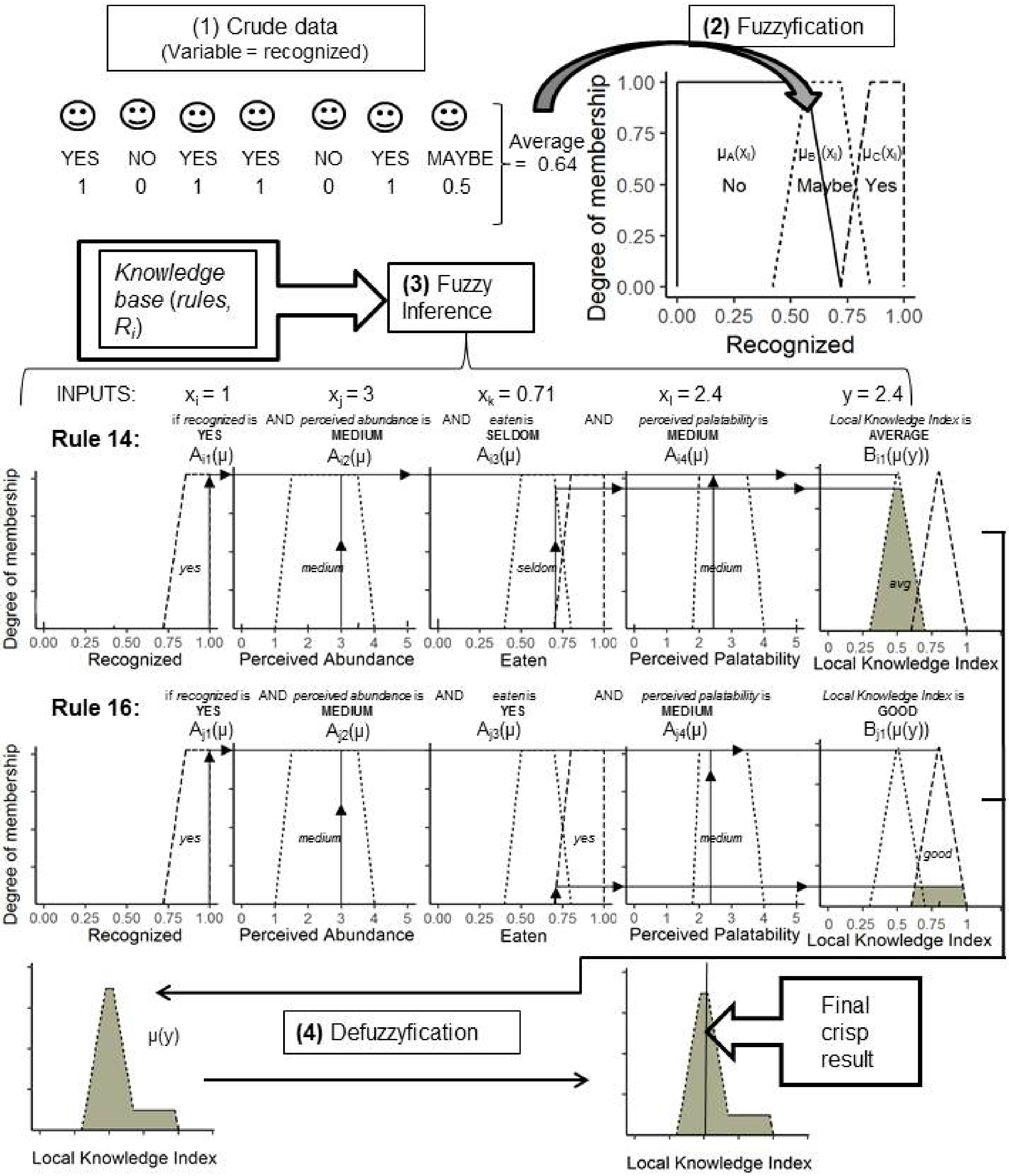

Figure A2. General outline of the structure of a Mamdani Fuzzy Inference System,

In the following section, we specify the numerical domain of each variable, the pertinent transformations of the data, and the exact values of the corners of each trapezoid. We also explain why we chose those particular values for the fuzzy membership functions.

Recognized. Each YES answer collected was transformed to 1, NO to 0, and MAYBE to 0.5. An average of all answers was then calculated. The fuzzy membership functions were all trapezoids except those of the output, which were triangular. The corners of the trapezoids are the points (0, 0, 0.57, 0.72) for NO; (0.42, 0.57, 0.72, 0.85) for MAYBE and (0.72, 0.85, 1, 1.1) for YES. Because the sample was very small, we skewed the fuzzy membership functions of this variable towards NO: at least 6 out of 7 ranchers had to recognize a species to move it out of the NO category. A species would qualify as a YES only if all ranchers recognized it.

Perceived abundance. The five possible answers *(Very low*, *low*, *medium*, *high*, *very high*) were transformed to natural numbers from 1 to 5: very low → 1; low → 2, medium → 3; high → 4; very high → 5. The mean of the values for the responses given by the seven ranchers was then calculated and used as input for the FIS. The fuzzy membership trapezoids were LOW (0, 0, 1.8, 2); MEDIUM (1, 1.5, 3.5, 4); and HIGH (3.5, 4, 5, 5). The scale of 1 to 5 has a clear middle, low and high, and further distinguishes very low and very high categories. We felt that this scheme was a natural way of categorizing perceived quantities. We set the fuzzy-membership functions to occupy more or less equal space across each number, but the medium trapezoid was made slightly bigger because we deemed it preferable that the results tend to the medium category to avoid mischaracterizing a species as either scarce or abundant.

Eaten. Like the r*ecognized* variable, each YES answer was transformed to 1, NO to 0, and SELDOM to 0.5, followed by calculation of the average of all answers as input for the FIS. Trapezoid corners were NO (0, 0, 0.57, 0.72), MAYBE (0.42, 0.57, 0.72, 0.85); and YES (0.72, 0.85, 1, 1). In setting these numbers, we used the same reasoning as for the variable *recognized*: most ranchers must answer yes for the answer to be considered YES; hence the trapezoids were bigger on the NO side.

Perceived palatability. Like *perceived abundance*, answers had five levels, and were transformed to natural numbers from 1 to 5. The mean was then used as the input for the FIS. We defined the following fuzzy membership functions for this variable: LOW (0, 0, 1.8, 2.3); MEDIUM (1.8, 2, 3.5, 4); and HIGH (3.5, 4, 5, 5). Because we considered the 1 to 5 scale a good measure in itself, the sizes of the trapezoid were set to cover the corresponding intuitive ranges of each category; LOW (=1 or 2), MEDIUM between two and four (centered around the three), and HIGH from four to five.

Local Knowledge Index (LKI). This index captures local ranchers' overall knowledge and assessments of a plant. We set this index's fuzzy membership functions as triangles, with the following values: BAD (0, 0.2, 0.4); MEDIUM (0.3, 0.5, 0.7); GOOD (0.5, 0.7, 0.9); and VERY GOOD (0.7, 0.9, 1). Triangle functions were useful for the output because they have a clear symmetry axis around which the results can gravitate and form groups when performing the final step of defuzzification. We selected the range of the output between to be $0 \leq LKI \leq 1$ because that range communicates the result intuitively. The output category *very good* was reserved for exceptional cases

A1.2 PLANT COMMUNITY SAMPLING FIS

This FIS was constructed to inform us about: (1) the importance of the species for browsing in the landscape, and (2) whether the species had vegetative traits required of a fodder plant. Variables are shown below in figure A3.

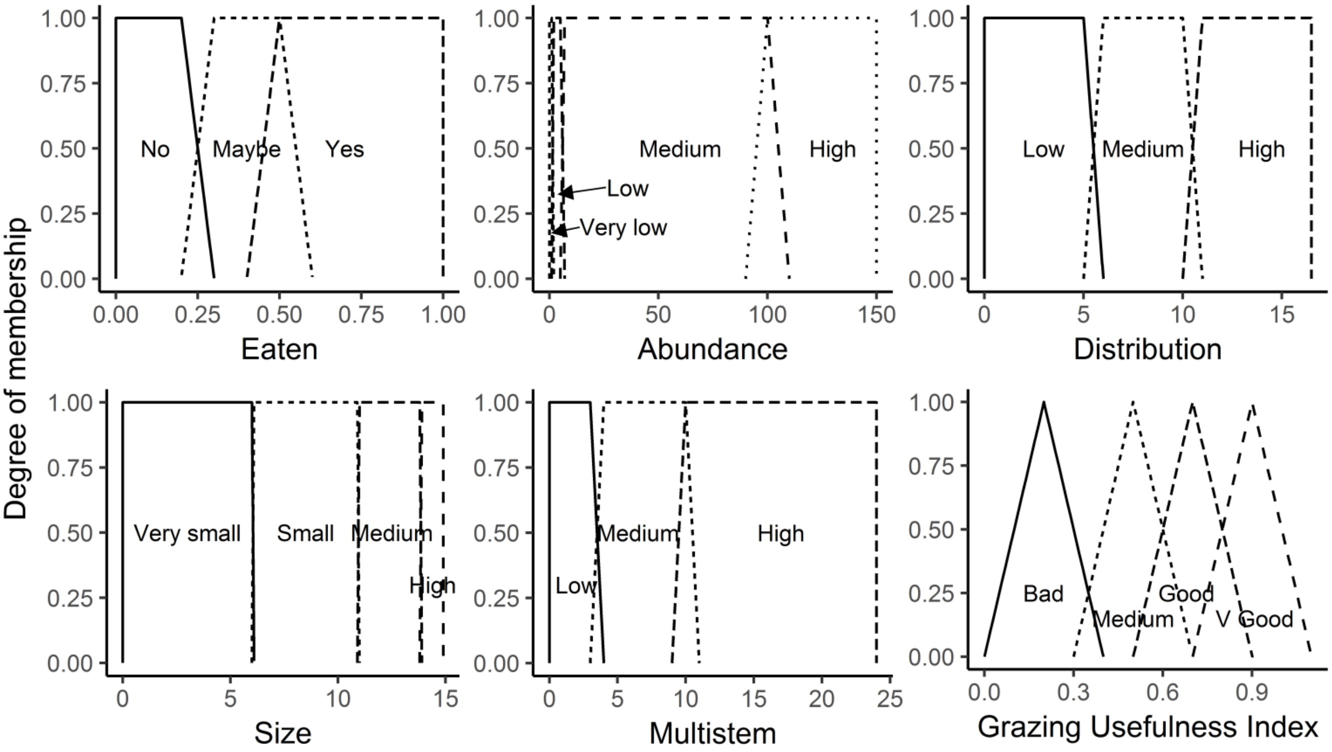

Figure A3. Variables and corresponding fuzzy membership functions considered for the browsing FIS

Our reasons for choosing these variables as inputs are as follows. Browsing signs (the variable *eaten*) are the most important clue for deducing how much cattle like to eat a species. *Size* is the next most important basis for making an additional cut: small or very small species are discarded as plants useful for browsing. For the remaining three variables, it was necessary to review knowledge about growth habit, number of stems, and the relative abundance and distribution. We present the most-important facts next.

Eaten. For a given species, the value of this variable is the number of observations of browsing, divided by the total observations of the species. The fuzzy membership trapezoids were NO (0, 0, 0.3, 0.4); SELDOM (0.2, 0.3, 0.5, 0.6); and YES (0.4, 0.5, 1, 1). The 0.4 limit for YES was set by the observation of the Y/N proportion of *Tithonia diversifolia*, which was relatively uncommon and hence a good reference point for how much browsing we can expect from a plant with proven silvopastoral usefulness. Values below 0.4 were not considered conclusive evidence of being eaten, since a cow could be merely tasting a plant or chewing it by mistake. The *seldom* interval was extended to 0.6 for similar reasons: the observations could be due to repeated “taste trials” by different cows. Conversely, this category also starts at 0.2 to account for the cases in which the plant species is eaten, but its low presence in plots is due to sampling stochasticity.

Size. This variable was calculated as the mean height (m) × mean cover (m^2) of each species. The result was then transformed logarithmically to make the domain [0, 15]. The fuzzy membership functions for this variable were VERY SMALL (0, 0, 6, 6.1); SMALL (6, 6.1, 10.9, 11); MEDIUM (10.9, 11, 13.8, 13.9); and HIGH (13.8, 13.9, 14.9, 15). The size of each category was selected on the basis of common sense. On our logarithmic scale, 6.1 (the upper limit of the VERY SMALL category) corresponds to 0.045 m^2, or 450 cm^2: the volume of a cylinder that measures roughly 20 × 22 cm. The SMALL category was for plants up to 6 m^3, MEDIUM up to 11 m^3, and BIG from 13.8 to 15 m^3.

Multistem: The number of stems on a plant is related to its capacity to regenerate from resprouting: resprouters tend to be multi-stemmed, as well as shorter than non-sprouting plants (Midgley, 1996; Kruger, Midgley and Cowling 1997; Paciorek *et al*., 2000; Vesk, Warton and Westoby, 2004; Clarke, Lawes and Midgley, 2010; Shibata *et al*., 2016). Multi-stemmed architecture is also found to increase persistence in disturbed environments (Nzunda, Griffiths and Lawes, 2007; Bellingham and Sparrow, 2009). This architecture is also important for resisting damage from browsing by big animals, or from cut-and-carry practices (Bond and Midgley, 2001). It is also indicative of the ability to grow in the understory (Tanentzap *et al*., 2012), but doesn’t seem to correlate with the ability to reproduce clonally from cuttings (Vieira, Coutinho and da Rocha, 2013, but see Itoh *et al*., 2002). In our work, raw data for this variable was distributed between 1 and 24. Membership trapezoid functions were the following: LOW (0, 0, 3, 4); MEDIUM (3, 4, 10, 11); and HIGH (9, 10, 24, 24). Up to 4 stems was considered to be a low number: it could be the normal architecture of the plant, rather than indicating resprouting. A plant with 3 to 11 stems was considered as being in the

MEDIUM or average range of the variable *multistem*. A plant with 10 or more stems was in the HIGH range.

Abundance: The literature on invasive species provides many reasons why abundance is an indicator of traits desired in a silvopastoral context. Indeed, ruderal plants such as *Tithonia diversifolia (*which besides its use as fodder is reported as an invasive species; Yang *et al*., 2012) that disperse widely, grow rapidly, and are tolerant of competition and disturbed conditions seem to be prime candidates for acclimation as new silvopasture crops. Studies indicate that abundance is a good predictor of intrinsic competitive abilities, as species are found at similar proportions in both native and introduced ranges (Pearson *et al*., 2017; Firn *et al*., 2011), and competitive traits are desirable in a crop breeding context (e.g. Jabran *et al*., 2015). In our work, raw data ranged from 1 to 440. All data higher than 150 was scaled to 150 to diminish the time needed for calculations in the R environment. The trapezoids had the following ranges: VERY LOW (0,0,1,2); LOW (1,2,5,7); MEDIUM (5, 7, 100, 110); and HIGH (90, 100, 150, 150). The VERY LOW category was created to accommodate singletons, which were abundant. A limit of seven individuals was set as the upper bound of the low category, and a limit of 100 for the medium category, to follow a roughly logarithmic scale, which is adequate when dealing with species abundances.

Distribution: This variable quantifies the degree of presence of each species in the different transects and vegetation types. Distribution in different sites and environments is an indicator of usefulness for grazing because widely disseminated species ought to contribute more to nourishment of cattle. Also, finding a plant in various places means it is successful in colonizing new spaces, a quality associated with traits like early germination, quick rapid growth, tolerance to varied soil conditions, and the ability to grow in large numbers (Kleunen, Dawson and Maurel, 2015).

The input value *D* for this variable was the result of a function of the number of different types of vegetation *V* (up to 3) and the number of different sites *S* (up to 16) in which the species appeared:

$$D = S\left(1 + (0 + V^2)\left(e^{\left(\frac{-S}{2.4}\right)}\right)\right) \qquad \textbf{[A8]}$$

This function is meant to assign a higher importance to species that are distributed in a larger variety of plant communities. To do so, it increases more rapidly when plants appear in more than one of the three vegetation types (OAK, TDF and RIP), but quickly becomes linear when appearances in different transects also become plentiful (Figure A4).

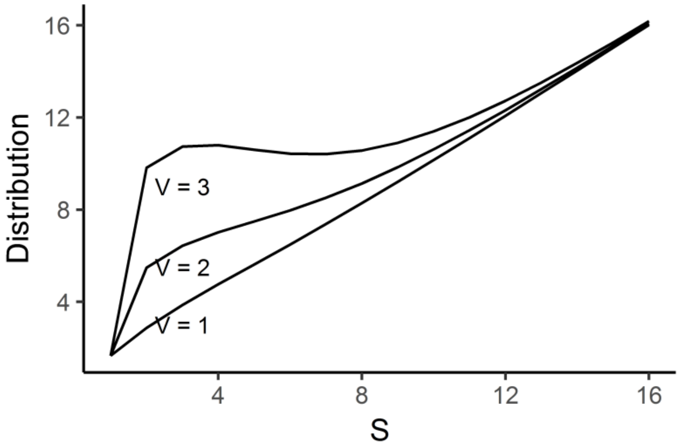

Figure A4. Graph of the *Distribution* variable of the browsing FIS. When the number of sites (S) is greater than 1, *Distribution* grows more rapidly when V = 2 or V = 3. However, *Distribution* tends to become linear again as S increases.

Raw data was distributed in the following intervals: $S \in [0, 16]$ and $V \in [1, 3]$. Input data for the FIS after substituting these numbers in the function was between 1 and 17. The fuzzy membership functions were then LOW (0, 0, 5, 6); MEDIUM (5, 6, 10, 11); and HIGH (10, 11, 16.5, 17). If a plant appeared in five TDF sites, for example, its score was 5.62 (LOW-MEDIUM), while a plant that appeared in five sites in all three types of vegetation had a score of 10.6 (MEDIUM-HIGH).

Grazing Usefulness Index (GUI). This output variable mimicked that of the interview FIS: its value was distributed between 0 and 1, with triangular membership functions. The triangles were BAD (0, 0.2, 0.4); MEDIUM (0.3, 0.5, 0.7); GOOD (0.5, 0.7, 0.9); and VERY GOOD (0.7, 0.9, 1)

In building the rules for this FIS, we followed the same reasoning as for the LKI: the most relevant variable was that of being eaten or not. Abundance was the next criterion, since low abundance implies low importance for browsing. For the next abundance-related criterion, *distribution*, we reasoned that “the more the better”. Then followed *size*: small sizes were penalized. Finally, the *multistem* variable was a plus: if a plant had already scored “good” on the other variables, being multi-stemmed was the final step to upgrade the value for the output from “good” to “very good”. Please consult the supplementary material online for the full table of rules.

A1.3 BROMATOLOGICAL INFORMATION FIS

A thorough search was conducted regarding the significance of the bromatological-analysis results. We sought information on the main effects of the following variables: ash content, acid detergent fiber, non-structural carbohydrates content, and crude protein levels. Dry-matter content, crude fiber and fat content were reported, but left out of the FIS because the number of rules grows exponentially for each additional variable. Analyses were also made for anti-nutritional factors: tannins, saponins, glycosides and alkaloids. Due to laboratory difficulties, we analyzed only eight species for tannins. Fuzzy membership functions are presented in Figure A5. Justifications for the variables, as well as for their fuzzy membership functions, are presented below.

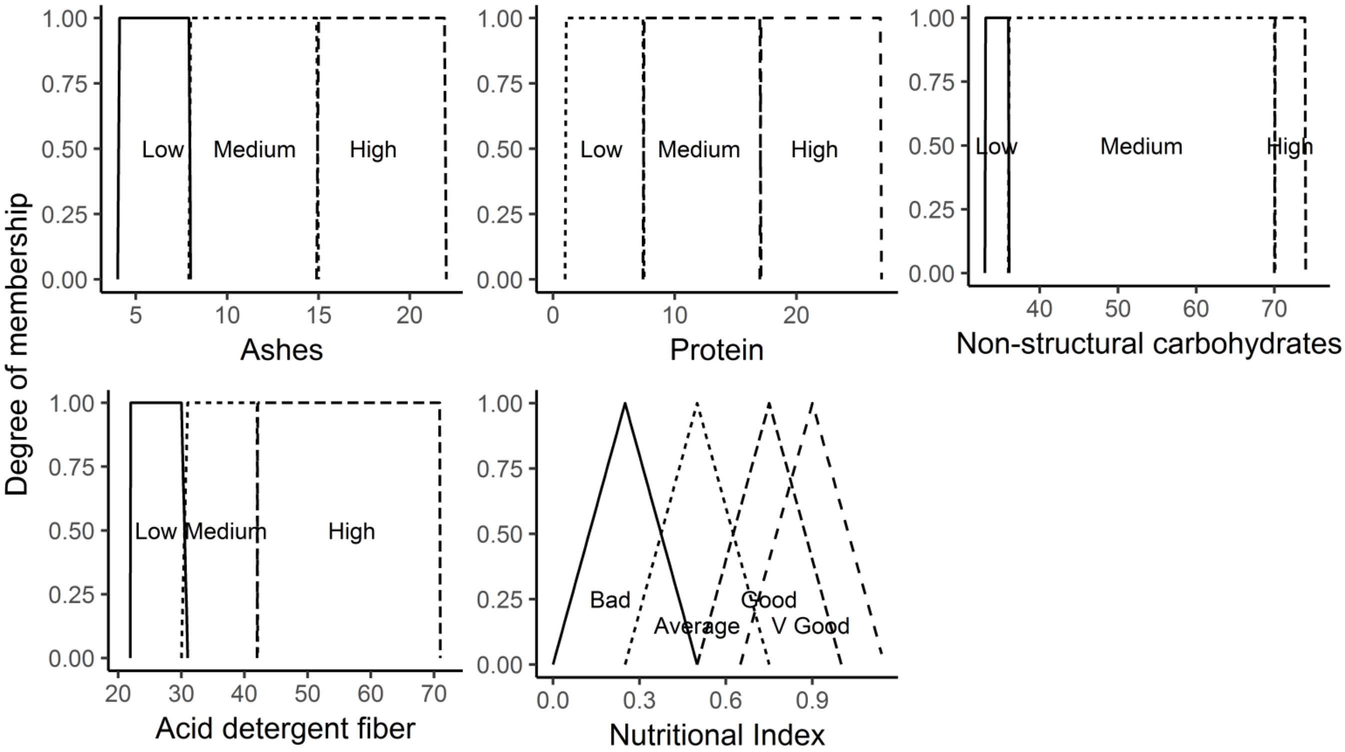

Figure A5. Fuzzy membership functions of each variable in the bromatological FIS.

Ashes. The fraction of ashes left after incineration reflects the mineral content of forage (Hoffman, 2005). For this variable, we judged that “the more the better”. Raw data was distributed between 4 % and 22% ash content. Trapezoids were LOW (4, 4.1, 7.9, 8); MEDIUM (7.9, 8, 11.9, 12); and HIGH (11.9, 12, 21.9, 22). We based these intervals upon information found in Hoffman (2005).

Protein. The content of crude protein (CP) is one of the most-important parameters for assessing the quality of forage. The aminoacids that compose protein are necessary for building milk and muscle (Minson 2012b). CP also affects digestibility of forages: adding up to 6.97% CP in the form of supplements increases degradation of neutral detergent fiber (NDF) in a linear form (Sampaio *et al*., 2009). In our work, raw data CP content was between 1% and 27%. No numerical transformations were performed. The fuzzy membership functions constructed were LOW (1, 1.1, 7.4, 7.5); MEDIUM (7.4, 7.5, 17, 17.1); HIGH (17, 17.1, 26.9, 27) based on data of protein content forages around the world (Minson 2012b; the mean CP content in tropical forages being around 15 g / 100 g). A less-stringent low limit for the high category (17 g /100 g) was chosen to allow more plant species to fit into this interval, in order to make this variable the principal driver of the system. This consideration was the principal factor in the rules ordering, since a main objective for silvopastoral systems is the cultivation of high-protein supplements.

Non-structural carbohydrates (NSC): simple carbohydrates (sugars) are the most readily available energy that cattle absorb from food (Moore and Hatfield, 1994). Supplementing crude protein along with starch also increases the microbial assimilation of nitrogenated compounds in the rumen (Souza *et al*., 2010). Between 33% and 74% of carbohydrates were present in the samples. The fuzzy membership trapezoids were set as LOW (33, 33.1, 36, 36.1); MEDIUM (36, 36.1, 70, 70.1); and HIGH (70, 70.1, 73.9, 74). The high and low categories had to be made narrow because equal-size functions cause the FIS to yield puzzling results, which turned out to be an effect of a negative correlation between the content of NSC and both the content of ashes and crude protein. (See Results, in the main text.) Making the MEDIUM trapezoid bigger corrected this problem.

Acid Detergent Fiber (ADF) In this analysis, forage is mixed with strong acid solutions. The procedure recovers the most indigestible components of the plant tissue, and enables estimation of the proportions of cellulose, lignin and other hard-to-break materials located in cell walls (Van Soest, 1967). These molecules interfere with digestion of forage (Minson 2012c) because they, themselves are digested slowly and incompletely (Buxton and Redfearn, 1997). Hence, ADF analysis is a quick way of estimating indigestible elements present in a plant’s tissues (Van Soest, 1994). In our samples, ADF contents were distributed between 23% and 65%. Membership functions were LOW (21.9, 22, 30, 31); MEDIUM (30, 31, 42, 42.1); HIGH (42, 42.1, 70.9, 71) The trapezoids were based upon the distribution of the raw data in absence of other evidence: the first quartile, 30.7, seemed adequate for the inflexion point from the LOW to the MEDIUM category. The same for the “high” trapezoid: 41.27 was the 3rd quartile, so we placed the step between the MEDIUM and HIGH trapezoids around this number.

The fuzzy membership functions of *NI* were constructed following the same reasoning for the other output variables. Rules for this FIS were made such that plants that had “high” levels of any of the three major nutritional components (ash, CP or NSC) were qualified as good, placing greater weight on the content of protein overall. From this point on, the presence or absence of ADF either lowered the final value, or did not affect it. We invite the reader to consult the supplementary material online, where the list of rules is presented for all three FISs.

A2. ADDITIONAL TABLES FOR THE RESULTS.

Table A1. Secondary metabolites compounds present in various plant species. *Qualitative analysis. V. Ab. = Very abundant; Ab. = Abundant; Mod. = Moderated; Scarc. = Scarce; Neg. = Negative.

Species	Condensable tannins (g/100 g)	Saponins*	Cyanogenic glycosides*	Alkaloids (Dragendorff)*	Alkaloids (Meyer*)	Alkaloids (Wagner)*
C. houstoniana	NA	Scarc.	Neg.	Neg.	Neg.	Neg.
D. barbatum	NA	Scarc.	Neg.	Neg.	Neg.	Mod.
A. schiedeana	23.26	Scarc.	Neg.	Scarc.	Neg.	Mod.
D. cinereum	NA	Scarc.	Neg.	Mod.	Neg.	Mod.
I. edulis	0.31	Neg.	Neg.	Mod.	Neg.	V. Ab.
A. leptopoda	0	Neg.	Neg.	Scarc.	Scarc.	V. Ab.
Critonia sp.	0.16	Neg.	Neg.	Scarc.	Mod.	V. Ab.
C. simplicifolia	0	Neg.	Neg.	Mod.	Mod.	Ab.
T. decandrum	0.26	Mod.	Neg.	V. Ab.	Neg.	V. Ab.
M. albida	NA	Neg.	Neg.	V. Ab.	Neg.	V. Ab.
S. bonplandiana	0.27	Neg.	Neg.	V. Ab.	Neg.	V. Ab.
M. tomentosa	0	Neg.	Neg.	Scarc.	Ab.	V. Ab.
V. auriculata	0	Scarc.	Neg.	V. Ab.	Mod.	Ab.
S. salignus	0	Scarc.	Neg.	V. Ab.	Mod.	V. Ab.

L. ruscifolia .	NA	Neg.	Neg.	Ab.	V. Ab.	Ab.
V.perymenioides	0	Mod.	Neg.	V. Ab.	Mod.	V. Ab.
S. rhombifolia	0	Neg.	Neg.	V. Ab.	V. Ab.	Ab.
M. chiapense	0	Neg.	Neg.	V. Ab.	V. Ab.	V. Ab.
C.ternifolia	NA	Neg.	Neg.	V. Ab.	V. Ab.	V. Ab.
S. humilis	NA	Scarc.	Neg.	V. Ab.	V. Ab.	V. Ab.
A. villosa	NA	Neg.	Neg.	V. Ab.	V. Ab.	V. Ab.
C. molle	NA	Neg.	Neg.	V. Ab.	V. Ab.	V. Ab.
C. pseudoniveus	NA	Scarc.	Neg.	V. Ab.	V. Ab.	V. Ab.
E. collinum	NA	Neg.	Neg.	V. Ab.	V. Ab.	V. Ab.
P. berlandieri	0	Neg.	Neg.	V. Ab.	V. Ab.	V. Ab.
S. sessilis	NA	Scarc.	Neg.	V. Ab.	V. Ab.	V. Ab.

CAPITULO III

CANOPY GAPS WITH FODDER INSIDE AS A WAY OF ENRICHING SILVOPASTORAL PLOTS

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CANOPY GAPS WITH FODDER INSIDE AS A WAY OF ENRICHING SILVOPASTORAL PLOTS

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ABSTRACT

We propose a way to enrich silvopastoral plantations with overgrown trees, by sowing understory fodder in canopy gaps cut inside such plots. We planted *Tithonia diversifolia* in canopy gaps of varying size inside a *Gliricidia sepium* plantation. *T. diversifolia* final dry biomass was statistically equal in shadowy middle-sized gaps and sunnier, bigger ones, displaying high tolerance to shadow. Mortality during first stages of growth was lowest in open gaps. Analysis of soil humidity and light availability in relation to growth suggests a mild effect of evaporation in bigger gaps, and revealed that uptake of water by nearby trees is high. These details suggest middle-sized gaps would be the best option for such type of management.

Keywords: Canopy Gaps, Silvopastoral Systems, Agroforestry, *Tithonia diversifolia*, *Gliricidia sepium*

INTRODUCTION

Diversifying agricultural practices, embracing environmental-friendly processes and techniques, is a must nowadays for the livestock sector given its impact (Gerber and Steinfeld, 2008). Mixed-strata silvopastoral systems, where both the understory and the canopy have silvopastoral uses, have been mentioned and investigated as a conservation-friendly silvopastoral alternative (Ibrahim *et al*., 2001). Nicodemo *et al*., 2015 cultivated nine legume species beneath *Eucalyptus* canopy, showing that these have different success of establishment and produce different amounts of biomass. Araújo *et al*., (2017) also cultivated three different species of foraging legumes underneath the shadow of eucalyptus trees. Their results show that increasing shadow diminishes the biomass production. This reduction is not surprising considering that legumes are generally adapted to very illuminated and dry conditions. But what about other types of fodder plants, better suited for the shadowy conditions of the understory? Many plants exist that have such characteristics, some of which have been actually used in silvopastoral systems (Lin *et al*., 2001). Cultivation of these could be an opportunity to produce an appreciable amount of fodder even in fairly closed canopy conditions.

What benefits can be derived of growing fodder in a partially shadowy environment? We think the main objective is diversifying plantations, but there are some potential production perks. Shadow can enhance the nitrogen content of grasses and the crude protein content of plants (Bernardi, de Jonge and Holmgren, 2016; Esquivel-Mimenza *et al*., 2013). Lin *et al*., 2001 showed that the crude protein content of forage cultivars increases when grown under shaded conditions, as well as the intermodal length and leaf area. On the other hand, Takahashi, Seino and Kohyama, 2005 showed increased light availability in gap openings can increase the leaf nitrogen content per area of broad-leaved species growing in the understory of temperate forests. These investigations suggest a benefit from a nutritional point of view, due to the enhanced protein content. This adds to the fodder produced by two layers + the diversification incentives.

This study was inspired by observing that, beneath the canopy of a fodder tree plantation in a tropical dry forest (TDF) environment, a very dense and productive population of an understory/ruderal forb grew vigorously and spontaneously. What if this understory environment could also be used for fodder plants other than light demanding conventional herbaceous fodder plants? The plantation is made up of the species *Gliricidia sepium*, which is a popular multi-purpose tree that has extended silvopastoral use, especially in Latin America. It is commonly used as a live fence and its foliage can be fed fresh or processed to cattle (Simmons and Stewards, 1994). The trees were planted in open grassland for a silvopastoral experiment, and hence individuals were allowed to grow beyond the normal useful height for pruning-carrying silvopastoral systems. Pruning trees is a normal course of action when managing silvopastoral systems, since they lose their silvopastoral value as they grow, due to cattle (and ranchers) not being able to reach the foliage easily. The owner of the terrain expressed his concern about the usefulness of the plot, given that almost nothing was provided by it. It’s clear that to convince cattle ranchers to conserve such plots, something has to be produced off them (in the absence of any other incentives). Since some minimal openness should be present for some appreciable growth of plant biomass, we thought of the possibility of creating gaps of different size within the plantation to sow fodder within those.

A description of forest frontier vegetation within the study zone revealed an abundance of underappreciated plants with potential for cultivation in silvopastoral systems (Dechnik-Vázquez *et al*., in press). Among the species found, the one we planted in gaps was *Tithonia diversifolia*, because there was a lot of existing knowledge about its use. It appeared therefore the safest choice for experimenting. It is very adaptable, being found in a wide variety of climates and soil conditions. It is normally grown in open sun conditions but it also grows in shadowy places (Dechnik-Vázquez, *pers. obvs.*). It has a useful ability to sequester phosphorous from the soil even when it’s unavailable for other plants, which makes it fit to silvopastoral production in places where the soil is degraded (Jama *et al*., 2000). Nowadays it is one of the most used forages in silvopastoral systems in Latin America (Ruiz *et al*., 2017).

Observations prior to the study suggested growth of this species is very dependent on light and water. Hence we thought it was an ideal candidate for checking how anticipated small light and humidity variations inside a gap could affect a silvopastoral crop. As far as we know, planting *T. diversifolia* underneath a partial canopy of trees has not been investigated. With the plantation available, it appeared reasonable trying to mix these well-known species.

Here we investigated sowing *T. diversifolia* within gaps inside a *G. sepium* tree plantation, assessing the suitability of planting forb-like silvopastoral forage inside gaps within an artificial forest plantation, and checking if this particular species is suitable for cultivation in partially shadowed environments. We analyzed in detail growth responses to small variations in physical factors.

METHODS

Study site

The study was carried out in the upper Tablón river basin (UTRB), which was included since 1995 within the La Sepultura Biosphere Reserve, situated in the Sierra Madre de Chiapas mountain range, in the state of Chiapas, south of Mexico (16°16′40” − 16°12′40“N and 93°37′10” − 93°32′55“W). Climate is seasonally dry with mean temperatures that vary between 25 and 28 °C and precipitation in the range of 2003 ± 484 mm annually, distributed mainly from May to October (CONAGUA, 2016).This reserve is managed according to a governmental instituted plan (Lillo *et al*., 1999) that classifies the territory in core zones and buffer zones, managed by the local inhabitants. The field work was done in a communally owned land or *ejido* called Los Ángeles (within the buffer zone) where extensive cattle ranching is a major economic activity. Silvopastoral approaches are nowadays supported by governmental institutions (García-Barrios and González-Espinosa, 2017). Tropical dry forest (TDF) is one of the dominant vegetation types in lower sites and montane pine-oak forest at higher elevations. The plantation is localized within a TDF type landscape, surrounded by agricultural terrains and forested patches.

Experiment setup and data collection

T. diversifolia was planted in canopy gaps made in a *G. sepium* silvopastoral plantation. The trees in this plantation were planted in 2009, being the result of a fertilization experiment on *G. sepium* (Morales Díaz, 2011). Individuals nowadays have a height of ~ 7 m. The plot has a size of approximately 46 x 60 m and is situated in terrain with slope that varies between 10 to 20 degrees, orientated in such a way that the rows follow closely the course of the sun through the day. Different light treatments were constructed by cutting trees down in rows, ending up with six gaps (Figure 1a). Additionally, a shadowed control row for assessing the effect of the full canopy (without gaps) was planted. Gaps inside the plot can be seen in Google Maps® (Figure 1c).

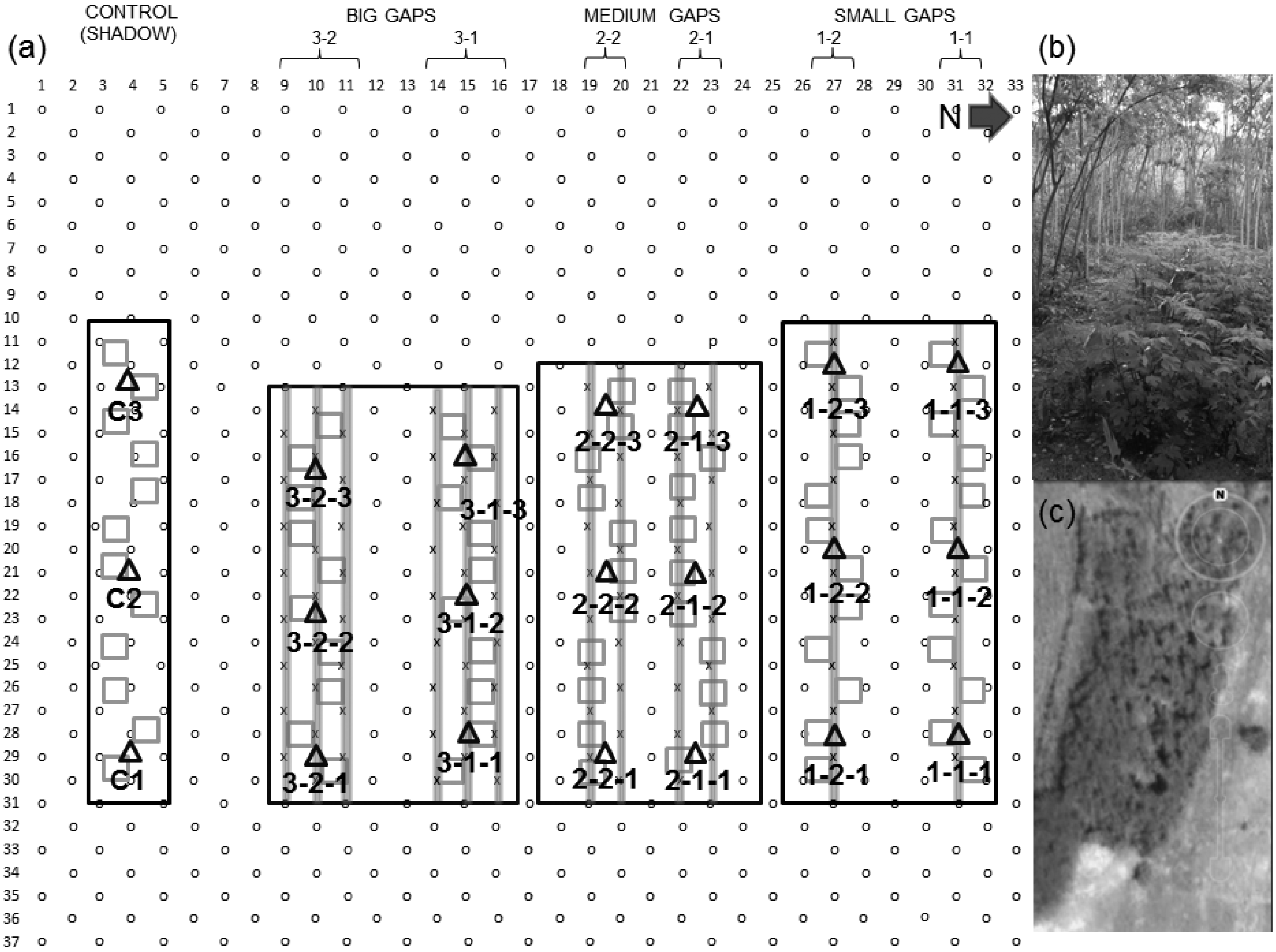

Figure 1. (a) Map of the gaps. Each small open circle represents a tree. Cut trees are marked by an x and highlighted by a gray line. *T. diversifolia* plants were sown in the gray squares set randomly along both sides of the gap. Notice that each treatment contains two gaps (except the shadow one) and the triangles, representing sites were physical data was collected (soil humidity samples and hemispherical canopy photos). Distance between rows is 1.39 m and distance between trees in rows is 1.6 m. Area of each gap is approximately 44.5 m^2 for small ones, 60 m^2 for medium ones and 71.2 m^2 for big ones; (b) View inside a gap; (c) Aerial view image from Google Earth (image downloaded on 16 december 2018) of the study site. Coordinates are 16°16'5.85''N, 93°38'56.90''O

Tithonia diversifolia was planted in 1m^2 squares inside the cut rows. Stakes ~30 cm height were cut from wild plants found near the plantation and planted vertically, four each square, in the vertices. This size (30 cm or more) is adequate to guarantee good nutrient production according to Medina *et al*. (2009). Though *T. diversifolia* has the ability to propagate vegetatively, commercial root growth enhancer (Raizal®) was applied following manufacturer instructions to enhance this process and also to supply fertilizer (present in the root enhancer) to the shoots during the first stage of growth. Fifteen squares were set in the first two rows (almost closed canopy) and the shaded one (with the canopy intact), and twelve in the rows with middle and high light availability. We procured more squares in the less illuminated treatments since light has been observed to be crucial for rooting of *T. diversifolia* (Agboola, Idowu and Kadiri, 2006); hence we aimed to ensure there was a balanced amount of survivor plants in each treatment in the end. We set the location of the squares inside the rows by walking through them and choosing either left of right with a coin, in order to randomize the most the incidence of light on each *T. diversifolia* square inside each gap.

Stakes were planted on august 2016, in the middle of the rainy season. Data was taken from this month through august 2017. There were three differentiable subsets: that of the two months of growth in 2016, directly after the planting was done; that of the dry season between 2016 and 2017, and finally that of the period of growth during the humid season in 2017. It was with this last set that we conducted the analyses; where the main growth sprout due to high precipitation happened for those plants that survived the dry season. Therefore it was necessary to compare growth trajectories only for this period if we were to affirm there were differences in growth due to soil humidity and light fluctuations. Finalizing this year of growth, plants were cut at 50 cm height, (the optimal height for further dry biomass production according to Partey, 2011), bagged, dried and then weighted, to calibrate the growth measurements with dry biomass weight. For all plants we measured total height in centimeters and the total plant cover with two perpendicular axes, were if two or more sections of the plant were clearly separated in space viewed from above, they were measured separately and then the cover was added.

Three fixed points were defined in each gap (resulting in 21 total measurement points) for sampling soil humidity and light conditions each month. For soil humidity, soil samples of the top 10 cm soil layer were taken around each of the 21 points, avoiding sampling from the same exact point .soil sample weight of was measured immediately in the field with a digital scale. Samples were then dried at the oven at 90 ºC for 4 days to obtain the dry weight. The difference in weight was then divided by the dry weight of the sample and multiplied by 100 to obtain the % water content in the soil (% Water; Reynolds, 1970). For light data, hemispherical canopy photos were taken in each of the 21 points, with a Canon® EOS400D digital camera, equipped with a Sigma® 8mm F3.5 fisheye lens with Lambert's equal-area projection. Photos were taken in the evening (between 5 and 7 pm), when the sun was setting and thus ambient light was diffuse, a requisite for analyzing canopy-gap openness. Analysis of the gap photos was carried out with the Gap Light Analyzer 2.0 software (Fraser *et al*., 1999). The following quantities were calculated: canopy openness (%) and total transmitted radiation (TTR: mols / m^2 / day).

Regarding the control of additional sources of variation, variation of soil composition in the parcel was observed to be low: the entire terrain surface had a uniform appearance and structure (being a sandy soil). Due to the terrain being previously selected for making an experiment with *G. sepium*, some factors were already controlled: the slope was uniform and the terrain was oriented along the east-west axis to ensure the plants had more or less a uniform pattern of shadowing during the day. Gaps were thus also cut along this direction, making the self-shadowing constant among gaps. Competition by other plants was controlled by cleaning the terrain each month. Re-growth of the *G. sepium* stubs left was also cut each month.

Data analysis

Growth data was further divided into 21 subsets, each for the estimated area of influence of light and humidity around each sampling point (were photos and soil humidity samples were taken; the triangles in fig. 1). Plant mortality was recorded in all treatments through the duration of the experiment. We checked homoscedasticity and normality for all variables. ANOVA's were carried out to know if there were significative differences between final biomass and also physical measurements (light and humidity) between gaps. A post-hoc Tukey test was also done to find which particular gaps had biomass differences between them. We summed all TTR data and % water data for each gap and point during the rainy season of 2017, to infer the relationship of these variables to final collected biomass. To further analyze the growth of *T. diversifolia,* growth of plants was averaged and subtracted between consecutive months. Mathematical models were then done using the final biomass/height (and cover) relationship, to interpolate biomass data during growth. For each point, we plotted calculated biomass in the last four months against elapsed days and fitted a linear model. The slopes of these linear models were then also checked for correlations with TTR and % water. We plotted growth simultaneously to TTR and % water, and fit two-dimensional polynomial models to the various scatterplots, to interpret variation in growth in relation to both physical factors. Statistical tests and model fitting was done with the R programming language (R Development Core Team, 2008).

RESULTS

Physical data

Canopy openness and TTR differences between gaps showed when graphed (Figure 2a, b). TTR patterns didn´t coincide with our rule-of-thumb expectations: gaps 3-2 and 2-1 were the most radiated ones, while gaps 2-2 and 3-1 were the least radiated ones. The amount of solar radiation that went through gaps in the humid season differed ($F = 5.43$; $p = 5.36 \times 10^{-5}$) but not % water ($F = 0.641$ $p = 0.697$). The bar graph of accumulated percentages of % water showed a small tendency to decrease in middle and bigger gaps in relation to canopy openness and it was actually lower in the control (higher shade) gap (Figure 2c). When plotting the data for each month of the rainy season, TTR and % water showed no apparent relationship (R^2=-0.132, p=0.15, figure 2d), but canopy openness and %

water had a distinguishable, significative negative correlation (R^2=-0.47, p=5.035 × 10^{-5}; figure 2e.)

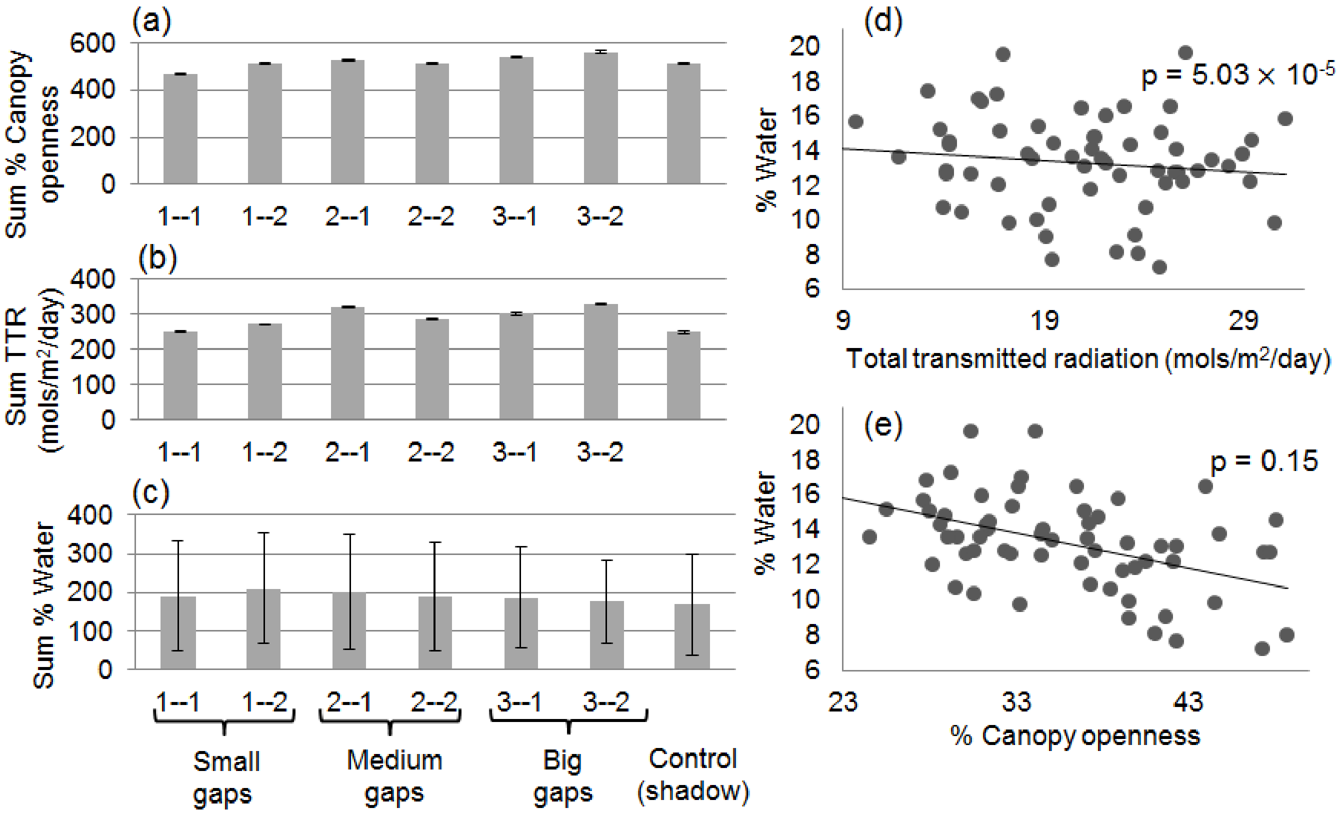

Figure 2. Panels (a), (b) and (c): Accumulated physical measurements (TTR, % canopy openness, % water) for each gap (error bars represent ± 1 standard error of the mean). (d) and (e): Correlations between measured % water with TTR and canopy openness per month.

Growth comparison between gaps.

Mortality was lowest in gaps 2-2 and 3-2 (Figure 3a). Total biomass growth was highest in gap 3-2, followed by gap 2-1 (Figure 3b). Average biomass per plant was higher in in gaps 3-1 and 3-2 (Figure 3c). According to the ANOVA, there were differences in growth between gaps (F = 5.5; p = 3.03 × 10^{-5}); the Tukey post-hoc test showed that gaps 3-2, 3-1, 2-2, 2-1 were equal and gaps 1-1, 1-2 and the control one were also equal, but there were differences between those. Hence, middle sized gaps allowed for the same growth as the bigger ones. Total biomass growth per sampling point was always bigger in the center of the most illuminated gaps (Figure 3d).

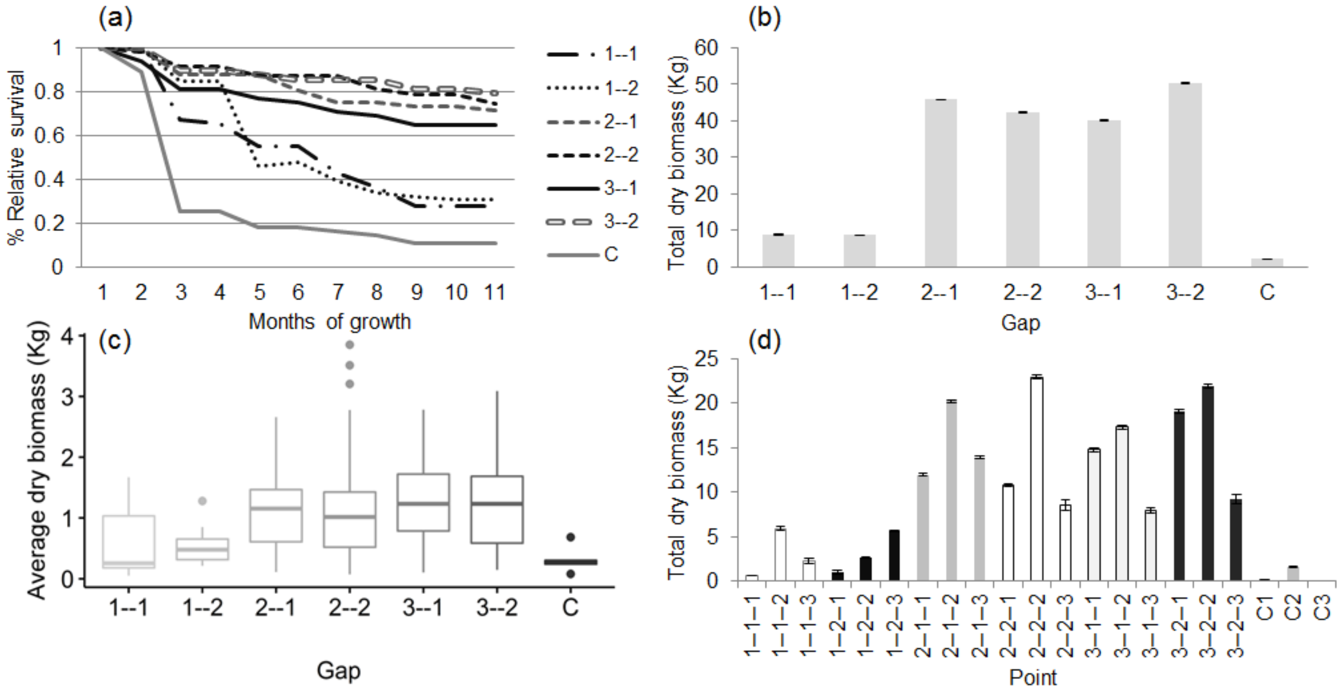

Figure 3. (a) Relative mortality curves in each gap; (b) Total dry biomass weight collected in each gap; (c) Whisker-and-box plot of the total dry biomass weight collected in each gap. Isolated points are outlier data points; (d) Total dry biomass weight collected in each sampling point (error bars: ± 1 standard error of the mean). Each color relates to each gap.

Growth in relation to physical measurements

Regarding growth in relation to % water or TTR, it appeared at first there wasn't a clear relationship of growth with % water. We understood this was an artifact of the data, since humidity was much higher in closed gaps. Isolating data for middle and bigger gaps showed a pattern; but then it was further evident that point 2—2—1 was an outlier, with high values of both TTR and % water but low biomass growth. Removing it uncovered a linear positive relationship (Figure 4a) with low correlation and marginally significative, (R^2 = 0.50, p=0.0557). For TTR, a significant correlation was present (R^2 = 0.848, p=0.0005; Figure 4b).

The height-biomass relationship showed exponential behavior. Analysis of the homoscedasticity of the residuals and the QQ plot for normality led us to remove five outliers (of a total of 185 points): plants with suppressed growth though positioned well in the center of the gaps. After removing these we ended with a good model fit ($y = 45 \times e^{1.2036 \times \text{Height}}$; $R^2 = 0.7411$, p~0, figure 4c), which was used to interpolate total biomass data for further analysis. For cover data, the residuals and QQ plots showed clear deviations from the assumptions of homoscedasticity and normality. A logarithmic transformation was applied, resulting in a better fit ($R^2 = 0.6963$, p~0), but these adjustments indicate that cover is not a good predictor overall of biomass for *T. diversifolia.* We used only the biomass predicted by height to conduct further model fitting.

The TTR-modeled biomass plot appeared as an indefinite cloud of points with no tendency of statistical correlation (R^2= 0.011, p = 0.47), yet the % water-calculated biomass plot showed a linear relationship (R^2= 0.667, $p = 4.36 \times 10^{-6}$). Notice how this is the inverse pattern of that of summed biomass (% water = higher correlation, TTR = lower correlation, when for summed biomass TTR = higher correlation and % water = lower). The slopes of each fitted linear function per sampling point for the rainy season of 2017 were correlated to TTR (R^2=0.67, p=0.0011), also showing the dependence on light for the growth of *T. diversifolia* (Figure 4f).

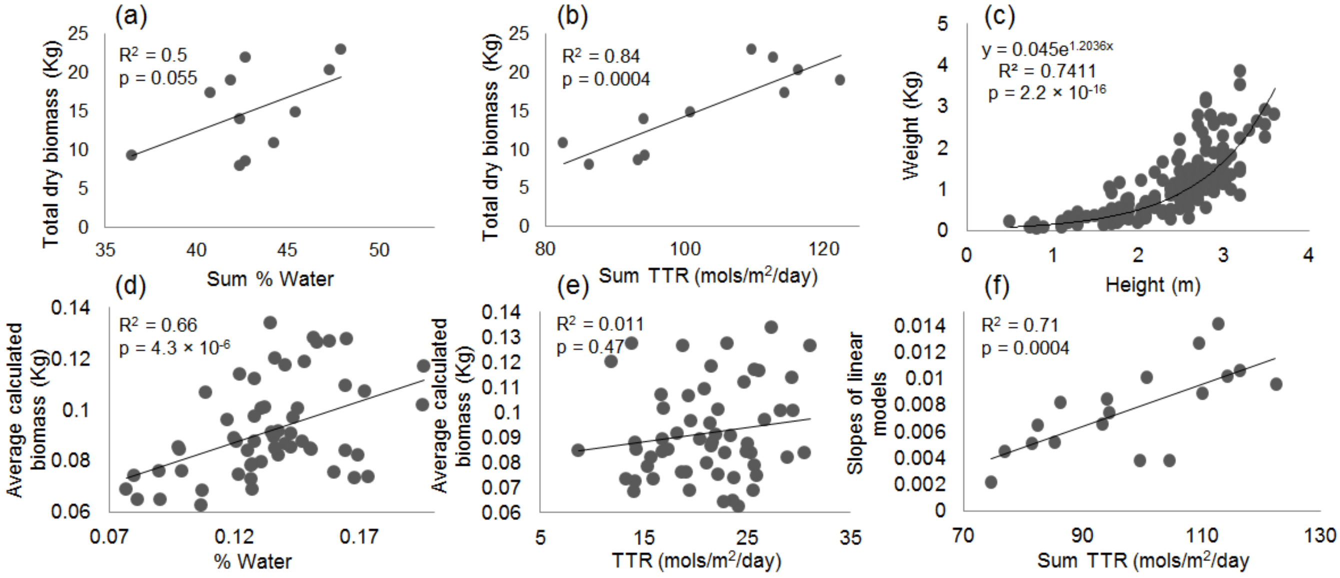

Figure 4. (a) and (b): Graphs of the relation between summed biomass % water and TTR for points inside gaps 2 and 3 (except point 2-2-1, see main text). (c) graph of the relation between final height and weight (with outliers removed);(d) and (e): graphs of interpolated biomass and % water and TTR values for each month in the rainy season in gaps 2 and 3 (including point 2-2-1); (f) relation between TTR and slopes of linear models fit to averaged growth trajectories in gaps 2 and 3.

3d statistical model fit.

The 3d graphs showed clouds of points were biomass increased with regards to both physical factors, as expected. This general outline was not met by some points, as the already mentioned point 2—2—1, and the furthest points, such as point 3—2—1, where the highest value of TTR was located, but where growth was lower. Generally, points with the biggest growth gains were located towards the center. Modeling then with monthly modeled data, a curved surface appeared where growth got higher symmetrically for both independent variables (R^2 = 0.3, p = 0.00063; Figure 5a). Modeling using the calculated slopes also resulted in a more or less symmetrical shaped surface with a notorious difference: the corners towards the maxima were oriented downwards (R^2 = 0.62, p = 0.2; Figure 5b). This implies growth is actually decelerated by high TTR/ % water. Though some points near the edges had smaller growth, as already mentioned, clouds of monthly data didn’t suggest at first sight such drastic decrease of growth with high humidity or TTR. Still, most fitted polynomial surfaces to different data arrangements resulted in half-cylinder shapes, with a curvature related to % water and/or TTR (Figure 5b, c, d). The model of added biomass/TTR/% water was a clear example of this (R^2 = 0.74, p = 0.07; Figure 5c). Also, the surface fit according to the added average biomass (R^2 = 0.6, p = 0.24; Figure 5d), where both high % water and TTR coincided with a decrease in average biomass gains.

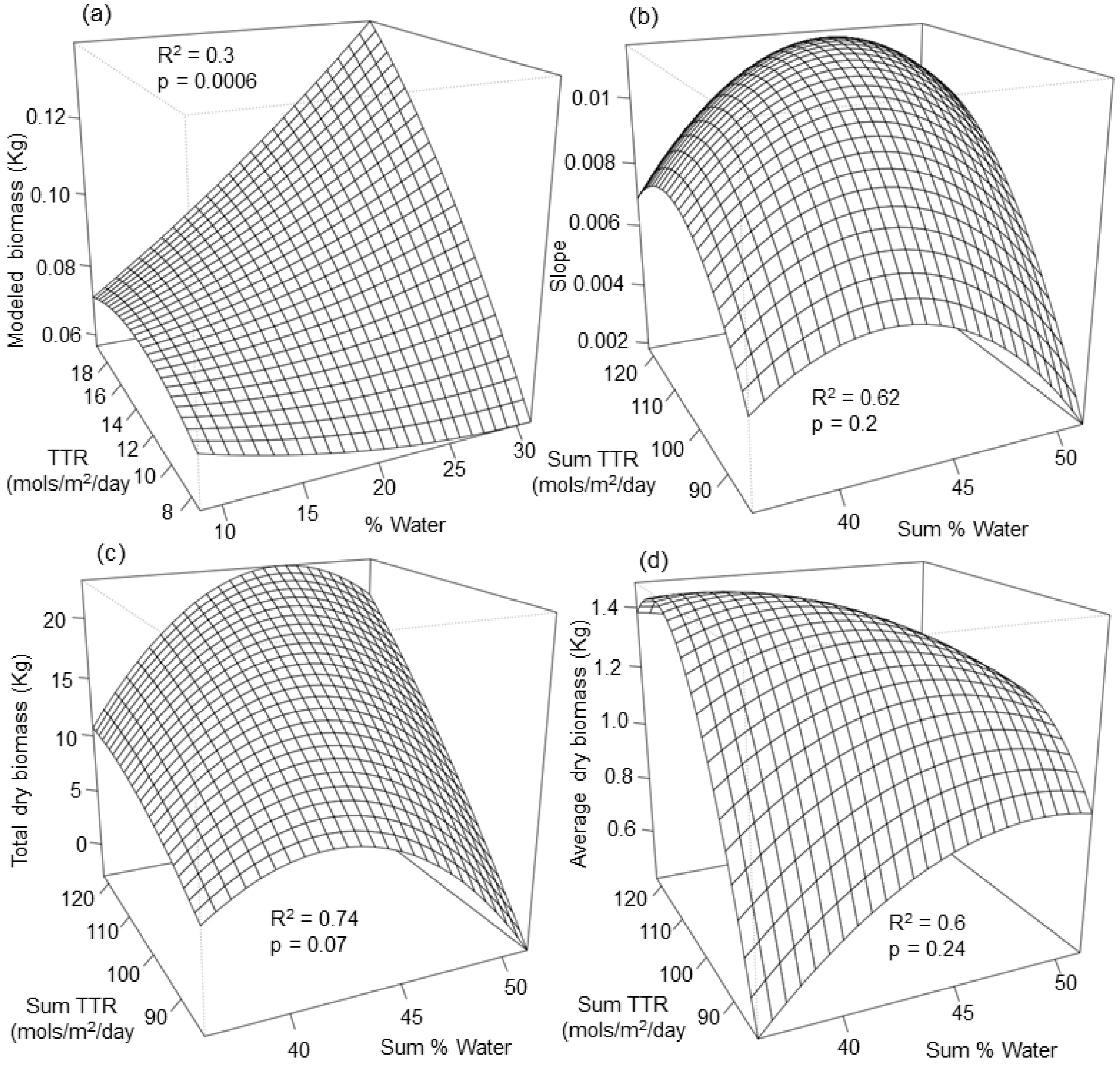

Figure 5. Fitted surfaces modeling the relation between TTR, % water and: (a) modeled monthly biomass gains obtained with the height/final biomass model; (b) the slopes of each linear model adjusted to the last four months of growth; (c) the summed biomass per sampling point, and; (d) the average biomass per sampling point.

DISCUSSION

Gap 2-1 had comparable TTR to gap 3-2 in spite of being perceivably smaller. Rule-of-thumb perceived canopy openness can differ from the actual amount of radiation entering the gaps. Soil humidity varied greatly, though canopy openness (and thus solar radiation) does affect it, to a small degree; what was notorious was the low humidity inside the intact understory. *Gliricidia* trees suck up soil water efficiently (Odhiambo *et al*., 2001) implying that a minimal opening is required not only for light but also because the negative effect of high tree density on soil water reserves. Growth was bigger in the middle sections of the gaps, similar to Lu *et al*., 2018. When sowing inside a gap, the area of influence of the trees in the periphery of the gap area must be taken into account. A minimal size of > 4 meters of distance between trees or gaps bigger than $60m^2$ seems to be ideal for cultivation of *T. diversifolia*.

Some plants were suppressed in growth despite being well in the center of the gaps, probably because of competition for light, since in open-field studies higher density yields more biomass (Ruiz *et al*., 2017). This shadowing was controlled though, due to the positioning of the gaps along the E-W axis and to squares having similar distance between them (also being randomized in their left-right position within the gaps, which randomized the incident light), so this source of variation was both controlled and randomized among gaps. Due to stakes being cut from the same or very close plants, it's probable that the genetic stock was pretty uniform, so this source of variation was also controlled. Differences in soil nutrients probably aren't what caused differences in growth, since *Tithonia* is very indifferent to being grown in poor soils (Rast *et al*., 2010). Competition with other plants probably also wasn't what caused this suppression, due to periodic cleaning of the plot.

Nevertheless, tolerance of *T. diversifolia* to shade appears high, which further cements its case as a useful agricultural species. Our plants grew in height more than others of most published studies. Gallego Castro, Ledezma and Arizama (2015) reported 70 cm after 56 days. Ours grew a comparable quantity in just 40 days. Muoghalu (2008) reported a growth of ~170 cm in 12 weeks (84 days), slightly smaller in comparison to ours which were around 180-190 cm in the same time. Etejere and Olaynika (2015) reported much smaller plants, 35 cm in height after 12 weeks, in sandy soils similar to the ones present in our parcel. Though our plants were bigger in height, they were smaller in weight. Mora-Delgado and Holguín (2018) reported smaller and heavier plants in their study: an average dry weight of 2.11 Kg for plants averaging 2.08 m height (n=40). For us, plants within the range of 210 cm in our study had a weight of 0.5 Kg and the average weight of the heaviest 40 plants was 2.29 Kg. Growth was also slightly smaller in weight to that reported by Ruiz *et al*. (2012) which was 1.75 cm (4.92 Kg) in 18 weeks (another interesting detail is that compared to this last study, our plants did not decrease in their growth after 8 weeks, but kept growing).

One should expect that growth would be modeled by symmetrical, monotonical functions if there weren't any interactions between TTR and % water. But some 3d models showed maxima being in the middle or near the middle of the graph space. There are effects that change growth in gaps, suggesting a deceleration of growth of an excess of any of these two variables. This downwards folding in the maximum % water of the models is particularly surprising, since we expected a monotonically growing behaving relationship of growth and humidity in any plant adapted to such a water-limited environment. These models clash with those obtained when plotting total dry biomass against only either TTR or % water, were the relationships uncovered were monotonically behaving. This happened except for figure 4e, where there was no clear relationship between TTR and growth. We believe this is where the apparently contradicting models converge, because this suggests that, while solar radiation is the most important factor to mortality and growth, very high TTR can be related to both high and low growth in the biggest gaps. This could be due to an effect on evaporation: maybe the effect of closer gaps is *compensating* for the diminished light by means of more water, since there would be less evaporation due to less radiation. All things put together, the primary limiting factor for *T. diversifolia* appears to be light availability, then water (still being very important though). It follows that middle-to-big sized gaps, but not excessively big ones, would be the best to avoid both excess evaporation and competition for water by neighboring trees.

We imagine a situation where landscape sections covered with a matrix of trees would have gaps cut in, of the right shape and size. Such “porous” silvopastoral tree matrix would mimic more faithfully a true forest and still be useful for silvopastoral uses, while also being resilient to climate change. Is this idea feasible? Some actual examples of artificial forests come from China (Feng, Yang and Zhang, 2006) and the United Arab Emirates (El-Keblawy and Ksiksi, 2005). In the latter, artificial forests have been found to host important biodiversity of plants and animals (Ksiksi *et al*., 2006). What about gap-management? Several lines of evidence support this idea. In China, it has been found in *Prunus armeniaca* forests that understory herbage diversity is low, suggesting management actions like opening the canopy and lowering tree density are key to enhancing community structure (Hu, Cheng and Wan, 2006). In *Shorea robusta* (Sal) man-made forests, densities of seedlings and saplings were higher in gaps, making them important habitats for enabling seedlings to survive into saplings (Sharma, Shrestha and Måren, 2018). Dupuy and Chazdon (2008) suggest that management systems that mimic natural canopy gaps could favor the regeneration of shade-tolerant tree species, helping accelerate the process of succession.

Our results directly contradict the conclusions upheld by Jose, Walter and Kumar (2017) where they downplay the potential role of gaps in silvopastoral management by referring a study (Dey and MacDonald, 2001) that posits that gap size has little effect on available light when openings are smaller than 0.04 ha. Here we found a clear difference in light availability between different small sized gaps that had a clear effect on fodder sown in the understory. Along with the recognition that habitat heterogeneity is crucial for high conservation value in grassland-forest frontiers (Erdős *et al*., 2018), other recent studies support gaps as a feasible option for management. Small gaps can act as foci for establishment of plants in the TDF (Dechnik-Vázquez *et al*., 2016), are beneficial for enhancing invertebrate community structure and composition (Perry *et al*., 2018) and accelerate restoration of the forest through creating structural heterogeneity (Forbes, Norton and Carswell, 2016). A similar type of management would be enrichment underplanting in strip opening (Magnoux, Cogliastro and Paquette, 2018). These types of techniques exemplify the need to fully embrace the fundamental role of disturbance in management.

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CAPITULO IV

Conclusión general

Las fronteras forestales dentro de la Reserva de la Biósfera de la Sepultura son efectivamente recursos silvopastoriles, debido a la presencia de una gran cantidad de plantas ramoneadas. De éstas, varias poseen alto contenido nutricional y fueron reconocidas por los productores. Esto implica que debemos de expandir nuestra visión de lo que representan las fronteras forestales dentro de regiones parecidas, ya que los beneficios obtenidos del bosque son básicamente aquellos que se obtendrían de los sistemas silvopastoriles. Es importante que reconozcamos esto, situándonos en la visión del campesino que vive rodeado del bosque. Si bien a un productor ganadero situado en territorios sin un componente explícito de conservación (como lo es una Reserva de la Biósfera), los sistemas silvopastoriles le representan una forma adecuada de hacer un aporte al medio ambiente; a un productor que está literalmente inmerso en el bosque, en donde hay decenas de plantas comestibles de diversas clases, un sistema silvopastoril podría parecerle redundante. Si deseamos que los proyectos de este tipo en territorios de conservación no fracasen, debemos de incluir esta visión en los planes de manejo y/o restauración. Cualquier plan de aprovechamiento a futuro requerirá evaluaciones adicionales rigurosas del potencial silvopastoril de las fronteras forestales, como saber con precisión qué extensión geográfica tienen estas zonas, cuál es su productividad por área y qué tanto podrían contribuir entonces a la alimentación del ganado.

Respecto al segundo experimento, la cantidad de luz disponible en claros de dosel parece adecuada (a partir de cierta apertura) para garantizar un adecuado crecimiento de plantas herbáceas. Pudimos observar además (una vez concluido el experimento) una gran cantidad de especies de aquellas que encontramos durante el muestreo, creciendo espontáneamente dentro de ésta (además de *T. diversifolia*), y con marcas de ramoneo. Los sistemas silvopastoriles tienen aún potencial no explorado de manejo con claros de dosel. Como se mencionó en la introducción, parecería que lo más adecuado sería un manejo sucesional. Es necesario crear un paradigma de este tipo para que los esfuerzos de conservación puedan integrarse sin problemas dentro de la necesidad que tienen las personas de usar los recursos de sus territorios. Este experimento contradice además las conclusiones de Jose, Walter and Kumar (2017), quienes minimizan y descartan el papel potencial de claros de dosel en el manejo silvopastoril refiriendo simplemente un estudio que presenta evidencia de que el tamaño de los claros del dosel tiene un efecto mínimo en la luz total presente. Aquí se encontró una clara diferencia en la disponibilidad de luz aún entre claros pequeños. Esto afectó el crecimiento de una planta forrajera en su interior. Esto se une a otros estudios que concluyen que los claros son focos de reclutamiento de especies pioneras en el bosque tropical seco (Dechnik-Vázquez *et al*., 2016), que son beneficiosos para incrementar la diversidad de la composición y estructura de las comunidades de artrópodos (Perry *et al*., 2018) y que aceleran la restauración del bosque a través de la heterogeneidad estructural que conllevan (Forbes, Norton and Carswell, 2016). Se ha demostrado además que este último factor (la heterogeneidad de hábitat) es crucial para mantener una biodiversidad alta en fronteras forestales con pastizales (Erdős *et al*., 2018). La evidencia implica considerar el importante papel del disturbio en los sistemas ecológicos. Este estudio se suma también a otros recientes (Braasch, 2017) que apelan a un cambio de paradigma para resolver problemas ambientales, dejando de lado la visión estática de la conservación (que no admite el manejo del ganado dentro de las reservas) hacia un paradigma que involucre más las estrategias campesinas y una visión más dinámica del manejo del ganado y los recursos forestales.

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ANEXOS

ANEXO A

Tabla A.1 Resumen de los resultados de las entrevistas

Especie	Varetas sembradas	Proporción de varetas que crecieron con éxito (sí / no)
Machaerium chiapense	74	0.027
Montanoa tomentosa	79	0.20
Acalypha leptopoda	90	0.51
Verbesina perymenioides	80	0.61
Sida acuta	146	0.02
Acalypha villosa	54	0.42
Croton pseudoniveus	62	0.11
Critonia sp.	70	0.02
Desmodium cinereum	56	0.04

ANEXO B

Tabla B.1 Listado completo de especies muestreadas y sus características

Principales características descriptivas de las 268 especies encontradas durante el muestreo de vegetación. La tabla está ordenada por el valor de GUI (Grazing Usefulness Index, por sus siglas en inglés) en el extremo derecho. Rm? = proporción de veces que la especie apareció con marcas de ramoneo. Regs. = número de registros. Dist. = Restulado de la ecuación que pondera la distribución de la especie (ver apéndice del capítulo II) Alt. Prom = Altura promedio. Cob. Prom. = Cobertura promedio.

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Cordia alliodora (Ruiz & Pav.) Oken	1	1	1.66	1	1	1	1	24	0.09	5	0.2
Allophyllus sp. 1	0	1	1.66	1	4	4	4	18	0.28	1	0.2
Heliotropium angiospermum Murray	0	1	1.66	1	1	1	1	210	1.48	12	0.2
Annona sp. 1	0	1	1.66	1	6	6	6	115	6.53	8.5	0.2
Annona sp. 2	0	1	1.66	1	2	2	2	110	0.92	8.5	0.2
Bocconia sp. 1	1	1	1.66	1	1	1	1	162	0.15	9	0.2
Vitis bourgaeana Planch.	0	1	1.66	1	1	1	1	35	0.02	3	0.2
Cardiospermum sp.	0	1	1.66	1	1	1	1	10	0.03	1	0.2
Coccoloba chiapensis Standl.	0	1	1.66	1	1	1	1	16	0.03	3	0.2
Chromolaena sp. 1	0	1	1.66	1	1	1	1	23	0.04	4	0.2
Boerhavia coccinea Mill.	0	1	1.66	1	3	3	3	45	0.38	3.7	0.2
Commelina sp. 1	0	1	1.66	1	1	1	1	95	0.21	5	0.2
Dioscorea convolvulacea Schltdl. & Cham.	0	1	1.66	1	1	1	1	120	0.13	1	0.2

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Byrsonima crassifolia (L.) Kunth	0	1	1.66	1	1	1	1	25	0.02	1	0.2
Crusea diversifolia (Kunth) W.R. Anderson	0	1	1.66	1	1	1	1	30	0.05	1	0.2
Eugenia sp. 1	1	1	1.66	1	2	2	2	15	0.06	5	0.2
Fabaceae sp. 1	1	1	1.66	1	1	1	1	32	0.01	2	0.2
Passiflora foetida L.	0	1	1.66	1	1	1	1	51	0.07	3	0.2
Miconia globulifera Naudin	0	1	1.66	1	1	1	1	62	0.24	5	0.2
Gonolobus sp. 1	0	1	1.66	1	1	1	1	26	0.07	4	0.2
Perymenium grande var. *grande*	1	1	1.66	1	1	1	1	12	0.05	6	0.2
Achimenes grandiflora (Schltdl.) DC.	0	1	1.66	1	2	2	2	7	0.06	1.5	0.2
Adenocalymma inundatum Mart. ex DC.	0	1	1.66	1	1	1	1	106	0.02	7	0.2
Senecio iodanthus Greenm.	0	1	1.66	1	1	1	1	16	0.06	2	0.2
Ipomoea laeta A. Gray	0	1	1.66	1	1	1	1	400	4.32	440	0.2
Lilliaceae sp. 1	0	1	1.66	1	1	1	1	30	0.42	5	0.2
Lycianthes sp. 1	0	1	1.66	1	12	12	12	160	9.05	5.6	0.2
Neurolaena macrocephala Sch. Bip. ex Hemsl.	0	1	1.66	1	2	2	2	115	2.76	5.5	0.2
Matelea sp.	0	1	1.66	1	1	1	1	21	0.11	2	0.2
Matelea sp. 1	0	1	1.66	1	1	1	1	60	0.17	5	0.2

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Trema micrantha (L.) Blume	1	1	1.66	1	2	2	2	37	0.17	8	0.2
Mikania sp.	0	1	1.66	1	1	1	1	30	0.03	1	0.2
Desmodium monticola Brandegee	1	1	1.66	1	1	1	1	22	0.43	5	0.2
No identificada 6	0	1	1.66	1	1	1	1	30	0.1	2	0.2
Passiflora ornithoura var. *chiapasensis* J.M. MacDougal	0	1	1.66	1	1	1	1	53	0.2	1	0.2
Calea palmeri A. Gray	1	1	1.66	1	5	5	5	120	3.27	3.6	0.2
Crossopetalum parviflorum (Hemsl.) Lundell	0	1	1.66	1	1	1	1	23	0.02	2	0.2
Passiflora sp.	0	1	1.66	1	1	1	1	20	0.03	1	0.2
Chiranthodendron pentadactylon Larreat.	1	1	1.66	1	1	1	1	120	0.63	9	0.2
Plumeria sp. 1	0	1	1.66	1	1	1	1	130	0.08	13	0.2
Poaceae sp. 1	0	1	1.66	1	1	1	1	150	8.95	NA	0.2
Pteridofita sp. 1	0	1	1.66	1	1	1	1	23	0	2	0.2
Ranunculus sp. 1	0	1	1.66	1	1	1	1	80	0.14	3	0.2
Rhus sp. 1	0	1	1.66	1	1	1	1	45	0.05	4	0.2
Robinsonella sp. 1	0	1	1.66	1	1	1	1	14	0.01	2	0.2
Sapindaceae sp. 2	0	1	1.66	1	1	1	1	150	0.09	4	0.2
Sapindus saponaria L.	1	1	1.66	1	2	2	2	90	0.3	9.5	0.2
Euphorbia schlechtendalii Boiss.	0	1	1.66	1	1	1	1	32	0.02	4	0.2
Senecio sp. 1	0	1	1.66	1	1	1	1	60	0.18	5	0.2
Solanum sp. 1	0	1	1.66	1	1	1	1	26	0.29	2	0.2
Trichillia sp. 1	1	1	1.66	1	1	1	1	66	0.47	14	0.2

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Trichilia trifolia L.	0	1	1.66	1	2	2	2	28	0.08	5	0.2
Ayenia truncata Rose	1	1	1.66	1	15	15	15	400	39.18	36.7	0.2
Allotoonia turbinata (Woodson) J.F. Morales & J.K. Williams	0	1	1.66	1	1	1	1	25	0.26	3	0.2
Echites tuxtlensis Standl.	1	1	1.66	1	1	1	1	48	0.17	4	0.2
Ageratum sp.	0	2	1.66	1	4	3	2	15 ± 7.07	0.08 ± 0.01	1.8	0.2
Anthurium sp.	0	2	5.48	2	5	4	2.5	32 ± 11.31	0.17 ± 0.05	3	0.2
Aspleniaceae sp. 1	0	2	5.48	2	11	7	5.5	35 ± 21.21	0.27 ± 0.28	1.5	0.2
Piper auritum Kunth	0	2	1.66	1	2	1	1	70 ± 42.43	0.55 ± 0.45	7.5	0.2
Clematis sp. 1	0	2	5.48	2	3	2	1.5	65 ± 7.07	0.14 ± 0.08	3.7	0.2
Mikania cordifolia (L. f.) Willd.	0	2	1.66	1	2	1	1	94 ± 8.49	0.23 ± 0.14	4.5	0.2
Hyptis decipiens M.E. Jones	0	2	1.66	1	6	5	3	29 ± 15.56	0.12 ± 0.05	1.5	0.2
Bocconia frutescens L.	0	2	1.66	1	6	3	3	41.5 ± 26.16	0.35 ± 0.22	2.5	0.2
Rhus galeottii Standl.	0	2	1.66	1	4	2	2	180 ± 14.14	6.6 ± 1.33	14.8	0.2
Guarea sp. 1	0	2	1.66	1	2	1	1	20 ± 0	0.03 ± 0	2	0.2
Ipomoea sp. 1	0	2	1.66	1	2	1	1	37 ± 18.38	0.04 ± 0.01	4	0.2
Lobelia sp.	0	2	1.66	1	2	1	1	11.5 ± 3.54	0.03 ± 0.02	1.5	0.2
Cedrela odorata L.	0	2	1.66	1	2	1	1	115 ± 106.07	4.56 ± 5.55	20	0.2

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Poaceae sp. 2	0	2	1.66	1	2	1	1	7 ± 4.24	2.83 ± 0.4	NA	0.2
Stenocereus pruinosus (Otto ex Pfeiff.) Buxb.	0	2	1.66	1	2	1	1	170 ± 113.14	0.07 ± 0.02	52.5	0.2
Tabebuia rosea (Bertol.) DC.	0	2	1.66	1	2	1	1	29 ± 8.49	0.16 ± 0.07	5	0.2
Stemmadenia sp. 1	0	2	1.66	1	2	1	1	42.5 ± 3.54	0.02 ± 0.01	3	0.2
Tetrorchidium brevifolium Standl. & Steyerm.	0	2	1.66	1	2	1	1	47.5 ± 3.54	6.33 ± 8.42	5	0.2
Urtica sp. 1	0	2	1.66	1	2	1	1	95 ± 83.44	0.65 ± 0.39	8.5	0.2
Cissus verticillata (L.) Nicolson & C.E. Jarvis subsp. verticillata	0	2	1.66	1	2	1	1	43.5 ± 2.12	0.21 ± 0.02	3	0.2
Vitis berlandieri Planch.	0	3	5.48	2	4	2	1.33	163.33 ± 83.86	2.81 ± 4.11	4.8	0.2
Ipomoea cordata L.B. Sm. & B.G. Schub.	0	3	2.87	2	4	2	1.33	13 ± 8.72	0.09 ± 0.06	1.8	0.2
Cucurbita sp. 1	0	3	5.48	2	10	4	3.33	18 ± 10.58	0.21 ± 0.15	3.1	0.2
Enterolobium cyclocarpum (Jacq.) Griseb.	0	3	5.48	2	3	1	1	117.33 ± 192.83	1.76 ± 3.04	13	0.2
Manihot esculenta Crantz	0	3	6.44	3	3	1	1	11 ± 7.81	0.02 ± 0	1.3	0.2
Gonolobus sp.	0	3	1.66	1	4	2	1.33	27.33 ± 14.19	0.25 ± 0.32	3.2	0.2

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Paullinia sp. 1	0	3	1.66	1	3	1	1	20 ± 13.11	0.06 ± 0.07	3	0.2
Verbesina platyptera Sch. Bip. ex Klatt	0.33	3	5.48	2	9	6	3	25.67 ± 5.13	0.22 ± 0.14	2.7	0.2
Salicaceae sp.	0.33	3	5.48	2	4	2	1.33	82 ± 102.27	0.47 ± 0.66	3.8	0.2
Canavalia villosa Benth.	0	3	1.66	1	4	2	1.33	19.33 ± 11.02	0.06 ± 0.05	2	0.2
Cassia absus L.	0	4	1.66	1	4	1	1	43.75 ± 14.93	0.09 ± 0.03	1.5	0.2
Agave sp. 1	0	4	5.48	2	5	2	1.25	16.75 ± 3.2	0.08 ± 0.02	11.8	0.2
Agave angustifolia Haw.	0	4	1.66	1	4	1	1	49.7 ± 34.93	1.89 ± 2.58	13.5	0.2
Arrabidea sp. 2	0	4	1.66	1	6	2	1.5	32.75 ± 21.06	0.11 ± 0.04	2.3	0.2
Brongniartia sp. 1	0	4	1.66	1	4	1	1	13.25 ± 2.99	0.06 ± 0.06	2	0.2
Cissus sp. 1	0	4	5.48	2	5	2	1.25	62 ± 73.97	0.13 ± 0.17	2.6	0.2
Arrabidea floribunda (Kunth) Loes.	0	4	1.66	1	6	2	1.5	25 ± 4.16	0.22 ± 0.17	3.2	0.2
Euphorbia hyssopifolia L.	0	4	2.87	2	4	1	1	27.25 ± 4.86	0.08 ± 0.03	2.5	0.2
Elytraria imbricata Pers.	0.25	4	5.48	2	4	1	1	12.25 ± 3.95	0.04 ± 0.03	2	0.2
Justicia sp. 1	0.25	4	5.48	2	5	2	1.25	33.5 ± 12.66	0.11 ± 0.01	3.6	0.2
Malvastrum sp.	0	4	1.66	1	4	1	1	9.75 ± 4.11	0.03 ± 0	1.5	0.2

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Orchidaceae sp. 1	0	4	2.87	2	9	4	2.25	9.75 ± 4.03	0.1 ± 0.07	4.9	0.2
Quercus sp. 2	0.25	4	6.44	3	4	1	1	193.75 ± 106.41	3.98 ± 3.34	29.2	0.2
Anthurium sp. 1	0	5	1.66	1	7	2	1.4	10.8 ± 3.7	0.08 ± 0.04	3.4	0.2
Aspleniaceae sp.	0	5	7.02	4	9	3	1.8	21.8 ± 19.78	1.11 ± 2.33	1.2	0.2
Borreria chiapensis Brandegee	0	5	1.66	1	8	3	1.6	16.6 ± 5.55	0.06 ± 0.05	1.1	0.2
Ardisia densiflora Krug & Urb.	0.4	5	1.66	1	7	3	1.4	26 ± 22.12	0.33 ± 0.55	5.9	0.2
Heliotropium sp. 1	0.2	5	1.66	1	22	8	4.4	41.4 ± 11.26	0.38 ± 0.2	3	0.2
Pteris sp.	0	5	1.66	1	7	2	1.4	25.6 ± 14.1	0.23 ± 0.22	2.1	0.2
Selaginella sp.	0	5	6.44	3	13	5	2.6	14.8 ± 7.66	0.54 ± 0.89	1.2	0.2
Ipomoea tuxtlensis House	0	5	1.66	1	20	10	4	16.2 ± 3.83	0.24 ± 0.22	1	0.2
Cochlospermum vitifolium (Willd.) Spreng.	0	5	5.48	2	5	1	1	24.2 ± 17.58	0.29 ± 0.43	3.2	0.2
Petrea volubilis L.	0.2	5	2.87	2	16	10	3.2	65.6 ± 54.9	3.68 ± 8.04	10.9	0.2
Astragalus sp. 1	0	6	1.66	1	9	3	1.5	22 ± 7.92	0.08 ± 0.06	1.3	0.2
Laubertia contorta (M. Martens & Galeotti) Woodson	0	6	2.87	2	8	3	1.33	80.83 ± 78	0.41 ± 0.82	3.1	0.2
Matelea cordifolia (A. Gray) Woodson	0.17	6	1.66	1	6	1	1	51.67 ± 24.89	0.27 ± 0.24	4.8	0.2

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Eryngium gracile F. Delaroche	0	6	5.48	2	29	10	4.83	16.83 ± 9.77	0.1 ± 0.11	2.1	0.2
Macrosiphonia hypoleuca (Benth.) Müll. Arg.	0.17	6	5.48	2	15	4	2.5	27.17 ± 26.03	0.78 ± 0.76	2.2	0.2
Baccharis trinervis Pers.	0.17	6	1.66	1	12	5	2	115.33 ± 122.58	3.12 ± 6.79	6.5	0.2
Bursera concinna Sandwith	0.14	7	2.87	2	7	1	1	93.14 ± 88.28	1.28 ± 2.98	11.7	0.2
Commelina diffusa Burm. f.	0	7	2.87	2	26	8	3.71	27 ± 16.37	0.21 ± 0.2	1.8	0.2
Verbesina oaxacana DC.	0.14	7	5.48	2	24	8	3.43	62.71 ± 63.36	1.89 ± 2.54	4.7	0.2
Polypodium sp.	0	7	5.48	2	42	11	6	17.86 ± 4.67	0.43 ± 0.31	1.5	0.2
Begonia sp. 1	0	8	1.66	1	9	2	1.13	51.75 ± 44.55	0.12 ± 0.04	4.8	0.2
Orchidiaceae sp. 2	0	8	7.02	4	12	5	1.5	10 ± 3.7	0.1 ± 0.12	4.8	0.2
Mimosa pudica L.	0	8	5.48	2	18	5	2.25	27.62 ± 12.64	2.28 ± 4.47	1.9	0.2
Casearia obovata Schltdl.	0.2	10	10.6	5	12	3	1.2	72.3 ± 47.43	0.55 ± 0.56	9.5	0.2
Pachyrhizus sp. 1	0	10	7.02	4	11	2	1.1	39.9 ± 46.09	0.05 ± 0.02	1.4	0.2
Perymenium sp. 2	0.1	10	5.48	2	13	2	1.3	23.9 ± 11.46	0.06 ± 0.03	4.6	0.2
Ruellia pringlei Fernald	0.2	10	10.8	4	15	6	1.5	115.8 ± 132.4	3.43 ± 7.64	14.1	0.2

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Serjania sp.	0.1	10	7.97	6	11	2	1.1	38.3 ± 32.38	0.07 ± 0.07	1.9	0.2
Stevia sp.	0.1	10	1.66	1	21	5	2.1	24 ± 6.72	0.03 ± 0.03	2.1	0.2
Verbesina auriculata DC.	0.18	11	1.66	1	11	1	1	107.09 ± 98.52	0.97 ± 1.98	8	0.2
Acacia farnesiana (L.) Willd.	0	12	10.74	3	20	6	1.67	189.17 ± 162.83	22.44 ± 57.07	20.5	0.2
Tetramerium sp. 1	0.17	12	5.48	2	22	4	1.83	34.67 ± 12.56	0.09 ± 0.11	1.5	0.2
Ximenia americana L.	0.08	13	10.6	5	21	3	1.62	52.77 ± 54.61	0.66 ± 1.1	2.9	0.2
Verbesina sp.	0.15	13	10.6	5	68	24	5.23	45.92 ± 49.21	2.03 ± 5.02	6.1	0.2
Solanum chrysotrichum Schltdl.	0	14	6.44	3	15	2	1.07	75.29 ± 52.59	0.53 ± 0.92	4.7	0.2
Crotalaria incana L.	0	14	10.74	3	27	5	1.93	15.9 ± 16.08	0.21 ± 0.34	1.3	0.2
Oplismenus hirtellus (L.) P. Beauv.	0.07	15	1.66	1	23	5	1.53	22.13 ± 15.4	0.18 ± 0.37	2.1	0.2
Lopezia macrophylla Benth.	0	15	6.44	3	20	3	1.33	20.8 ± 14.55	0.08 ± 0.13	2.4	0.2
Dioscorea mexicana Scheidw.	0	15	1.66	1	33	5	2.2	13.47 ± 6.73	0.09 ± 0.05	1.7	0.2
Pseuderanthemum sp. 1	0.07	15	5.48	2	21	4	1.4	21.8 ± 9.47	0.05 ± 0.03	2.4	0.2

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Sigesbeckia sp. 1	0	15	6.44	3	22	3	1.47	12.67 ± 4.3	0.06 ± 0.05	2.7	0.2
Bidens triplinervia Kunth	0	15	6.44	3	31	5	2.07	27.73 ± 11.32	0.3 ± 0.35	4.4	0.2
Tradescantia andrieuxii C.B. Clarke	0.06	16	1.66	1	26	3	1.63	17.38 ± 7.61	0.24 ± 0.14	3.3	0.2
Costus sp.	0.06	17	6.44	3	47	9	2.76	13 ± 7.44	0.18 ± 0.27	4.1	0.2
Bomarea edulis (Tussac) Herb.	0.06	17	5.48	2	46	14	2.71	72.88 ± 50.32	0.18 ± 0.23	3	0.2
Perymenium ghiesbreghtii B.L. Rob. & Greenm.	0.06	17	1.66	1	27	3	1.59	17.29 ± 13.33	0.05 ± 0.07	1.5	0.2
Arrabidaea mollissima (Kunth) Bureau & K. Schum.	0	20	10.6	5	21	2	1.05	42.9 ± 26.74	0.11 ± 0.09	6	0.2
Cnidosculus aconitifolius (Mill.) I.M. Johnst.	0	22	10.43	6	23	2	1.05	176.14 ± 171.63	3.19 ± 10.77	17.1	0.2
Jatropha curcas L.	0.09	22	10.41	7	28	2	1.27	80.5 ± 79.26	1.3 ± 2.84	10.4	0.2
Ruellia nudiflora (Engelm. & A. Gray) Urb.	0.14	22	7.02	4	42	5	1.91	19.09 ± 15.79	0.1 ± 0.12	3.3	0.2
Gouania stipularis DC.	0.09	22	7.49	5	29	4	1.32	57.8 ± 60.32	0.44 ± 0.81	2.1	0.2
Gouania lupuloides (L.) Urb.	0.18	28	6.44	3	47	6	1.68	72.6 ± 52.75	0.42 ± 0.59	2.2	0.2
Asteraceae sp. 4	0.17	29	10.57	8	59	6	2.03	21.41 ± 17.73	0.16 ± 0.15	1.9	0.2

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Smallanthus oaxacanus (Sch. Bip. ex Klatt) H. Rob.	0.03	32	5.48	2	59	6	1.84	19.03 ± 7.53	0.18 ± 0.2	2.7	0.2
Asplenium arcanum A.R. Sm.	0.09	33	10.8	4	115	10	3.48	27.64 ± 18.63	0.38 ± 0.53	1.2	0.2
Eupatorium sp. 1	0.03	36	2.87	2	48	8	1.33	13.58 ± 4.87	0.32 ± 1.58	1.7	0.2
Tragia nepetifolia Cav.	0	37	2.87	2	48	3	1.3	22.38 ± 14.01	0.2 ± 0.17	2.3	0.2
Barleria oenotheroides Dum. Cours.	0.15	39	7.02	4	56	4	1.44	63.13 ± 34.48	0.23 ± 0.36	4.4	0.2
Desmodium barbatum (L.) Benth.	0.05	44	1.66	1	163	13	3.7	86.41 ± 34.07	0.73 ± 0.98	3.4	0.2
Cyclanthaceae sp. 1	0	46	10.41	7	74	14	1.61	22.87 ± 10.18	0.12 ± 0.33	3.7	0.2
Centrosema molle Mart. ex Benth.	0.11	65	10.57	8	131	11	2.02	34.22 ± 40.85	0.29 ± 0.57	2	0.2
Acacia cornigera (L.) Willd.	0.06	70	10.57	8	80	3	1.14	74.7 ± 102.91	2.53 ± 7.62	7.3	0.2
Mascagnia sepium (A. Juss.) Griseb.	0.19	93	1.66	1	126	4	1.35	17.82 ± 8.2	0.12 ± 0.18	3	0.2
Senna guatemalensis var. *chiapensis* (Standl.) H.S. Irwin & Barneby	0.17	96	10.43	6	134	6	1.4	82.96 ± 76.67	0.91 ± 2.22	5.1	0.2

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Quercus sp. 1	0.15	107	10.41	7	221	10	2.07	91.64 ± 95.38	1.68 ± 3.76	7.6	0.2
Ruellia inundata Kunth	0.17	109	4.76	4	220	12	2.02	45.21 ± 23.32	0.24 ± 0.51	2.9	0.2
Acacia pennatula (Schltdl. & Cham.) Benth.	0.05	109	13.52	13	127	6	1.17	78.71 ± 98.99	1.47 ± 3.58	7.4	0.2
Sida acuta Burm. f.	0.21	52	10.43	6	60	4	1.15	16.46 ± 11.39	0.09 ± 0.11	2.4	0.244
Calea urticifolia (Mill.) DC.	0.21	62	10.43	6	128	13	2.06	41.97 ± 32.12	0.81 ± 1.95	2.8	0.244
Acalypha schlumbergeri Müll. Arg.	0.22	67	10.43	6	101	6	1.51	46.52 ± 40.59	0.29 ± 0.72	2.5	0.278
Macroptilium atropurpureum (Moc. & Sesse ex DC.) Urban	0.23	26	3.86	3	27	2	1.04	47.42 ± 35.61	3.77 ± 9.34	2.3	0.305
Cardiospermum corindum L.	0.24	17	10.43	6	25	3	1.47	31.53 ± 19.84	0.27 ± 0.39	2.4	0.328
Canna indica L.	0.24	21	1.66	1	38	4	1.81	32.4 ± 20.75	0.34 ± 0.27	8.3	0.328
Liabum andrieuxii (DC.) Benth. & Hook. f.	0.24	84	10.9	9	171	12	2.04	136.02 ± 112.63	2.91 ± 5.39	15.4	0.328
Licania arborea Seem.	0.5	2	1.66	1	3	2	1.5	102 ± 60.81	2.1 ± 1.91	16.3	0.35
Senna atomaria (L.) H.S. Irwin & Barneby	0.5	2	1.66	1	2	1	1	57 ± 60.81	0.57 ± 0.75	5.5	0.35

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Piper berlandieri C. DC.	0.5	2	1.66	1	9	5	4.5	40 ± 9.9	0.37 ± 0.16	4.1	0.35
Zanthoxylum ferrugineum Radlk. ex Donn. Sm.	0.5	2	1.66	1	2	1	1	23.5 ± 9.19	0.05 ± 0.02	4.5	0.35
Salix humboldtiana Willd.	0.5	2	1.66	1	2	1	1	490 ± 0	25.92 ± 10	66	0.35
Ficus maxima Mill.	0.5	2	2.87	2	2	1	1	27.5 ± 24.75	0.04 ± 0.03	4	0.35
Wimmeria mexicana (DC.) Lundell	0.5	2	1.66	1	2	1	1	16 ± 4.24	0.02 ± 0.02	3.5	0.35
Psidium guajava L.	0.5	4	10.8	4	10	5	2.5	82 ± 79.68	3.35 ± 4.73	10.4	0.35
Ficus palmeri S. Watson	0.5	4	1.66	1	4	1	1	56.7 ± 30.78	0.56 ± 0.49	8.8	0.35
Swietenia sp. 1	0.5	4	1.66	1	5	2	1.25	18.75 ± 14.31	0.32 ± 0.53	5	0.35
Gaudichaudia albida Schltdl. & Cham.	0.33	6	1.66	1	6	1	1	40.2 ± 14.29	0.24 ± 0.16	1.3	0.35
Psychotria acuminata Benth.	0.25	8	7.02	4	13	4	1.63	129.25 ± 129.9	6.52 ± 15.11	11.1	0.35
Bidens sp. 1	0.25	8	10.8	4	11	2	1.38	48.1 ± 26.98	0.23 ± 0.27	4.4	0.35
Cucurbita sp. 2	0.38	8	1.66	1	11	3	1.38	34.38 ± 28.81	0.21 ± 0.49	4	0.35
Acalypha mollis Kunth	0.38	8	2.87	2	9	2	1.13	39.5 ± 22.37	0.06 ± 0.07	5.4	0.35
Desmodium caripense (Kunth) G. Don	0.33	9	6.44	3	12	2	1.33	46 ± 62.02	0.2 ± 0.28	9.2	0.35

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Tithonia diversifolia (Hemsl.) A. Gray	0.4	10	2.87	2	66	18	6.6	45.3 ± 11.05	1.06 ± 0.64	5.9	0.35
Psychotria chlorobotrya Standl.	0.36	11	1.66	1	15	4	1.36	42.55 ± 21.44	0.16 ± 0.14	4.2	0.35
Picrasma sp. 1	0.25	12	1.66	1	23	3	1.92	102.17 ± 86.32	2.55 ± 3.35	10.8	0.35
Arrabidea chica (Bonpl.) B. Verl.	0.29	14	2.87	2	33	5	2.36	93.29 ± 48.34	3.32 ± 5.55	7.9	0.35
Dioscorea pringlei B.L. Rob.	0.31	16	6.44	3	18	2	1.13	38.75 ± 28.83	0.07 ± 0.06	1.4	0.35
Perymenium macrocephalum Greenm.	0.33	18	3.86	3	28	4	1.56	47.11 ± 29.43	1.5 ± 5.51	4.1	0.35
Swietenia humilis Zucc.	0.25	20	10.9	9	23	2	1.15	53.9 ± 33.05	0.31 ± 0.31	5.6	0.35
Apoplanesia paniculata C. Presl	0.32	71	11.4	10	85	6	1.2	39.55 ± 40.65	0.17 ± 0.36	3.1	0.35
Viburnum hartwegii Benth.	0.38	13	10.74	3	13	1	1	19.54 ± 13.82	0.06 ± 0.05	3.5	0.355
Marsdenia trivirgulata Bartlett	0.32	50	10.41	7	70	4	1.4	38.9 ± 29.65	0.16 ± 0.16	1.7	0.364
Arrabidea sp. 1	0.29	17	10.43	6	33	8	1.94	66.35 ± 52.22	0.79 ± 1.51	5.1	0.365
Aphelandra scabra (Vahl) Sm.	0.29	68	10.57	8	107	8	1.57	55.85 ± 36.06	0.33 ± 0.49	4.8	0.365

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Lantana camara L.	0.37	27	10.43	6	87	13	3.22	61.63 ± 42.82	0.6 ± 0.67	4	0.365
Thouinidium decandrum (Bonpl.) Radlk.	0.29	7	5.48	2	10	3	1.43	204.14 ± 167.94	13.99 ± 18.55	36.3	0.369
Piper umbellatum L.	0.35	17	5.48	2	33	4	1.94	52.88 ± 44.34	0.49 ± 0.57	4.6	0.37
Sambucus sp. 1	1	2	5.48	2	3	2	1.5	29 ± 15.56	0.04 ± 0.02	2.3	0.37
Russelia floribunda Kunth	1	5	5.48	2	14	5	2.8	93 ± 45.22	1.86 ± 1.8	5.6	0.37
Casearia corymbosa Kunth	0.27	26	10.43	6	42	9	1.62	64.92 ± 108.26	1.64 ± 4.88	8.6	0.39
Chusquea simplicifolia Munro ex Hemsl.	0.44	32	2.87	2	99	15	3.09	80.19 ± 86.63	3.84 ± 16.69	5.2	0.42
Fleischmannia hymenophylla (Klatt) R.M. King & H. Rob.	0.43	7	5.48	2	24	8	3.43	70.14 ± 39.08	1.49 ± 2.32	5.5	0.43
Ageratina sp. 1	0.47	15	2.87	2	18	3	1.2	38.93 ± 31.61	0.43 ± 0.32	3.1	0.448
Calea colimensis McVaugh	0.45	47	10.41	7	91	8	1.94	83.43 ± 56.22	0.51 ± 0.85	4.1	0.449
Sida rhombifolia L.	0.64	11	2.87	2	16	3	1.45	33.91 ± 14.1	0.29 ± 0.31	6	0.45
Desmodium incanum DC.	0.58	12	3.86	3	14	2	1.17	27.25 ± 11.23	0.11 ± 0.11	1.7	0.45

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Chromolaena glaberrima (DC.) R.M. King & H. Rob.	0.69	16	1.66	1	32	4	2	72.69 ± 36.87	0.31 ± 0.24	4.3	0.45
Caesalpinia mexicana A. Gray	0.81	16	1.66	1	17	2	1.06	55.5 ± 36.35	0.15 ± 0.16	2.9	0.45
Justicia caudata A. Gray	0.28	131	10.41	7	305	12	2.33	31.44 ± 17.96	0.24 ± 0.34	3.2	0.45
Lantana hirta Graham	0.56	9	2.87	2	10	2	1.11	77.33 ± 54.54	0.28 ± 0.38	6.6	0.45
Machaerium acanthothyrsum Pittier	0.67	6	1.66	1	9	3	1.5	65.83 ± 30.73	0.37 ± 0.37	5.7	0.453
Erythrina goldmanii Standl.	0.5	6	2.87	2	6	1	1	46.5 ± 42.22	0.09 ± 0.06	3.8	0.453
Bernardia mexicana (Hook. & Arn.) Müll. Arg.	0.5	6	6.44	3	9	2	1.5	53.5 ± 25.21	0.37 ± 0.29	4.1	0.453
Bouvardia ternifolia (Cav.) Schltdl.	0.64	25	10.8	4	53	5	2.12	51.6 ± 42.19	0.39 ± 0.6	3.4	0.455
Calea sp. 1	0.5	8	6.44	3	16	4	2	135.12 ± 88.5	0.82 ± 0.65	5.9	0.456
Lasiacis ruscifolia (Kunth) Hitchc.	0.28	96	10.41	7	239	9	2.49	58.9 ± 50.66	0.7 ± 1.14	2.5	0.457
Vernonia leiocarpa DC.	0.26	100	12.01	11	219	12	2.19	95.46 ± 73.3	1.71 ± 3.35	7.9	0.48
Acalypha burquezii V.W. Steinm. & Felger	0.5	18	5.48	2	21	2	1.17	22.5 ± 14.04	0.13 ± 0.09	3.4	0.48
Quercus sp. 3	0.5	18	5.48	2	25	3	1.39	33.5 ± 32.55	0.26 ± 0.58	4.3	0.48

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Perymenium sp. 1	0.76	29	5.48	2	52	4	1.79	62.52 ± 39.94	0.25 ± 0.28	4.8	0.48
Salvia mexicana L.	0.56	16	10.41	7	20	3	1.25	73 ± 39.14	0.12 ± 0.13	4.2	0.49
Senna argentea (Kunth) H.S. Irwin & Barneby	1	2	1.66	1	2	1	1	70 ± 56.57	2.98 ± 3.11	12.5	0.5
Verbesina hypoglauca Sch. Bip. ex Klatt	1	2	1.66	1	7	6	3.5	71 ± 69.3	1.16 ± 1.63	6.9	0.5
Russelia sarmentosa Jacq.	1	2	1.66	1	3	2	1.5	65 ± 21.21	1.46 ± 1.58	6.3	0.5
Marsdenia coulteri Hemsl.	0.67	3	1.66	1	3	1	1	13 ± 4.36	0.01 ± 0.01	3.3	0.5
Grajalesia ferruginea Miranda	0.67	3	1.66	1	4	2	1.33	19.67 ± 13.43	0.15 ± 0.14	8	0.5
Ficus sp. 1	1	3	1.66	1	3	1	1	25.67 ± 9.29	0.13 ± 0.11	14.3	0.5
Cytharexylum hintoni Moldenke	0.67	3	2.87	2	6	3	2	132.33 ± 76.79	0.37 ± 0.55	5.2	0.5
Senecio salignus DC.	1	3	1.66	1	23	14	7.67	133.33 ± 30.55	5.32 ± 2.39	14.7	0.5
Acalypha schlechtendaliana var. *mollis* Müll. Arg.	1	3	2.87	2	6	3	2	66.33 ± 72.54	0.43 ± 0.3	17.5	0.5
Trichillia sp. 2	0.67	3	1.66	1	3	1	1	94 ± 80.67	0.06 ± 0.08	7.7	0.5

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Malpighia sp. 1	1	4	1.66	1	10	3	2.5	46.25 ± 11.09	0.32 ± 0.24	3.2	0.5
Acalypha tricholoba Müll. Arg.	0.75	4	5.48	2	5	2	1.25	77.25 ± 49.98	4.8 ± 8.36	4.4	0.5
Liabum caducifolium B.L. Rob. & Bartlett	0.6	5	10.74	3	6	2	1.2	234 ± 122.19	2.64 ± 2.68	22.8	0.5
Luehea candida (Moc. et Sessé ex DC.) Mart.	0.8	5	2.87	2	8	3	1.6	46.6 ± 16.89	0.3 ± 0.32	6	0.5
Critonia sp.	0.36	14	10.6	5	23	3	1.64	108.5 ± 69	1.04 ± 1.32	9	0.5
Coccoloba barbadensis Jacq.	0.31	16	6.44	3	34	14	2.13	105.19 ± 71.69	2.77 ± 4.22	13	0.5
Eupatorium collinum DC.	0.35	20	10.41	7	48	7	2.4	146.25 ± 118.16	2.38 ± 4.86	9.4	0.5
Heliocarpus reticulatus Rose	0.39	23	10.9	9	31	6	1.35	128.7 ± 115.41	1.45 ± 3.16	11.3	0.5
Lysiloma acapulcense (Kunth) Benth.	0.31	29	12.73	12	35	5	1.21	112.66 ± 128.5	2.65 ± 6.79	13.4	0.5
Lasianthea fruticosa K.M. Becker	0.33	55	7.02	4	207	14	3.76	115.62 ± 66.65	1.27 ± 1.6	5.3	0.5
Inga edulis Mart.	0.6	15	5.62	5	19	4	1.27	35.8 ± 29.87	0.33 ± 0.44	7	0.5
Celtis iguanaea (Jacq.) Sarg.	0.42	12	7.02	4	31	7	2.58	99.83 ± 160.75	2.3 ± 3.97	5.5	0.54

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Desmodium cinereum Poepp. ex Griseb.	0.44	25	7.02	4	77	15	3.08	66.6 ± 53.65	0.74 ± 1.65	3.9	0.57
Calliandra houstoniana (Mill.) Standl.	0.48	33	8.52	7	47	5	1.42	94.45 ± 72.43	1.02 ± 1.53	6.7	0.59
Mimosa albida Humb. & Bonpl. ex Willd.	0.5	26	11.4	10	57	7	2.19	50.81 ± 33.02	1.76 ± 6.03	2.9	0.6
Trixis inula Crantz	0.51	47	10.9	9	105	22	2.23	78.81 ± 45.2	1.08 ± 1.77	6.3	0.6
Montanoa tomentosa subsp. *xanthiifolia* (Sch. Bip. ex K. Koch) V.A. Funk	0.51	47	10.8	4	83	9	1.77	98.72 ± 101.22	1.12 ± 1.83	8.4	0.6
Machaerium chiapense Brandegee	0.53	40	7.97	6	65	4	1.63	114.2 ± 122.66	1.71 ± 3.74	12.3	0.605
Siphonoglossa sessilis (Jacq.) D.Gibson	0.69	134	5.48	2	158	4	1.18	20.57 ± 10.47	0.1 ± 0.13	2.1	0.69
Croton alamosanum N.E.Rose	0.83	12	3.86	3	20	5	1.67	71.83 ± 48.6	0.59 ± 1.02	4.6	0.7
Coursetia mexicana S. Watson	0.64	14	6.44	3	19	3	1.36	47.86 ± 27.3	0.26 ± 0.32	3.5	0.7
Crusea setosa (M. Martens & Galeotti) Standl. & Steyerm.	0.76	21	6.44	3	35	6	1.67	42.1 ± 21.38	0.2 ± 0.5	5.6	0.7
Acalypha schiedeana Schltdl.	0.75	24	10.43	6	30	3	1.25	65.62 ± 79.74	0.92 ± 3.51	5.7	0.7

Especie	Rm?	Regs.	Dist.	# sitios	# tallos	Max # tallos	Media # tallos	Alt prom (± 1 S.D.)	Cob prom (± 1 S.D.) m^2	Media diam tallos (mm)	GUI
Guazuma ulmifolia Lam.	0.68	25	10.43	6	32	3	1.28	74.28 ± 51.38	0.91 ± 1.41	6.4	0.7
Quercus peduncularis Née	0.89	27	2.87	2	40	4	1.48	59.44 ± 70.36	0.77 ± 3.03	4.9	0.7
Verbesina perymenioides Shult - Bi. P.	0.86	35	7.49	5	74	7	2.11	185.26 ± 120.87	2.73 ± 3.57	13.9	0.7
Croton pseudoniveus Lundell	0.8	35	10.6	5	51	4	1.46	66.23 ± 48.67	0.5 ± 0.98	5	0.7
Acalypha villosa Jacq.	0.72	65	8.52	7	194	21	2.98	86.38 ± 77.21	1.13 ± 1.77	5.8	0.7
Malpighia hintonii Bullock	0.43	136	10.57	8	292	9	2.15	75 ± 63.22	1.11 ± 2.55	5.7	0.77
Acalypha leptopoda Müll. Arg.	0.55	110	10.43	6	325	16	2.95	75.12 ± 47.68	0.94 ± 1.58	3.3	0.80
Calea ternifolia Kunth	0.59	414	12.01	11	1051	13	2.54	84.75 ± 57.3	0.85 ± 2.6	4.9	0.835

ANEXO C

Tabla C.1 Resultados de los análisis bromatológicos para establecer contenidos de compuestos anti-nutricionales. *Análisis cuantitativo: M. Abund = Muy abundante; Abund. = Abundante; Mod. = Moderado; Esc. = Escaso; Neg. = Negativo.

Especie	Taninos condensables (g/100 g)	Saponinas	Glucósidos cianogénicos*	Alcaloides (Dragendorff)*	Alcaloides (Meyer*)	Alcaloides (Wagner)*
Calliandra houstoniana	NA	Esc.	Neg.	Neg.	Neg.	Neg.
Desmodium barbatum	NA	Esc.	Neg.	Neg.	Neg.	Mod.
Acalypha schiedeana	23.26	Esc.	Neg.	Esc.	Neg.	Mod.
Desmodium cinereum	NA	Esc.	Neg.	Mod.	Neg.	Mod.
Inga edulis	0.31	Neg.	Neg.	Mod.	Neg.	M. Abund.
Acalypha leptopoda	0	Neg.	Neg.	Scarc.	Esc.	M. Abund.
Critonia sp.	0.16	Neg.	Neg.	Scarc.	Mod.	M. Abund.
Chusquea simplicifolia	0	Neg.	Neg.	Mod.	Mod.	Abund.
Thouinidium decandrum	0.26	Mod.	Neg.	M. Abund.	Neg.	M. Abund.
Mimosa albida	NA	Neg.	Neg.	M. Abund.	Neg.	M. Abund.
Salix bonplandiana	0.27	Neg.	Neg.	M. Abund.	Neg.	M. Abund.
Montanoa tomentosa	0	Neg.	Neg.	Esc.	Abund.	M. Abund.
Verbesina auriculata	0	Esc.	Neg.	M. Abund.	Mod.	Abund.
Senecio salignus	0	Esc.	Neg.	M. Abund.	Mod.	M. Abund.
Lasiacis ruscifolia .	NA	Neg.	Neg.	Abund.	M. Abund.	Abund.
Verbesina perymenioides	0	Mod.	Neg.	M. Abund.	Mod.	M. Abund.
Sida rhombifolia	0	Neg.	Neg.	M. Abund.	M. Abund.	Abund.
Machaerium chiapense	0	Neg.	Neg.	M. Abund.	M. Abund.	M. Abund.
Calea ternifolia	NA	Neg.	Neg.	M. Abund.	M. Abund.	M. Abund.

Especie	Taninos condensables (g/100 g)	Saponinas	Glucósidos cianogénicos*	Alcaloides (Dragendorff)*	Alcaloides (Meyer*)	Alcaloides (Wagner)*
Swietenia humilis	NA	Esc.	Neg.	M. Abund.	M. Abund.	M. Abund.
Acalypha villosa	NA	Neg.	Neg.	M. Abund.	M. Abund.	M. Abund.
Centrosema molle	NA	Neg.	Neg.	M. Abund.	M. Abund.	M. Abund.
Croton pseudoniveus	NA	Esc.	Neg.	M. Abund.	M. Abund.	M. Abund.
Eupatorium collinum	NA	Neg.	Neg.	M. Abund.	M. Abund.	M. Abund.
Piper berlandieri	0	Neg.	Neg.	M. Abund.	M. Abund.	M. Abund.
Siphonoglossa sessilis	NA	Esc.	Neg.	M. Abund.	M. Abund.	M. Abund.