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Tesis Doctoral

Recursos fitogenéticos para la alimentación en la Barranca del Río Santiago (Jalisco, México)

Plant genetic resources for food in the Barranca del Río Santiago (Jalisco, Mexico)

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TITULO: *RECURSOS FITOGENÉTICOS PARA LA ALIMENTACIÓN EN LA BARRANCA DEL RIO SANTIAGO (JALISCO, MÉXICO)*

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TÍTULO DE LA TESIS: Recursos fitogenéticos para la alimentación en la Barranca del Río Santiago (Jalisco, México)

DOCTORANDO/A: Martin Pedro Tena Meza

INFORME RAZONADO DEL DIRECTOR DE LA TESIS

El doctorando presenta y desarrolla un amplio estudio experimental de los recursos fitogenéticos para la alimentación en la Barranca del Río Santiago (Jalisco, México) a partir de un amplio trabajo de campo. La metodología empleada es correcta e incorpora técnicas novedosas de análisis estadístico y analítico, en particular orientadas a los estudios etnobotánicos y de variabilidad genética. La tesis aporta una visión aplicada de la conservación de recursos genéticos en México.

El resultado es original en el contexto de los estudios fitogenéticos aplicados a la alimentación, al incorporar varios factores y las posibles relaciones en el éxito final de programas de domesticación de especies. La tesis ha dado lugar a las siguientes publicaciones:

Revistas indexadas:

Tena Meza, M., Navarro-Cerrillo, R.M. & Brizuela Torres, D. Distribution of Malpighia mexicana in Mexico and its implications for Barranca del Río Santiago. J. For. Res. (2020). https://doi.org/10.1007/s11676-020-01157-z

Capítulo de libro

Tena, M., Navarro-Cerrillo, R., Ávila R., Villavicencio, R. (2019) 'Wild phytogeneticresourcesforfood in the Barranca del Río Santiago, Mexico: A Firstapproach to sustainability. InCollinson, P., Young, I., Antal, L., Macbeth, H. (Ed.) Food and Sustainability in theTwenty-first Century. BerghahnBooks. ISBN 978-1- 78920-237-3 hardback; ISBN 978-1-78920-238-0 ebook. https://www.berghahnbooks.com/title/CollinsonSustainability

Revista arbitrada

Ávila R., M. Tena, M. Ocegueda 2016. Sharing in death In Ávila R., et al. 2016. Sharing food. Colección Estudios del Hombre 35: 215-235. Universidad de Guadalajara. México. ISBN 978-607-742-555-7 Disponible en: http://www.publicaciones.cucsh.udg.mx/pperiod/esthom/pdfs/35_Sharing_food.pdf.

Jiménez, L., Barrientos, L., Tena, M. (2020) Caracterización Fisicoquímica y Fitoquímica de frutos de Sapuche (RandialaevigataStandl.). e-CUCBA, 13: 30-39.

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Tena, M., Ávila, R., Navarro-Cerrillo, R. (2018) Tequila, heritage and tourism: Is the Agave landscape sustainable? In Xavier-Medina, F., Tresserras, J., (Ed.) Food, Gastronomy and Tourism. Social and Cultural Perspectives. Estudios del hombre 38:49-68. Disponible en: http://www.publicaciones.cucsh.udg.mx/pperiod/esthom/pdfs/38_Food_Gastronomy_Tourism.pdf.

Tena, M., Ávila, R., Jiménez, C. (2015) ¿En qué sentido es el tequila un patrimonio? In Ávila, R. y Tena, M. (Cord.) Biodiversidad, sostenibilidad y patrimonios alimentarios. Estudios del hombre 34: 129-142. Disponible en: http://www.publicaciones.cucsh.udg.mx/pperiod/esthom/pdfs/esthomBiodiversidad_sostenibilidad_patrimonios_alimentarios.pdf

Por otro lado, se han presentado 4 comunicaciones orales en Congresos Internacionales.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 24 de junio de 2020

Firma del director

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Fdo.: Rafael Mª Navarro-Cerrillo

Dedico esta tesis

A la vida que me ha dado tanto.

A mis padres (†) quienes siempre se preocuparon por la educación de sus hijos.

A mi esposa y a nuestros hijos y nietos que han sido la motivación para emprender nuevos proyectos y que soportaron estoicamente la distancia y falta de atención durante el dilatado proceso de la tesis.

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Recursos fitogenéticos para la alimentación en la Barranca del Río Santiago (Jalisco, México)

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RESUMEN

El objetivo de esta tesis fue evaluar el estado que guardan los recursos fitogenéticos para la alimentación en la Barranca del Río Santiago, esta se localiza en el occidente de México, en la ecorregión de los cañones occidentales, lugar donde coinciden el clima cálido subhúmedo y las selvas cálido secas. Este tipo de vegetación durante la temporada de lluvias se encuentra verde y densa en comparación con la temporada seca cuando la vegetación pierde su follaje y presenta un aspecto gris y yermo.

Duarante la exploración etnobotánica realizada en las 72 338 ha que forman la zona de estudio, los campesinos reportaron 196 taxa con uso alimenticio, que representan 52 familias botánicas. Las más representativas son: Fabaceae, Cactaceae, Solanaceaey Anacardiaceae. La mayor parte de los registros (84%) corresponde a plantas nativas y se distribuyen en siete ambientes diferentes de acuerdo con el tipo de manejo que realizan los campesinos, la mayor parte crecen de manera silvestre (43%), en los traspatios (15%) y en las huertas de riego (14%). La estructura vegetal que más se consume son los frutos (54%), y los tipos de alimento más frecuentes son las frutas (33,85%), los vegetales (23,2%) y los bocadillos (19,4%). El número total de plantas alimenticias registradas es similar o superior al de otras zonas del país con condiciones semejantes.

A partir del análisis del inventario de recursos fitogenéticos se definió la estrategia para conocer el tipo de relaciones y las condiciones que presentan los recursos fitogeneticos para la alimentación y el conocimiento tradicional que conservan sus pobladores sobre los mismos. Se eligió trabajar con: (a) el *grupo de especies silvestres* que pudieran tener mayor impacto en la conservación de la zona de estudio y en el beneficio para sus pobladores; (b) seleccionar *una especie silvestre en particular*, que pudiera servir a manera de *especie paraguas* para la conservación de la zona de estudio y sus recursos fitogénicos; (c) un *cultivar nativo marginal*; y (d) un *cultivar nativo en expansión* (*cultivo industrial*).

No obstante que los rancheros de la barranca reconocen una gran cantidad de hierbas comestibles (19% del total) y que tienen una amplia tradición de consumo, este tipo de plantas es cada vez más escaso y difícil de consumir debido al uso de pesticidas en los campos de cultivo; por lo que se consideró que las plantas leñosas (árboles y arbustos, que integran el 52% del total de los registros) son el grupo de especies comestibles más importantes desde el punto de vista ecológico, económico y social. Este recurso se presenta en el interior de la

Barraca como un grupo heterogéneo, con diferente grado de diversidad, nivel de conservación, distribución y uso. Se sugiere la propagación y plantación de estas especies para la regeneración de áreas perturbadas de la Barranca con lo cual se pueden mitigar los efectos del cambio climático por los beneficios ambientales que proporcionan además de contribuir a la reducción de la pobreza y contribuir a la seguridad alimentaria de los pobladores. De este este grupo de especies leñosas se seleccionó a *Malpigia mexicana* A. Juss, un arbusto o árbol pequeño con amplia tradición de uso alimenticio en la zona de estudio y otras regiones de México, la cual tiene un alto potencial como *especie paraguas*, dada su afinidad taxonómica y cultural con el cultivo de Acerola. Para esta especie se elaboró un modelo predictivo de distribución a nivel nacional en el que se observa que la mayor probabilidad de ocurrencia es afín a la distribución de las selvas cálido secas en la depresión del Río Balsas y en el Occidente de México, incluyendo la Barranca del Río Santiago.

Además de la siembra de maíz, existen dos cultivos tradicionales difundidos en la Barranca: el cultivo de *Spondias purpurea* L. (un cultivo marginal en descenso) y el cultivo de *Agave tequilana* F.A.C. Weber (un cultivo industrial en expansión). De manera independiente para cada una de estas especies, se realizó el estudio agroecológico de sus plantaciones y su distribución en la zona de estudio. En el caso de la ciruela mexicanase registra el manejo de siete cultivares en 871 ha plantadas con *S. purpurea,* y se corrobora que el cañón reúne los requerimientos del cultivo en cuanto a clima y suelo. No obstante su cultivo es poco rentable y la mayor ganancia queda en manos de los intermediarios, aun así, este representa para algunas familias una breve temporada para trabajar y obtener algunos ingresos sin salir de su localidad. Por otro lado, en al caso del agave utilizado como materia prima para la elaboración del tequila (*A. tequilana*), se localizaron 1017,58 ha plantadas en la zona de estudio, de las cuales el 96% se localiza dentro del área que cubre la declaratoria de *El Paisaje Agavero y las Antiguas Instalaciones industriales de Tequila* como Patrimonio Cultural de la Humanidad. Sin embargo, a pesar de que entre los objetivos de la declaratoria existe la preservación del entorno natural, el actual método de cultivo del agave en el interior de la Barranca no contribuye a ello, la plantación en pendientes pronunciadas y el manejo del monocultivo implica el uso de grandes cantidades de agroquímicos y el desplazamiento de otras especies de agave originalmente incluidas en la norma oficial mexicana para la elaboración del tequila. Además en la zona de estudio se presentan altas temperaturas nocturnas que reducen el potencial de la planta para la producción de los azucares necesarios para la elaboración de la bebida, cuestión que es minimizada en la relación costo-beneficio del sistema de producción.

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Palabras clave: Etnobotánica, recursos fitogenéticos, alimentación, Barranca del Río Santiago, México.

SUMMARY

The objective of this thesis was to assess the state of plant genetic resources for food in the Barranca del Río Santiago, it is located in western Mexico, in the ecoregion of the western canyons, place where the warm sub-humid climate and the hot dry forests coincide. This type of vegetation during the rainy season is green and dense compared to the dry season when the vegetation loses its foliage and appears gray and barren.

During the ethnobotanical exploration carried out in the 72 338 ha that makes up the study area, farmers reported 196 taxa with food use, representing 52 botanical families. The most representative are Fabaceae, Cactaceae, Solanaceae, and Anacardiaceae. Most of the records (84%) correspond to native plants and are distributed in seven different environments according to the type of management carried out by the farmers, most of them grow wild (43%), in the backyards (15 %) and the irrigation gardens (14%). The most consumed plant structure is fruits (54%), and the most frequent types of food are fruits (33,85%), vegetables (23,2%) and sandwiches (19,4%). The total number of registered food plants is similar to or higher than in other areas of the country with similar conditions.

Based on the analysis of the inventory of plant genetic resources, the strategy was defined to know the type of relationships and the conditions that plant genetic resources present for food and the traditional knowledge that their inhabitants have about them. It was chosen to work with: (a) the group of wild species that could have the greatest impact on the conservation of the study area and the benefit to its inhabitants; (b) select a particular wild species that could serve as an umbrella species for the conservation of the study area and its phytogenetic resources; (c) a marginal native cultivar; and (d) an expanding native cultivar (industrial cultivation).

Even though the ranchers of the ravine recognize a large number of edible herbs (19% of the total) and that they have a long tradition of consumption, this type of plants is increasingly scarce and difficult to consume due to the use of pesticides in the cultivation fields; therefore, woody plants (trees and shrubs, which make up 52% of the total records) were considered to be the most important group of edible species from the ecological, economic and social point of view. This resource is presented in the interior of the Barraca how a heterogeneous group,

with different degrees of diversity, level of conservation, distribution, and use. The propagation and planting of these species are suggested for the regeneration of disturbed areas of the Barranca, with which the effects of climate change can be mitigated due to the environmental benefits they provide, in addition to contributing to poverty reduction and contributing to food security of the settlers. From this group of woody species, *Malpigia mexicana* A. Juss was selected, a shrub or small tree with a long tradition of food use in the study area and other regions of Mexico, which has a high potential as an umbrella species, given its taxonomic and cultural affinity with the culture of Acerola. For this species, a predictive distribution model was developed at the national level, in which it is observed that the highest probability of occurrence is related to the distribution of the dry warm forests in the depression of the Río Balsas and Western of Mexico, including the Barranca of the Santiago River.

In addition to planting corn, there are two traditional crops widespread in the Barranca: the culture of *Spondias purpurea* L. (a declining marginal crop) and the culture of *Agave tequilana* F.A.C. Weber (an expanding industrial crop). Independently for each of these species, the agroecological study of their plantations and their distribution in the study area was carried out. In the case of the Mexican plum, the management of seven cultivars in 871 ha planted with *S. purpurea* is recorded, and it is corroborated that the canyon meets the cultivation requirements in terms of climate and soil. Despite its cultivation is not profitable and the greatest profit remains in the hands of the intermediaries, even so, this represents for some families a brief season to work and earn some income without leaving their town. On the other hand, in the case of the agave used as raw material for the production of tequila (*A. tequilana*), 1017,58 ha were planted in the study area, of which 96% are located within the area covered the declaration of The Agave Landscape and the Old Industrial Facilities of Tequila as Cultural Heritage of Humanity. However, despite the preservation of the natural environment among the objectives of the declaration, the current method of cultivation of agave in the interior of the Barranca does not contribute to this, planting on steep slopes and managing monoculture involves the use of large quantities of agrochemicals and the displacement of other agave species originally included in the official Mexican standard for the production of tequila. Also, in the study area, there are high night temperatures that reduce the potential of the plant for the production of the sugars necessary for the elaboration of the drink, an issue that is minimized in the cost-benefit ratio of the production system.

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Keywords: Ethnobotany, plant genetic resources, food, Barranca del Río Santiago, Mexico.

Capítulo 1. Introducción General

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El reconocimiento del patrimonio natural como elemento fundamental para lograr el desarrollo sustentable en el planeta es primordial, más aún, ahora que el cambio climático, la pérdida de los ecosistemas y su diversidad, la reducción, escasez y contaminación de recursos de tierra y agua, entre otros problemas de tipo ambiental, minimizan la posibilidad de incrementar la producción de alimentos en el mundo. El hambre y la malnutrición crónicas afectan actualmente a más de mil millones de personas y en 2050, según las previsiones, la población mundial habrá alcanzado los 9200 millones de habitantes. Para alimentarlos a todos, la producción agrícola debe de aumentar en un 60%. Los recursos fitogenéticos para la alimentación y la agricultura constituyen la base biológica de la producción agrícola y la seguridad alimentaria mundial, su pérdida reduce de manera drástica nuestras opciones y las de las generaciones futuras de garantizar la seguridad alimentaria, el desarrollo económico y la paz mundial (FAO, 2011).

1.1. Biodiversidad para la alimentación

La biodiversidad para la alimentación y la agricultura incluye además de la variación genética intra e interespecífica de las especies, la diversidad de los ecosistemas que contribuyen a la producción agrícola y alimentaria; incluye también las plantas cultivadas y los animales domesticados en sistemas agrícolas, ganaderos, forestales y acuícolas, las especies forestales y acuáticas obtenidas, los parientes silvestres de especies domesticadas, otras especies silvestres recolectadas para la obtención de alimentos y otros productos, e incluye también lo que se conoce como "biodiversidad asociada", esto es, la amplia gama de organismos que viven en los sistemas de producción alimentarios y agrícolas, y alrededor de ellos, manteniéndolos y contribuyendo a la producción de los mismos (FAO, 2019).

Los productos de los bosques y selvas han sido cosechados por las poblaciones humanas con fines de subsistencia e intercambio durante miles de años (Ticktin, 2004). En México la vegetación natural, la diversidad biológica y los servicios ambientales que proporcionan son una fuente importante de recursos para la población, estos aportan, además de la madera, otros recursos tales como: tierra de monte, resinas, gomas, fibras, tintes, medicinas, ceras, plantas vivas y alimentos; la mayoría de estos productos no tienen valor comercial o no cuentan con un mercado amplio y consolidado, lo que dificulta el obtener estimaciones precisas de su producción y consumo el cual realizan comunidades de escasos recursos económicos (SEMARNAT, 2016).

El patrimonio biológico de México ha beneficiado históricamente a la población del país, pero su sobreexplotación ha traído como consecuencia el severo deterioro de los servicios ambientales. Al mismo tiempo, el capital natural de México ofrece un gran potencial para el desarrollo y la generación de beneficios para toda la población. A pesar de ello, las políticas históricas de explotación de los recursos naturales no han favorecido la conservación de la biodiversidad ni su uso sustentable, y tampoco el bienestar social (CONABIO, 2006). Un reto de la mayor envergadura para México es la producción de alimentos de manera sustentable ante la demanda futura de alimentos. No obstante que este es un tema de seguridad nacional, no se tiene una aproximación a una agricultura sustentable que asegure la alimentación de las generaciones futuras, al tiempo que no sólo no afecte más a los ecosistemas naturales y sus servicios, sino que ayude a restaurarlos y reponerlos en las zonas donde han sido deteriorados por una producción agrícola del todo insatisfactoria (Sarukhán et al., 2017).

México es un país mega diverso. Posee una flora integrada por más de 30 mil especies, y está considerado como centro de origen y diversidad de cultivos de gran importancia a escala mundial (Villaseñor, 2003). Sin embargo, presenta un déficit entre el valor de los productos agrícolas que importa y los que exporta. Muestra también un alto nivel de erosión genética y sólo se conoce y conserva una parte de sus recursos genéticos (INIFAP, 1995).

1.2. Alimentación en México

Según datos de 2012 del Consejo Nacional de Evaluación de la Política de Desarrollo Social, el 45,5% de la población en México se encuentra en situación de pobreza. De ellos, el 9,8% vive en pobreza extrema, es decir que casi 10 de cada 100 mexicanos o mexicanas presentan 3 o más carencias sociales y su ingreso es menor al valor de la canasta alimentaria. Sumado a ello, el 23,3% de la población presenta un grado de inseguridad alimentaria moderada o severa. Por primera vez, se acepta que en este país más de 20 millones de personas dejaron de hacer algún alimento por falta de recursos, se durmieron con hambre o dejaron de comer para que otro miembro de la familia pudiera hacerlo (Cruz, 2013). De acuerdo con la FAO et al., (2018), en México durante el trienio 2015-2017 existían el 4.8 millones de personases (3,8% de la población) que no cuenta con alimentos suficientes para satisfacer sus necesidades energéticas para llevar una vida sana y activa. Durante el mismo trienio, 11,3 millones de personases (8,9% de la población) pasaron días completos sin alimentación, ya sea por la falta de dinero o de recursos para obtener alimentos. Por otro lado México es uno de los países con una de las mayores tasas de obesidad de la región, en 2016 el 28,9% de la población presenta sobrepeso. Paradójicamente en el país se producen más frutas y verduras que las que son necesarias para alimentar adecuadamente la población (400gr/día/persona); sin embargo, su disponibilidad para la población es deficitaria.

1.3. Aspectos geográficos de la zona de estudio Barranca del Río Santiago

1.3.1. Fisiografía

La cuenca Lerma-Chapala-Santiago es una de las más importantes del país (125 370 Km^2) y el río Lerma-Santiago es el segundo más largo de México (1281 km); el río Santiago nace en el lago de Chapala y recorreré 562 km antes de desembocar en el océano Pacífico (IMTA y CEA, 2011), la mayor parte del trayecto (unos 500 km) los realiza en el fondo de una profunda barranca que existe por lo menos desde el Mioceno temprano, la cual tuvo su origen en una falla geológica producida por el fracturamiento profundo "*rifting*" (Rodríguez-Castañeda y Rodríguez-Torres, 1992). Esta falla delimita las provincias fisiográficas de la Sierra Madre Occidental y el Eje Neovolcánico Transversal; fuera del cañón el río Santiago delimita el Eje Neovolcánico con la Llanura Costera del Pacífico antes de desembocar en las costas del estado de Nayarit (INEGI et al., 2008).

Una porción de 72 338 ha de la Barranca del Río Santiago (BRS) que se localiza al nor-noroeste de la ciudad de Guadalajara entre las coordenadas: 20°43'00" y 21°08'00" N; 103°13'00" y 103°53'00" W, fue seleccionada como zona de estudio, en esta se incluyen terrenos de seis entidades municipales del Estado de Jalisco: Guadalajara, Zapopan, Ixtlahucán del Río, San Cristóbal de la Barranca, Amatitán y Tequila (Figura 1.1), donde en términos generales el cañón tiene una profundidad de 500 m y un acho que va desde aproximadamente uno a una decena de kilómetros; al inicio de la zona de estudio el cauce

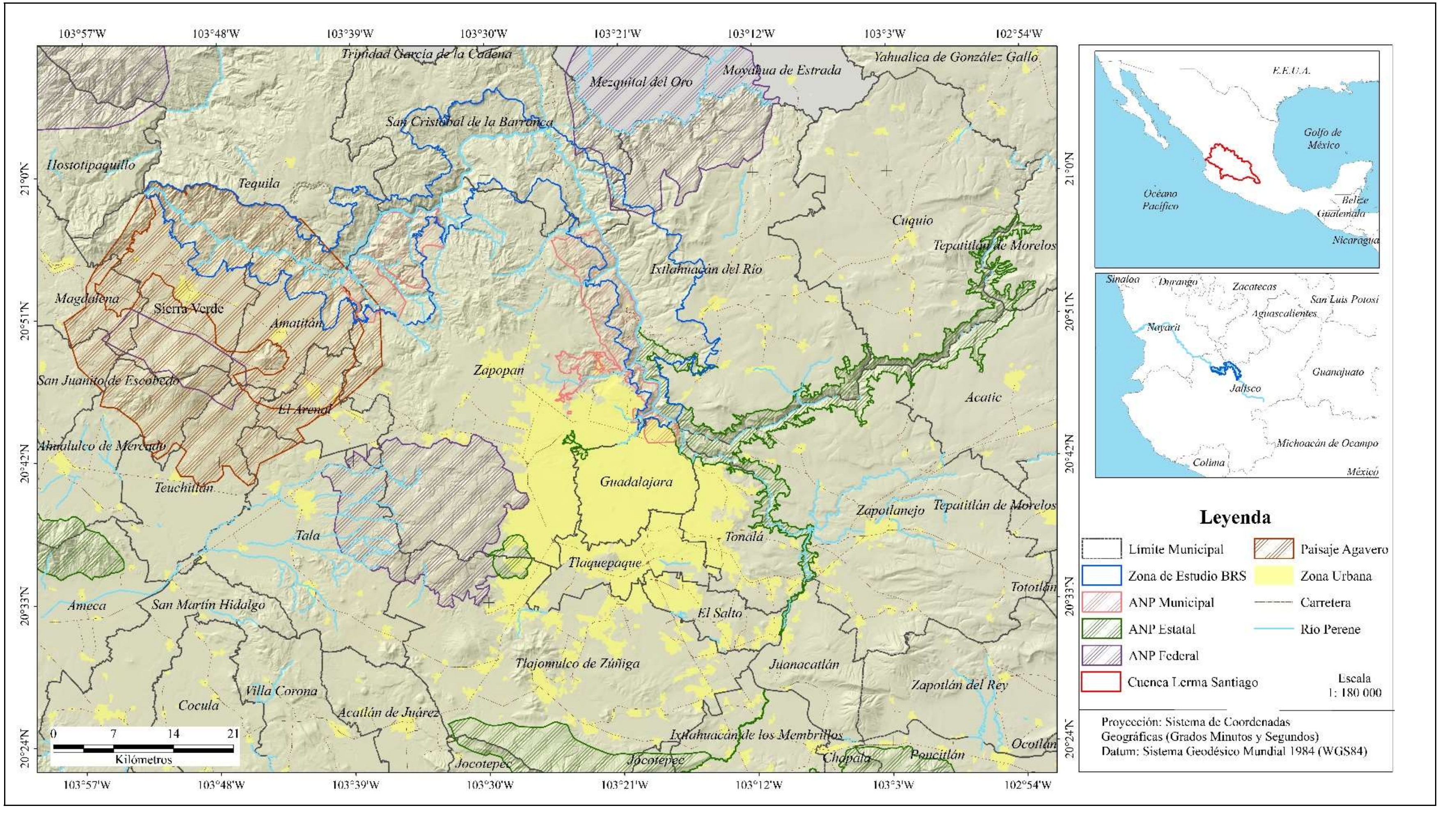

Figura 1.1. Ubicación geográfica de la zona de estudio, de la cuenca Lerma – Santiago en México, y de la barranca y el río Santiago en el occidente de México. Se incluyen áreas naturales protegidas vinculadas a la zona.

del río se encuentra a unos 1000 msnm, los cuales van disminuyendo aguas abajo hasta la cota de 570 msnm en el límite poniente de la zona de estudio. La barranca forma parte de la región biogeográfica de la costa del pacifico e irrumpe entre los valles centrales del Estado de Jalisco y la Sierra Madre Occidental separando a esta del sistema neo volcánico, dando origen a paisajes de belleza singular, al mismo tiempo que marca el límite (Figura 1.2) de las provincias fisiográficas y ecorregiones en el occidente de México (Cervantes-Zamora et al., 1990; INEGI, 2008).

1.3.2. Clima

En la Figura 1.3 se muestra la distribución de los climas prevalecientes en la BRS, el 72% corresponde al tipo Aw_0 (Cálido subhúmedo, temperatura media anual mayor de 22°C y temperatura del mes más frio mayor de 18°C con lluvias en verano) el cual se considera típico del cauce del cañón; en los márgenes norte y sur participan los climas (Semicálidos subhúmedos) $(A)C(w_0)$ y $(A)C(w_1)$, el primero (con el 15% de la superficie) es el más seco y colinda con las estribaciones de la Sierra Madre Occidental, el segundo (con el 12% de la superficie) es el mismo tipo que prevale en la región de los valles (García, 1998); la descripción de los tipos de clima se muestran en el Anexo 1 (Tabla A1.1) Por su clima cálido la región se considera libre de heladas, las cuales se presentan tanto en los valles como en las montañas circundantes. El régimen de lluvias se presenta en los meses de junio a septiembre (época húmeda), con bajo rango de precipitación en el resto del año (época seca), en la Figura 1.3 se observa que en el 60% de la superficie de la BRS (región oeste) llueve entre los 800 y 1200 mm; mientras que en el 40% restante, localizado aguas arriba (región este) se precipitan entre 600 y 800 mm (Vidal Zepeda, 1990). En la zona de estudio (al igual que en toda la región) se encuentra bien definido el periodo de secas de siete meses (noviembre a mayo) y la época de lluvias que dura cinco meses (junio a octubre), esta última es precedida por un periodo aproximado de 90 días con temperaturas cálidas; esto se puede observar en la figura A1.1., donde se presentan los gráficos de la temperatura y precipitación anual en seis estaciones climatológicas vinculadas a la Barranca del Río Santiago.

1.3.3. Suelos

De acuerdo con el INEGI (1982; 2004) son tres tipos de suelos los que predominan en la zona de estudio (Figura 1.4); el más abundante es el tipo *litosol* el cual cubre el 57,5% de la superficie de la barranca, son poco profundos y se ven limitados por la presencia de roca,

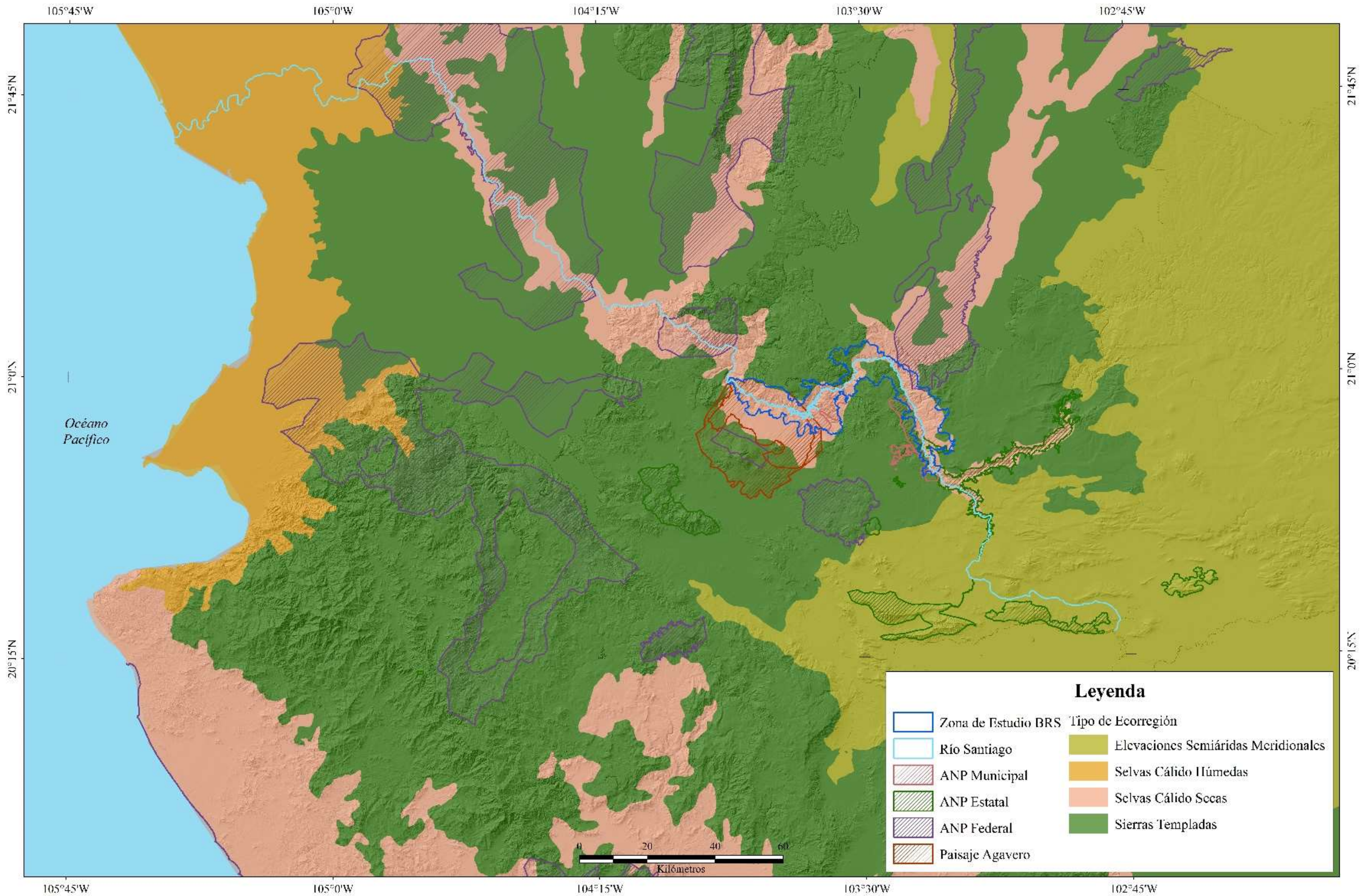

Figura 1.2. Ecorregiones y áreas naturales protegidas vinculadas a la zona de estudio Barranca del Río Santiago, elaboración con datos de Cervantes-Zamora, et al. (1990) e INEGI, et al. (2008).

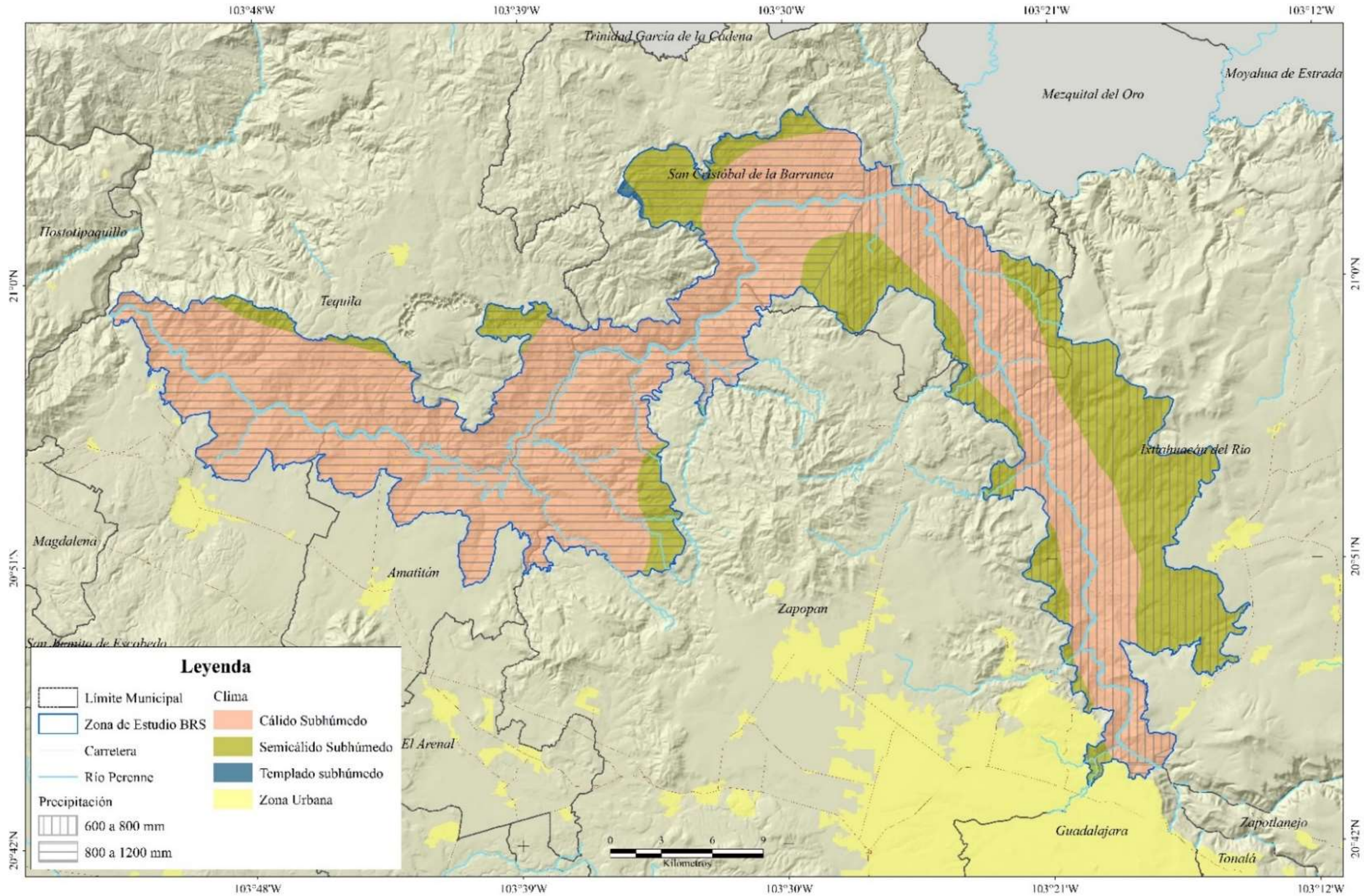

Figura 1.3. Tipo de clima y precipitación en la zona de estudio Barranca del Río Santiago. Elaboración con datos de García (1998) y Vidal Zepeda (1990).

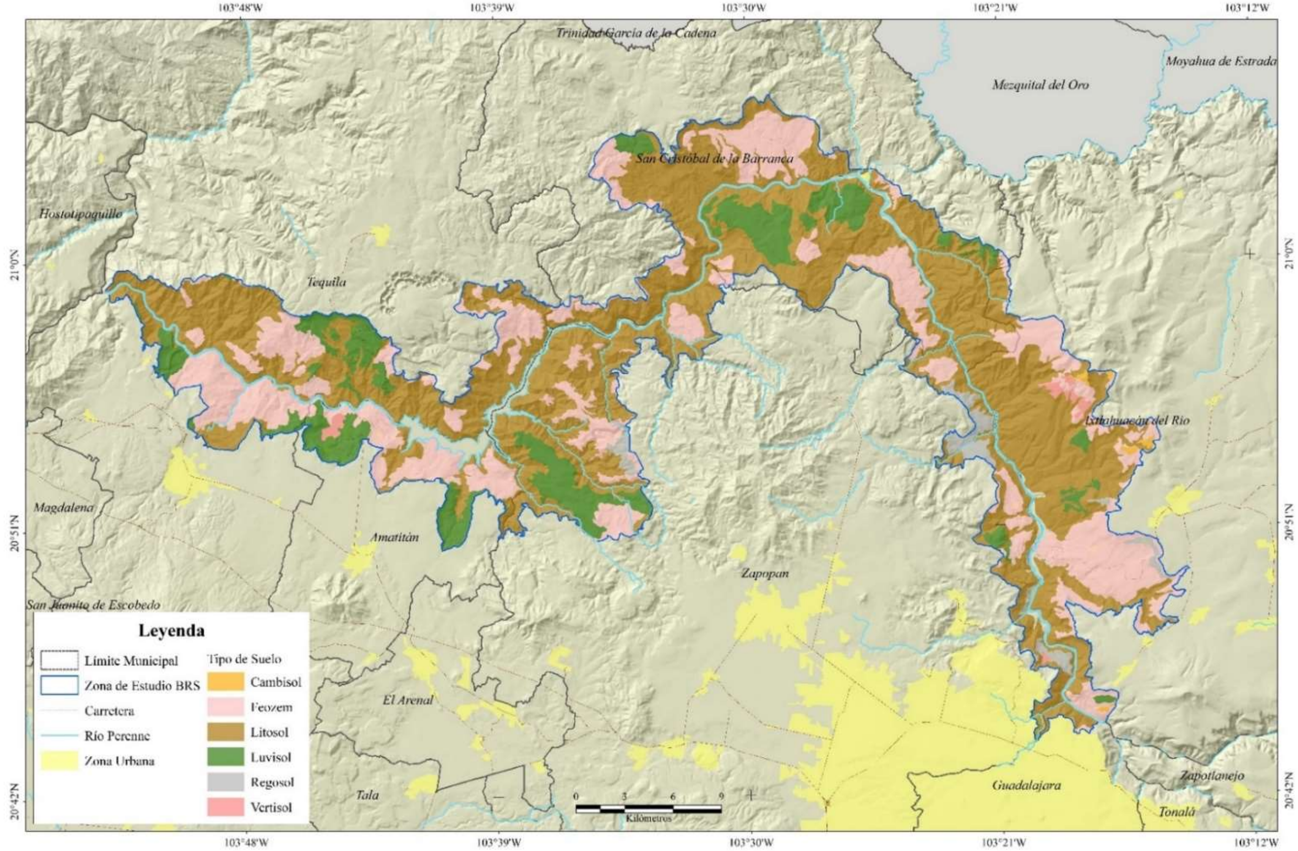

Figura 1.4. Tipos de suelos presentes en la en la zona de estudio Barranca del Río Santiago, elaboración propia a partir de la digitalización y adecuación de cartas impresas del INEGI (1982).

tepetate o caliche endurecido, su fertilidad natural y la susceptibilidad a la erosión son muy variables dependiendo de otros factores ambientales. Le sigue los suelos tipo *feozem* que cubren el 28,5% de su superficie, son de color pardo y se asocian a regiones con un clima suficientemente húmedo para que exista lavado pero con una estación seca, son suelos fértiles que soportan una gran variedad de cultivos, sus principales limitaciones son las inundaciones y la erosión. En el tercer sitio se encuentran los suelos de tipo *luvisol*, los cuales ocupan el 11,3% de la BRS, acumulan arcilla donde la vegetación es generalmente bosque o selva, se caracterizan por tener un enriquecimiento de arcilla en el subsuelo; son rojos o amarillentos aunque también presentan tonos pardos sin llegar a ser obscuros, son suelos con alta susceptibilidad a la erosión. La superficie restante de la BRS (2,7%) está cubierto por suelos de tipo cambisol, regosol y vertisol.

1.3.4. Uso de suelo y vegetación

De la misma manera como ha ocurrido a nivel global, en la Barranca del Río Santiago ha ocurrido una pérdida sustantiva de los ecosistemas terrestres, principalmente por su transformación en campos agrícolas y pastizales. En México se han elaborado inventarios de los diferentes usos del suelo desde hace aproximadamente 40 años. Sin embargo, no son comparables debido a que han utilizado diferentes fuentes de información (SEMARNAT, 2013), razón por la cual y para nuestra zona de estudio, no es posible estimar con precisión la pérdida de la biodiversidad a partir de los cambios en la cobertura y uso del suelo, solo es posible observar algunas tendencias, la interpretación de las mismas se dificulta en términos de la delimitación en la cartografía de los tipos de uso y vegetación, lo cual se debe en parte a lo estrecho de nuestra zona de estudio y los cambios abruptos en altitud que ocurren en el interior de la misma, así como la escala a nivel nacional en que fue elaborada la cartografía.

Nueve lustros atrás el INEGI (1974) determino el uso limitado de la BRS para el desarrollo de actividades productivas: 47% de su superficie para el desarrollo de praticultura limitada y moderada, 45% para la conservación de la vida silvestre y el 8% para el desarrollo de praticultura intensa y actividad agrícola de manera moderada e intensa (Figura 1.5).

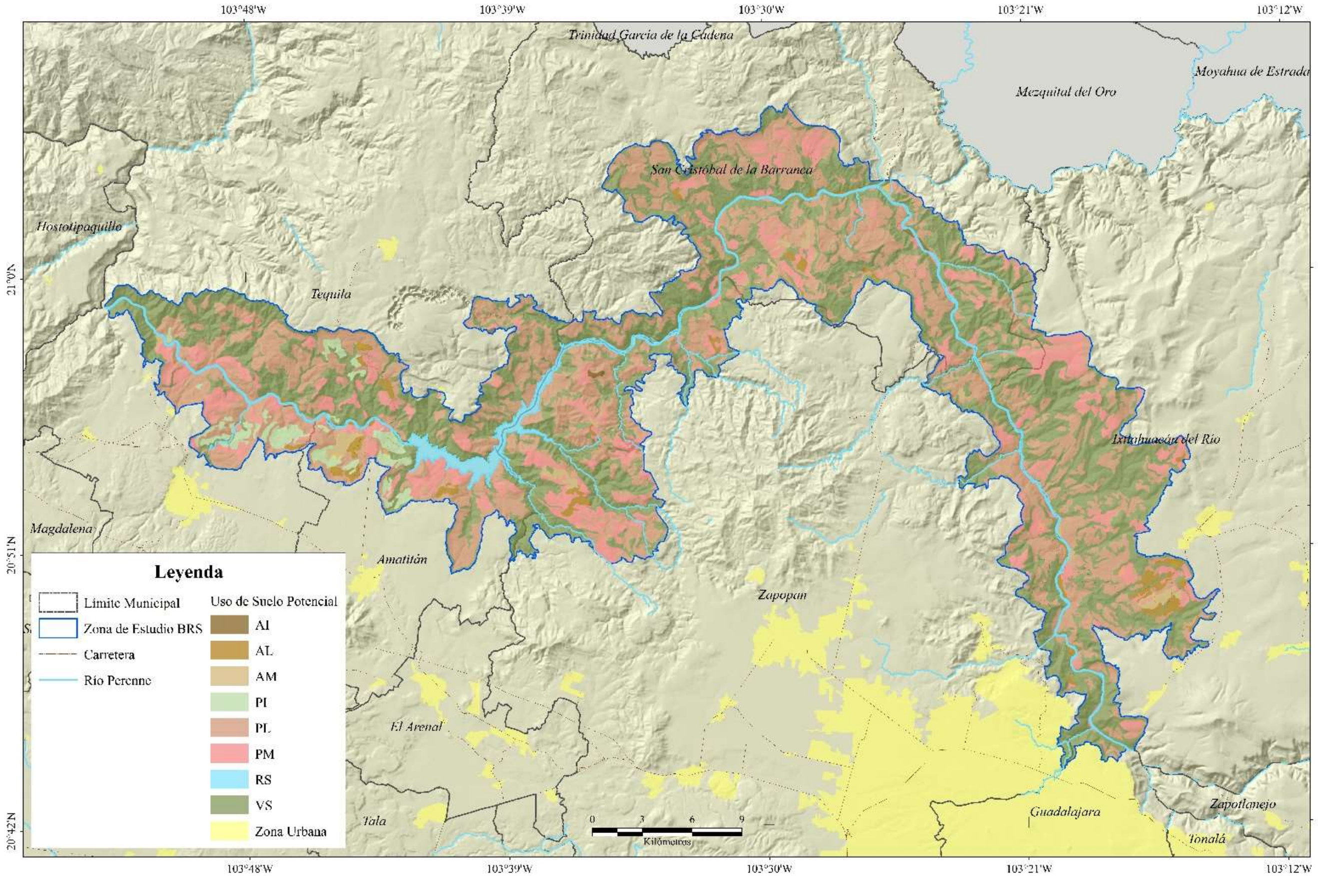

Figura 1.5. Uso potencial del suelo en la Barranca del Río Santiago, elaboración propia a partir de la digitalización de cartas impresas del INEGI (1974).

Interpretación de Leyenda. AI: Agricultura intensa; AL: Agricultura limitada; AM: Agricultura moderada; PI: Praticultura intensa; PL: Praticultura limitada: PM: Praticultura moderada; RS: Río Santiago; VS: Vida silvestre

La vegetación de la BRS forma parte de la provincia florística de la Costa Pacífica (Rzedowski y Reyna, 1990), de acuerdo con el tipo de vegetación potencial (Rzedowski, 1990) el 91% de la superficie corresponde a selva baja caducifolia[1], el 9% restante corresponde a bosques templados presentes en partes altas en los límites de la barranca. De acuerdo con la serie 1 de uso del suelo y vegetación, publicada por el SARH (1992) el 57% de la BRS corresponde a usos no forestales y áreas perturbadas, la superficie de selva baja se encuentra solo de 4 puntos porcentuales (21%) por arriba de la selva fragmentada (17%), mientras que el 5% corresponde a bosques templados (Figura 1.6). En la cartografía más reciente de uso de suelo y tipo de vegetación (Figura 1.7), se considera que en el interior de la BRS él tipo de vegetación con mayor superficie es la vegetación secundaria arbustiva de selva baja caducifolia (31,7%), seguido por la selva baja caducifolia (27,5%); pastizal inducido (12,1%), seguido por el uso de suelo para agricultura temporal permanente (11,4%), bosque de encino (9,6%), ubicado en partes altas de la barranca (INEGI, 2016).

La importancia del bosque tropical caducifolio (como también se conoce a la selva baja caducifolia) se debe a que esta es la vegetación tropical más ampliamente distribuida en México (Trejo, 1996). Su característica más sobresaliente es la estacionalidad que presenta debido a la distribución desigual de la precipitación a lo largo del año, durante la temporada de lluvias se encuentra verde y en la época seca cuando el follaje se pierde y presenta un aspecto gris y yermo. De manera reciente en dos trabajos florísticos realizados en la Barranca del Río Santiago (López et al., 2011; Sahagún-Godínez et al., 2014) y en el estudio técnico justificativo y programa de manejo del área protegida de los Ríos Santiago y Verde (SEMARNAT - Secretaría de Medio Ambiente y Desarrollo Territorial, 2016), mencionan la presencia de ocho tipos de vegetación, aunque no todos los trabajos mencionados coinciden en el número total y tipos de vegetación presentes, aunque sí son coincidentes en mencionar que el bosque tropical caducifolio es la vegetación dominante, los tipos de vegetación adicionales que se mencionan son: Bosque de *Quercus*, bosque de encino y pino, matorral inducido, pastizal inducido, bosque de galería, bosque mesófilo de montaña, vegetación rupícola.

[1] El termino *selva baja caducifolia* es sinónimo de *bosque tropical caducifolio*, el cual se traduce en los capítulos siguientes como *tropical deciduous forest* (TDF).

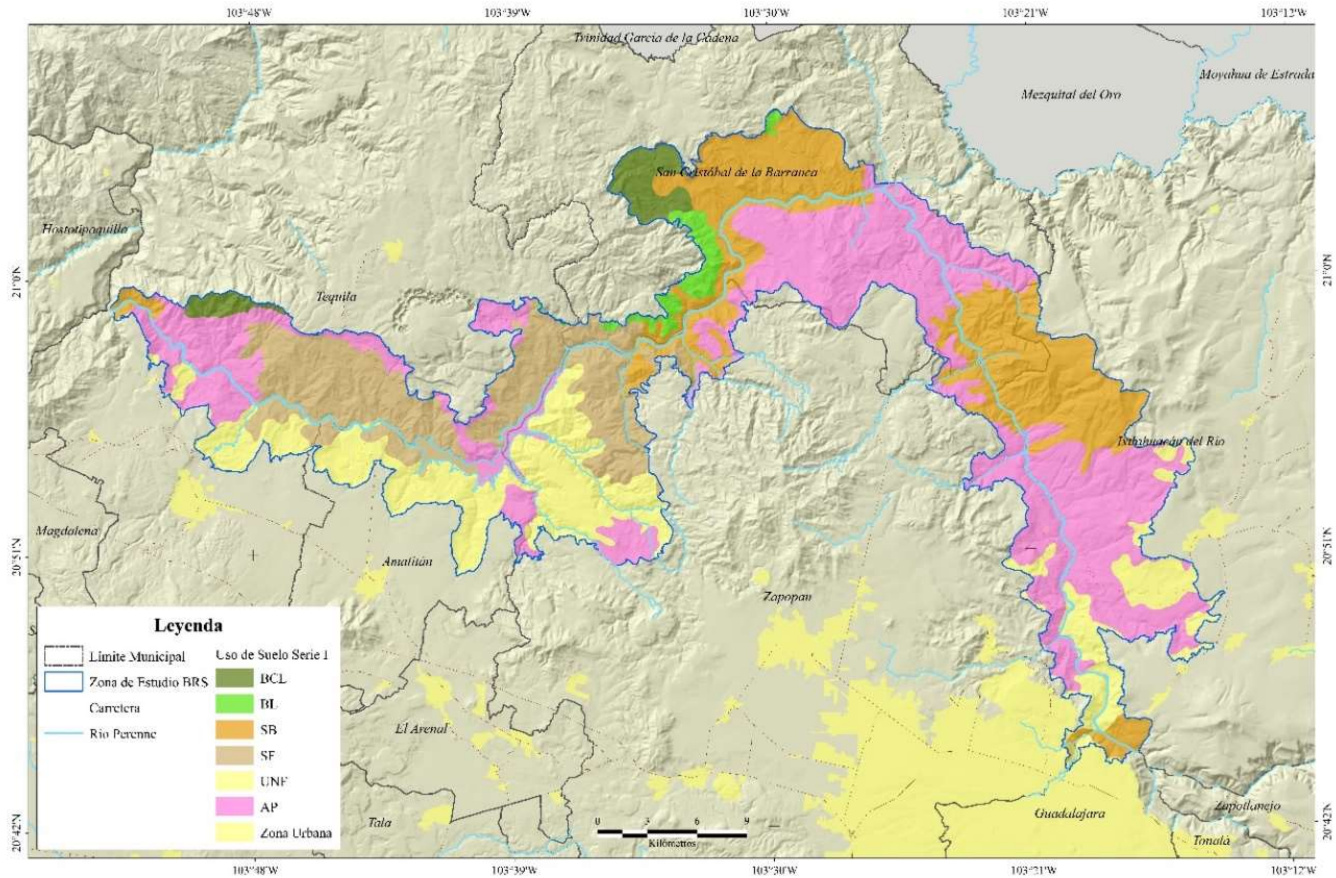

Figura 1.6. Tipo de vegetación y uso de suelo de la zona de estudio de acuerdo con serie 1 (SARH, 1992)

Interpretación de Leyenda. BCL: Bosque de coníferas y latifoliadas BL: Bosque de latifoliadas SB: Selva baja SF: Selva fragmentada UNF: Usos no forestales; AP: Áreas perturbadas

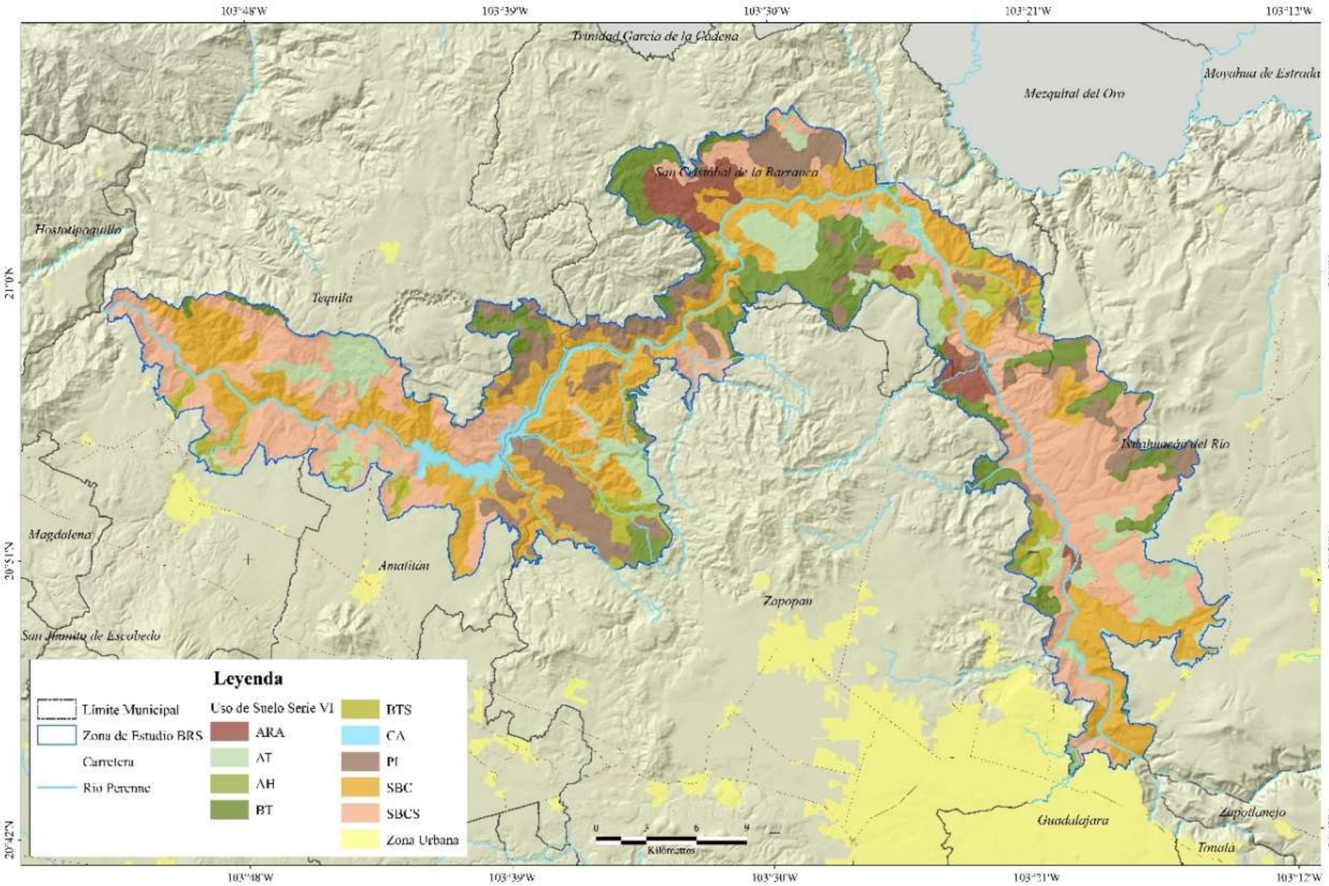

Figura 1.7. Tipo de vegetación y uso de suelo de la zona de estudio de acuerdo con la serie 6 (INEGI, 2016).

Interpretación de Leyenda: ARA: Agricultura de riego anual; AT: Agricultura de temporal; AH: Asentamientos humanos; BT: Bosque templado; BTS: Bosque templado secundario; CA: Cuerpo de agua; PI: Pastizal inducido; SBC: Selva Baja caducifolia; SBCS: Selva baja caducifolia secundaria

1.4. Estado de conservación de la zona de estudio

Las condiciones naturales de la Barranca del Río Santiago han sido alteradas por la creación de diferentes obras hidráulicas para el riego de cultivos y la generación de energía eléctrica; del proyecto sistema hidrológico del río Santiago solo se han construido seis centrales hidroeléctricas que aporta por el momento solo el 32% de la generación de energía eléctrica estimada (IMTA y CEA 2011), mismas han inundado diferentes tramos de la barranca. Más grave aún son las descargas de aguas residuales de origen municipal e industrial de la zona metropolitana de Guadalajara y de los municipios colindantes, que alteran de manera significativa la calidad del agua del río Santiago y de sus afluentes, aun cuando se supone que el río depura gradualmente su cauce (Op. cit.) la realidad es otra, sobre todo cuando en tiempo de secas el volumen de agua disminuye significativamente y se concentran en la presa Santa Rosa los escurrimientos de los desechos urbanos e industriales. Por otro lado, de acuerdo con los pobladores de la barranca, en los últimos años se ha acentuado la disminución en el número y caudal de los nacimientos de agua al interior de la barranca, debido al incremento de pozos profundos en los valles colindantes. Lo cual pone en problemas el abastecimiento de agua potable para la población y el riego de las huertas.

Vinculadas al cauce del río Santiago y la barranca se han establecido las siguientes áreas naturales protegidas (CONABIO, 2015; SEMARNAT-CONANP, 2017; Bezaury-Creel et al., 2009) cuya ubicación se observa en la Figura 1.8.

1. *Cuenca Alimentadora del Distrito Nacional de Riego 043 del Estado de Nayarit*. Área Federal formada por diferentes polígonos en el occidente de México que cubren 2 329 026,75 de hectáreas, algunos de estos polígonos son colindantes y/o se encuentran vinculados a la zona de estudio.
2. *Área Municipal de protección Hidrológica de la Barranca del Río Santiago en el Municipio de Zapopan*. Constituida por dos polígonos separados que en conjunto suman 17 729,91 hectáreas, incluidos por completo en nuestra zona de estudio. Además de proteger la barranca del río Santiago, mantiene la conexión de esta con

otras áreas municipales protegidas: Bosque del Nixticuil, San Esteban, El Diente; y con el área estatal protegida del bosque de La Primavera.

3. *Zona sujeta a conservación Barranca de Oblatos-Huentitan*. Decretada por el Ayuntamiento de Guadalajara, incluye parte de la barranca y de la zona urbana de la ciudad de Guadalajara (164 hectáreas), con poca representación en nuestra zona de estudio. Incluye atractivos turísticos y recreativos, esta área de la barranca mantiene una fuerte carga administrativa para su urbanización.
4. *Área natural protegida de interés estatal de las barrancas de los Ríos Santiago y Verde*. Decretada a finales de 2016 por el Gobierno del Estado de Jalisco (de 21 383,08 hectáreas). Por su cercanía con la Ciudad de Guadalajara, representa una fuente trascendente de recursos ambientales "disponibles" sobre todo de agua y espacios urbanos para la expansión y desarrollo de la metrópoli y la región.
5. *El Paisaje Agavero y las Antiguas Instalaciones Industriales de Tequila.* Declarado por la UNESCO como patrimonio cultural de la humanidad, donde la Barranca del Rio Santiago se incluye como uno de sus dos atractivos naturales del paisaje, el otro es el volcán de Tequila, mismo que forma parte de la primera área mencionada (Cuenca Alimentadora del Distrito Nacional de Riego 43). En la zona de estudio se incluyen 7 745,23 ha de la zona de protección núcleo del paisaje agavero y 10 382,2 ha de su zona de amortiguamiento.

Las cinco áreas mencionadas fueron decretadas, pero no todas tienen un plan de manejo y las que lo tienen no lo aplican, por lo que se consideran *áreas protegidas sólo en el papel*, por ejemplo el paisaje agavero solo atiende acciones de difusión pero no de preservación ni de conservación.

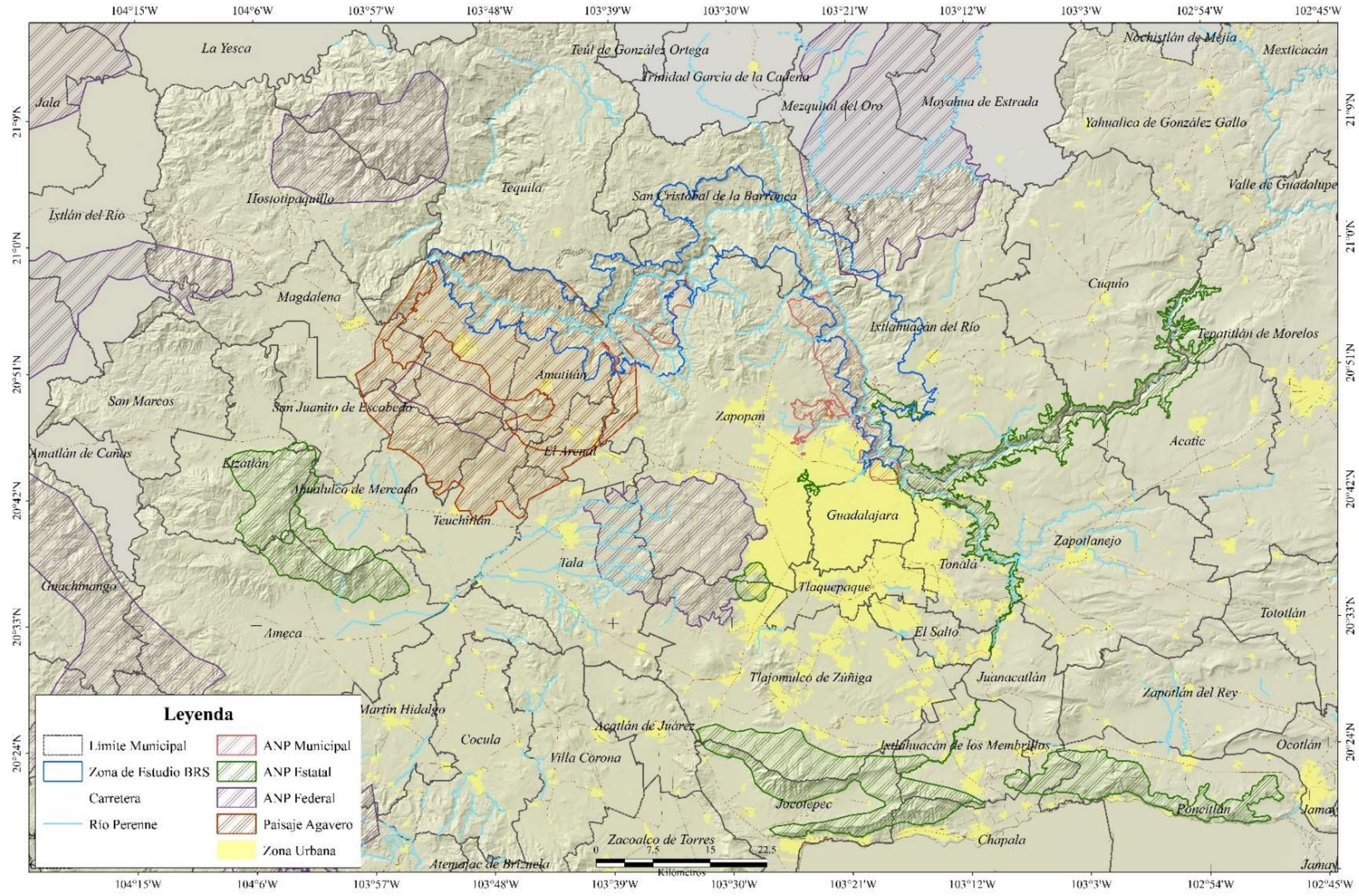

Figura 1.8. Áreas naturales protegidas (ANP), ubicadas dentro y vinculadas a la zona de estudio Barranca del Río Santiago

1.5. Aspectos históricos y sociales de la Barranca del Río Santiago

1.5.1. Época prehispánica

Los primeros grupos humamos que arribaron a Mesoamérica (hace unos 13 mil años), ingresaron por la costa del Pacífico y posiblemente se internaron tierra adentro siguiendo los ríos Santiago-Lerma y Balsas-Mezcala, y se establecieron en los sistemas lacustres de Chapala-Zacoalco-Sayula, valle de México y valle de Puebla (Zizumbo–Villarreal et al., 2008). Estas rutas pluviales fueron utilizadas durante las primeras centurias de la era actual, por los grupos del centro-norte de Jalisco (Mesoamérica) y del noroeste de Zacatecas (Aridoamérica) para mantener sistema de intercambio comercial a larga distancia a través del rio Bolaños (afluente del rio Santiago), lo cual incidió y modificó las costumbres de ambas regiones (Cabrero, 1985; 2007)

La convergencia de los ríos Bolaños y Santiago ocurre unos 40 km de nuestra zona de estudio, y a corta distancia de la laguna de Magdalena en torno a la cual se desarrolló alrededor del año 500 antes de Cristo la cultura conocida como la tradición Teuchitlán. López-Cruz (2016) planteo que la Barranca del Río Santiago sería un paso natural para acceder al corredor del río Bolaños y dirigirse al norte y conectar con la ruta comercial del centro del país hacia el sur de los Estados Unidos. Es claro que en nuestra zona de estudio existía un mosaico cultural estrechamente interrelacionado con la región en que existieron el intercambio de ideas, materias primas, estilos cerámicos he ideologías (López-Cruz, 2016).

1.5.2 Época de la colonia

El occidente de México, fue el último bastión de la Nueva España en ser sometido durante la época de la colonia. En 1527, Nuño de Guzmán llegó al occidente de México y encontró al norte de la Barranca del Río Santiago grupos de indígenas seminómadas con escaso desarrollo técnico, mientras que al sur de la barranca había grupos sedentarios con un nivel alto de organización (Macias et al., 2004). La ciudad de Guadalajara capital del Reino de la Nueva Galicia se estableció en el valle delimitado por la Barranca del Río Santiago, la cual funciono como una barrera natural para defenderse de los indígenas levantiscos, al mismo tiempo que fue una dificultad para el traslado de personas y mercancías hacia los reales de minas de Zacatecas y demás poblaciones al lado norte del río; para ello se establecieron dos rutas paralelas que cruzan nuestra zona de estudio por los poblados de Ixcatán y de San

Cristóbal de la Barranca (Rueda, 2009); a los cuales se les proveyó de puentes, a otros cruces secundarios que también se encuentran se encuentran en la zona de estudio se les implementaron canoas. Durante la época colonial en la barranca del río Santiago se establecieron haciendas entre pueblos indígenas y ranchos, dado su clima propicio y la abundancia de agua para el desarrollo de la agricultura (Zúñiga, 1997).

Dentro de ese ámbito rural se distinguen tres tipos de productores agrícolas tomando en cuenta su relación con la tenencia de la tierra: las comunidades indígenas, los hacendados y los rancheros (Ultreras et al., 2018).

1.5.3. México independiente

Diguet (1903) describió la región situada al norte del río Santiago como muy poco favorecida en lo que respecta a su suelo, ya que en general sólo ofrece llanos, a menudo desolados por las sequías, y macizos montañosos escarpados; por lo cual su población está constituida en gran proporción por tribus más o menos nómadas. Por el contrario, consideró que la parte sur del río, con sus lagos, sus ríos, sus bosques y su suelo fértil, representaba la parte rica de la comarca. En especial se reconoció el potencial de la barranca en cuanto al clima y recursos hídricos propicios y disponibles para la producción de alimentos; la explotación de recursos naturales y el establecimiento de industrias ligadas a la ciudad de Guadalajara. Alrededor del cañón del Río Santiago y sus barrancos tributarios existían haciendas y ranchos, los cuales se dedicaban en términos generales al cultivo de caña, maíz y a atender huertas con plantas de tierra caliente, en las que se cultivaban más de 50 diferentes tipos de plantas comestibles (tanto nativas como introducidas) destacaban por razones obvias aquellas poblaciones que contaban con un paso para cruzar el río Santiago (Portillo, 1889).

El occidente de México empezó a ser objeto de estudios serios a finales del siglo XIX (Diguet, 1898) dado el aislamiento en que se encontraba, época en que se seguían utilizando las mismas rutas de comercialización que existían durante la época de la colonia; dos de las cinco principales vías de comunicación que existían a mediados del siglo XIX en Jalisco se utilizaban para cruzar el río (dentro del área de estudio) para mantener la comunicación con los minerales de Zacatecas (Macias et al., 2004).

1.5.4. Desarrollo del campo

El desenvolvimiento del capitalismo mundial al cual estamos ligados en forma dependiente, viene creando presiones socioeconómicas sobre el resto de las culturas mundiales. Estas presiones se han considerado básicas en el desarrollo deseado por los pueblos e incluso se han planteado como condiciones inevitables del desarrollo cultural mundial (Hernández-X, 1988)

A final de la década de 1970 se hizo evidente el agotamiento del modelo económico que fue llamado "sustitución de exportaciones", el cual sostenía en buena medida, un sector agrícola no sano desde el punto de vista frio de las leyes del mercado, lo cual hizo evidente la crisis de la sociedad agraria con todos los ranchos y los rancheros. La economía global enfermo al agro mexicano, desde hace décadas la gente del campo se marcha a las ciudades de México o estuvo emigrando hasta hace poco, a los Estados Unidos; cada día vive menos gente en el campo o vive de él (Ávila y Gómez, 2006). Desde la crisis macroeconómica de 1982 y el ajuste estructural de ella derivado, la agricultura de México ha sufrido un profundo proceso de ajuste encaminado a privilegiar la capitalización del campo a través de empresas agroindustriales capaces de competir en los mercados nacional e internacional. A través de ello se pretende que la agricultura del país esté acorde con el paradigma competitivo imperante a nivel mundial (Macías, 2013).

Durante mucho tiempo la Barranca del río Santiago, de acuerdo con los relatos de los informantes, las huertas de riego y las siembras de temporal eran muy productivas, no se aplicaban fertilizantes ni pesticidas (no existían tantas plagas), razón por la cual siempre había trabajo en el campo. En aquellos tiempos la barranca abasteció de alimentos no sólo a sus pobladores, sino también a otras poblaciones de la región y del país. En la actualidad la mayoría de los pobladores practican la agricultura de autoconsumo en el "cuamil" o en la parcela, en terrenos agrestes donde siembra maíz con el propósito de no dejar de tener que comer, comercializan algunos excedentes cuando los obtienen, sobre todo de las huertas de secano o de riego.

Económicamente la zona de la barranca es una zona depauperada, donde predominan terrenos que desde el punto de vista agrológico sólo pueden ser utilizados como reserva para la vida silvestre, entre los se mezclan espacios en los que es posible desarrollar la silvicultura y praticultura, y en menor proporción otros sitios donde se puede realizar agricultura limitada o moderada (INEGI, 1976; 1974). No obstante que en algunos escalones de la barranca se practica la agricultura mecaniza e incluso con riego, la mayor parte corresponde a agricultura de subsistencia que se realiza en terrenos con pendientes que van de los 6° a los 15°, aunque se utilizan también terrenos escarpados con pendientes mayores para realizar agricultura tradicional (cuamil o milpa). Los cañones por donde corren los afluentes permanentes del río Santiago, se han utilizado (si se tiene acceso) para establecer huertas de riego donde se cultiva el tradicional mango de la barranca. También existen huertas de secano donde se cultiva la ciruela mexicana *Spondias purpurea* L. lo cual puede representar exiguos ingresos debido a los canales de comercialización que operan en la zona.

Algunos campesinos se han visto obligados dado el estado de marginación en que se encuentran al cultivo de enervantes, lo cual tampoco resuelve sus condiciones de precariedad dado que, como en el caso de los demás productos que se producen en la barranca, el productor es el que menos beneficios obtiene en la cadena de comercialización.

1.6. Los habitantes de la Barranca del Río Santiago

En México y en otras partes de América Latina se ha observado un gran traslape entre los territorios indígenas y las regiones de alto valor biológico (Toledo et al., 2010; Tetreault et al., 2011), en México la población indígena se concentra en el centro y sur del país, en el estado de Jalisco solo existen como autóctonos los grupos huichol y náhuatl que habitan la zona norte y la zona sur respectivamente (INPI, 2018). A la llegada de los españoles al occidente de México, muchos de los asentamientos nativos fueron reconocidos como *pueblos indígenas* y se utilizó el término de *ranchería* para los lugares que estos habitaban de modo provisional; otros fueron borrados del mapa por cuestiones militares o bien para facilitar la evangelización de los nativos; sin embargo, las principales razones del despoblamiento de los diversos centros indígenas fueron las enfermedades y las bajas tasas de natalidad, para mediados del siglo XVII la población indígena se había reducido a niveles críticos (Goyas, 2013), con lo cual las pequeñas poblaciones indígenas del interior de la barraca y sus alrededores fueron desapareciendo a través del tiempo por el mestizaje.

Los pobladores actuales de la barranca se piensan como campesinos o agricultores (no indígenas), término que podríamos equiparar con el de "*ranchero*", término acuñado en 1956 por Francois Chevalier en su estudio sobre la formación de los grandes latifundios de México, el cual marcó una nueva etapa en la investigación científica y en la historia del campo. En esta se señala al ranchero como una de las figuras más destacadas, la cual emergió desde la época colonial (Skekriit, 1990). Es en el occidente de México donde se han realizado la mayor parte de los estudios sobre la *sociedad* y *cultura ranchera*, los cuales refieren a un grupo de personas cuya realidad sociocultural, es rica y compleja (Ávila y Gómez, 2006). Los rancheros conservan mucho de solitario y no dejan de ser introvertidos; son iconoclastas pero muy creyentes, aunque poco practicantes. Son reservados, pero cuando se presentan las circunstancias se echan para adelante, no se arredran (González 1989, 1992, citado por Ávila y Gómez, 2006).

Al ranchero se le describe como un revolucionario, es un modernizador y es un conservador; algunos son fundamentalmente agricultores otros son ganaderos aun cuando se les reconoce un conjunto de actividades que van desde el comercio en pequeño y la arriería hasta la fabricación casera de productos para el mercado. Se subraya el carácter 'necio' y poco socializado del ranchero, especialmente el ganadero. Por 'ignorante' no es receptivo a las propuestas productivas y organizativas de los extensionistas (Skerritt, 1990). En consecuencia podemos considerar como rancheros a los habitantes de la barranca, no obstante que la mayoría aprovecha cualquier oportunidad para migrar a las ciudades cercanas en busca de mejor calidad de vida incluyendo la educación de los hijos y la salud de la familia y porque las actividades del campo han dejado de ser redituables, ahora los ranchos están abandonados y sus habitantes son mayores de cuarenta años a los cuales se les dificulta obtener trabajo en la ciudad.

1.7. Los recursos fitogenéticos para la alimentación en la Barranca del Río Santiago

El Occidente de México, al ser zona de transición desde el punto de vista, fisiográfico, biogeográfico y cultural presenta rasgos distintos a las del resto del país. Es aquí donde confluyen cinco de las quince regiones fisiográficas del país (Sierra Madre occidental, Llanura Costera del Pacífico, Mesa del Centro, Eje Neovolcánico, Sierra Madre del Sur), razón por la cual se presentan singulares contrastes en el clima y la biota del lugar.

Debido a su constitución fisiográfica y desarrollo cultural, el occidente de México se considera un ámbito rico en recursos fitogéneticos para la alimentación y la agricultura, parte de los cuales se consignan en el Informe Nacional sobre Recursos Fitogenéticos (Molina y Córdoba, 2006), donde también se plante su enorme potencialidad, pese a los cual se les ha prestado poca atención. Los datos biológicos, ecológicos, genéticos y evolutivos señalan al occidente de México como el centro de domesticación inicial del complejo de especies característico de la agricultura mesoamericana (Zizumbo-Villarreal et al., 2008).

De manera similar como ocurre en otras partes del mundo, en el Occidente de México, y en la Barranca del Río Santiago, la diversidad de recursos fitogenéticos para la alimentación y el conocimiento tradicional que existe sobre los mismos se encuentran amenazados y con alto riesgo de desaparecer por el efecto los actuales procesos de apropiación y producción perniciosos y por el cambio climático.

En México el estudio de los RFA se encuentra limitado y enfocado al trabajo que preferentemente realizan compañías transnacionales a los cultivares de alto valor comercial, quedando desatendidos los cultivos marginados y las plantas silvestres con potencial alimenticio. Se requiere prestar mayor atención a la conservación de las especies silvestres de uso directo, indirecto o potencial, ya que se encuentran amenazadas por el cambio de uso de suelo, por el uso de herbicidas y el incremento de sustancias nocivas en la atmósfera, etc., lo que modifica el equilibrio ecológico y pone en peligro la diversidad genética al promover la desaparición de muchas especies silvestres útiles o utilizables (Esquinas, 1983).

1.8. Justificación e hipótesis

1.8.1. Justificación

Si tomamos en cuenta que el proceso civilizatorio alrededor del mundo ocurrió en torno a la domesticación y el desarrollo agrícola, y que estos procesos se basaron en la capacidad de los individuos para reconocer y seleccionar aquellos recursos fitogenéticos que podían cubrir sus necesidades, ahora, resulta paradójico que el modelo de desarrollo imperante se empeña en reducir a su mínima expresión la diversiadad de recursos fitogenéticos para la alimentación. Es evidente e inevitable el conflicto que existe entre la necesidad de incrementar la alta producción agrícola y la necesidad y el compromiso de preservar la biodiversidad.

La BRS un ecosistema utilizado desde tiempos inmemorables para proveer de alimentos a los antiguos y actuales pobladores del occidente de México; sin embargo, el patrón alimentario de los pueblos de la BRS se ha deteriorado en las últimas décadas, como consecuencia de las transformaciones ocurridas en los patrones culturales exógenos, los cuales han incidido en cambios en los sistemas productivos, así como en la explotación y aprovechamiento de los recursos silvestres alimentarios.

Es por ello que este trabajo plantea como punto central de investigación el abordaje de la diversidad de recursos fitogéneticos para la alimentación desde la perspectiva de la etnobotánica como ciencia que estudia la relación hombre-planta y se complementa con la caracterización agroecológica de la zona de estudio y con enfoques de cultura alimentaria.

A partir de los saberes tradicionales que poseen los pueblos de la BRS sobre las especies silvestres y cultivares tradicionales, junto con la caracterización ambiental realizada mediante sistemas de información geográfica, se pretende contribuir con información básica para la generación de proyectos enfocados al desarrollo sustentable de la BRS y a la mejora de la alimentación y calidad de vida de sus pobladores. La información podrá ser utilizada en la implementación de políticas públicas y como herramientas para la gestión y conservación de la biodiversidad en la BRS.

1.8.2. Hipótesis

La hipótesis de este trabajo es que las poblaciones de rancheros en la Barranca del Río Santiago mantienen un cumulo importante de conocimientos etnobotánicos relativos al uso y aprovechamiento de recursos fitogenéticos para la alimentación. Lo cual se refleja en el uso de especies silvetres y el manejo de sus cultivares tradicionales.

1.9. Objetivo general y estructura de la tesis

El objetivo general de esta tesis es obtener una descripción del estado que guardan los recursos fitogenéticos para la alimentación en la Barranca del Río Santiago, abundando en el grado de uso y nivel de conocimiento que tienen sobre los mismos, los pobladores de la barranca y, generar información relevante a partir del conocimiento y manejo que realizan los campesinos barranqueños.

Para su cumplimiento se plantearon las preguntas siguientes a manera de objetivos específicos, mismos que se abordan en los capítulos de la tesis que se señalan:

- *¿Cuál es el número y cuáles son las especies silvestres o cultivares tradicionales presentes en la Barranca del Río Santiago?*

  En el **capítulo dos** de la tesis se presenta el inventario realizado de los recursos filogenéticos para la alimentación que se encuentran presentes en la Barranca del Río Santiago.

- *¿Cuál es el grupo de especies más importantes desde el punto de vista ecológico, económico y social en la Barranca del Río Santiago?*

  El **capítulo tres** de la tesis se centra en las características de las especies leñosas (arbóreas y arbustivas) con usos alimenticios presentes en la Barranca del Río Santiago, con características para ser utilizadas en programas de restauración dado su valor ecológico económico y social.

- *¿Cuáles son las características bajo las cuales se realiza el aprovechamiento y cultivo tradicional de la especie arbustiva con mayor antigüedad de uso en la barranca del Río Santiago?*

  En el **capítulo cuatro** se analiza bajo criterios agroecológicos la presencia y distribución de la ciruela mexicana *Spondias purpurea* L. en la Barranca del Río Santiago, utilizando un sistema de información geográfica se determinaron las características ambientales del cañón y de los predios donde se realiza el cultivo, su distribución actual y potencial.

- *¿Cómo se distribuye de manera general y en específico para la Barranca del Río Santiago una de las especie con mayor potencial de uso alimenticio?*

  En el **capítulo cinco** se presenta el modelo de predicción de la distribución de *Malpighia mexicana* a nivel nacional, incluyendo la Barranca del Río Santiago y su nivel de coincidencia en México con la distribución potencial de la ecorregión de las Selvas Cálido Secas.

- *¿Cuáles son las actuales condiciones agroecológicas vinculadas al cultivo industrial de Agave tequilana Weber y su denominación de origen a nivel nacional con respecto a las presentes en la zona donde se dice que pudo haber surgido la especie y sus técnicas de aprovechamiento?*

  En el **capítulo seis** se describen las características agronómicas bajo las cuales se realiza el cultivo del agave tequilero, con respecto a los criterios agroecológicos establecidos para el cultivo y su relación con la zona de denominación de origen.

- *¿Qué tan sustentable es el paisaje agavero y las actividades turísticas realizadas a su interior?*

  En el **capítulo siete** se trata el tema del origen del tequila, la actividad de la industria tequilera y el potencial turístico del paisaje agavero, en el contexto de su declaración como patrimonio cultural de la humanidad y de mejora de la calidad de la oferta turística desde una perspectiva sostenible.

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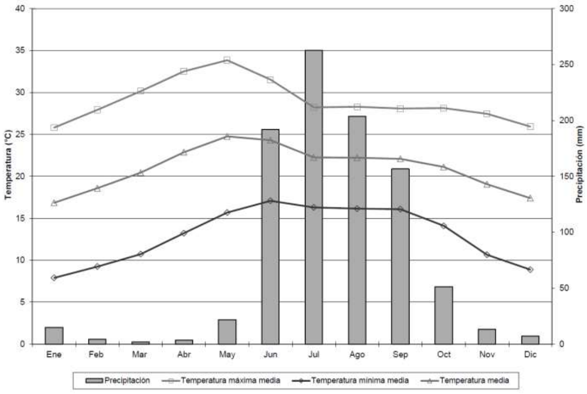
ANEXO 1

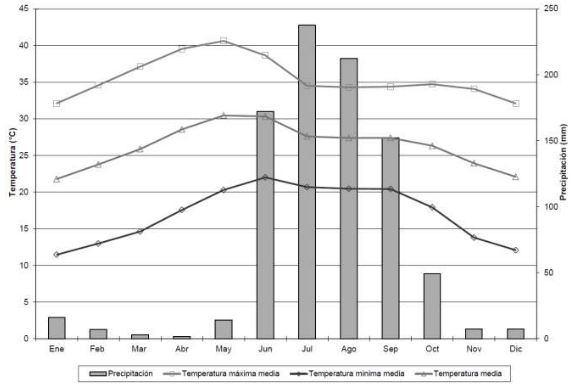
Tabla A1.Tipos de clima y porcentaje de cobertura de la superficie de la Barranca del Río Santiago

Clima	*Características de Temperatura*	*Características de Precipitación*	*% Sup. BRS*
Aw_o	Cálido subhúmedo, temperatura media anual > 22°C y temperatura del mes más frio >18°C.	Precipitación del mes más seco de 0 a 60 mm; lluvias de verano con índice P/T < 43.2 y porcentaje de lluvia invernal del 5% al 10.2% del total anual.	72,4
$(A)C(w_o)$	Semicálido subhúmedo, temperatura media anual > 18°C, temperatura del mes más frio <18°C, temperatura del mes más caliente >22°C.	Precipitación del mes más seco < 40 mm; lluvias de verano con índice P/T < 43.2, y porcentaje de lluvia invernal del 5% al 10.2% del total anual.	15,0
$(A)C(w_1)$	Semicálido subhúmedo, temperatura media anual > 18°C, temperatura del mes más frio < 18°C, temperatura del mes más caliente > 22°C.	Precipitación del mes más seco < 40 mm; lluvias de verano con índice P/T **entre** 43.2 y 55 y porcentaje de lluvia invernal del 5% al 10.2% anual.	1,.5
$C(w_o)$	Templado, subhúmedo, temperatura media anual entre 12°C y 18°C, temperatura del mes más frio entre -3°C y 18°C; temperatura del mes más caliente < 22°C.	Precipitación en el mes más seco < 40 mm; lluvias de verano con índice P/T < 43.2 y porcentaje de precipitación invernal del 5% al 10.2% del total anual.	0,1

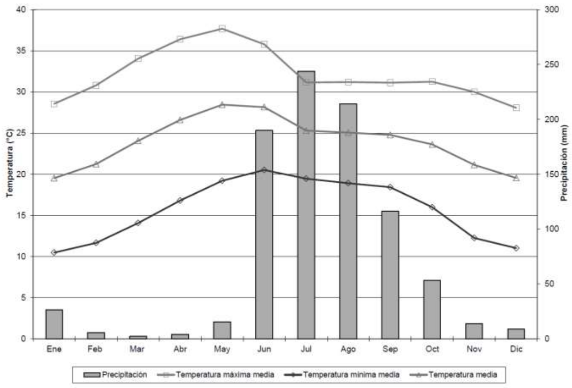
Fuente de la clasificación y caracterización del clima: García, 1998.



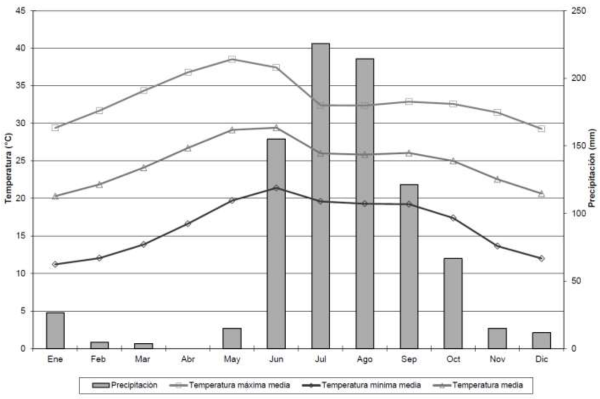
La Experiencia



Santa Rosa



Puente Arcediano



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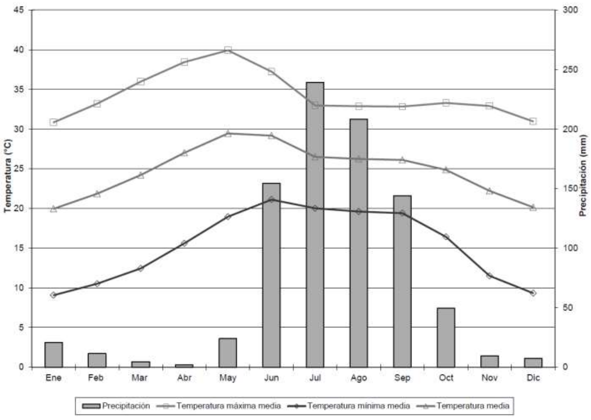

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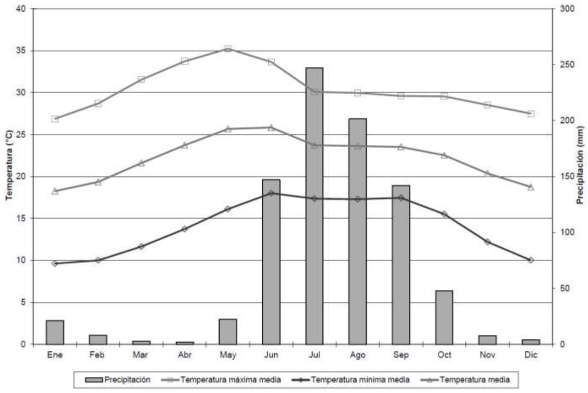

Tequila

Figura A1. Distribución mensual de temperatura y precipitación en las estaciones climáticas referidas a la Barranca del Río Santiago (Tomadas de Ruíz et al. 2012)

Chapter 2

Inventory of phytogenetic resources for food in Barranca del Río Santiago, Jalisco, Mexico

Abstract

An ethnobotanical exploration was carried out in Barranca del Río Santiago (BRS) located in western Mexico with the purpose of recording traditional cultivars and wild species with nutritional properties. A total of 196 plant taxons were recorded; a majority (84%) correspond to native plants in the ravine; from those, 115 records are wild plants (70%) predominantly tree species with a total of 69 records equivalent to a 35% of the total registered food plants. Of the total number of native tree species, 12 belong to the Fabaceae (Leguminosae) family which rated the highest percentage (9,7%) of the total number of records. The latter coincides with the prevailing type of vegetation in the ravine: tropical deciduous forest (TDF), where Fabaceae is one of the most outstanding families.

In addition to the aforementioned and because of the existing limitations in developing agriculture due to the ravines's orography it is significant that among the total (196) records of cultivated or wild native and introduced plants, trees and shrubs (102 woody plants) represent 52% of the total phytogenetic resources for food; this is undoubtedly associated to the duration of dry season in the region, which lasts between 6 to 7 months, in a way demonstrating the forestry vocation of the ravine. For a long time and even more now, the governmental sector has promoted developing protected natural areas within Barranca del Río Santiago whereas at the same time large dams are created and pollution in the river becomes uncontrollable. The data generated in this paper will be useful to shape and implement development and preservation projects, not only for protected areas (only in writing at the moment) but also for the entire ravine, covering the states of Jalisco and Nayarit.

Keywords: Phytogenetic resources for food, Santiago River (Río Santiago), tropical deciduous forest, ethnobotany

2.1. Introduction

The present state of things for mankind and the entire planet demands the use and preservation of all useful resources in order to meet the needs of the current population and future generations. In addition to being the only autotrophic beings on the planet, plants provide house, shelter and livelihood to the rest of the species with which they share their habitat. Over thousands of years at least 10% of the current flora in any geographic area is or has been used by local populations (Caballero and Cortés, 2001), hence the importance of conducting ethnobotanical inventories that allow detection and study of these ethnofloristic resources.

7 000 species of useful plants have been described for México (Caballero and Cortés, 2001) from which at least 1 000 are for food use (Caballero, 1987). In almost any inventory of useful plants, the most frequent uses are as food and as medicine. It has been estimated that more than 50% of the reported species in Mexico have between two and five uses and about 25% have more than five different uses (Caballero et al*.,* 1998). A long ethnobotanical research tradition in Mexico has obtained international recognition for several decades now (Martínez, 1994). There has been significant progress in the joint multidisciplinary work with sciences such as archeology, anthropology, ecology, medicine, agronomy, botany, among many others. Some related papers to our study area and research topic are mentioned below.

Being the northern limit of Mesoamerica, the western region of México operated as a contact area with the northern towns. Zizumbo-Villarreal and Colunga-GarcíaMarín (2008; 2010) present the Chapala-Santiago-Mantanchen route as a biological-cultural corridor, both before and after the origin of agriculture and domestication of plants in western México; from the analysis of paleoecological, archaeological, biological and evolutionary data of the milpa production system we have been able to gather that the following species: *Zea mays* L., *Phaseolus vulgaris* L., *Cucurbita* spp., and different species of *Agave* spp., and *Spondias purpurea* L. have been consumed for over 9 000 years now. All these species have putative wild populations located in this specific region of Mesoamerica. The high cultural development achieved by Mesoamerican civilizations during the early Classic Period (100 CE - 400 CE) can be explained by the way their food system was structured during the

Formative Period in western Mexico (2400 BCE - 100 CE). Zizumbo-Villarreal et al., (2014) reconstructed this putative pre-ceramic system with 29 native cultivated and domesticated plants with which more than 66 dishes could be prepared. All these plants can be found in Barranca del Río Santiago. Through the recovery of traditional recipes within Soyatlán community, located south of the State of Jalisco, Solís (2009) identifies 95 types of edible plants belonging to 38 botanical families. 40% of the recorded plants are wild, 48,4% are backyard species and the remaining 7,4% share both categories. As for the forms of intake, they are divided in more or less proportional parts between (1) direct consumption or simple cooking, (2) consumption through the use of a more complex preparation and (3) the plant can be consumed both one way or the other.

Among the terrestrial ecosystems in Mexico, one of the most significant is the tropical deciduous forest (TDF) (or low deciduous forest). It is a low forest vegetation community that thrives on hillsides in warm weather conditions and markedly concentrated rains during 6 or less months of the year. Consequently, it presents two very different seasonal aspects, the tender and lush green in the rainy season, and the gray and desolate in the dry season of the year (Rzedowski and Calderón, 2013). These forests bring about around 20% of the species in Mexico's flora. Despite this they suffer a high rate of deforestation, and currently only 30 % of the original surface remains in a relatively good state of preservation (Trejo, 2005). The fact that inhabitants of this ecosystem use the highest percentage of plant species, sometimes higher than 60%, is of significant relevance (Dorado, cited by Soto, 2010).

The TDF grow in fertile soils; they usually have a closed canopy and are mostly surrounded by woody plants where Leguminous and Bignoniaceae families predominate alongside with poor soil cover formed by few herbs (Penington, et al., 2000). The so-called dry forests have a wide distribution in Mexico extending from parallel 29° north latitude to the Guatemala border. They have an established preference for the Pacific slope with important entrances in the basins of the Lerma-Santiago and Balsas rivers. They're also represented in discontinuous patches on the Mexic49o’s Gulf slope and on the Yucatan Peninsula (Trejo, 2010).

The general objective of this chapter was to conduct an inventory of phytogenetic resources for food in Barranca del Río Santiago (BRS), Jalisco, Mexico, and to deepen the knowledge of use and appreciation that residents of the ravine have on them. To achieve this objective, the following specific objectives have been considered: 1) Get to know the level of use and preservation of wild edible phytogenetic resources, 2) Get to know the level of use and conservation of traditional food cultivars and 3) To reflect on those phytogenetic resources for food whose study should be prioritized for the purpose of utilization and preservation. The results of this study provide relevant information on their proper use and conservation as phytogenetic resources for food in order to preserve and benefit the economy of the rural communities of the BRS, as well as for the protection of these resources.

2.2. Methodology

2.2.1. Study area

The BRS is located in western Mexico, on the northern limits of what cultural anthropologists call the Mesoamerican cultural area (Kirchhoff, 1967). The study area is of great significance because it represents a field of strong interaction between Holarctic and Neotropical kingdoms, which constitutes a biological mix and is a corridor between the temperate ecosystems of central Jalisco and the tropical environments of the Pacific coast (Challenger, 1998) (Figure 1).

This is important because of the zone's physiographic constitution, the degree of cultural development achieved by the pre-Colombian peoples who inhabited it and its rich phytogenetic resources combined with the fact that it produces a space where a broad range of plants were domesticated (Vargas-Ponce et al., 2007; Zizumbo-Villareal et al., 2014).Moreover it was a corridor through which human groups moved along thus diffusing ideas and alimentary habits (López-Cruz, 2016).

The botanical explorations of the region for scientific purposes date back to 1791 with Sessé and Mociño's Royal Botanical Expedition to New Spain (McVaugh, 1972) but it was not until the mid-nineteenth century when those articles about Mexican foliage first appears

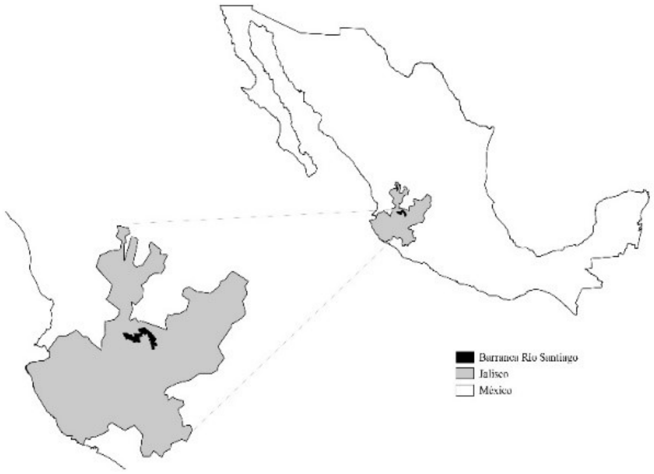

Figure 2.1. Barranca del Río Santiago study area.

in literature; some of these articles relate it to altitude, climate and / or other environmental factors (Rezedowski, 2006). For over two hundred years numerous botanists of national and foreign origin have taken an interest in Jalisco's flora but the records are far from complete and our knowledge of the region's flora remains inadequate. To date, botanical studies have been published on only 25 of the estimated 166 families of dicotyledonous plants that exist in the State of Jalisco which according to the National Report on the State of Phytogenetic Resources for Food and Agriculture (Molina and Córdova, 2006) is justifiably recognized for its rich biodiversity even though the floristic and ethnobotanical studies required to understand this in terms of conservation and sustainable exploitation have not yet been conducted.

Recent botanical studies carried out at different sites of BRS divided in sections near Guadalajara have helped to increase our knowledge of the area's flora. For example in just one of those sections researchers recorded 869 species, 47 of which are endemic and unique in Mexico (University of Guadalajara, 2009). Of these, six are classified as 'protected species' because their existence is deemed to be 'threatened'. Unfortunately, at present there are only two guides to arboreal species and a few isolated botanical studies that together represent only a modest contribution towards efforts to systematize our knowledge of the area (López et al. 2011; Sahagún-Godínez et al. 2014). Although Mexico has signed several international protocols for biological conservation, initiatives undertaken in this regard in BRS are insufficient.[2]

2.2.2. Botanical records

Considering that the vegetation of BRS has been a relatively well studied subject by different authors, two basic sources of information were used in this investigation to study the flora of the BRS i) the account of 1141 angiosperm species generated by Shalisko (2014) in canyons of western Mexico based on the information obtained from the "Global Biodiversity Information Facility" (GBif,) and "Biodiversity Network databases of Western Mexico" (ReBiOMex,), and ii) the botanical records of previous field research in the studied region (López, et al. 2011; Sahagún-Godínez et al., 2014). Two years later the same references were collated with the "coterranean" floristic listing in protected natural areas of Santiago and Verde rivers which are adjacent to our study area (Ministry of Environment and Territorial Development, 2016).

Each of the species in the initial account was collated with specified bibliography and with specialized databases on the subject, regarding: (1) existing ethnobotanical knowledge about food uses of its belonging taxon; (2) edible plant organs; (3) any previous physical-chemical analysis on it, and; (4) records of its use as food within the study area or in any other region. So it was that the number of records was reduced to less than half (445 species) including several medicinal species, an associated characteristic of many plants usually used for food. A third filtering was carried out after the prospective field trips where informants provided information about the species distribution and confirmed an existing food use, which reduced the number of possible species to 204, close to half.

2.2.3. Ethnobotanical exploration

To verify the presence of each of the species as well as their nutritional use within the study area, ethnobotanical explorations were carried out adapting some of the methodological

[2] A more detailed description of the study area can be found in the Introduction Chapter of this thesis.

strategies proposed by different authors (Hernández-X, 1985; Casana-Martinez et al., 1996). The tasks were adapted, as far as possible, to the limitations imposed by the ravine concerning its wide extension, the rugged terrain, the lack of roads, the scattered ranches with small population and the planting of illegal crops.

The first ethnobotanical recognition of the area was carried out based on the existing bibliography and the available cartography of the area, using QGis, Google Hearth, and INEGI's digital platform: My Digital Map. This allowed the planning of the tours, routes and villages to visit.

Drastic changes in vegetation phenology (TDF) made it partially difficult to determine the field area and plant collection during the dry season. A field guide was prepared with photographs we took and other electronic or bibliographic resources such as the published papers on the trees and shrubs of the ravine (López et al., 2011, Sahagún-Godínez et al., 2014). This guide was presented to the informants both printed and digitally (using a tablet); they were also shown plans of the town to facilitate the location of the plants.

When venturing for the first time in a ranch or small town we did our best to contact the municipality's representative (Municipal Delegate), the ejido commissioners and associations of small owners or other relevant social actors to explain and justify our presence in the community. To exemplify, an interview was applied initiating the *snowball method* in order to locate the best informants, namely people to whom the community refers to as those who "know best about hill plants". The basic methodological techniques applied to learn about the species used for food purposes in the BRS were:

a) Participant observation
b) Semi-structured interviews (to farmers)
c) Directed interviews (for officials)
d) Field exploration
e) Collection of plants in the company of the informants
f) Database generation

During the period July 2013 - September 2016, 140 working days were held in 60 locations within BRS, in which a total of 107 informants were interviewed, of which 26% were housewives. During the interviews a digital recorder was used with the purpose of maintaining the attention of the informant and better capturing their arguments, attitude and type of answers to the questions posed. Digital photography was used to store precise details during ethnobotanical explorations. Given the widespread use of cell phones (mobile) that have audio and photography applications, working in the study area with a camera and a recorder was no bother to most of the informants.

2.2.4. Processing of ethnobotanical information

With obtained information from the field trips, the previous account of 204 records was cleared by eliminating: (1) the species whose presence in the BRSwas not recognized by the informants, (2) those that could not be recognized or collected during the field tours or were not specifically reported in relevant floristic papers. Species growing in the SA not having reported food use were eventually added, for there are existing reports in other regions.

As proposed by Vogl et al., (2004), the data was stored to be managed from an *Access* database consisting of a series of charts with specific topics relating to each other in a hierarchical manner. Those species with presence in the BRS and with a food use record were considered as a valid log both in the study area and other regions. As part of the ethnobotanical exploration a result of 164 botanical collections are to be kept in the collection of the Botany Institute of the University of Guadalajara.

2.3. Results

A total number of 196 vegetable taxons were recorded, corresponding to 178 species and 18 varieties of plants with edible use.[3] Most of these (89,3%) are grouped into 46 botanical families belonging to the Magnoliopsida class (dicotyledonous) while a smaller group (10,7%) correspond to eight botanical families belonging to the Liliopsida Class (monocotyledonous). A complete list of taxons and their characterization is presented in Table 2.1.

[3] Varieties corresponding to *Zea mays* L., *Spondias purpurea* L. and *Manguifera indica* L. cultivars; in the document the term Taxons will be used to include all species and varieties.

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
		Liliopsida					
Arecaceae							
Cocos nucifera L.	Coco	Stipe	Introduced	Yes	2	5	2; 7
Asparagaceae							
Agave angustifolia Haw.	Mezcal	Acaulescentscent	Native	No	7	2; 4	1; 5
Agave guadalajarana Trel.	Mezcal	Acaulescentscent	Native	No	7	2	5
Agave tequilana F.A.C. Weber	Mezcal azul	Acaulescentscent	Native	Yes	1; 4	2	5; 9
Agave vilmoriniana A. Berger	Mezcal	Acaulescentscent	Native	No	7	2; 4; 7	1; 5
Dasylirion acrotrichum (Schiede) Zucc.	Palmita	Acaulescentscent	Native	No	7	2	5
Dasylirion simplex Trel.	Palmita	Acaulescentscent	Native	No	7	2	5
Bromeliaceae							
Ananas comosus (L.) Merr.	Piña	Acaulescentscent	Native	Yes	6	5	2
Bromelia plumieri(E. Morren) L.B. Sm.	Cocuixtle	Acaulescentscent	Native	Yes	1	5	2
Cyperaceae							
Cyperus esculentus L.	Coquillo	Graminiform	Introduced	No	8	1	7
Dioscoreaceae							
Dioscorea convolvulacea Schltdl. & Cham.	Camote del cerro	Herb clambering	Native	No	7	1	1
Dioscorea remotiflora Kunth	Camote del cerro	Herb clambering	Native	No	7	1	1
Dioscorea sparsiflora Hemsl.	Camote del cerro	Herb clambering	Native	No	7	1	1
Iridaceae							
Tigridia pavonia (L. f.) DC.	Cacomite	Herbaceous	Native	No	7	1	1
Musaceae							
Musa paradisiaca L. var. *Manzano* [M. acuminata x M.balbisiana]	Platano manzano	Pseudostem	Introduced	Yes	2	5	2

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family / Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Poaceae							
Cymbopogon citratus (DC.) Stapf	Zacate limón	Graminiform	Introduced	Yes	6	3	7; 7
Zea mays L. var. *Elotero*	Maíz	Graminiform	Native	Yes	5	6	1
Zea mays L. var. *Morado*	Maíz	Graminiform	Native	Yes	3; 4; 6	6	3
Zea mays L. var. *Negro*	Maíz	Graminiform	Native	Yes	3; 4; 6	6	3
Zea mays L. var. *Pozolero*	Maíz	Graminiform	Native	Yes	3; 4; 6	6	3
Zea mays L. var. *Tampiqueño*	Maíz	Graminiform	Native	Yes	3; 4; 6	6	3
		Magnoliopsida					
Adoxaceae							
Sambucus nigra L.	Sauco	Shrub	Introduced	Yes	6	5	2
Amaranthaceae							
Amaranthus hybridus L.	Quelite	Herbaceous	Native	No	8	8	1
Iresine celosiodes L.	Quelite guillita	Scandent	Native	No	8	8	1
Anacardiaceae							
Mangifera indica L. var. *Barranquello*	Barranquello	Arborescent	Introduced	Yes	2	5	2
Mangifera indica L. var. *Manila*	Manila	Arborescent	Introduced	Yes	2	5	2
Mangifera indica L. var. *Petacon*	Petacon (externas)	Arborescent	Introduced	Yes	2	5	2
Pistacia mexicana HBK	Pistache mexicano	Arborescent	Native	No	7	5	6
Rhus jaliscana Standl.	Agrito	Shrub	Native	No	7	5	6; 6
Spondias mombin L.	Jovo, Ovo	Arborescent	Native	Yes - No	6	5	2; 7; 6
Spondias purpurea L. var. *Corpeña*	Corpeña	Arborescent	Native	Yes	1	5	2
Spondias purpurea L. var. *Huentiteca*	Huentiteca	Arborescent	Native	Yes	1	5	2
Spondias purpurea L. var. *Huesona*	Huesona	Arborescent	Native	Yes	1	5	2
Spondias purpurea L. var. *Mansa*	Mansa; Grande	Arborescent	Native	Yes	1	5	2; 7; 6

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family / Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Spondias purpurea L. var. *Mostrenco*	Mostrenco	Arborescent	Native	Yes - No	1;7	5	2; 7; 6
Spondias purpurea L. var. *Roja*	Roja	Arborescent	Native	Yes - No	1;7	5	2; 7; 6
Spondias purpurea L. var. *Sanjuaneña*	Sanjuaneña	Arborescent	Native	Yes	1	5	2
Annonaceae							
Annona cherimola Mill.	Chirimoya	Arborescent	Introduced	Yes	2	5	2; 7; 6
Annona longiflora S. Watson	Anona de cerro	Arborescent	Native	No	7	5	2
Annona reticulata L.	Anona roja	Arborescent	Native	Yes	2	5	2
Annonna muricata L.	Guanabana cultivar	Arborescent	Native	Yes	2	5	2; 7; 6
Apocynaceae							
Gonolobus uniflorus Kunth	Taloyote	Herb clambering	Native	No	7	5	1; 6
Macrosiphonia hypoleuca (Benth.) Muell.	Flor de San Juan	Sufrutescent	Native	No	7	4	8
Plumeria rubra L.	Corpeña	Arborescent	Native	No	7	4; 5	6; 1
Stemmadenia donnell-smithii (Rose) Woodson	Huevos de toro	Arborescent	Native	No	7	9	6
Stemmadenia tomentosa Greenm.	Mancuernilla	Arborescent	Native	No	7	9	6
Thevetia ovata (Cav.) A.DC.	Ayoyote	Arborescent	Native	No	7	5	2
Thevetia thevetioides (Kunth) K. Schum.	Codo de Frayle	Arborescent	Native	No	7	5	2
Asteraceae							
Bidens pilosa L	Aceitilla	Herbaceous	Native	No	8	3; 4	1; 7
Dahlia coccinea Cav.	Camila	Herbaceous	Native	No	8	1	1
Dahlia spp	Camila (2)	Herbaceous	Native	No	8	1	1
Pectis uniaristata DC.	Limoncillo	Herbaceous	Native	No	7	10	7; 7
Porophyllum macrocephalum DC.	Japite	Herbaceous	Native	No	7	10	1
Tagetes filifolia Lag.	Anis	Herbaceous	Native	No	7	10	7
Begoniaceae		Herbaceous					

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family / Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Begonia angustiloba A. DC.	Begonia	Herbaceous	Native	No	7	4	6
Begonia biserrata Lindl.	Begonia	Herbaceous	Native	No	7	4	6
Begonia gracilior Burt-Utley & McVaugh	Begonia	Herbaceous	Native	No	7	4	6
Bignoniaceae							
Crescentia alata Kunth	Cuastecomate	Arborescent	Native	No	7	5	2; 5
Bixaceae							
Amoreuxia palmatifida DC.	Saya	Sufrutescent	Native	No	7	1; 6	1; 6
Bombacaceae							
Ceiba aesculifolia (Kunth) Britten & Baker F.	Pochote	Arborescent	Native	No	7	5; 6	1; 6
Pseudobombax palmeri (S. Watson) Dugand	Clavellina	Arborescent	Native	No	7	4	1
Boraginaceae							
Ehretia latifolia Loisel	Capulín blanco	Arborescent	Native	No	7	5	2
Brassicaceae							
Nasturtium officinale W.T. Aiton	Berro	Aquatic	Introduced	No	7	10	1
Cactaceae							
Cephalocereus alensis (F.A.C. Weber) Britton &Rose	Viejito	Arborescent	Native	No	7	5	2
Hylocereus undatus (Haw.) Britton & Rose	Pitahaya	Scandent	Native	No	6; 7	5	2
Isolatocereus dumortieri (Scheidw.) Backeb.	Organo	Columnar pachycaulous	Native	No	7	5	2
Mammillaria scrippsiana (Britton & Rose) Orcutt	Chilitos	Crasicaule globosa	Native	No	6; 7	5	6
N*opalea cochenillifera* (L.) Salm-Dyck	Nopal (largo)	Crasicaule Shrub	Native	No	6	2	1
Nyctocereus serpentinus (Lag. & Rodr.) Britton &Rose	Reyna de noche	Columnar pachycaulous	Native	No	6	5	2
Opuntia atropes Rose	Nopal blanco	Shrub pachycaulous	Native	Yes	6; 7	2; 5	1; 2

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Opuntia ficus-indica (L.) Miller	Nopal manso	Shrub pachycaulous	Native	Yes	1; 4	2; 5	1; 2
Opuntia fuliginosa Griffiths	Nopal de cerro	Shrub pachycaulous	Native	No	7	2	1
Opuntia jaliscana Bravo	Sangre de toro	Shrub pachycaulous	Native	No	6; 7	5	1; 2
Opuntia undulata Griffiths	Oreja de elefante	Shrub pachycaulous	Native	Yes	6	2; 5	1; 2
Pachycereus pecten-aboriginum (Engelm. ex S.Watson) Britton & Rose	Organo	Columnar pachycaulous	Native	No	7	5	2
Pereskiopsis aquosa (F.A.C. Weber) Britton & Rose	Patilon	Shrub pachycaulous	Native	No	7	5	2
Pilosocereus alensis (F.A.C. Weber) Byles & G.D.Rowley	Viejito	Columnar pachycaulous	Native	No	7	5	2
Stenocereus dumortieri (Scheidw.) Buxb.	Pitayo cimarrón	Columnar pachycaulous	Native	No	7	5	2
Stenocereus queretaroensis (F.A.C. Weber) Buxb.	Pitaya	Columnar pachycaulous	Native	Yes - No	1; 7	5	2
Cannabaceae							
Aphananthe monoica (Hemsl.) J.-F. Leroy	Palo chino	Arborescent	Native	No	7	5; 6	6
Cannabis sativa L.	Mariguana	Herbaceous	Introduced	No	2; 4	6	3
Celtis caudata Planch.	Granjeno	Arborescent	Native	No	7	5	2
Celtis iguanaea (Jacq.) Sarg.	Iguanero	Arborescent	Native	No	7	5	2
Crateva palmeri Rose	Granadilla	Arborescent	Native	No	7	5	2
Caricaceae							
Carica papaya L.	Papaya	Arborescent	Native	Yes - No	2; 6	5	2
Jacaratia mexicana A. DC.	Bonete	Arborescent	Native	No	7	5	1; 6
Chenopodiaceae							
Chenopodium ambrosioides L.	Epazote	Herbaceous	Native	No	8	10	8
Chenopodium graveolens Willd.	Epazote de zorrillo	Herbaceous	Native	No	8	10	8
Cucurbitaceae							
Citrullus lanatus (Thunb.) Matsum. y Nakai	Sandia	Repent	Introduced	Yes	2; 4; 6	5	2

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Cucurbita argyrosperma K. Koch subsp. *argyrosperma*	Calabaza criolla (cultivada)	Repent	Native	Yes	3; 4	4; 5; 6	1; 6
Cucurbita argyrosperma K. Koch	Calabaza amarga	Repent	Native	No	8	6	6
Cucurbita ficifolia Bouché	Chilacayote	Repent	Native	Yes	3	5	1
Cucurbita moschata Duchesne	Calabaza de castilla	Repent	Native	Yes	3; 4	5	1
Cucurbita pepo L.	Calabacita tierna	Herbaceous	Native	Yes	5	4; 5	1
Momordica charantia L.	Cunde amor	Repent	Introduced	No	8	6	6
Sechium edule (Jacq.).Sw.	Chayote	Herb clambering	Native	Yes	2	1; 5; 8	1
Ebenaceae							
Diospyros digyna (Jacq.)	Zapote prieto	Arborescent	Native	Yes	2	5	2
Euphorbiaceae							
Cnidoscolus chayamansa McVaugh	Chaya	Shrub	Native	Yes - No	6	3	1
Dalembertia populifolia Baill.	Trabuco	Shrub	Native	No	7	1	6
Jatropha curcas L.	Cacahuatillo	Arborescent	Native	No	6	6;8	1;6
Manihot aesculifolia (Kunth) Pohl.	SD	Shrub	Native	No	7	SD	SD
Manihot caudata Greenm	Churumbel	Shrub	Native	No	7	6	6
Manihot rhomboidea Müll. Arg.	SD	Shrub	Native	No	7	SD	SD
Fabaceae							
Acacia acatlensis Benth.	SD	Arborescent	Native	No	7	4; 5	1
Acacia cochliacantha Humb. & Bonpl. ex Willd.	SD	Arborescent	Native	No	7	4; 5	1
Acacia coulteri Benth.	Temachaca	Arborescent	Native	No	7	8	1
Acacia farnesiana L. Willd.	Huizache	Arborescent	Native	No	7	5; 8	1; 6
Crotalaria pumila Ort.	Chipil	Herbaceous	Native	No	8	4; 10	1
Enterolobium cyclocarpum (Jacq.) Griseb.	Parota	Arborescent	Native	No	7	6	4
Erythrina flabelliformis Kearney	Colorin	Arborescent	Native	No	7	4	1

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family / Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Erythrina montana Rose & Standl.	Colorin	Arborescent	Native	No	7	4	1
Inga vera Willd.	Jiniquil	Arborescent	Native	No	7	6	2
Leucaena esculenta (Moc. & Sessé ex DC.) Benth.	Guaje	Arborescent	Native	Yes - No	1; 7	5; 8	4
Leucaena leucocephala Lam.	Verde	Arborescent	Native	Yes - No	1; 7	5; 8	4
Macroptilium gibbosifolium (Ort.) A. Delgado	Jicamita	Herb clambering	Native	No	7	1	1
Phaseolus acutifolius A.Gray	Tepari	Herb clambering	Native	Yes	3; 7	6	4
Phaseolus coccineus L.	Ayocote	Herb clambering	Native	Yes	3; 8	5; 6	4
Phaseolus vulgaris L.	Frijol	Herb clambering	Native	Yes	4; 5	5; 6	4
Pithecellobium dulce (Roxb.) Benth	Guamuchil	Arborescent	Native	No	1; 4; 7	6	6
Prosopis laevigata H. & K. ex Willd	Mezquite	Arborescent	Native	No	7	5	6
Senna sp	Caca de gato	Shrub	Native	No	7	5	6
Tamarindus indica L.	Tamarindo	Arborescent	Introduced	Yes	2	5	6; 6; 7
Fagaceae							
Quercus rugosa Née	Encino	Arborescent	Native	No	7	5	7
Juglandaceae							
Carya illinoensis (Wangenh.) K. Koch	Nuez cascara de papel	Arborescent	Introduced	Si	2	5	6
Juglans regia L.	Nogal	Arborescent	Introduced	No	2	5	6
Lamiaceae							
Hyptis albida Kunth	Salvia (Blanca)	Shrub	Native	No	7	3; 4	7
Hyptis suaveolens (L.) Poit.	Chía de monte	Herbaceous	Native	No	7; 8	3; 6	7; 7
Mentha spicata L.	Yerbabuena	Herbaceous	Introduced	Yes	6	3	7; 7; 8
Ocimum basilicum L.	Albahaca	Herbaceous	Introduced	Yes	6	3	8
Origanum vulgare L.	oregano	Herbaceous	Introduced	Yes	6	3	8
Salvia hispanica L.	Chia (cultivada)	Herbaceous	Native	Yes	4	6	9

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3] Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Vitex mollis Kunth	Ahuilote	Arborescent	Native	No	7	5	2
Vitex pyramidata B.L. Rob.	Negrito	Arborescent	Native	No	7	5	2
Lauraceae							
Persea americana Mill.	Aguacate	Arborescent	Native	Yes	2; 6	5	1
Malpighiaceae							
Byrsonima crassifolia (L.) Kunth	Nanche	Arborescent	Native	Yes	7	5	2
Malpighia mexicana A. Juss.	Manzanita	Shrub	Native	No	7	5	2
Malvaceae							
Gossypium aridum (Rose & Standl.) Skovst	Algodón	Shrub	Native	No	7	6	6
Guazuma ulmifolia Lam.	Guacima	Arborescent	Native	No	7	5	6
Hibiscus phoeniceus Jacq.	SD	Shrub	Native	No	7	4	6
Malva parviflora L.	Malva quesitos	Herbaceous	Introduced	No	7	5; 8	1; 6
Malvaviscus arboreus Cav.	Obelisco	Shrub	Native	No	6; 7	4	6
Moraceae							
Brosimum alicastrum SW.	Capomo	Arborescent	Native	No	7	6	2; 7; 7
Ficus goldmanii Standl.	Higuera Negra	Arborescent	Native	No	7	5	2
Ficus insipida Willd.	Higuera Blanca	Arborescent	Native	No	7	5	2
Ficus pertusa L.	Camichin	Arborescent	Native	No	7	5	2
Morus celtidifolia H.B.K.	Mora	Arborescent	Native	No	7	5	2
Myrtaceae							
Psidium guajaba L.	Guayaba	Arborescent	Native	Yes - No	2; 6; 7	5	2; 6; 7
Psidium sartorianum (Berg.) Ndzu	Arrayan	Arborescent	Native	Yes	2	5	2; 6; 6; 7
Nyctaginaceae							
Salpianthus macrodonthus Standl.	Catalina	Herbaceous	Native	No	8	10	1

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious
[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts
[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family / Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Olacaceae							
Ximenia parviflora Benth	SD	Shrub	Native	No	7	5	2
Oleaceae							
Forestiera tomentosa S. Watson	Aceituna	Arborescent	Native	No	7	5	2
Oxalidaceae							
*Oxalis corniculata*L.	Agrito	Herbaceous	Native	No	8	3	1
Passifloraceae							
Passiflora edulis Sims	Pasiflora	Herb clambering	Introduced	Yes	6	5	2
Passiflora foetida L	Pasiflora de campo	Herb clambering	Introduced	No	8	5	2
Passiflora suberosa L.	Pasiflora de campo	Herb clambering	Native	No	7	5	2
Piperaceae							
Peperomia campylotropa A. W. Hill	Pimienta	Herbaceous	Native	No	7	3	1
Piper auritum Kunth	Hoja Santa	Shrub	Native	No	6; 7	3	8
Polygonaceae							
Rumex crispus L.	Lengua de vaca	Herbaceous	Introduced	No	8	3	1
Portulacaceae							
Portulaca oleracea L.	Verdolaga	Herbaceous	Native	No	8	3	1
Punicaceae							
Punica granatum L.	Granada	Arborescent	Introduced	Yes	2; 6	5	2
Rhamnaceae							
Karwinskia humboldtiana (Schult.) Zucc.	Margarita	Arborescent	Native	No	7	5	2
Karwinskia latifolia Standl.	SD	Arborescent	Native	No	7	5	2
Rosaceae							
Prunus persica (L.) Batsch	Durazno	Arborescent	Introduced	Yes	2; 6	5	2

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family / Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Prunus serotina Subsp. *Capuli* (Cav.) McVaugh	Capulin	Arborescent	Native	Yes	2; 6; 7	5	2
Rubiaceae							
Coffea arabica L.	Café	Shrub	Introduced	Yes	2	5; 6	2; 7
Genipa sp.	SD	Arborescent	Native	No	7	5	2
Randia capitata DC.	Zapuche	Arborescent	Native	No	7	5	6
Randia laevigata Sandl.	Zapuche	Arborescent	Native	No	7	5	6
Rutaceae							
Casimiroa sapota Oerst; C. edulis	Zapote Blanco	Arborescent	Native	No	7	5	2
Citrus aurantifolia (Christm.)Swing	Naranja-lima	Arborescent	Introduced	Yes	2	5	2
Citrus aurantium L.	Naranja amarga	Arborescent	Introduced	Yes	2; 6	4; 5	7; 8
Citrus limetta Risso	Lima chichona	Arborescent	Introduced	Yes	2	5	2
Citrus limon (L.) Burm.	Limón	Arborescent	Introduced	Yes	2; 6	5	8
Citrus reticulata Blanco	Mandarina	Arborescent	Introduced	Yes	2	5	2
Citrus sinensis (L.)Burm	Naranja dulce	Arborescent	Introduced	Yes	2	5	2
Sapotaceae							
Manilkara zapota (L) P. Royen	Chicozapote	Arborescent	Native	Yes	2	5	2
Mastichodendron capiri (A. DC.) Cronquist	Tempizque	Arborescent	Native	No	1	5	2
Pouteria campechiana H.B.K.	Miguelito	Arborescent	Native	Yes	2	5	2
Pouteria sapota Jacq	Mamey	Arborescent	Native	Yes	2	5	2
Sideroxylon cartilagineum (Cronquist) T.D. Penn	Huizilacate	Arborescent	Native	No	7	5	2
Sideroxylon persimile subsp.*subsessiliflorum* (Hemsl.) T.D. Penn.	Guencho	Arborescent	Native	No	7	5	2
Solanaceae							
Capsicum annuum L.	Chile	Herbaceous	Native	Yes	1; 2; 3; 4; 5; 6; 7	5	8

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious

[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts

[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

Table 2.1. Plant genetic resources for food present in the Santiago River Canyon

Family Species	Common name	Biological form	Origin	Handling	Habitat[1]	Part used [2]	Type of food [3]
Capsicum annuum var. *glabriusculum* (Dunal) Heiser y Pickersgill.	Piquín	Sufrutescent	Native	No	6	5	8
Capsicum chinense Jacq.	Chile habanero	Herbaceous	Native	Yes	6	5	8
Jaltomata procumbens (Cav.) J. L. Gentry	Jaltomata	Herbaceous	Native	No	8	5; 10	1; 2
Physalis angulata L.	Tomate cascara	Herbaceous	Native	No	8	5	1
Physalis philadelphica Lam.	Tomate cultivado	Herbaceous	Native	Yes - No	2; 4; 5	5	1
Physalis pubescens L.	Tomatillo	Herbaceous	Native	No	8	5	1
Solandra maxima (Moc. & Sessé ex Dunal) P.S.Green	Copa de oro; Guayacán blanco	Shrub	Native	No	6; 7	5	2
Solanum americanum Mill.	Hierba mora	Herbaceous	Native	No	7	5	6
Solanum candidum Lindl.	Chichilegua	Herbaceous	Native	No	7	5	6
Solanum lycopersicum L.	Jitomate cultivado	Herbaceous	Native	Yes	2; 5; 6	5	1
Solanum lycopersicum var. *cerasiforme*	Ojo de Venado	Herbaceous	Native	No	8	5	1; 8
Solanum stoloniferum Schltdl. & Bouché	Papa cimarrona	Herbaceous	Native	No	8	1	1
Verbenaceae							
Lantana camara L.	Frutilla	Shrub	Native	No	7	3; 5	6; 7
Vitaceae							
Vitis cinerea (Engelm.) Millardet	Uva silvestre	Woody clambering	Native	No	7	3; 5	6

[1] Habitat: 1) Rainfed orchards, 2) Irrigation orchards, 3) Cuamil, 4) Monoculture dryland, 5) Irrigation monoculture, 6) Backyard, 7) Wild, 8) Adventitious
[2] Part used: 1) Root, 2) Stem, 3) Leaves,4) Flowers, 5) Fruits, 6) Seeds, 7) Floral scape, 8) Young shoots, 9) Latex, 10) Aerial parts
[3]Type of food: 1) Vegetables, 2) Fruit, 3) Cereal, 4) Legumes, 5) Alcoholic drinks, 6) Snack food, 7) Soft drink, 8) Seasoning, 9) Food industry

The families grouping the largest number of taxons are Fabaceae (9,7%), Cactaceae (8,2%), Solanaceae and Anacardiaceae (each with 6,6%) which together group 31% (61 records) of food resources reported in BRS. 22 families are represented by only one species, altogether representing 10,7% of the records.[4] 17 families compiling from two to four species represent 22,5%[5] while eleven families that have between 5 and 8 records together account for 35,7% of the total number of edible plants.[6] Most of the reported taxons (84%) are native to Mesoamerica; the remaining (16%) corresponds to introduce plants in the form of cultivars or weeds.

Registered food plants show 16 types of growth (biological form). The most common types were: *Arborescent*, *herbaceous and shrubs*, which together group 71,4% of total taxons; in the next group there are six forms of growth[7,] with 23,5% of the records included; the remaining plants (5,1%) present 7 different biological forms.[8]The species distribution according to their type of growth is shown in Table 2.

Edible plants are distributed in eight types of natural and modified by man environments (see Table 3, the term adventitious is included without being a habitat type); considering that several taxons have presence in more than one habitat a relative record of 247 habitat was obtained, from which the estimation of their distribution percentages was elaborated. The wild area is the one that gathered most of the records: 42,5%, followed by Backyard (15%) and Irrigation Orchard (14,2%). These three, as a whole, account for 71,7% of the total taxa registered environments. The rest of the conducted records percentages correspond to: Adventitious (9,3%), Rainfed orchards (6,5%), Monoculture dryland (5,7%), Cuamil (4%), Monoculture irrigation (2,8%).

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[4] Adoxaceae, Arecaceae, Bignoniaceae, Bixaceae, Boraginaceae, Brassicaceae, Capparaceae, Cyperaceae, Ebenaceae, Fagaceae, Iridaceae, Lauraceae, Musaceae, Nyctaginaceae, Olacaceae, Oleaceae, Oxalidaceae, Polygonaceae, Portulacaceae, Punicaceae, Verbenaceae, Vitaceae.

[5] Amaranthaceae, Annonaceae, Begoniaceae, Bombacaceae, Bromeliaceae, Cannabaceae, Caricaceae, Chenopodiaceae, Dioscoreaceae, Juglandaceae, Malpighiaceae, Myrtaceae, Passifloraceae, Piperaceae, Rhamnaceae, Rosaceae, Rubiaceae.

[6] Apocynaceae, Asparagaceae, Asteraceae, Cucurbitaceae, Euphorbiaceae, Lamiaceae, Malvaceae, Moraceae, Rutaceae, Poaceae, Sapotaceae.

[7]Acaulescent, Herb clambering, Shrub pachycaulous, Graminiform, Columnarpachycaulous, Repent.

[8]Suffrutescent, Scandent, Aquatic, Globosa pachycaulous, Stipe, Pseudostem, Woody clambering.

Table 2.2. Biological type grouping of 196 phytogenetic resources for food inn Barranca del Río Santiago, Mexico.

Biological Form	*Taxa number*	*Percentage*
Arborescent	84	42,86
Herbaceous	38	19,39
Shrub	18	9,18
Herb clambering	12	6,12
Acaulescent	8	4,08
Graminiform	7	3,57
Shrub pachycaulous	7	3,57
Columnarpachycaulous	6	3,06
Repent	6	3,06
Sufrutescent	3	1,53
Scandent	2	1,02
Aquatic	1	0,51
Globose pachycaulous	1	0,51
Stipe	1	0,51
Pseudostem	1	0,51
Woody clambering	1	0,51

Table 2.3. Habitats where phytogenetic resources for food are distributed in Barranca del Río Santiago, Mexico.

Environment	*Records*	*Percentage**
Wild	105	42,51
Backyard	37	14,98
Irrigation orchards	35	14,17
Adventitious	23	9,31
Rainfed orchards	16	6,48
Monoculture dryland	14	5,67
Cuamil	10	4,05
Irrigation monoculture	7	2,83

* Calculation based on 247 records

It is relevant that from 196 taxa registered, 125 correspond to native wild plants (61,8%), 63 records (32,1%) correspond to cultivars (native and introduced) and 10 taxons (3,11%) correspond to nativecultivarsthat also grow wild.[9]

There are 10 existing types of plant structures used for edible purposes (latex is also accounted without being edible). Table 2.4, shows the records distribution in three groups; fruit consumption (54,4% of 226 relative records) is notorious, the second group is constituted by reports on the use of seeds (11%), flowers (8,9%), leaves (6,6), root (5,3%) and stem (4,9%). This group, as a whole, amounts to 36,7%. The third group consists of the *entire aerial part* (for herbs), *young shoots*, *latex* and *floral scape*, all together accounting for 8,9% of the total relative records of consumed plant parts.

Table 2.4. Type of plant structure of 196 edible plants and their relative percentage to 226 records

Plant Structure	*Number of records*	*Percentage*
Fruits	123	54,42
Seeds	25	11,06
Flowers	20	8,85
Leaves	15	6,64
Root	12	5,31
Stem	11	4,87
Aerial parts	9	3,98
Young shoots	8	3,57
Latex	2	0,88
Floral scape	1	0,44

[9] *Carica papaya* L.; *Cnidoscolus chayamansa* McVaugh; *Leucaena esculenta* (Moc &Sessé ex Dc Benth.; *L. leucocephala* Lam.; *Physalis philadelphica* Lam.; *Psidium guajaba* L.; *Spondias mombin* L.; *S. purpurea* L.var.*Mostrenco; S. purpurea* var.*Red; Stenocereus queretaroensis* F.A.C. Weber) Buxb.

For the 196 phytogenetic food resources 237 relative records were found on the type of food they constitute, from which nine groups were established (See Table 2.5). The most frequent one is *direct consumption of fruits* (34,8%), followed by the categories of *vegetables* and *snacks* (23,2% and 19,4% respectively). To lesser extent *non alcoholic beverages* followed with 9,7%; next are uses such as *seasoning*, *legumes*, *cereal*, to prepare *alcoholic beverages*, and those that are part of the *food industry*, altogether accumulating 13,9% of the total relative records.

Table 2.5. Variety of foods provided by 196 edible plants and their relative percentage to 237 record

Food Type	*Number of records*	*Percentage*
Fruit	80	33,76
Vegetables	55	23,21
Snack food	46	19,41
Soft Drink	23	9,70
Seasoning	13	5,49
Legumes	6	2,53
Cereal	5	2,11
Alcoholic drinks	7	2,95
Food industry	2	0,84

2.4. Discussion

Learning about the inventory of useful plants is a way of learning about plant resources, which represents a real and accessible alternative to the rural and urban population (Zamora et al., 2009). It is important to note that the 196 edible plants registered for BRS represent only 13% of approximately 1 500 possible edible species registered for Mexico (Casas, 2010).

2.4.1. Description of phytogenetic resources

The plants were grouped into 53 botanical families; the most abundant were Fabaceae, (9,7%), Cataceae (8,2%), Solanaceae and Anacardiaceae (each of the latter with 6,6%). The predominance of edible species in these families coincides with their level of presence in the predominant vegetation type: tropical deciduous forest (TDF), an equivalent of what has been called Low Deciduous Forest, or Seasonally Dry Tropical Forest (Miranda and Hernández-Xolocotzi, 1963; Pennington et al., 2000; Trejo, 2010; Lot and Atkinson, 2010), where the most important families are: Fabaceae, Compositae, Euphorbiaceae, Cactaceae, Burseraceae, Malpighiaceae, Rubiaceae, Anacardiaceae, Rhamnaceae, Convolvulaceae, Bignoniaceae, Boraginaceae, Rutaceae and Verbenaceae.

The family with the highest number of edible species in BRS is Fabaceae or Leguminosae, which relates to the fact that this family occupies, in terms of the number of taxons that it gathers, the third place worldwide and second in Mexico (Lewis et al., 2013; Villaseñor, 2016) and it stands out due to the high frequency of plants with high nutritional value (Caballero and Cortés, 2001). Although many papers on useful flora report that herbaceous plants are generally used in greater proportion than trees and shrubs (Op.Cit.), for the case of BRS it was the woody species (trees and shrubs) the ones representing highest percentage for food resources (52%) compared to herbaceous plants and other scarce presence forms of growth. One possible reason could be that trees are the most conspicuous expression of vegetation, and that these are dominant in the TDF ecosystem unlike the herbaceous stratum which is no longer evident during the dry season. This is consistent with what was reported for the State of Yucatan by Zizumbo-Villarreal et al. (2010) when they pointed out that among 32 most important native phytogenetic food resources fruit trees correspond to 20 species. Of the 196 plants we report as edible in BRS, 84 are trees (42,9%) and 18 are shrubs (9,18%), this amount (102) exceeds the 96 edible woody plants recorded in BRS in a previous study (Tena et al., 2019); 48 of the current reported species are present in the BRS tree guides (López et al., 2011; Sahagún-Godínez et al., 2014).

TDF from different parts of Mexico shows relatively small resemblance in terms of its flora (Rzedowski and Calderón, 2013), so the comparison of papers on useful plants in this type of vegetation will have differences not only in terms of type of species but also in the number and types of uses that are given to them depending on the informants and their level of knowledge, traditions and their social and cultural origin (Zamora et al., 2009). In the coast of Jalisco, a similar environment to the study area, Rendón and Nuñez (1999) reported 246 useful plants belonging to 76 botanical families. The main usage from inhabitants is medicinal to 88 species and 44 families, followed by usage as food to 77 species and 40 families. This number of edible species represents only 39% of the reported species in BRS by this paper; we found that there is a coincidence with the following most important families with nutritional use: Fabaceae, Solanaceae, Cactaceae, Cucurbitaceae and Lamiaceae. For their part, Gispert and Rodríguez (1998) reported a total of 159 species of which 99 are medicinal and 60 for food usage in two Cora communities settled in a very similar environment to our study area: the canyons region in the State of Nayarit, with presence of TDF and sub-evergreen tropical forest. In the State of Veracruz, Lascurain et al. (2010) identified 140 edible wild fruits species.

It is important to concede that a majority of the 196 plants registered in this study 83,7% (164 taxons) are considered to be native in BRS area (the Mesoamerican West) and only 16,3% (32 taxons) are introduced plants from other parts of America or from the old continent. Most of the native plants are wild (70,1%), another part (24,4%) are cultivated and a smaller proportion (6,1%) are tree species that show both wild and cultivated forms. Native wild plants constitute emergency resources during times of scarcity as a substitute for staple foods (Caballero, 1987). 51,8% of the 164 native wild taxons with food usage correspond to trees and shrubs that produce mostly edible fruits for direct consumption. The native wild herbaceous accounts for 20% behaving like wild or adventitious species (weeds), which are used as “quelites” and provide from different plant structure (foliage, flowers, tubers) to diverse food uses.

The native cultivated species are 39, among which stand out those used as food since preceramic times such as agaves and Mexican plum, which alongside with corn, beans, squash, chili, nopales, fruits and vegetables were the basis food in Mesoamerican cultures. 25 of the 33 reported plants by Zizumbo-Villareal et al. (2014) have presence in BRS as part of the Food System during the Mesoamerican formative period. *Agave tequilana* cultivation and tequila production first started in BRS and surrounding valleys (Jiménez, 2008) and then moved to the highlands in the State of Jalisco and other Mexican regions. However, the volume (tons) of harvested agave in Jalisco had a -5,7% decrease during 2012-2017 period (SIAP, 2018), a situation that has encouraged setting agave cultivation non-favorable lands within BRS.

A smaller proportion of native species (6,1%) are tree species that show both wild and cultivated forms and correspond to: a) three Mexican plum taxons (*Spondias mombin*; *S. purpurea* var.*Mostrenco; S. purpurea* var.*Red*); b) three direct consumption species producing fruits:(*Stenocereus queretaroensis; Carica papaya; Psidium guajaba*); four more species(*Cnidoscolus chayamansa; Leucaena esculenta; L. leucocephala; Physalis philadelphica*)which are used to be consumed as vegetables, all of them in addition to being found in the wild are cultivated in backyards and rainfed orchards.

On the other hand, of the 32 introduced species (16% of the total records), a majority (24 records) are cultivars, mainly trees and fruit shrubs (17) that were introduced since the time of the Colony, such as bananas, mango and different species of citrus and coffee[10]; to a lesser extent there are aromatic herbaceous plants grown in backyards. Other introduced species (7) behave like weeds (arvense) excluding *Malva parviflora*, these other species have varieties grown for food purposes in other parts of the world: *Nasturtium officinale*; *Cyperus esculentus*; *Momordica charantia*; *Passiflora foetida*; *Rumex crispus*; *Cannabis sativa.* The last one has a long tradition of illegal cultivation in BRS and can be replaced by cultivation of oil and seed producing varieties to be consumed as false cereal; we also observed some aloof plants from the crop without being considered wild populations. *Juglans regia* individuals were seen growing in isolation, perhaps as a relic of old plantations. The type of habitat characteristics where the species were found varied depending on whether they were in a natural environment or an agro-system.

2.4.2 Phytogenetic resources preservation status

Most of RFA's correspond to *wild plants* part of TDF (42,5% of 247 relative records, since a species can appear in various habitat types or forms of usage). Vegetation's conditions differs far and wide across the ravine due to the intervention degree to which it has been subject over time; the main affectation reflects in a decreasing vegetation cover and loss of species, which entails the loss of knowledge about them. To exemplify there is the loss of a number of species in some areas such as: *Malpighia mexicana*; *Casimiroa sapota*; *Mastichodendron capiri*. The substitution of the gallery forest along Santiago river and its

[10] At different times different crops such as cane and rice have been introduced in BRS. They have not been taken into account since they have since disappeared or resulted in unsuccessful attempts to settle the crop in the area.

tributaries due to the establishing of mango and other fruit orchards has led to the disappearance in some areas of: *Brosimum alicastrum*, *Peperomia campylotropa*, *Piper auritum*, *Sideroxylon persimile*, among others.

Housewives handling of their *backyard* (home or solar garden) varies from one house to another and from one locality to another. The two most important aspects for its establishment and preservation without doubt are the size of the plot and water quality and availability which is not abundant in most communities. 37 different types of cultivars were registered (among others surely present, although in some cases it was not possible to enter the property). Selected plants usually perform other usages in addition to being consumed: they can have healing properties or they can beautify and give shadow or protection to the house. Essential aromatic plants of European origin are also included as well as different types of chili peppers, one or several types of nopales, the fundamental lemon tree and some other citrus and other fruit trees such as peach and pomegranate, and if space allows it, any kind of *guamúchil* tree, *guaje* or plum.

Irrigation orchards are located on the Santiago river banks and in glens where its permanent tributaries run through. 35 records with predominant tropical fruit trees (18) introduced during the Colony were obtained such as plantain, mango, citrus and coffee, combined to a lesser extent with American fruit trees (11) such as *mamey*, *zapotes*, avocado and custard apples; it was shown to be common to establish arable crops in some areas of the garden. The high number of edible species records in this specific cultivation system is probably due to the fact that a permanent water supply and the abruptness of the land makes it difficult to eliminate uncultivated adventitious arvense (wild or weeds) so they become tolerated as long as they do not interfere with the crops.

23 *adventitious plants* (ruderal and arvense included) represent 9,3% of 247records included in 8 considered operation systems (production). A majority (87%) are native and correspond generally the species called “quelites” which has been consumed since immemorial times as part of Mesoamerican peoples diet. *Dahlia coccinea* is also included, considered by presidential decree as the national flower. In BRS its tubers are beneficial simply by consuming them directly; current gastronomy seeks to use the ligules or petals of

its flowers. Additionally there are four introduced species that show adventitious behavior, three of them are cultivated for food purposes in other regions.

Rainfed orchards are formed by one or several cultivars of *Spondias purpurea*, even though the lack of humidity reduces the number of RFAs to 16 when compared to irrigation orchards. Depending on the region, other food perennial crops such as *Agave tequilana*, *Bromelia plumieri*, *Opuntia* spp, and wild plants such as *Leucaena* spp., *Pithecellobium dulce* and *Mastichodendron capiri* were incorporated.

In some places of the ravine where more or less flat lands allow the use of a tractor or draft animals to prepare the land, a *dry land monoculture* can be established either with *Zea mays*, *Agave tequilana* or *Opuntia ficus-indica*. Those who plant corn mechanically usually use it for sale as fodder or to feed their small cattle herds; they use improved seeds provided by government agencies to farmers. Agave sowing is done by very few farmers with enough capital access to invest the necessary resources in this crop. Nopal is grown in nearby areas to Guadalajara, which enables its commercialization as a fresh product for both local and foreign consumption. In this type of arable land some advantageous farmers use small areas to sow *Phaseolus vulgaris*, *Cucurbita* spp., *Salvia hispanica* or any other crop that promises higher profits. Usually the presence of guamúchil trees within the boundaries of the site is tolerated.

In the *cuamil* traditional system of cultivation 10 taxons whose production is dedicated to self-consumption and occasional exchange or sale within the community were registered. The base crop is corn; mainly a local variety called "*Tampiqueño*" which is a cross of Tabloncillo and Tuxpeño strains (CONABIO, 2010) which according to the farmers used to be very productive but over time has downgraded. The variety called "Purple" is also used although to a lesser extent corresponding to *Elotes Occidental* strain with high presence in the west of the country and highly prized to be consumed as corn and in the preparation of *pozole, pinole* and *chicalés.* Another corn variety is the so called "*Pozolero*" corresponding to Tabloncillo strain (Ron et al., 2006). Both *Purple* and *Pozolero* varieties are the ones with the best market price, a fact that turns farmers into giving them special treatment. In the past, *cuamil* was the basis of food production in Mexico, given that corn was cultivated together with guide beans, squash and chili in addition to handling quelite weeds, altogether ensuring food supply from the very first rains of the season; this situation changed when introducing herbicides and with the increase in corn planting densities to obtain higher profit per area. What happened then was that chili, squash and beans are now seeded as mono crops. Given the fact that sowing *cuamil* requires a lot of physical work and brings little profit, *Agavetequilana* cultivation has slowly replaced it in the most rugged and scarcely accessible lands used for illicit crops.

Wide availability of water in mechanized flat lands has allowed the development of *monoculture under irrigation*. In the past they were used to cultivate sugar cane, banana and even rice; now the main focus is on the production of season vegetables with high market value such as: *Cucurbita pepo* (baby squash) and *Zea mayz* var. Elotero (corn), although others have also been introduced such as *Capsicum annuum* (chili), *Physalis philadelphica* (leaf tomato) and *Solanum lycopersicum* (tomato). Recently, papaya cultivation with technified irrigation has been also introduced.

2.5. Conclusions

It is considered that in spite the changes in land use at Barranca del Río Santiago the total number (196) of phytogenetic resources for food obtained is significant and is a clear reflection of the level of knowledge that local communities have with regarding the possibility of obtaining food from their local flora. The latter acknowledges the ability of BRS to maintain sustainable communities based on a diverse and healthy diet.

The fact that 52% of the total registered taxons are wild native trees and bushes is relevant to confirm the silvicultural vocation of the ravine and that the use of their natural resources must be done from an agrosilvicicultural perspective. For this to happen, marginalized fruit crops must be reconsidered (30 trees and bushesrepresenting 15,3% of the total records) as they can play an important role in ecosystems preservation since they are essential in providing a healthy diet to BRS communities and can help improve food and family's economy by selling the ravine's cultivated products. In the same vein, the promotion of 106 registered native wild and woody, acaulescent and pachycaulous species should be considered for the purpose of restoring degraded areas in BRS, understanding that tree planting is one of the most effective strategies for mitigating climate change. In addition the diet of local communities could be substantially improved and their inhabitants could obtain economic resources from selling them in *ad hoc* local markets.

Although the relevance of many of the mentioned species and/or cultivars in this paper has had recognition for Mesoamerica and other regions of the world, it is still necessary to deepen the selection of priority species for their study and preservation in BRS. To summarize, it is necessary and urgent to increase the ethnobotanical knowledge of local floras through relevant studies that allow us to enhance our understanding of local human activities towards these species and how these activities may be changing.

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Chapter 3.
Wild Phytogenetic Resources for Food in the Barranca del Río Santiago, Mexico: a first approach to sustainability[11]

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Abstract

Vegetation is the most outstanding part of terrestrial ecosystems, in the case of the Deciduous Tropical Forest, trees are the most conspicuous element, during the dry season when the vegetation has a gray, barren and suffocating appearance, a large part of its tree elements are covered with flowers and fruits; it is the tropical vegetation with greater distribution in Mexico, it houses almost 20% of the flora of the country which is rich in traditional uses. In the west of Mexico, this vegetation is distributed along the canyon of the Santiago River and connects the tropical environments of the Pacific coast with the temperate ecosystems of the center of the country; Western Mexico is highly significant because it represents an area of strong interaction between the Holarctic and Neotropical realm, its physiographic constitution and the degree of cultural development achieved by the pre-Columbian peoples that inhabited it and its rich plant genetic resources combined to produce a space where a wide range of plants were domesticated. The ethnobotanical exploration carried out in an area of 72 338 ha allowed to know in a particular way the role of 93 species (woody) as a plant genetic resource for food, 72 species of trees and 21 species of shrubs are reported, which are distributed in 31 botanical families, Fabaceae and Cactaceae are the best-represented families with 14% and 11% of the records; the native species are the most numerous (88%). 32% of the reported species have been considered a priority for reforestation in Mexico due to the characteristics they present in terms of their social value, the environmental service they provide, their potential use for food security and poverty reduction.

3.1. Introduction

The manner in which food production is carried out can compromise the capacity of the land to provide food for all those on the planet, and the ambition in the twenty-first century for food security through the production of sustainable foods requires, among other things, environmental sustainability in terms of biodiversity. For this reason, to conserve and organize biodiversity becomes a priority activity, as understood in the International Treaty on Plant Genetic Resources for Food and Agriculture adopted by the Thirty-First Session of the Conference of the Food and Agriculture Organization of the United Nations on 3 November 2001[12] and the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture.[13]

Bearing this in mind, wild plants can be put to a number of uses, among which the following stand out:

- their nutritional use
- the opportunity to create new crops
- their potential to be included into sustainable development programmes

Within Mexican tropical vegetation, deciduous forest is the most extensive. It holds third place in national plants diversity (Flores-Vilella and Gerez, 1994). In spite of its environmental relevance, it suffers a high deforestation rate and nowadays only 30% of the original surface remains in a relatively good state of preservation (Trejo, 2005). This paper presents an outline of the wild and sociocultural conditions of the phytogenetic alimentary resources of the prevailing dry deciduous forest in Barranca del Río Santiago (BRS), a unique canyon in western Mexico, in which an area of approximately 723 square kilometres was selected for studying.

[12] www.fao.org/plant-treaty/overview/en/
[13] www.fao.org/nr/cgrfa/cgrfa-global/cgrfa-globplan/en/

This chapter highlights important findings about botanical data from our work in the canyon, supplemented by interviews with local people about their food habits. The objective of our chapter is to introduce to the important role that trees and bushes play of a database on phytogenetic resources for food in BRS, created to generate ethnobotanical and ethnoecological records on the canyon's flora. It also shows some worrying aspects about the flora's leveraging. Considering that the salient features of the dry deciduous forest are trees and bushes, the first segment of the database only takes into account trees and bushes with one or several structures that are used, now and then, by the inhabitants of the canyon for alimentary purposes. Herbaceous plants will be addressed in previous chapter. Evidence concerning the presence and use of these resources will prove useful in designing alimentary plans, sustainable farming and environmental programmes for the sustainable development of the villages surrounding the canyon, and to support handling the agave landscape as a cultural heritage of humanity and the treatment of the protected natural areas by different government areas within the study area.

3.2. Methodology

3.2.1. Study area

The BRS is located in western Mexico, on the northern limits of what cultural anthropologists call the Mesoamerican cultural area (Kirchhoff, 1967). The zone has great significance because it represents an area of strong interaction between Holarctic and Neotropical kingdoms, which constitutes a biological mix and is a corridor between the temperate ecosystems of central Jalisco and the tropical environments of the Pacific coast (Challenger, 1998) (Figure 3.1). This is important because the zone's physiographic constitution, the degree of cultural development achieved by the pre-Colombian peoples, who inhabited it, and its rich phytogenetic resources combined to produce a space where a broad range of plants were domesticated (Vargas-Ponce et al. 2007; Zizumbo-Villareal et al. 2014). Moreover, it was a corridor through which human groups moved, diffusing ideas and alimentary habits.

3.2.2. Botanical Resources

The predominant vegetation in the BRS is a variant of the ‘dry jungle system’, or ‘deciduous tropical forest’ (DTF), and is comprised of low-growing forest vegetable communities that prosper on hillsides in warm climatic conditions, with a pluvial regimen that lasts for six months or less, in a cycle divided into two main periods: the dry season and the rainy season (Rzedowsky and Calderon, 2013). This type of vegetation is distinguished by the numerous ecoregions, habitats and ecosystems it contains, and it offers a beneficial environment to the many people who exploit its bounty. In this type of environment, inhabitants have varied uses for most of the plants – in some cases, for over 60% of them (Dorado 2000, cited by Soto 2010).

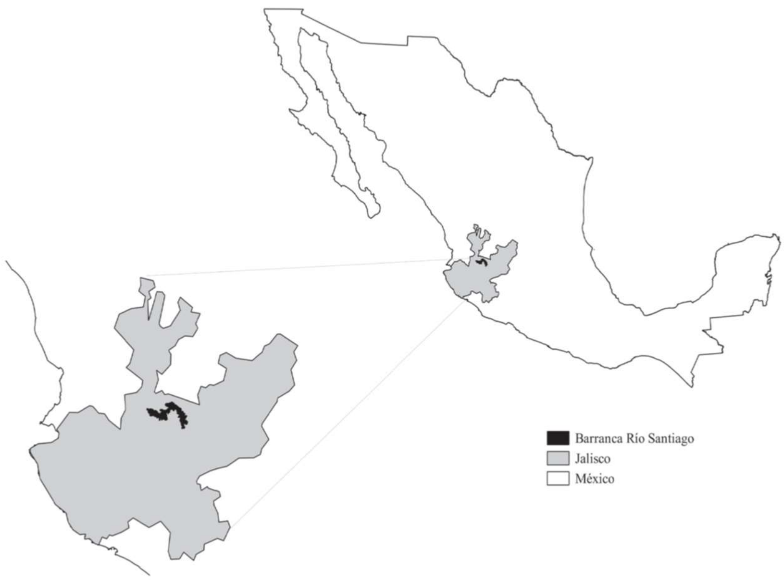

Figure 3.1. The Barranca del Rio Santiago study area.

The botanical explorations of the region for scientific purposes date back to 1791 with Sessé and Mociño’s *Real Expedición Botánica a Nueva España* [Royal Botanical Expedition in New Spain] (McVaugh, 1972), but it was not until the mid-nineteenth century when those articles about Mexican foliage first appear in the literature; some of these articles relate it to altitude, climate and/or other environmental factors (Rezedowski, 2006). For over two hundred years, numerous botanists of national and foreign origin have taken an interest in Jalisco's flora; but the records are far from complete and our knowledge of the region's flora remains inadequate. To date, botanical studies have been published on only 25 of the estimated 166 families of dicotyledonous plants that exist in the State of Jalisco, which, according to the *Informe Nacional sobre el Estado de los Recursos Fitogenéticos para la Agricultura y la Alimentación* [National Report on the State of Plant Genetic Resources for Agriculture and Food], is justifiably recognised for its rich biodiversity, even though the floristic and ethnobotanical studies, required to understand this in terms of conservation and sustainable exploitation, have not yet been conducted (Molina and Córdova, 2006).Therefore, our study is aimed at work on this.

Recent botanical studies carried out at different sites of the BRS, divided in sections near Guadalajara, have helped to increase our knowledge of the zone's flora. For example, in just one of those sections, researchers recorded 869 species, 47 of which are endemic to this area and unique in Mexico (Universidad de Guadalajara, 2009). Of these, six are classified as 'protected species' because their existence is deemed to be 'threatened'. Unfortunately, at present, there are only two guides to arboreal species and a few isolated botanical studies that together represent only a modest contribution towards efforts to systematise our knowledge of the area (López et al. 2011; Sahagún-Godínez et al. 2014). Although Mexico has signed several international protocols for biological conservation, initiatives undertaken in this regard in the BRS are insufficient. In summary, it is necessary, and urgent, to increase not only the knowledge of in situ floristic species, but also, through ethnobotanical studies, to increase our understanding of local human attitudes towards these species and how such attitudes may be changing.

3.2.3. Processing of information

In light of the lack of a catalogue of vascular plants or any inventory of edible plants in the specific area of study, a database has been constructed to register pertinent species reported in botanical studies performed in situ, and in neighbouring areas with similar features (SEMADET, 2016). Furthermore, to assess the presence of these plants and the villagers' interaction with them, more than a hundred ethnographic forays into the canyon (72 338 Ha) were made with an ethnobotanical approach, focusing on the human settlements in accessible areas relevant for the purposes of our investigation. More than seventy inhabitants were interviewed and grouped through focused questionnaires and open-ended, but directed, interviews, most of which involved women and elderly people. The main objective of those interviews was to determine which foods people in the zone had eaten in the past, and which ones are still included in their current diet.

Data from both assignments were reviewed and checked against literature from other ethnobotanical investigations, both within and outside of Mexico, in order to verify the presence of each species within the study area and the reported use for alimentary purposes of every one of the species integrated into the final database. These data are complemented by the results of field surveys, our own botanical collections and information from numerous inhabitants of the area gathered through the questionnaires, in order to review the extent to which this was based on local flora and, so, the sustainability of these species.

3.3. Results

Following analysis of the 1218 entries in the original database, every single one of the species was examined considering: (1) the ethnobotanical knowledge about the taxonomic family to which it belongs; (2) its morphologic characteristics; (3) any previous physical-chemical analysis; and (4) the background of its alimentary use within the study area or any other region.

In a second review, species were eliminated from the database if their presence in the study area (BRS) could not be confirmed by the interviewees, nor recognised and collected during the ethnobotanical exploration, nor listed in any herbarium or in any specific flora listing. Eventually only registered species present within the study area and with confirmed evidence of present-day uses in or outside of the study area were included in the database.

By following this methodology, the analysis of the 1 218 entries has led to the identification of 196 wild edible species (herbaceous and woody plants)[14] distributed in 50 botanical families, the most prominent of which are *fabaceae*, *cactaceae* and *solanacea*. It is important to note that this number is far from insignificant and that these 196 represent 13% of the approximately 1500 edible vegetable species recorded in Mexico (Casas, 2010). Of the 196 species, 93 are trees or bushes with fruits, foliage or roots or edible starches. Half of these (45) are listed as edible in the two existing flora guides on the BRS. The other half are found within the inventories of the investigative exploration (Table 3.1.).

Table 3.1. Edible trees and shrubs in the Barranca del Río Santiago, Jalisco, Mexico.

Family Species	Shape	Origin
Anacardiaceae		
Mangifera indica L.	Arborescent	I
Rhus jaliscana Standl.	Shrubby	N
Spondias mombin L.	Arborescent	N
Spondias purpurea L.	Arborescent	N
Annonaceae		
Annona cherimola Mill.	Arborescent	N
Annona longiflora S. Watson	Arborescent	N
Annona reticulata L.	Arborescent	N
Annonna muricata L.	Arborescent	N
Apocynaceae		
Stemmadenia donnell-smithii (Rose) Woodson	Arborescent	N
Stemmadenia tomentosa Greenm.	Arborescent	N
Thevetia ovata (Cav.) A. DC.	Arborescent	N
Thevetia thevetioides (Kunth) K. Schum.	Arborescent	N
Bignoniaceae		
Crescentia alata Kunth	Arborescent	N
Bombacaceae		
Ceiba aesculifolia (Kunth) Britten & Baker f.	Arborescent	N
Pseudobombax palmeri (S. Watson) Dugand	Arborescent	N
Boraginaceae		
Ehretia latifolia Loisel	Arborescent	N

[14] The terminology used for edible species or edible plants accounts for any type (weed, bush or tree) with one or more structures used for alimentary purposes

Table 3.1. Edible trees and shrubs in the Barranca del Río Santiago, Jalisco, Mexico.

Family Species	Shape	Origin
Cactaceae		
Cephalocereus alensis (F.A.C. Weber) Britton & Rose	Arborescent	N
Isolatocereus dumortieri (Scheidw.) Backeb.	Arborescent	N
Opuntia atropes Rose	Shrubby	N
Opuntia fuliginosa Griffiths	Shrubby	N
Opuntia jaliscana Bravo	Shrubby	N
Opuntia undulata Griffiths	Shrubby	N
Pachycereus pecten-aboriginum (Engelm. ex S. Watson) Britton & Rose	Arborescent	N
Pilosocereus alensis (F.A.C. Weber) Byles & G.D. Rowley	Arborescent	N
Stenocereus dumortieri (Scheidw.) Buxb.	Arborescent	N
Stenocereus queretaroensis (F.A.C. Weber) Buxb.	Arborescent	N
Cannabaceae		
Aphananthe monoica (Hemsl.) J.-F. Leroy	Arborescent	N
Celtis caudata Planch.	Arborescent	N
Celtis iguanaea (Jacq.) Sarg.	Arborescent	N
Capparaceae		
Crateva palmeri Rose	Arborescent	N
Caricaceae		
Carica papaya L.	Arborescent	N
Jacaratia mexicana A. DC.	Arborescent	N
Ebenaceae		
Diospyros digyna Jacq.	Arborescent	N
Euphorbiaceae		
Dalembertia populifolia Baill.	Shrubby	N
Manihot aesculifolia (Kunth) Pohl	Shrubby	N
Manihot caudata Greenm.	Shrubby	N
Manihot rhomboidea Müll. Arg.	Shrubby	N
Fabaceae		
Acacia acatlensis Benth.	Arborescent	N
Acacia cochliacantha Humb. & Bonpl. ex Willd.	Shrubby	N
Acacia coulteri Benth.	Arborescent	N
Acacia farnesiana L. Willd.	Arborescent	N
Enterolobium cyclocarpum (Jacq.) Griseb.	Arborescent	N
Erythrina flabelliformis Kearney	Arborescent	N
Erythrina montana Rose & Standl.	Arborescent	N
Inga vera Willd.	Arborescent	N

Table 3.1. Edible trees and shrubs in the Barranca del Río Santiago, Jalisco, Mexico.

Family Species	Shape	Origin
Leucaena esculenta (Moc. & Sessé ex DC.) Benth.	Arborescent	N
Leucaena leucocephala Lam.	Arborescent	N
Pithecellobium dulce (Roxb.) Benth.	Arborescent	N
Prosopis laevigata (Humb. & Bonpl. ex Willd) M.C.Johnst.	Arborescent	N
Tamarindus indica L.	Arborescent	I
Fagaceae		
Quercus rugosa Née	Arborescent	N
Juglandaceae		
Juglans regia L.	Arborescent	I
Lamiaceae		
Hyptis albida Kunth	Shrubby	N
Vitex mollis Kunth	Arborescent	N
Vitex pyramidata B.L. Rob. ex Pringle	Arborescent	N
Lauraceae		
Persea americana Mill.	Arborescent	N
Malpighiaceae		
Malpighia mexicana A. Juss	Shrubby	N
Malvaceae		
Gossypium aridum (Rose & Standl.) Skovst	Shrubby	N
Guazuma ulmifolia Lam.	Arborescent	N
Hibiscus phoeniceus Jacq.	Shrubby	N
Malvaviscus arboreus Cav.	Shrubby	N
Mirtaceae		
Psidiuma guajaba L.	Arborescent	N
Psidium sartorianum (O. Berg) Nied.	Arborescent	N
Moraceae		
Brosimum alicastrum Sw.	Arborescent	N
Ficus goldmanii Standl.	Arborescent	N
Ficus insipida Willd.	Arborescent	N
Ficus pertusa L.	Arborescent	N
Morus celtidifolia Kunth	Arborescent	N
Olacaceae		
Ximenia parviflora Benth.	Shrubby	N
Oleaceae		
Forestiera tomentosa S. Watson	Arborescent	N
Piperaceae		
Piper auritum Kunth	Shrubby	N

Table 3.1. Edible trees and shrubs in the Barranca del Río Santiago, Jalisco, Mexico.

Family Species	Shape	Origin
Punicaceae		
Punica granatum L.	Arborescent	I
Rhamnaceae		
Karwinskia humboldtiana (Schult.) Zucc.	Arborescent	N
Karwinskia latifolia Standl.	Arborescent	N
Rosaceae		
Prunus persica (L.) Batsch	Arborescent	I
Prunus serotina Subsp. *Capuli* (Cav.) McVaugh	Arborescent	N
Rubiaceae		
Coffea arabica L.	Shrubby	I
Genipa sp.	Arborescent	N
Randia capitata DC.	Shrubby	N
Randia laevigata Standl.	Shrubby	N
Rutaceae		
Casimiroa sapota Oerst.	Arborescent	N
Citrus aurantifolia Swingle	Arborescent	I
Citrus aurantium L.	Arborescent	I
Citrus limetta Risso	Arborescent	I
Citrus limon (L.) Osbeck	Arborescent	I
Citrus sinensis (L.) Osbeck	Arborescent	I
Sapotaceae		
Manilkara zapota (L) P. Royen	Arborescent	N
Mastichodendron capiri (A. DC.) Cronquist	Arborescent	N
Pouteria campechiana (Kunth) Baehni	Arborescent	N
Pouteria sapota (Jacq) H.E.Moore & Stearn	Arborescent	N
S*ideroxylon cartilagineum* (Cronquist) T.D. Penn	Arborescent	N
Sideroxylon persimile subsp. *subsessiliflorum* (Hemsl.) T.D. Penn.	Arborescent	N
Verbenaceae		
Lantana camara L.	Shrubby	N

Origin: N= Native, I=Introduced

Most of these species are arboreal (77%) and the remaining (23%) are shrubs. As for their origins, 82 are native, and 11 are cultivars that were introduced into the BRS long ago. The distribution of these species in situ varies considerably due to temperature and rain patterns, as the eastern area of the BRS is drier and cooler than the western area, but the variation is mainly because of its usage record. In addition, the anthropogenic stress has been different in each area. In this regard it is fair to say that the greatest threat faced by these species has been the change in land use, mainly on account of livestock farming and the advance of agricultural frontiers involving excessive use of agrochemicals, in spite of state regulations from the Project of Ecological Land Management of the State of Jalisco, which ban such land use in the study area and regard it as a protected area of environmental resources.

Of the 93 arboreal and shrub species reported as phytogenetic resources for nourishment, 85 were acknowledged as such by the local residents of the study area. The remaining 8 are present in the site and might as well be eaten. Most edible species in the BRS (61%) are considered to have at least one additional use; some of them have even four other uses. Besides their edible use, they can have aesthetic or medicinal value and can be used for forage or as living barriers. Furthermore, knowledge about the use of plants is heterogeneous in the different areas of the BRS, mainly considering that nowadays the few young people who still live there are not acquainted with them, in comparison with the knowledge that older people still have about plants. 30 of the 93 species reported in the BRS are acknowledged as 'priority species for the reforestation in Mexico', and as shown in Table 3.2., 60% of these were prioritized for its (1) ecological and social importance, 30% for its (2) ecological, economic, and social importance, seven percent for (3) its social importance and four percent for (4) its economic importance.

In the same table, it can be seen that the most important social value or environmental service provided by half of the species included in the table, are: (1) the ornamental value of the plant, (2) the shade they provide, (3) soil and water conservation and (4) soil formation. 9 of these species can be used to achieve food security by having fruits or seeds or edible parts, being medicinal, fodder, used as firewood and for the production of honey. Finally, in

Table 3.2. Edible trees and shrubs in the Barranca del Rio Santiago considered primary to reforestation in Mexico because of their social and environmental service, and their use for food security and poverty alleviation.

Priority Species	Reasons for Prioritisation (Importance)	Environmental services or social value [a]	Use for food security[b]	Use for the reduction of poverty[c]
Acacia farnesiana L. Willd.	Ecological and social	1; 2; 4; 5; 6; 8; 9; 10	1; 2; 3; 4; 5	1; 2; 3; 4
Annona cherimola Mill.	Ecological and social	- - -	- - -	- - -
Annonna muricata L.	Ecological and social	5; 6; 7	1; 2; 5	2
Annona reticulata L.	Ecological and social	- - -	- - -	- - -
Brosimum alicastrum SW.	Ecological, economic and social	1; 3; 6; 8; 9; 10	1; 2	4
Carica papaya L.	Ecological and social	4; 6	- - -	- - -
Casimiroa sapota Oerst	Ecological and social	- - -	- - -	- - -
Ceiba aesculifolia (Kunth) Britten & Baker f.	Ecological and social	- - -	- - -	- - -
Crescentia alata Kunth	Ecological and social	4; 8; 9	- - -	- - -
Diospyros digyna (Jacq.)	Ecological and social	- - -	- - -	- - -
Enterolobium cyclocarpum (Jacq.) Griseb.	Ecological, economic and social	1; 2; 4; 5; 6; 8; 10	1; 2; 3; 4; 5	3; 4
Genipa sp.	Ecological, economic and social	1; 2; 4; 8; 9	- - -	- - -
Guazuma ulmifolia Lam.	Ecological, economic and social	1; 2; 3; 4; 5; 8; 9; 10	3	4
Inga vera Willd.	Ecological, economic and social	1; 4; 5; 8; 9	- - -	- - -
Jacaratia mexicana A. DC.	Ecological and social	- - -	- - -	- - -
Juglans regia L.	Economic	- - -	- - -	- - -

[a]: 1= Soil and water preservation including catchment areas; 2= Soil protection; 3= Biodiversity preservation; 4= Aesthetic values; 5= Fertility enhancement; 6= Soil recovery; 7= Dune fixation 8= Live barriers; 9= Shadow; 10 = Wind barrier.

[b]: 1= Fruits, seeds or edible parts; 2= Medicinal; 3= Forage; 4= Firewood and carbon; 5= Honey

[c]: 1= Saw wood; 2=Essential Oils; 3=Gums and resins; 4= Rural construction

Source: Authors' elaboration with data from FAO-CONAFOR (2012)

Table 3.2. (continuation) Edible trees and shrubs in the Barranca del Rio Santiago considered primary to reforestation in Mexico because of their social and environmental service, and their use for food security and poverty alleviation.

Priority Species	Reasons for Prioritisation (Importance)	Environmental services or social value [a]	Use for food security[b]	Use for the reduction of poverty[c]
Leucaena esculenta (Moc. & Sessé ex DC.) Benth.	Ecological and social	- - -	3; 4	- - -
Leucaena leucocephala Lam.	Ecological, economic and social	1; 2; 4; 5; 6; 9; 10	1; 5	1; 2; 4
Manilkara zapota (L) P. Royen	Ecological, economic and social	4; 6; 9	- - -	- - -
Morus celtidifolia H.B.K.	Ecological and social	- - -	- - -	- - -
Pithecellobium dulce (Roxb.) Benth	Social	1; 2; 4; 5; 6; 8; 9	- - -	- - -
Pouteria campechiana H.B.K.	Ecological and social	- - -	- - -	- - -
Pouteria sapota Jacq	Ecological and social	- - -	- - -	- - -
Prosopis laevigata H. & K. ex Willd	Ecological and social	- - -	3	1
Prunus serotina Subsp. *Capuli* (Cav.) McVaugh	Ecological, economic and social	1; 3; 4; 6; 8; 9; 10	- - -	- - -
Psidiuma guajaba L.	Ecological, economic and social	1; 2; 4; 5; 6; 9; 10	- - -	- - -
Psidium sartorianum (Berg.) Ndzu	Ecological and social	- - -	- - -	- - -
Spondias mombin L.	Ecological and social	- - -	- - -	- - -
Spondias purpurea L.	Ecological and social	- - -	- - -	- - -
Tamarindus indica L.	Social	2; 4; 9; 10	1; 2; 3	3; 4

[a]: 1= Soil and water preservation including catchment areas; 2= Soil protection; 3= Biodiversity preservation; 4= Aesthetic values; 5= Fertility enhancement; 6= Soil recovery; 7= Dune fixation 8= Live barriers; 9= Shadow; 10 = Wind barrier.

[b]: 1= Fruits, seeds or edible parts; 2= Medicinal; 3= Forage; 4= Firewood and carbon; 5= Honey

[c]: 1= Saw wood; 2=Essential Oils; 3=Gums and resins; 4= Rural construction

Source: Authors' elaboration with data from FAO-CONAFOR (2012) the table, it can be seen that 8 species can be used for poverty reduction because they can provide wood for the sawmill, essential oils, rubber and reins and construction materials.

However, the BRS is also host to non-woody plants that belong to the so-called DTF habitat, which are also exploited as food sources. To date, the total number of species for food use is 196 records, including the woody plants of this chapter. Nevertheless, the study zone is undergoing a process of reduction and degradation of its vegetable cover that entails a significant degree of genetic – and, in a sense, cultural – erosion of its wild vegetable resources.

3.4. Discussion

The ninety-six species of trees and shrubs, reported to contain one or more structures used for food in the BRS, are indicative of the potential of the region regarding food production. The fact that 88.5% are native to the area is also an indication that these might be within the ethnobotanical knowledge that the BRS inhabitants possess about their food resources. It is evident that the potential of these phytogenetic resources for food is not identical for all these species, but for at least 31% of them there is an 'official' recognition in reforestation in Mexico because of their ecological and social importance, their environmental benefits and the social value that they represent, as well as because of their potential for food security and their contribution in the reduction of poverty.

Many of the species treated here correspond to traditional crops that now have high commercial value internationally (e.g. *Carica papaya* and *Persea americana*). There are also introduced species from which specific cultivars have been generated for the area (e.g. *Mangifera indica*), as well as marginalised crops (such as *Annona* spp., *Pouteria* spp., *Spondias* spp.) and a large number of wild species capable of generating new cultivars (e.g. *Malpighia mexicana*), and many others used as seasonal food that can provide food in times of shortages.

Biodiversity for food and agriculture encompasses the components of biological diversity that are essential for feeding human populations and improving the quality of life, while the genetic resources for plants are the raw material on which the world depends in order to improve the productivity and quality of crops (Food and Agriculture Organization, 2018a, 2018b). Hence, it is a priority to give greater attention to the conservation of wild plant species for direct, indirect or potential use. Yet, these are threatened by the change of land use, by the use of herbicides and the increase of harmful substances in the atmosphere, putting genetic diversity at risk by promoting the disappearance of useful or usable wild species (Esquinas, 1983). Furthermore, the FAO recognises that, over the past one hundred years, agricultural crops worldwide have lost 75% of their genetic diversity (Food and Agriculture Organization, 2005).

On a global scale, studies indicate that the loss of biodiversity does not slow down. On the contrary, it will continue to increase if additional public policies related to rural development and better food availability are not implemented (Netherlands Environmental Assessment Agency, 2010). An example is that modern agriculture and forestry have caused, until 2010, almost 60% of the total reduction of terrestrial biodiversity. Furthermore, according to the Mean Species Abundance, by 2050 the expected loss of biodiversity will be in the region of 55% (Kok, et al. 2018).

Tragically, although Mexico is still classified, in principle, as a 'mega-diverse' country, its biodiversity is disappearing fast. DTF once covered approximately 14% of the nation's territory (some 280 000 km^2), whereas today, over three-quarters of that surface area (around 210 000 km^2) has been converted to alternative uses, including secondary vegetation, agricultural land, dams, urban, industrial and tourist developments, and diverse means of communication. In fact, in some regions of the country, the natural vegetation (i.e. not affected by humans – the so-called pristine type) has been lost completely (Rzedowsky and Calderón, 2013).

In relation to this, it becomes opportune to refer here to Villaseñor, who has pointed out:

> Mexico has a long and growing tradition of studying its vascular flora, reflected in the significant increase in recent decades of specimens housed in national scientific collections and abroad, backed by an immense bibliography. However, the knowledge of national floristic richness is still unsatisfactory mainly due to the difficulty of synthesising scattered information in such publications along with the lack of well-curated databases of specimens documenting this richness. (Villaseñor, 2016)

Furthermore, Luna and colleagues (2011) write:

> Because of these circumstances, Mexico now often appears on the 'Red Lists' compiled by the International Union for Nature Conservation; it ranks first in Latin America as regards endangered species, of which there are 897 species (Luna et al. 2011). This means that 'the source of … foods, medicines and potable water, as well as the means of subsistence of millions of people, could be at risk due to the rapid reduction of the world's animal and vegetable species (IUCN, 2019).

Unfortunately, we do not know with any precision just what the state of biodiversity is in Mexico today. The paucity of information on the vegetable cover of its territories impedes making any detailed comparative comments (Flores-Vilella and Gerez, 1994; Rzedowsky, 2006). In fact, only a few biological groups have been diagnosed in any depth in this regard. So, it is worth mentioning a paper by Vega (2001) in which he reviews the Mexican economy for a period of sixty years (1940–2000). He demonstrates the unsustainability of economic and social development in Mexico, and points out that the common marker, whether it is a period of material well-being or of economic slowdown, has been the concentration of national income and the sum total of 'environmental passive'. This means that the periods of economic expansion, as well as the recessive ones, correspond to cases of social exclusion and 'severe ecological degradation processes, depletion of natural resources and environmental contamination' (Vega, 2001). In Mexico the costs of environmental protection represent 1% of the *producto interno bruto* (P.I.B.), whereas the official estimate of the total costs of environmental degradation corresponds to 5.7% of P.I.B. In other words, the country is losing six times more due to environmental degradation than it is investing in preventing, controlling, reducing or compensating for environmental degradation or managing the protection of the environment (CONABIO, 2016). Moreover, the FAO has found that Mexico lacks public policies to foster the study and evaluation of the genetic variation of its woody species, and has failed to develop mechanisms to monitor and assess such problems as the vulnerability of plants and their genetic erosion. 'Extreme poverty, environmental degradation and loss of natural resources are highlighted among priorities that require immediate attention in our country. To the extent that these priorities are addressed and resolved, the preservation and sustainable use of natural resources, based on forestry, favourable changes in equity issues, and insecurity will be promoted' (Food and

Agriculture Organization, 2012). Although in the BRS the native vegetation has been transformed by anthropocentric activity, and agricultural production has become permeated by the technologies of the Green Revolution with little implementation of sustainable or environmentally friendly techniques, nevertheless the area has much to contribute as regards plant genetic resources for food.

3.4.1. Dietary use of the plants

As is the case throughout Mexico, the dietary base of the people who inhabit the BRS had its origins in pre-Hispanic times. Maize (*Zea mays*), beans (*Phaseolus vulgaris*), nopal (*Opuntia* spp.) and chilli peppers (*Capsicum annuum*) form part of the population's primordial sustenance, complemented, especially in rural and peri-urban areas, by the consumption of wild products and of plants grown in traditional gardens. We discovered one example of this in Ixcatán, a town in the BRS, whose residents still consume a basic alimentary package of pre-Hispanic origin but complement their alimentation by eating twenty-one wild edible species that we identified during the course of our study. Of these, nine are arboreal species characterised by seasonal production for a few months each year; and the commercialisation of 30% of this provides an important economic income for those families who are engaged in its collection for about four months.The oter twelve species are herbaceous in nature, growing only during the rainy season and consumed in situ, though some have significant commercial potential (Sandoval Lozano 2015).

A relevant case in BRS is the capomo (*Brosimum alicastrum*), a plant widely known as an alimentary species throughout the Mesoamerican territory. And yet, Pennington and Sarukán (2005) did not report its existence in their estimated species distribution for the specific BRS area. During our fieldwork we completed more than twenty new recordings of this plant, which provided an idea of the breadth of its distribution beyond the limits already established by Pennington and Sarukán (2005); this is partly due to the lack of botanical collections of the species in the study area. Another significant case is that of *Malpighia mexicana*, a species related to the cultivation of acerola (*M. glabra*, *M. emarginata*) which is considered the most important natural source of ascorbic acid; in a preliminary analysis conducted by our account, we found vitamin C values for *M. mexicana* that were similar to commercial species. Although the plant is well represented in the BRS, it is no longer consumed.

Despite these precedents, however, it is clear that consumption of wild plants by townspeople in the BRS is declining steadily. As is the case almost everywhere else, this reduction in the consumption of traditional wild products, that are potentially sustainable and have various alimentary properties, is primarily due to cultural factors; that is, changes in eating patterns and the growing tendency to include industrially processed food products in daily diets, even though they are usually only of mediocre alimentary quality – and some may even be harmful to human health. On the themes of health and nutrition, much remains to be resolved in Mexico. During the period, 2011-2012, chronic infantile malnutrition and acute malnutrition in children under five was at 13,6% and 1,6% respectively, well above the average for Latin America and the Caribbean which for 2015 was 11,3% and 1,3% respectively. During the same period, 2011-2012, the prevalence of overweight children under five was at 9%, well above the average for Latin America and the Caribbean which was 7,2% for 2014. For the year 2014, worrying levels of overweight scores (64%) and obesity (28%) were recorded in the adult (over 18 years of age) population. Consumption of ultra-processed foods (with high content levels of sugar, fat and salt) of lower nutritional value constituted one of the main factors that caused this increase in weight. In 2013, Mexico ranked high among the thirteen countries of Latin America and the Caribbean as regards the sale of ultra-processed foods and drinks, with 212,2 kilos per person. The high level of sales of these products relates to the lack of regulation of markets, rapid urbanisation and adoption of modern ways of life, and all the marketing. All of this caused an increase in the disponibility and disequilibrium of ultra-processed products, and a preference for their consumption (Food and Agriculture Organization, Pan American Health Organization 2017). This situation was not much different in the populations of the barranca, where once avenues of communication had opened, and before the arrival of education and health services, the distribution and sale of fizzy drinks, beers, fried food and processed cookies took a hold.

3.5. Conclusion

In summary, constructing alimentary alternatives for sustainability in the twenty-first century requires a great deal of high-quality research as well as proposals for innovation and development. The issues of conservation and restoration of biodiversity, as well as the sustainable use of resources, must be an integral part of sustainable development strategies, which in terms of primary production concern agriculture, forestry, fisheries and energy (Kok et al. 2018). In the Mexican case, the state, private entities and institutions devoted to scientific research and higher education, must join forces to supply the material and intellectual resources required: (1) to conduct rigorous, systematic studies that assess the current condition of the nation's vegetable resources; (2) to elaborate prognoses of their future evolution; (3) to propose changes in land use; and (4) to design public policies that will guide the exploitation and conservation of wild phytogenetic resources.

3.6. References

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Chapter 4

Agroecological Characterization of Mexican Plum *Spondias purpurea* L. in Barranca del Río Santiago, Jalisco, Mexico.

Abstract

Since it is part of the food system that contributed to the development of Mesoamerican cultures the presence and food use of *Spondias purpurea* L. in western Mexico and in Barranca del Río Santiago (BRS) has been dated many centuries ago. Today, however, its cultivation has become marginal due to the lack of promotion from official sectors as well as by the changes in the eating habits of the urban and rural populations. The State of Jalisco is one of Mexico's most important regions for cultivation of Mexican plum. 80% of its cultivated area is located in the center-west of the state, in BRS. An agroecological characterization of the ravine and of the environmental conditions under which the cultivation of *S. purpurea* is conducted were created through the collection, analysis and generation of climatic, physiographic and edaphic information specific to the study area in addition to the use of a geographic information system (GIS) and later compared with information on the agroecological requirements of the species reported by the literature. The used variables were: climate type, minimum, maximum and daytime temperatures (annual averages), thermal oscillation, accumulated precipitation, available humidity, accumulated evapotranspiration, photoperiod, altitude, slope, soil types and soil texture. 871 plum cultivated hectares were recorded. Due to the natural conditions of the ravine 65% are cultivated on 6º to 15º slopes which presents serious restrictions on soil management; another 23% of the area is located on steep terrain with slopes above 16º inclination where no agricultural activity is recommended. With the exception of this variable the climatic and soil characteristics of the ravine are conducive to the development of tropical agriculture extensively covering the requirements for the cultivation of *Spondias purpurea*. Even though the ravine's potential for hosting wild populations of the species is well known, little evidence was found of them. By contrast the settling of plantations is encouraged on account of the plant's rusticity and the low cost which it represents. Given the environmental conditions of the ravine, the species origin backgrounds, its millennial exploitation as well as its long cultivation tradition in the region, it is confirmed that the study area meets favorable conditions to the development of the species and to establish orchards.

Key words: *Spondias purpurea***,** dry tropics, traditional agriculture, agroclimatological analysis.

4.1. Introduction

Mexican plum *Spondias purpurea* L., along with other plants such as: *Zea mays* L*.,* *Phaseolus* spp*.,* *Cucurbita argyrosperma* Huber, *Solanum lycopersicum* L. var. *cerasiforme,* (Dunal) Spooner, J. Anderson & R.K. Jansen, *Physalis philadelphica* Lam., *Capsicum annum* L. and *Hyptis suaveolens* (L.) Point., are part of the plant nucleus that gave rise to the food system of the Mesoamerican West (the western side of Mexico), an important center to edible plants domestication during the formative period from 2400 BCE to 100 CE. (Zizumbo-Villarreal et al., 2014). Moreover, the western center of Mexico —specifically the intersection by the states of Jalisco, Nayarit and Michoacan, its considered as one of the two genetic origin points of *S. purpurea* (Miller and Schaal, 2005; Fortuny-Fernández et al., 2017).

At the time of the Europeans arrival *S. purpurea*'s crops were all over western Mexico extending to the northern region of South America. At present time its fresh fruits are consumed directly or used as raw material for the preparation of soft drinks, jams, syrups, *atoles*, wine and *chicha*. Its protein and fat content are low but it has appreciable amounts of calcium, phosphorus, iron and ascorbic acid. It is considered a promising fruit for its high market acceptance, for being a rustic species with high resistance to drought and for being adaptable to reproduce in poor soils (Cuevas, 1992). In addition to different food uses, the plant is also exploited as a medicinal resource which has been registered in different key works on Mexican pharmacopoeia since the Colonial period to the present (Universidad Nacional Autónoma de México, 2009). Commercial farms are scarce in México; Avitia et al. (2003) report 27 states where there are small commercial gardens; in accordance with Cruz and Rodríguez (2012) the planted area at national level increased from 7,249 ha in 1981, to 12,183 ha in 2004, and for more recent times the estimate is of 15,000 ha.

Mexican plum's locations are distributed in the tropical zones of the American continent on both sides of Equator up to 28-35° north and south latitude, with an optimum latitude of 5 to 22° (Ruíz et al., 2013). It thrives in regions with low humidity having well-defined dry and humid seasons, both on the slopes and slopes of the hills and in the plains (Calderón, 1987); it is also found in anthropic environments such as paddocks, *acahuales*, family gardens and pastures (Cuevas, 1992; Cruz and Rodríguez, 2012; Vázquez-Yanes et al., 1999).

In Mexico the natural populations of *Spondias* grow both on the Atlantic and Pacific slopes, on sea level and up to 1200 m altitude (Cuevas, 1992). It is part of the dominant stratum in the low deciduous forest (Pennington and Sarukhán, 2005), and it is similarly found in tropical and subtropical deciduous forests in Central America (Macía and Barford, 2000).

The species distribution in Mexico has been studied by Pennington and Sarukhán (2005) developing a map of potential distribution using the GARP program based on botanical records of the species. For their part, Miller and Knoouft (2006) generated predictive distribution maps on possible areas where wild and cultivated populations may be present. Similarly, Arce-Romero et al. (2017) evaluated *S. purpurea*'s potential distribution from available records and conclude that there are 7 million 400 thousand hectares (3,8% of the national territory) with suitable conditions for its development in Mexico; of this surface 11% corresponds to optimal conditions for the development of the crop.

Spatial and time characterization of the climatological and edaphic information available for a particular region allows us to understand the type of management that farmers give to their crops and permits the assessment of their restrictions and possible effects on production (Alcaraz, 2011; Collazo et al., 2011). The use of these data is even more relevant if we consider that it is seldom possible to benefit from more than 10% of the information contained in the basic cartography (Alcaraz, 2011).

The general objective of this investigation is to study the current and potential distribution of Mexican plum in BRS as of the following specific objectives: (1) Elaborate an inventory of the farms where it is grown; (2) Generate an environmental database of the canyon and (3) Elaborate the agroclimatic characterization of the sites where the species is distributed using a geographic information system (GIS) and estimate its potential distribution. For the case in hand, the possibility of applying models of niche analysis and potential prediction on the species distribution was discarded due to: (a) the low climatic variability in BRS, (b) the existing agroecological knowledge reported by the literature on the specific requirements for the species (c) previous approaches have already defined

Spondias distribution in Mexico and Mesoamerica (Pennington and Sarukhán, 2005; Miller and Knoouft, 2006; Arce-Romero et al., 2017). Considering the previous and given the size of the study area, more conventional methods were preferred which have also been used in the analysis of cultivated species distribution (De León et al., 1991; Tinoco et al., 2010; Collazo et al., 2011).

4.2. Methodology

4.2.1. Study area

There is an enormous geological fault in the western side of Mexico on which the Santiago River runs starting its path in Chapala's Lake running into the Pacific Ocean. The fault and the river coincide with the intersection of Sierra Madre Occidental and the Neovolcanic Plateau (Rodríguez and Rodríguez, 1992). A fraction of this route is locally known under the name of Barranca del Río Santiago (BRS) which was the selected study area. It is constituted by 72,338 hectares located northwest of Guadalajara city, an area delimited by the coordinates: 20°43'00" and 21°08'00" N; 103°13'00" and 103°53'00" W., including territory from six municipal entities of the State of Jalisco: Guadalajara, Zapopan, Ixtlahuacán del Río, San Cristóbal de la Barranca, Amatitán and Tequila (Figure 4.1). The riverbed at the top of the study area in Guadalajara is 1000 masl and is 570 masl in the Municipality of Tequila, closing the study area.

Among the unique characteristics of the BRS are landscapes of high scenic value formed by the irruption of the ravine between the valleys in the State of Jalisco and Sierra Madre Occidental which causes the occurrence of significant changes in the environment within a very short distance towards the interior of the ravine. The mild climate becomes warm, similar to the one prevailing in the Pacific Coast, which entails changes in the vegetation and the rest of the biota of the place, a circumstance that has attracted the attention of botanical collectors since XIX century who at the time described for the first time more than 400 species in the adjacent ravines to Guadalajara (Acebedo-Rosas et al., 2008).

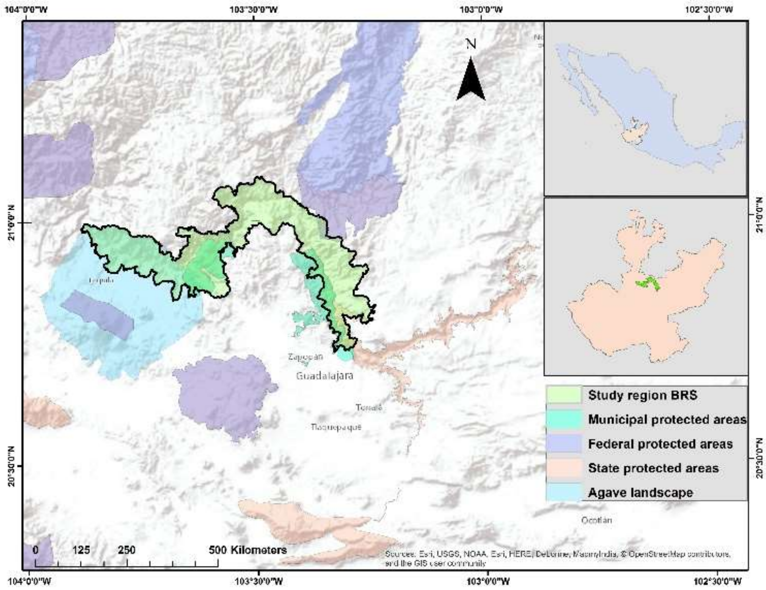

Figure 4.1. Location of the BRS study area including protected areas.

Within BRS different protected natural areas have been decreed by the Zapopan and Guadalajara City Councils, having connectivity with other protected polygons (Nixticuil, Sn. Esteban, El Diente) and specially with the recently decreed protected natural area of estate interest of the ravines of Santiago and Verde rivers. In addition, the study area (BRS) corresponds to one of the two natural attractions that frame the agave landscape, declared by UNESCO as a cultural heritage of humanity (UNESCO, 2008).

Barranca del Río Santiago (BRS) stands out because of a tropical environment surrounded by mountains and valleys with a temperate climate; these attributes have allowed it to be historically highlighted for its production of «hot earth» foods amongst which protrude the fruits of *S. purpurea* —the only arboreal species grown in rain-fed orchards usually located on steep slopes. Like other marginalized crops in the area, they bring meager profits to the farmers. Chapter 1 of this thesis introduction includes geographical, climatic, historical, social and conservation aspects of the study area.

4.2.2. Species Distribution

An inventory of the existing populations of *S. purpurea* was carried out through the following information tools.

Wild populations: The used sources were a) Exploratory tours within BRS; b) Records of botanical collections obtained from the National Forestry and Soils Inventory (Inventario Nacional Forestal y de Suelos - 2012), the Botanical Institute Herbarium (Herbario del Instituto de Botánica - IBUG), the National Biodiversity Information System of Mexico (Sistema Nacional de Información sobre Biodiversidad de México) (SNIB), Trópicos.org, and Global Biodiversity Information Facility (GBIF); c) the following bibliographic references that include information on the estimation of the potential national distribution of *S. purpurea*: Pennington and Sarukhán (2005), Miller and Knoouft (2006), Arce-Romero et al. (2017).

Cultivated populations: Information was obtained through the following procedure: a) field work conducted within BRS to establish geographical location of plum-grown plots; b) *S. purpurea* cultivated plots data was digitized to learn their location and surface, and c) by using satellite images from Google Earth to corroborate the presence of plum trees. Both field and desk data were entered to the ArcMap V10.3 program, using the Universal Transversal Mercator (UTM) coordinate system in zone 13, northern hemisphere.

4.2.3. Agroecological requirements of *S. purpurea*

General climate: Ecocrop (2007) indicates the species distribution in both humid tropical climates (Ar) and dry climates (Aw) which means that *S. purpurea* requires tropical and subtropical climates to grow (Campos and Espíndola, 2007); in semi-arid and sub-humid climates it shows hydro-periodicity in terms of flowering, fruiting and foliar development patterns: flowering and fruiting occur during the dry season and foliar development during the rainy season (Ruiz et al. 2013).

a) Thermal regime: The plant requires average temperatures between 19 and 29º Celsius, with a difference of less than 10 degrees between the coldest and the hottest month. Optimum temperatures are considered between 24 and 24.5º C. While the extreme maximum temperature is 40°C, cold harms plum plants: they can support low temperatures between 0 and 8°C for short periods of time (Campos and Espíndola 2007; Cruz and Rodríguez, 2012; Ruiz et al. 2013).

b) Rainfall regime: The plant develops in regions of low humidity, hence it remains without foliage during the dry season (Cuevas, 1992). The range of precipitation in which the species is found varies between 500 and 1800 mm per year and the optimum precipitation is between 800 and 1100 mm (Campos and Espíndola 2007; Cruz and Rodríguez, 2012; Ruiz et al. 2013).[15] Regarding the rainfall distribution, the cited authors in previous paragraphs mention that the plant is tolerant to drought and high temperatures, it endures seasons of low water between 5 and 8 months and apparently requires a dry season in the productive stage. In fact, the best fruit quality apparently occurs in places with a long dry season (EcoPort, 2001).

c) Relative humidity: It can be low to medium according to Ruiz et al. (2013), while Campos and Espíndola (2007) report values between 75 and 85%. On the other hand, Cruz and Rodríguez (2012) report that high relative humidity stimulates the vegetative stage.

d) Edaphic requirements: The species has presence in a great variety of soils (Pennington and Sarukhán, 2005), such as: sandy, stony, shallow, alluvial, clayey, limestone (calcareous), and their combinations (Vázquez-Yanes et al., 1999; Campos and Espíndola, 2007, Cruz and Rodríguez, 2012). The plant grows well in thin soils but responds favorably to deep soils, so it is noted that the plant requires soils of medium depth with at least 60 cm thick, from a commercial perspective, obviously (Campos and Espíndola, 2007; Cruz and Rodríguez, 2012; Ecocrop, 2007; Ruiz et al. 2013). The aforementioned authors suggest ph requirements in ranges from 4.3 to 8.0; the optimum value is slightly acid (6.5), while it is not very tolerant to saline soils. They also point out that the plant requires well-drained soils and that it has a good response to fertile soils. The capacity of *S. purpurea* to establish mycorrhizal symbiosis is also reported, which helps to promote the absorption of nutrients (Pimienta and Ramírez, 2004).

4.2.4. Selection and generation of environmental variables

Climatic and edaphic conditions of the study area were compared with the agroecological requirements of the crop to establish the characterization of the environmental conditions in which the plum crop is developed in the BRS. To this purpose and in accordance with some of the established criteria in similar works (De León et al. 1991; Tinoco et al. 2010; Collazo et al. 2011), the fourteen environmental variables presented in Table 4.1., were selected as

[15] Data adjusted to the general criteria of the mentioned authors.

predictors of the optimum agroecological condition of the species: ten climatic, two topographic and two edaphic.

Table 4.1. Climate and edaphic variables in the climate characterization of BRS and cultivation of *Spondias purpurea* L.

Variable (Unit of measure)	*Information source*	*Result*
Climate type (Unit)	García, 1998	-----
Annual minimum average temperature (ºC)	Medina et al. 2016	Map (Fig. 4.2A)
Average annual temperature (°C)	Medina et al. 2016	Map (Fig. 4.2B)
Annual high average temperature (°C)	Medina et al. 2016	Map (Fig. 4.2C)
Annual daytime average temperature (°C)	Generated	Map (Fig. 4.2D)
Annual temperature oscillation (°C)	Generated	Map (Fig. 4.3A)
Annual cumulative precipitation (°C)	Medina et al. 2016	Map (Fig. 4.3B)
Available humidity wet months (mm)	Generated	Map (Fig. 4.3C)
Potential evapotranspiration (mm)	Medina et al. 2016	Map (Fig. 4.3D)
Annual average photoperiod (daylight hours)	Medina et al. 2016	---
Altitude (masl)	Generated	---
Slope (° deg)	Generated	Map (Fig. 4A)
Soil type (Unit)	INEGI, 1982	Map (Fig. 4B)
Soil texture (Unit)	Sánchez et al. 2018	------

Climatic variables were obtained from the existing climatic cartography for the Mexican continental territory with a reference period from 1961 to 2010, in raster format and geographic coordinates projection using the WGS84 Datum (World Geodetic System 1984), with an arc resolution of 30 seconds (949 m: 900 m approx) previously generated by the work of Medina-García et al. (2016). Layers of minimum temperature, average temperature, maximum temperature, precipitation, evapotranspiration and photoperiod for each month of the year were transformed from RST format to TIFF, with a 151 meters resolution so that the edges of the focal area of study could be preserved in a truthful manner at the time of conducting the later extractions to the study area. Layers of annual average temperature and photoperiod were generated (arithmetic average of the values for each month of the year), as well as the layers of precipitation and accumulated evapotranspiration (sum of the twelve months of the year). Annual average daytime temperature was calculated from the values of the twelve months of the year according to the procedure suggested by Tinoco et al. (2010) and Collazo et al. (2011). Annual temperature oscillation was calculated using the formula suggested by WorldClim for the generation of variable BIO_7 (Fick and Hijmans, 2017). Available humidity in the soil (when the precipitation levels are higher than the potential evapotranspiration) was calculated for each month of the year; a layer of the wettest season of the year (June - September) was generated. Once these variables were generated, the corresponding portion of BRS area was extracted using its vector layer as a mask; the layers were reprojected to the UTM Z13N system in order to calculate surface values in metric units. Additionally, the climate chart was used in raster format in a 1:1000000 scale, generated by García (1998) available in the National Biodiversity Information System (SNIB).

As for the edaphic variables, the soil types were obtained from the edaphological charts in PDF format in a 1:50,000 scale (INEGI, 1982), from which the area corresponding to BRS was digitized. The soil texture layer was extracted from vectorial information elaborated by Sánchez et al. (2018). Topographic variables were elaborated from the digital elevation model of INEGI (2013) with a 30 m in pixel size resolution from which the coverage of BRS was extracted to elaborate the altitude and slope layers, subsequently vectorized.

Finally, for each of the variables, categories were defined according to their range of values, and surfaces were calculated for both the study area as for each of the cultivated plots with *S. purpurea*.

4.3 Results

4.3.1 *S. purpurea* distribution in Barranca del Río Santiago

Even when inhabitants of BRS recognize the natural presence of *S. purpurea* it was possible to record only one individual in the field; however, in several orchards, «male» trees could be observed, which according to the informants, were taken from the field into the orchards to increase the production of fruits. Only six botanical records were found for BRS hold by the IBUG Herbarium of the University of Guadalajara: a collection that will increase with the registration of nine cultivars including a wild specimen provided by this work. 871 ha cultivated with *S. purpúrea* were registered within the 72 338 ha covering BRS.

4.3.2 Environmental variables

Location of plum-grown plots are included in the generated maps showing the distribution variables of BRS study area (Figures 4.2, 4.3 and 4.4). Respective values of the variables for both BRS and *S. purpúrea* cultivated plots are shown in Annex 4 (Table A4.1).

Hot sub-humid **climate** Aw_o predominates in 72,4% of BRS's surface. Climates of the semi-warm / sub-humid type, (A)C(w_o) and (A)C(w_1) have presence in the rest of the surface. *S. purpurea* demands a tropical or subtropical, humid or dry climate to grow and 99% of BRS presents a favorable climate for its cultivation. 98,6% of plum cultivated area is identified with Aw_o, which is the hottest and wettest of the three climate types.

Temperature varies within BRS depending on: (1) the depth of the ravine (500 m in general), (2) the influence area of the river bed and Santa Rosa Dam and (3) the decline of the riverbed (1000 masl at the beginning and 570 masl in the final part). The ravine is a frost-free zone; **minimum temperature** values in most of the ravine (89,2%) oscillate between 12 and 16°C; the lowest range (from 9 to 11°C) occurs in a small part of the surface (10,8%) in the limits with the mountains (Figure 4.2-A); most plum-grown plots (81%) are between 14 and 16°C of minimum temperature, and only 19% are in the range of 12 to 13°C. Values of **annual average temperature** vary between 17 and 25°C; in 86,5% of BRS the annual average temperature is in the range between 21 and 25°C; in the rest of the surface (13,5%) temperature is maintained between 17 and 20°C (Figure 4.2-B); 86% of plum cultivated area remains between 23 and 25°C and only 14% is between 21-22°C.

Maximum annual temperatures in 91% of BRS's surface (Figure 4.2-C) are in the range between 27 and 32°C; the rest of the surface presents the lowest extreme values (24°C) and the highest (34°C); most of the surface with plum (80%) is in the range of 30-32°C, 18% is located in the range of 33-34°C while the remaining 2% is located between 27-29°C.

The annual average **daytime temperature** calculated for BRS (Figure 4.2-D) is between 27 and 30°C in 57% of its surface, while 40% varies between 24 and 26°C; the plums are almost entirely (95%) in the range of 27-30°C and only 5% in the range of 24-26°C.

Annual **thermal oscillation** values presented in BRS (Figure 4.3-A) are between 22 and 27°C. In 51% of BRS's surface, the annual temperature oscillates between 24 and 25°C; as for the *S. purpurea* cultivated areas, 76% is in the range of 26-27°C of annual thermal oscillation.

The analysis for raster layers of accumulated rain inside BRS shows (Figure 4.3-B) a tendency to less rain in the deep parts of the ravine (71% of its surface), with values between 822 and 900 mm precipitation per year; while in the periphery, in areas of higher altitude highest values are obtained, although they do not exceed 965 mm of annual precipitation. 82% of plum cultivated surface is in the range of 857 to 900 mm of rain. **Available humidity** in the study area (Figure 4.3-C) occurs during most of the rainy season (June to September), when the precipitation values are higher than those of evapotranspiration. Available humidity in 92% of BRS's surface ranges between 160 and 327 mm; 94% of plum cultivated surface is found to be in the same range. This is a typical condition of dry forests, which is considered the species main habitat.

In Figure 4.3-D, BRS presents cumulative potential **evapotranspiration** values (ETo) between 1350 and 1849 mm, much higher than the precipitation values (822 and 965 mm). In general terms, it is observed that the highest values between 1678 and 1849 mm occur in the last third downstream of the river bed, which represents 13,4% in the studied surface. As shown in Figure 4.3-D, 27,3% of the plum orchards are located in sites with a lower ETo value, between 1350 and 1520 mm. 55,8% of plum plots are located in sites with potential evapotranspiration between 1521 and 1677 mm; and 16,9% of the remaining surface is under the highest evapotranspiration regime, from 1678 to 1849 mm.

In BRS the annual average **photoperiod** is 12 hours with under two hour fluctuations throughout the year.

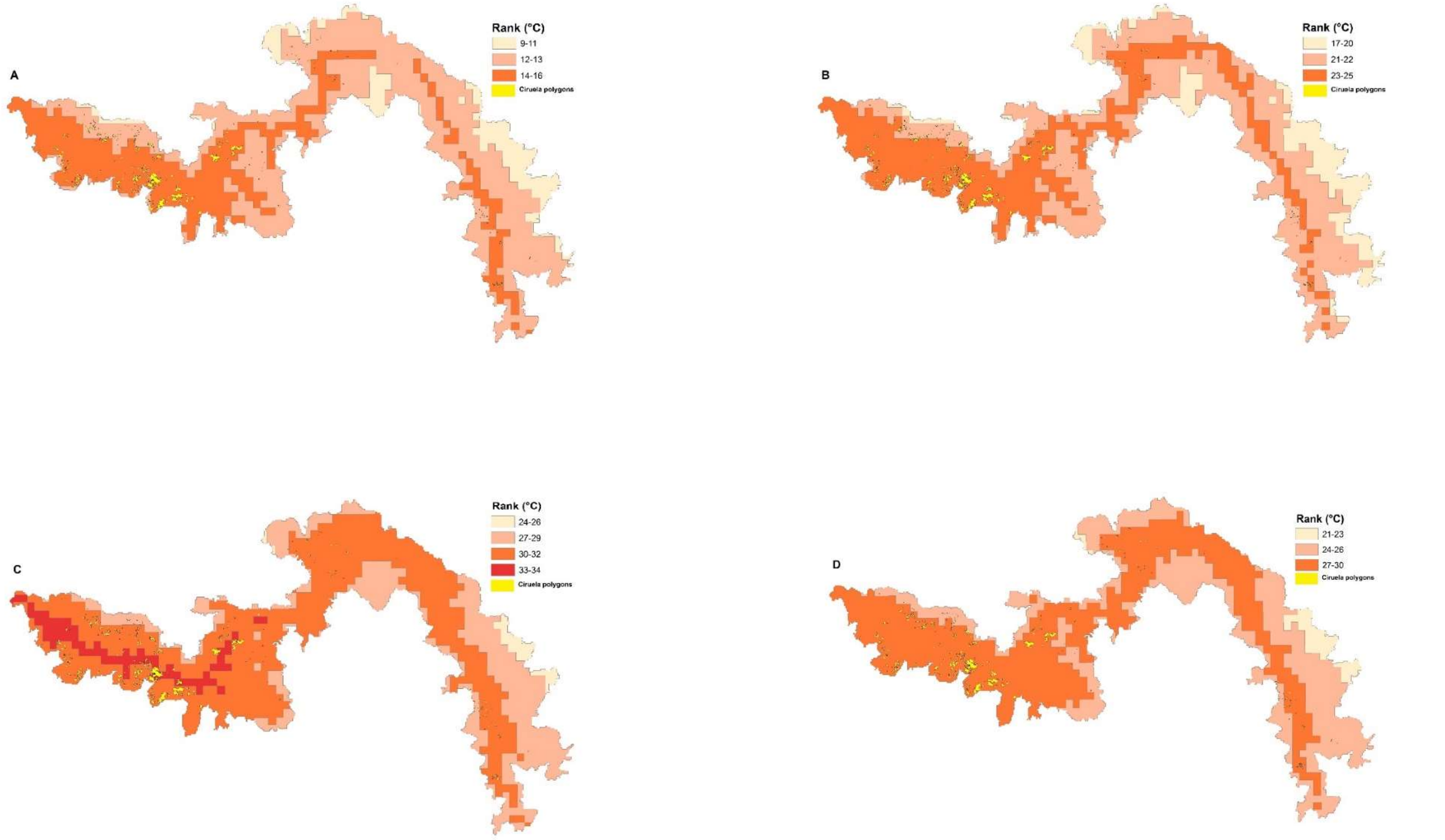

Figure 4.2. Distribution in the Barranca del Río Santiago of the cultivated plots with S. purpurea and of the variables: A) Minimum average annual temperature, B) Average annual temperature, C) Maximum average annual temperature, D) Average annual daytime temperature.

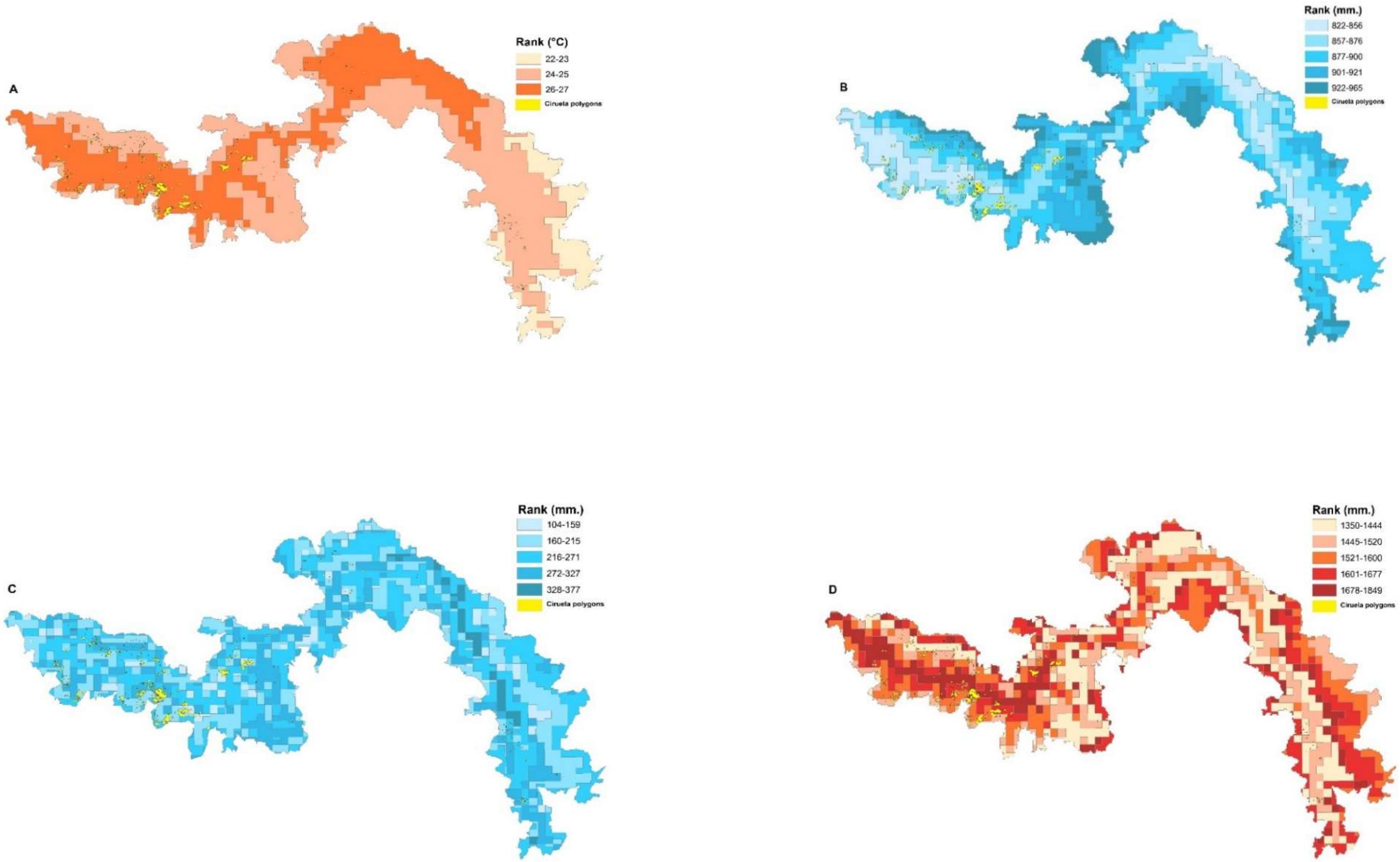

Figure 4.3. Distribution in the Barranca del Río Santiago of the cultivated plots with *S. purpurea* and of the variables: A) Annual thermal oscillation, B) Annual cumulated precipitation, C) Available humidity wet months, D) Annual cumulated evapotranspiration.

4.3.3 Edaphic and physiographic variables

Altitude in the study area varies between 637 and 2146 masl, although most of the plum orchards (60,6%) are in the lower part of BRS with altitude between 637 and 933 masl, where the climate is warmer. 34,4% of the cultivated area is between 934 and 1350 masl and only the remaining 5% of the surface is located at a higher altitude (1351- 2146 masl).

Figure 4.4-A shows that most of the Surface in BRS (66%) has **slopes** above 16°, corresponding with **steep terrain** where it is not possible to perform any agricultural activity; 26% of the surface corresponds to **sloping terrain** (from 6 to 15°) where agricultural activities can be carried out with high restrictions on soil management; and only 8% of the surface corresponds to **flat terrain** with slopes of 1 to 5°, which do not have restrictions to carry out productive activities. Most of *S. purpurea* plots (65%) are located on **steep slopes** followed by plantations on **steep terrain** (23%); a minimum part (12%) of the crop is on **flat terrain**. This confirms the adaptability of the species to develop on steep slopes.

Three types of soil predominate in BRS, which together cover 97,3% of the ravine's surface (Figure 4.4-B). The most abundant is lithosol with 57,5%, which covers the steep slopes on the banks of the river; these are thin soils with less than 10 cm depth. Followed by feozem type soils with 28,5% of the land cover, they present a dark superficial layer rich in organic matter and nutrients. The next type corresponds to luvisol soils with 11,3% of the surface in BRS; these are soils with clay accumulation and high susceptibility to erosion: red or yellowish color. Finally in 2,7% of the remaining area there are small portions of cambisol soil, regosol and vertisol (INEGI, 1982). 57% of the plantations are in feozem soil; 27,7% correspond to litosol type and 14,7% to luvisol.

90% of BRS's soil has medium **texture** with fine texture presence in some areas (8,4%) located mainly east of the study area, and a minimum portion (1,6%) of soil with coarse texture. The total cultivated area of *S. purpurea* is found in medium-textured soils, which have good drainage.

A

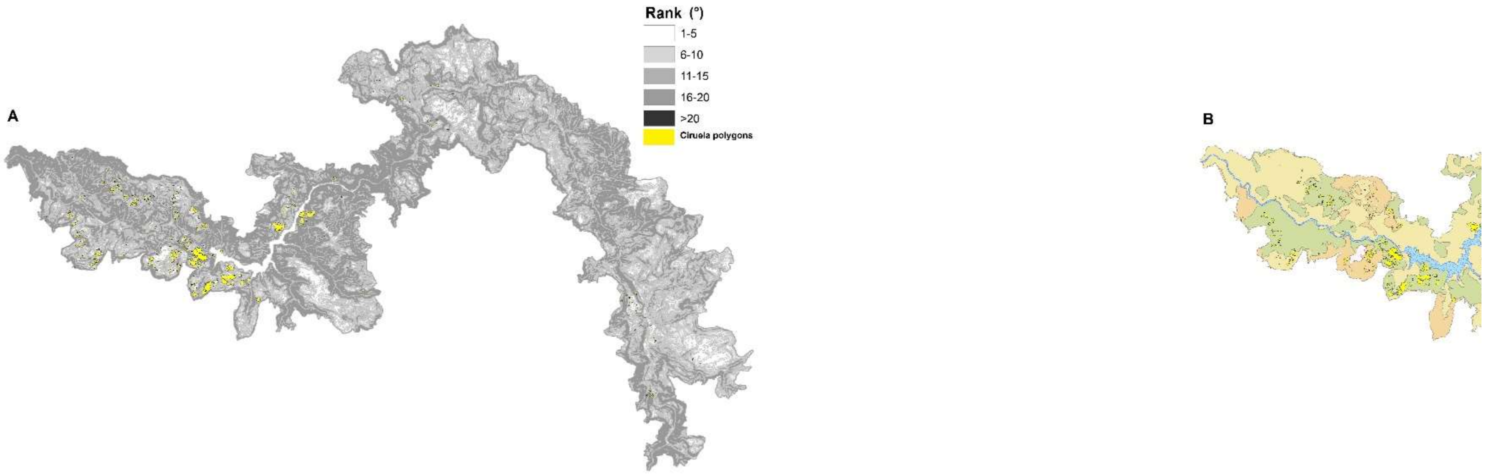

Figure 4.4. Distribution in the Barranca del Río Santiago of the cultivated plots with *S. purpurea* and of the variables: A) Slope, B) Soil type.

4.4. Discussion

Results in this paper partially cover the existing lack of information on cultivation of *S. purpurea* in the State of Jalisco, and specifically in BRS, a situation partly due to the lack of attention of the producers, agricultural technicians and extensionists who rather dedicate their efforts to higher demanded fruit trees in the local and international market (Cuevas, 1992). Plum plantations in BRS compete with plantings of *Opuntia ficus-indica* (L.) Mill. for regional consumption and with plantations of *Agave tequila* F.A.C. Weber for international tequila consumption.

During the last 38 years (1980 to 2017) the average national surface area planted with *S. purpurea* was in the order of 15 000 hectares, which obtained an average yield of five tons per hectare. During this period, there was a fairly constant increase in the price per tonne and production value amounting to $5 268,57 and $440,5 million pesos respectively in 2017 (see Figure A4.1). Under this scenario the state of Jalisco has maintained a constant presence among the states with larger tradition cultivating plums. Its participation during the referred period in terms of harvested area, production and production value was an average of 7,4%, 9,4% and 11,83% of the national total, respectively; having won first place at national level in 1984 in terms of harvested area and a production value of 12,3 and 31,6% respectively; in the same way Jalisco obtained first place in 1990 of the total national production contributing with 19,5% according to the data obtained from the statistics published by Agri-Food and Fisheries Information Service (SIAP, 2017).

Even though plum is cultivated in the State of Jalisco on the shore of Chapala Lake —in the southern zone and on the coast, it is BRS who provides the substantive part of the state production, specifically the municipalities of San Cristóbal de la Barranca, Tequila, Zapopan and Amatitán.[16] During the last 15 years (2003-2017) these municipalities accounted for 82%, 71% and 77% average of the harvested area, production and production value, respectively, of the total reported for the State of Jalisco (see Figure A4.2).

A need to deepen the study *S. purpurea* in the State of Jalisco is evident in comparison to other states in México; suffice to mention that in the work carried out by Ramírez, et al.,

[16] The municipality of Ixtlahuacan del Río, which is also part of BRS, has a smaller participation.

2007) 12 varieties are reported in central-western Mexico (states of Jalisco, Nayarit and Colima), of which 4 varieties are located in BRS. In Chapter 1 of this thesis six cultivars and a wild variety were reported in the total study area, although there is the possibility of increasing these numbers in future investigations.

871 ha of the 72 338 ha covering BRS were reported to be cultivating *S. purpurea*; this is a constantly changing surface when new plantations are established, when settled orchards are abandoned or replaced with more profitable crops. Crop yields depend on the handling provided by each farmer and the environmental conditions prevailing throughout the year; although the value of the harvest is largely determined by the competition held with the early arrival of fruits from other entities to the collection center in Guadalajara and the marketing abilities of each farmer.

BRS is already mentioned as a location with high potential for the species distribution (Pennington and Sarukhán, 2005), as well as with large probability to establish natural and wild plum populations (Miller and Knoouft, 2006), and the current and potential aptitude of *Spondias purpurea* facing scenarios of climate change has also been approached (Arce-Romero et al., 2017). However, the fact that there is basically no record of botanical collections within the area, nor the characterization / management of production systems is to be noted.

When comparing the values of the recorded variables in Mexican plum plots with the agroclimatic requirements produced by Cuevas (1992), Vázquez-Yanes et al. (1999), Pennington and Sarukhán (2005), Ecocrop (2007), Campos and Espíndola (2007), Cruz and Rodríguez (2012) and Ruiz et al. (2013) a high coincidence degree can be observed relating to the following aspects:

a) Phyllogeographic analysis of the species suggest that the origin point of *S. purpurea* is located in the western side of Mexico (Jalisco, Nayarit, Michoacán) which is also one of the domestication center points of the species (Fortuny-Fernández et al. 2017).
b) The native habitat of the wild progenitors of cultivated *S. purpurea* is the Mesoamerican dry forest (Miller and Knouft, 2006).

c) *S. purpurea* is considered to be a component of the dominant stratum of the deciduous tropical forest (Rzedowski and Mc.Vaugh 1966; Rzedowski and Rzedowski 1999; Pennington and Sarukhán 2005).

d) The deciduous tropical forest penetrates the deep canyons of Santiago River and its tributaries in the form of narrow strips measuring hundreds of kilometers long (Rzedowski, 2006).

BRS Agroecological characterization results and determining the condition of the plots growing plum, show that while the whole ravine meets the optimal conditions for cultivation, the farmers experience has allowed them to select the best sites for the establishment of the orchards.

Generally speaking, it can be said that subhumid warm weather (Aw_0) is the only one that prevails throughout the BRS, even though two variants of sub-humid semi-warm climates $(A)C(w_0)$ and $(A)C(w_1)$ are included, perhaps because of the scale of the climate map used (1:1000000) , however, the species is also distributed in these climates (Campos and Espíndola, 2007). In BRS almost the total (98,6%) of the cultivated area presents the first climate type which is the warmest and wettest of all three, evidently to avoid the possibility of cold temperatures and lower available humidity.

The **thermal regime** of the species (according to Campos and Spindola, 2007; Cruz y Rodríguez, 2012; Ruíz, et al. 2013) is satisfactorily met in the BRS. 24º C optimum temperature of the species is found in 38,6% of the ravine's surface where 86% of the plum orchards are located; the average temperature range (19 to 29º C) where the crop successfully thrives is found in 86,5% of the BRS's surface, where the entire plum orchards are located. In addition, the crop's requirement for the difference between the average temperature of the coldest month and the hottest month should not exceed 10 ºC is met. BRS is free from cold (and frost) temperatures which are harmful to plums; farmers avoid the cooler areas of the ravine where the average minimum temperatures can reach 9 to 11º C. All premises are located in places where the average annual minimum temperature is within the range of 12 to 16º C. Temperatures above 40º C which are harmful to the crops are not found in the study area; most of the BRS (60%) has a maximum annual average temperature ranging between 30 and 32º C, where almost 80% of the plum plots can be found.

The amount of **precipitation** occurring in BRS ranges from 822 to 965mm, thus covering the optimal crop requirements which range between 800 and 1100 mm (Ecocrop, 2001, Campos and Espíndola, 2007; Cruz y Rodríguez, 2012; Ruíz, et al. 2013), including the seven-month dry period, which is why, under this criterion, the crop could be grown throughout the ravine. Although farmers recognize the plant's ability to withstand drought, they prefer wetter sites to establish the crop in; they acknowledge that during the rainy season the plant stores some of the available moisture to produce the fruits, which is why they avoid less productive "drier" sites. The annual cumulative **evapotranspiration** values calculated for the interior of the ravine could not be linked to the distribution of plum-grown properties.

As for the number of **light hours**, the plant is reported both of neutral day and long day, with a marked preference for sunny environments specially in its reproductive stage, although it also grows with less luminosity available (Cruz and Rodríguez, 2012; Ruiz, et al. 2013); the average annual photoperiod of 12 hours determined for BRS is favorable for in the growth of *S. purpurea*; however the amount of light can be affected by the exposure of the plots in relation to the path of the sun, the altitude at which they are located inside the ravine and the presence of cliffs may reduce the amount of direct solar radiation.

Crop's requirements in terms of **altitude** are very wide, from sea level to 1200 masl (Cuevas, 1992). 95% the cultivated plots in BRS are within this range (between 637 and 1350 meters), corresponding to the middle and lower part of the ravine.

It is considered that the plant does not require good quality **soils** and that its produced in poor or thin soils (Cuevas, 1992; Campos y Espíndola 2007), however it is considered to have good response to soils of medium depth and good drainage (Cruz y Rodríguez, 2012; Ruiz et al. 2013); its cultivation is performed in a wide variety of soil types and their combinations. Plum plantations in BRS are distributed between three predominant soil types (litosol, feozem and luvisol), same ones which according to the specific conditions of each site present different thickness range, stoniness, nutrient content and susceptibility to erosion, which is not always considered by farmers who believe that plants thrive either way.

BRS soil texture is medium-averaged in 90% of its surface, a situation that favors the development of roots in the branches or stakes used in vegetative propagation when new plantations take place; to prevent the stake from rotting and drowning the roots farmers usually put stones at the bottom of the well. Even though the soils of the ravine are considered suitable by the literature and by farmers for the cultivation of Mexican plum, the lack of edaphological information at a suitable scale for the study area is evident in the following subjects: acidity, salinity, drainage, and ground biology.

Although it was possible to characterize BRS environmentally and determine the relevance of Mexican plum cultivation in it, it is necessary to deepen the knowledge of climatic and edaphic conditions of BRS with the purpose of achieving greater precision in the characterization of the ravine territory, where the relief makes monitoring difficult.

4.5. Conclusions

Agroclimatic characterization of *Spondias purpurea* crop and of BRS was elaborated using GIS to run georeferenced agroecological data, thus determining the cultivated area and its distribution within BRS. Agroclimatic and edaphic characterization allowed comparing the reported requirements for *S. purpurea* by several authors. As the environmental conditions at BRS coincide with the cited environmental requirements, it is confirmed that the study area meets favorable conditions for the development of the crop, although other aspects must be taken into account such as cultivation practices, postharvest handling, added value to production and marketing, in order to achieve crop's sustainability. Even though Mexican plum is considered an identity element of BRS, the wild and cultivated populations are strongly threatened by changes in soil use, patterns of commercialization and consumption of local products.

Even though the state of Jalisco occupies an outstanding place in national production of Mexican plum, papers on floristic and ethnobotanical exploration, characterization of cultivars, and local management systems are few in comparison with those carried out in other states of the country. The species has a high potential to be included in reforestation programs and conservation of wildlife, as it can be grown on degraded land of low agricultural value, thereby supporting wildlife conservation and in turn re-delivering profits to the farmers; the species can also play an important role in agro-ecological programs for sustainable food production and to encourage diversification of forms of consumption both in farmers families and in large urban and gastronomic centers.

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ANNEX 4

Table A4.1. Surface of the river Santiago ravine and cultivated surface with plum by type of variable

	Surface of the canyon		*Surface with plums*	
Variables/ category	***Hectares***	***Percentage***	***Hectares***	***Percentage***
Clime type				
Awo	52 340,00	72,40	859,09	98,60
(A)C(w_o)	10 815,00	15,00	5,03	0,60
(A)C(w_1)	9 050,00	12,50	6,87	0,80
C(w_o)	99,38	0,10	0,00	0,00
	72 304,38	100,00	870,99	100,00
Annual minimum average temperature (°C)				
9-11	7 808,04	10,79	0,00	0,00
12-13	39 554,99	54,68	164,10	18,84
14-16	24 97,35	34,52	706,89	81,16
	72 337,38	100,00	870,99	100,00
Annual average temperature (°C)				
17-20	9 776,69	13,52	0,00	0,00
21-22	34 639,85	47,89	122,05	14,01
23-25	27 922,94	38,60	748,94	85,99
	72 339,48	100,00	870,99	100,00
Annual high average temperature (°C)				
24-26	1 553,95	2,15	0,00	0,00
27-29	22 211,18	30,70	15,81	1,82
30-32	43 316,54	59,88	694,05	79,69
33-34	5 257,73	7,27	161,13	18,50
	72 339,40	100,00	870,99	100,00
Annual daytime average temperature (°C)				
21-23	2 572,94	3,56	0,00	0,00
24-26	28 609,52	39,55	43,44	4,99
27-30	41 156,95	56,89	827,55	95,01
	72 339,41	100,00	870,99	100,00
Annual temperature oscillation (°C)				
22-23	7 184,35	9,93	0,37	0,04
24-25	36 724,96	50,77	205,60	23,61
26-27	28 428,00	39,30	665,02	76,35
	72 337,31	100,00	870,99	100,00

Table A4.1. (continue) Surface of the river Santiago ravine and surface cultivated with plum by type of variable

	Surface of the canyon		Surface with plums	
Variables/ category	**Hectares**	**Percentage**	**Hectares**	**Percentage**
Annual cumulative precipitation (mm)				
822-856	9 830,57	13,59	112,01	12,86
857-876	20 009,90	27,66	440,19	50,54
877-900	21 575,91	29,83	273,63	31,42
901-921	13 592,31	18,79	41,65	4,78
922-965	7 328,74	10,13	3,51	0,40
	72 337,43	100,00	870,99	100,00
Available humidity (mm)				
104-159	3 640,97	5,05	49,44	5,68
160-215	22 347,65	30,97	395,28	45,41
216-271	28 941,89	40,11	223,82	25,71
272-327	15 335,96	21,25	201,95	23,20
328-377	1 891,97	2,62	0,00	0,00
	72 158,44	100,00	870,49	100,00
Potential evapotranspiration (mm)				
1350-1444	17 284,28	23,89	83,51	9,59
1445-1520	14 635,44	20,23	154,30	17,72
1521-1600	14 565,19	20,14	272,48	31,28
1601-1677	16 172,31	22,36	213,37	24,50
1678-1849	9 680,24	13,38	147,33	16,92
	72 337,46	100,00	870,99	100,00
Altitude				
637-933	14 211,58	19,65	528,03	60,62
934-1136	18 553,48	25,65	177,33	20,36
1137-1350	20 149,62	27,86	122,04	14,01
1351-1628	13 169,77	18,21	40,83	4,69
1629-2146	6 252,87	8,64	2,76	0,32
	72 337,32	100,00	870,99	100,00
Slope				
1-5	5 539,69	7,59	103,77	11,91
6-10	9 720,65	13,32	290,23	33,32
11-15	9 667,86	13,24	275,48	31,63
16-20	9 056,79	12,41	81,53	9,36
>20	39 018,66	53,45	119,98	13,78
	73 003,66	100,00	870,99	100,00

Table A4.1. (continue) Surface of the river Santiago ravine and surface cultivated with plum by type of variable

	Surface of the canyon		**Surface with plums**	
Variables/ category	**Hectares**	**Percentage**	**Hectares**	**Percentage**
Soil type				
Cambisol	168,91	0,24	0,00	0,00
Feozem	19 877,44	28,48	489,92	57,23
Litosol	40 105,59	57,47	237,10	27,70
Luvisol	7 905,07	11,33	125,96	14,71
Regosol	1 355,97	1,94	1,32	0,15
Vertisol	372,12	0,53	1,71	0,20
	69 785,10	100,00	856,01	100,00
Soil texture				
Fine	5 995,01	8,39	2,49	0,29
Medium	64 314,88	90,02	867,98	99,65
Gross	1 137,51	1,59	0,52	0,06
	71 447,40	100,00	870,99	100,00

The total surface values show slight changes according to the type of file and their origin.

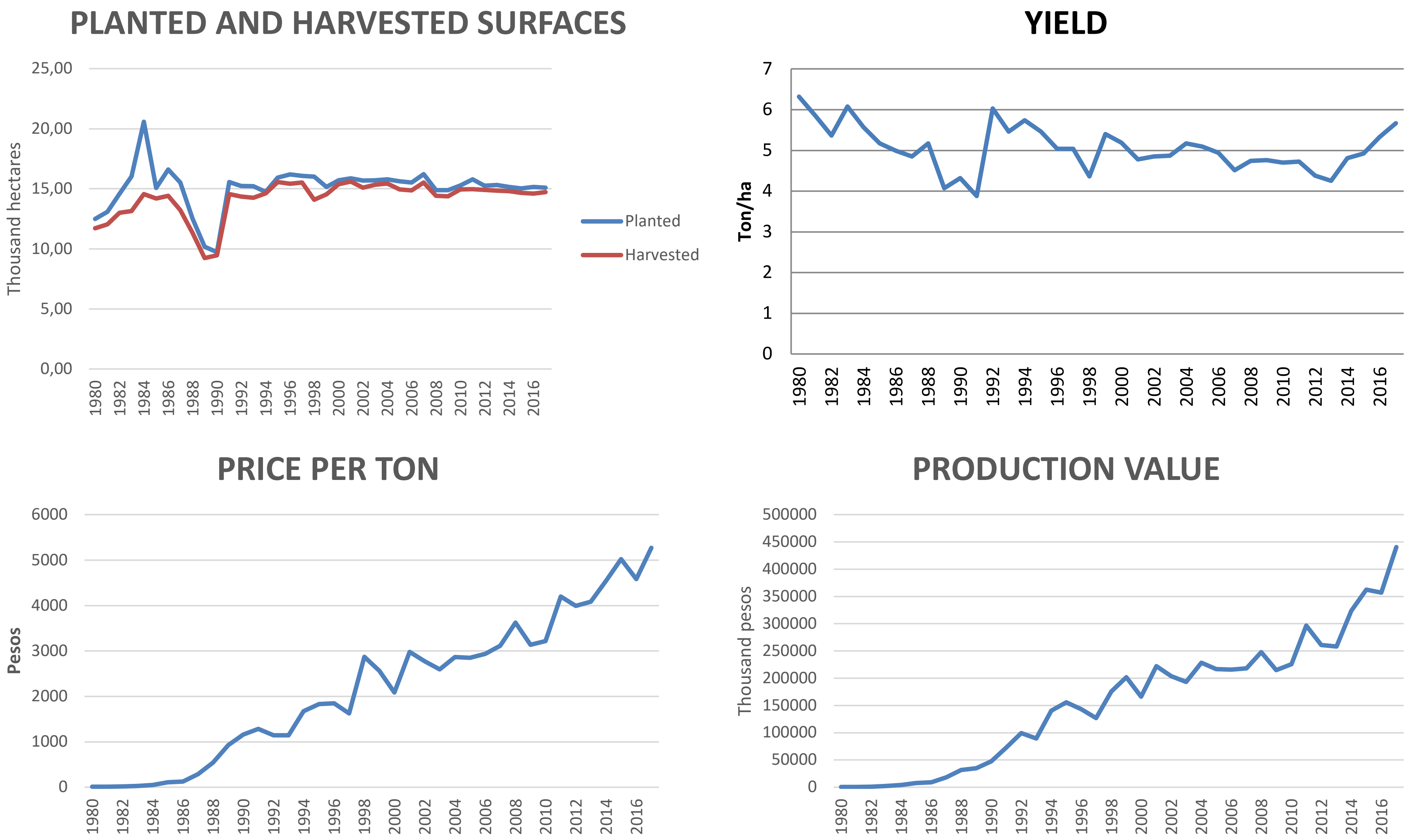

Figure A4.1. Surface, yield, price per ton and value of production in thousands of pesos for the cultivation of *Spondias purpurea* in Mexico for 38 years

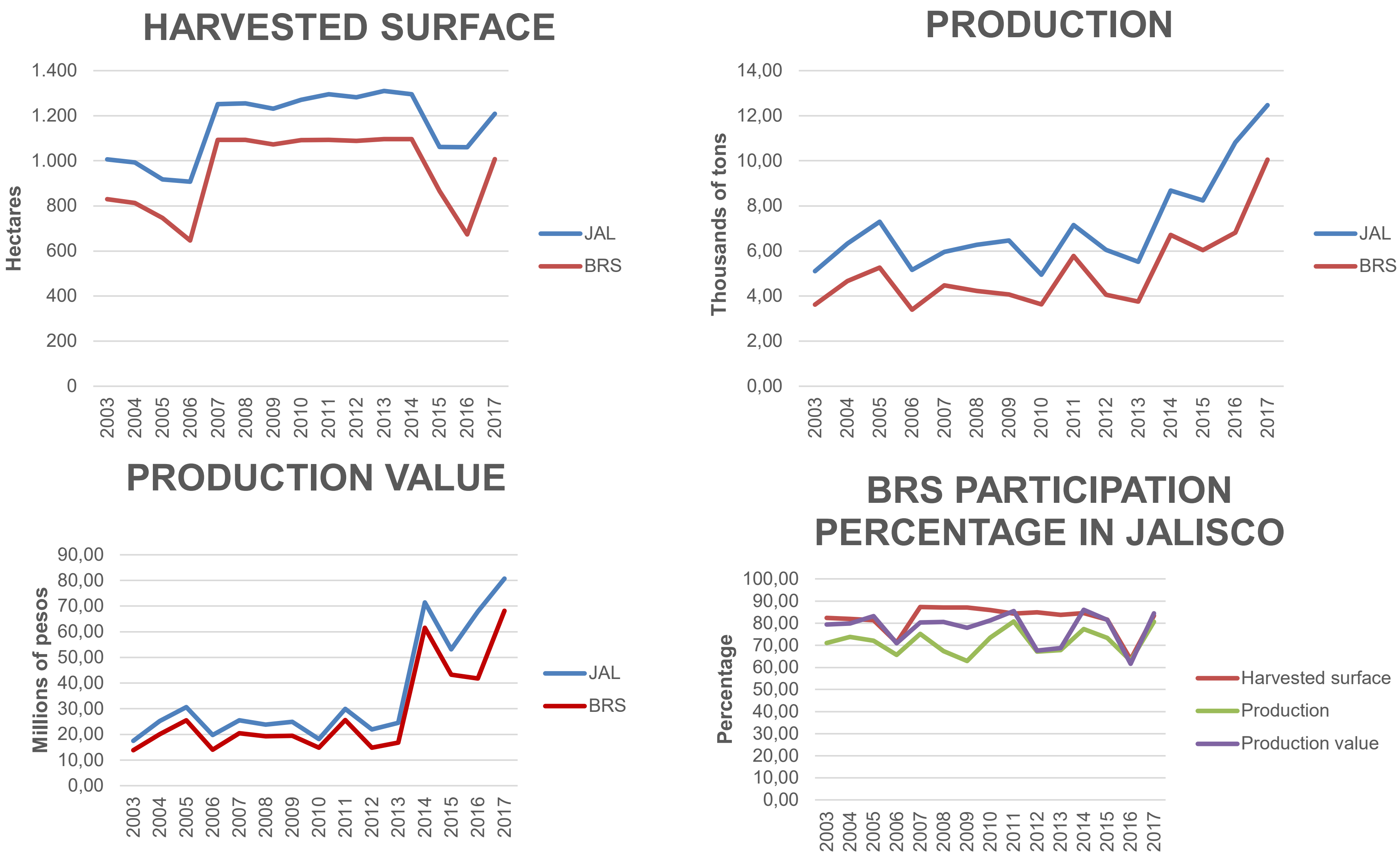

Figure A4.2. Participation of the Barranca del Río Santiago (BRS) in the production of Spondias purpurea in the State of Jalisco (JAL)

Chapter 5.

Distribution and potentiality of *Malpighia mexicana* A. Juss., In Mexico and its implications in the case of Barranca del Río Santiago

Abstract

Wild plants have a high economic potential as a resource although still in need to be fully explored. Such resources represent the most important alternative to develop new crops and, even more relevant, to improve the already existing ones since these resources are related with food and health: two major challenges faced by humanity. Mesoamerica is an origin point for different species including a large number of domesticated plants. *Malpighia mexicana* is a wild species with a wide tradition of food, medicinal, ornamental and fuel use in Mexico. It is found in the American origin group of tropical shrubs that produce edible red fruits, such as *Acerola*, which is considered the most important natural source of vitamin C in the world. Given the role played by *M. mexicana* in Mexico, particularly in Barranca del río Santiago (Santiago River Canyon) we decided to study its potential distribution to contribute to the knowledge in the species utilization and conservation. From the specie's botanical records and climatic data from World Clim 2.0 a distribution model within the Mexican Republic was generated through the MaxEnt program. The results indicate the species clear preference for dry tropical forests: most extensively in the areas of Balsas river depression and the central valleys of Oaxaca and high probability values of the species presence in the West country side, although it also presents high probability values in smaller surfaces, such as the region of Santiago river canyons witch are covered by dry tropical forest. Given the level of anthropization that threatens this type of vegetation it is necessary to implement programs aiming for the local ecosystems conservation considering the study and preservation of its species in order to regard them as promising resources for nourishment, therefore contributing to the sustainable development in various country regions.

Keywords: *Malpighia mexicana*; plant genetic resources for food. *Barranca del Río Santiago*; distribution in México.

5.1. Introduction

Plant genetic resources for food (PGRF) represent the basic natural essence to improve existing cultivars and to obtain new ones for food and agriculture. However, in western Mexico, as in other parts of the world, the permanence of the PGRF, its diversity, and traditional knowledge have been excluded by the current model of development, placing them in a vulnerable situation and at high risk of extinction.

The study of the PGRF in Mexico has been focused on species related to economically important cultivars or wild plants of high commercial value. At the same time, there has been little or no attention at all to marginalized crops and other wild plants with dietary potential. Hence, it is a priority to give greater attention to the conservation of wild species of direct, indirect or potential use, which are now threatened by the change of land use, herbicides and the increase of harmful substances in the atmosphere, etc., risking the genetic diversity by promoting the disappearance of useful or usable wild species (Esquinas, 1983).

Malpighiaceae is a family of tropical and subtropical plants with 75 genera and 1300 species, out of which 80 and 90% respectively are considered native to America. Even though morphological evidence suggests that the origin and diversification of the family are located in South America, it is possible that some genres such as *Malpighia* evolved in the tropical dry forests of Central Mexico (Anderson, 2013). Some species in the *Malpighiaceae* family are cultivated because of their attractive flowers, and sometimes due to their winged or edible fruits. In addition, some members of the family produce hallucinogens and are cultivated for these chemicals (Anderson et al. 2006). The genus *Malpighia* gathers 50 or more species that produce small drupes, which are dispersed by birds; about half of *Malpighia* species grow in Mexico and Central America. Of the 19 species in Mexico, 12 are endemic and the rest (7) are distributed in Central America (Davis and Anderson, 2010; Anderson, 2013). According to Stanley (1920), the genus *Malpighia* corresponds to erect shrubs or small trees -with opposite entire leaves in the Mexican species-, flowers in small axillary peaks, calyx with six to ten glands, jagged petals in different ways, drupe as fruits, usually red. The author identifies *M. umbellata* Rose, *M. punicifolia* L., *M. diversifolia* T. S. Brandeg, *M. glabra* l. as producers of edible fruits and does not mention *M. mexicana* Juss: a wild species whose fruits are consumed in western Mexico. Species of the genus *Malpighia* are also grown for its ornamental use; *Malpighia coccigera*, native to the West Indies, is cultivated worldwide in greenhouses as a miniature shrub (Anderson et al. 2006).

Different species of the *Malpighia* L. genus are known by the name «acerola», particularly *M. glabra* and *M. emarginata* (on a lesser extent, *M. punicifolia* L.) which began to be cultivated in different parts of the world in the 1940s. The increase of the cultivated area in the American continent continues to date. The growing interest in *acerola* is due to the fact that it is the most important natural source of ascorbic acid for food, cosmetic and pharmaceutical industries (Johnson, 2003). Additionally, its fruits are rich in phenolic compounds, including benzoic acid derivatives, phenylpropanoids, flavonoids, anthocyanins and carotenoids (Belwal et al. 2018). Extracts and bioactive compounds from the fruit have a high biological activity as antioxidant, anti-fungal, anti-tumoral, antihyperglycemic, radioprotective and treatment of infections and bleaching of skin (Caceres et al. 1993; De Rosso & Mercadante, 2005; Düsman et al. 2014; Belwal et al. 2018). The bark of the tree boiled in water is used as an astringent and remedy against fevers, disinfestation, diarrhea and dysentery (UNAM, 2009). Acerola fruits can be considered as a potential source for the development of new functional foods (Belwal et al. 2018).

Plants of *M. glabra* are found in the wild or cultivated from southern Mexico to Colombia and Venezuela, in the Caribbean and in South Texas. Zizumbo, et al. (2010) recognizes *Malpighia glabra* L. as a native phytogenetic resource for food and agriculture in the state of Yucatan. Meanwhile, Avilés-Peraza (2016) reports warm-subhumid climates and very dry or desert climates in the Yucatan Peninsula with presence of tropical forest as distribution area for *M. glabra*. Although *M. glabra* and *M. emarginata* are the most cultivated species because of the diversity of uses and the commercial value of their industrial production, these species are also sold in greenhouses of the United States of America as ornamental shrubs. *M. emarginata* is the correct name of *M. punicifolia* equivalent to the species cultivated for its rich in vitamin C fruits (Anderson et al. 2006). Other species such as *M. mexicana* Juss, are grown in the backyards for their edible fruits, although the details of this use are not fully documented.

Stanley (1920) recognizes *M. mexicana* as an erect shrub, or small tree, from 2 to 4.5 meters high; opposite leaves, oval to ovate, 3 to 10 cm long, obtuse or acute, commonly tomentose, conspicuously petiolate; of purple or violet flowers and red fruits the size of a cherry; distributed from the State of Durango to Oaxaca and Morelos. Although it is well represented in the western part of the country, its greater distribution and consumption within the region of Barranca del Río Santiago (BRS) in past times is acknowledged. According to Martinez (1987), the plant is called *huachacote* (Morelos); *manzanita del cerro, nancerol* (Chiapas); *nanche de cerro* (Puebla), *nanche de monte* (Oaxaca), wild red *nanche* (Maldonado-Peralta et al. 2016) and *manzanita* in the State of Jalisco. In addition to dietary use, it has been recognized as an ornamental and medicinal plant since prehispanic times. It is currently used in traditional medicine for the treatment of stomatal discomfort, diarrhea, dysentery and to disinfect wounds (UNAM, 2009).

Malpighia mexicana A. Juss., considers two synonyms: *M. edulis* Donn. Sm., And, *M. tomentosa* Pav. ex Moric.; it also includes as an infra-specific category, *M. mexicana* subsp. *guadalajarensis* (S. Watson) FK Mey. (Niedenzu, 1928; Tropicos, 2017). In Mexico, this is species is naturally distributed in deciduous tropical forest (Miranda and Hernández-Xolocotzi, 1963; Rzedowsky and Mc. Vaugh, 1966), although it can also grow in temperate climates and is cultivated outside its area of distribution (Ecosur, 2015; Maldonado-Peralta et al. 2016). Deciduous forests are the most abundant and widely distributed tropical vegetation in Mexico. It is characterized by the loss of foliage during the dry season, by its high floristic diversity and a high level of endemic species (Trejo, 2005). It is important to mention that in regions where *M. mexicana* grows wild or as a marginal crop, the plant has a long tradition of dietary and medicinal use, which has not been fully studied. Although different species of acerola have been largely cultivated for commercial purposes (Asenjo, 1959; Johnson, 2003), there is a lack of information about the fruit characteristics, nutritional properties and vitamin C content of *M. mexicana* despite its nutritional and commercial potential (Maldonado-Peralta et al. 2016a).

Ecological niche models (sometimes also referred to as species distribution models, see Peterson et al. 2011 for a discussion on conceptual differences) are a useful approach for the analysis of such a spatially and temporally complex process as the distribution of species. Even though models do not reflect with precision the mechanisms that lead to the observed distribution of a species, they are useful to describe the relationships between species and environmental variables at wide spatial scales. This characterization of species-environment relations can then be used to generate spatial predictions of species occurrence.

Different works on ecological niche modeling of Mexican plant species have been published, some of them including species reported in the BRS. Carrasco-Ortiz et al. (2019) analyzed the distribution of the genus *Dahlia* (Asteraceae) is Mexico. This genus has a wide distribution in Mexico; in the BRS at least two species are present: *D. coccinea* y D. *pugana.* Pennington and Sarukhán (2005) made distribution maps of 190 tropical tree species some of whom are present in the BRS. Linsky (2014) modeled the distribution of *Malpighia woodburyana* Vivaldi ex Acev.-Rodr., using only variables related to physiography, anthropogenic disturbance and conservation areas. Although this species is not present in Mexico, is the most closely related species for which distribution models have been produced.

A previous study, supported by the University Center of Biological and Livestock Sciences at the University of Guadalajara, has surpassed expectations on the content of vitamin C in *M. mexicana*'s fruits (data non-published). Although *M. mexicana* is well represented in the west part of the country, and despite the great natural diversity of the dry forests of the BRS, there are not previous studies related to this species in the area.

Within this context, the general objective of this chapter was to know the current distribution patterns and potential of the manzanita *Malpighia mexicana* Juss in Mexico in order to contribute to the valuation and use of this phytogenetic resource on a national level; the specific objectives are: a) to estimate the potential distribution of the species and the climatic factors that shape its potential distribution range; b) analyze the obtained predictions in the BRS in further detail. The proposed hypothesis is that the potential distribution of *Malpighia mexicana*, coincides with the distribution the warm-dry jungles of Mexico.

5.2. Materials and method

5.2.1. Study area

This paper examines the potential distribution of *M. mexicana* in the warm-dry tropical forests of Mexico, with emphasis on western central Mexico, in a portion of the geological fault strike-slip (Rodriguez-Castañeda and Rodriguez-Torres, 1992), known as the Canyon of the Santiago River (Fig. 5.1). Its location between the intersection of the Sierra Madre

Occidental and the Neovolcánica Plateau allows for connectivity with the coastal plains, making it a biological corridor between the tempered ecosystems from the central part of the State of Jalisco and the tropical coastal environments. The 72 338 ha portion considered as subarea of study is, located north of the city of Guadalajara, and bounded by the coordinates: 20° 43" and 00° 21"N; 08° 00"and 103° 13"W. The winding canyon includes territory of seven municipal entities of the State of Jalisco: Amatitán, Arenal, Guadalajara, Ixtlahucan del Río, San Cristóbal de la Barranca, Tequila and Zapopan; it also overlaps protected natural areas (PNA): most of the surface of the "Municipal hydrological Protection Area" known as 'La Barranca del Rio Santiago", and a portion of the PNA Oblatos-Huentitán canyon. In addition, the BRS presents connectivity with the polygons of the PNA Nixticuil - Sn. Esteban - El Diente, and the recently decreed PNA of the Barrancas de los Ríos Santiago y Verde.

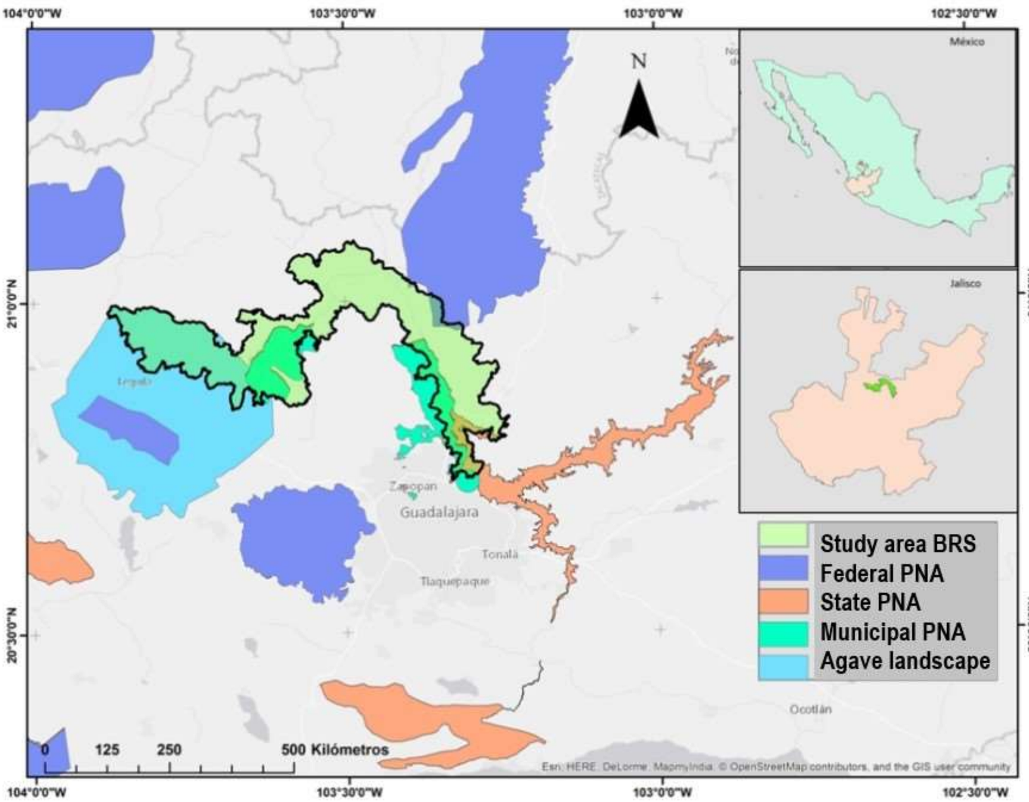

Figure 5.1. Location of the Barranca del Río Santiago (BRS) study area and adjoining protected natural areas by type of jurisdiction

Inside BRS there are three variants of tropical climates, according to the Köppen classification modified by Garcia (1998a): the warm sub-humid Aw_o predominates in 72,4% of the surface, while semi-warm sub-humid climates (A)C(w_o) and (A)C(w_1) cover 15% and 12,5% respectively. The annual total precipitation in accordance with García (1998b) is 600 to 800 mm in 55% of its surface and 800 to 1000 mm in the remaining 45%. However, agriculture has been the main productive activity inside the Canyon, although most farmers, especially those from low socio-economic profile, practice survival agriculture. The lack of relevant public policies has led to the clearance of the original vegetation and the consequent soil degradation, especially in areas with steep slopes where the productive capacity of the land is very low, which leads to the ecosystem degradation and loss of phytogenetic resources and its traditional knowledge of usage.

5.2.2. Species Distribution

A database was integrated with the species records available at GBIF-org (2018), the records from the collections of the Herbarium of the Botanical Institute of the University of Guadalajara (IBUG) and the Herbarium of the Universidad Autonoma de Guadalajara (GUADA), as well as collected specimens of the BRS recorded by the author. This initial database featured a total of 401 records, later reduced to 207 valid records once the duplicates from field observations without botanical collection information and others with inconsistent information were eliminated.

Climate variables

The climatic variables of WorldClim 2.0 (Fick and Hijmans, 2017) were used to carry out the modeling process. Among the 19 bioclimatic variables available the following were used: average annual temperature (BIO1), hottest month temperature (BIO5), minimum temperature in the coldest month (BIO6), temperature annual range (BIO7), annual precipitation (BIO12) precipitation in the wettest month (BIO13), precipitation in the driest month (BIO14) and precipitation seasonality (BIO15). A decision was made to use these variables since they express average and extreme conditions, as well as variability in both temperature and precipitation (Table 5.1).

Table 5.1. WorldClim climate variables considered for the study

Variables	Code	Unit
Average annual temperature	BIO1	°C
Maximum temperature in the warmest month	BIO5	°C
Minimum temperature in the coldest month	BIO6	°C
Annual temperature range	BIO7	°C
Annual precipitation	BIO12	mm
Precipitation in the wettest month	BIO13	mm
Precipitation in the driest month	BIO14	mm
Precipitation seasonality	BIO15	mm

Modeling process

Debugging records

A variety of sources of *M. mexicana* records was used in this study, so it is likely that the representativeness of the climatic conditions where the species inhabits is biased and that taxonomic identification errors may exist. Although there's no consensus on how to debug the records to be used in the modeling process, it's been widely demonstrated that correcting for sampling bias provides a better description of species' relationships with the environment and therefore better predictive accuracy (Kramer-Schadt et al. 2013, Boria et al. 2014, Fourcade et al. 2014). For the present work, we decided to take on an environmental filtering approach similar to that developed by Varela et al. (2014). As of this, the records were plotted in a scatter plot, with the axes being the variables of average annual accumulated precipitation and average annual precipitation. Records outside the usual conditions for *M. mexicana*, particularly those pointing towards high rainfall and low temperatures were discarded. Records packed under similar climatic conditions, not allowing more than two records overlap in the same conditions were also discarded. Of the 207 records remaining, 67 were removed, leaving a total of 140 (watch Figure A5.1 in Annex).

Determination of the environment for Maxent

Maxent is a method known as 'presence-background, since it compares the environmental conditions in the pixels with presence of species with the conditions of the entire study area, taking a sample of 10,000 background pixels (although the number is modifiable) to estimate the average environmental conditions of the study area as a basis for the aforementioned comparison (Merow et al. 2013*)*. This is relevant since the conditions of the background points are interpreted as the total conditions that the studied species can inhabit. The ideal study area from where the background points would be obtained should include all those areas within the range of environmental tolerances and dispersal range of the species and exclude those that are not (Elith et al. 2011). The overlapping of records to be used on the layer of terrestrial ecoregions of Mexico (INEGI et al. 2008) and a satellite image of a GIS server (ArcMap), enabled to observe that the vast majority of records occurred on warm-dry tropical forests ecoregions, some in the temperate highlands, and the lowest number of records were in very close proximity to the warm-wet tropical forests. Given that the ecoregions map was originally developed on a very large scale and that the tropical forests of Mexico present a wide variability, where the warm-dry tropical forest is the most widely distributed tropical vegetation in Mexico and its flora is a mixture of elements of diverse provenance and different entry routes (Rzedowsky and Calderón, 2013), it was decided to incorporate the polygons of these three ecoregions to define the extent of the background for modeling of *M. Mexicana* potential distribution (Fig. 5.2). Subsequently, based on field experience and satellite image aid, the edges of this polygon were adjusted to incorporate those records outside margins but close to warm-dry tropical forest. Inversely, regions of the northeast and northwest of the country corresponding to the temperate mountain ranges were excluded as they were far from the ecosystems typically inhabited by *M. mexicana*. The resulting polygon was used to define the background extent in the analysis of potential distribution with Maxent.

Determination of the Maxent configuration using the ENMeval tool

One relevant aspect of ecological niche modeling is the balance between complexity and generalization. Ideally, the aim is to find models that satisfy the imposed restrictions by the input data but not too strictly, so that their predictive capacity is maintained when contrasted

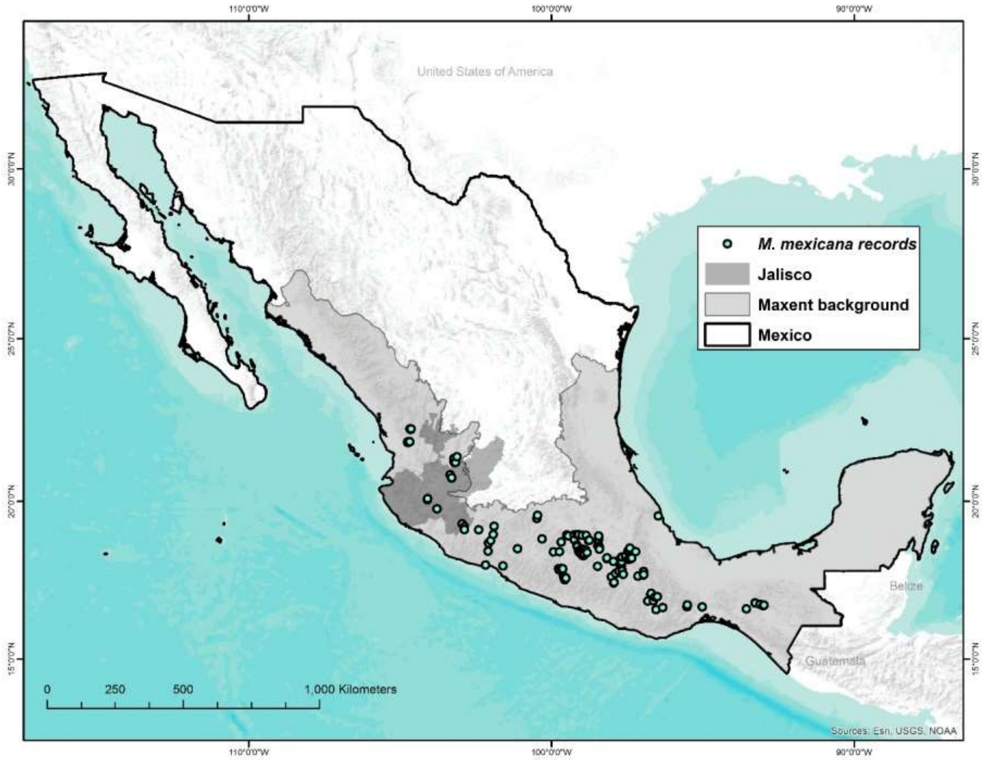

Figure 5.2. Extent of the background polygon and presence records for the Maxent calibration

with independent data (Peterson et al. 2011). Maxent regulates this balance in two ways: by means of the 'feature classes' (FC) to be allowed during the elaboration of the model and by means of the multiplier value of the 'regularization multiplier' (RM), FC's are mathematical transformations of the values of each one of the variables and they try to address the complex responses of the species to the climatic variables. The transformations that Maxent carries out are termed Quadratic (Q), Product (P), Threshold (T), Hinge (H) and Linear (L) and are explained with more detail in the annex (watch table A5.1).

On the other hand, RM regulates the fitting of the generated predictions to the input data. The R package (R Core Team, 2015) ENMeval (Muscarella et al. 2014) was used in this study to determine Maxent's configuration in terms of the aforementioned elements. The aim of using this tool is to facilitate the process to configure the parameters of the algorithm to better adjust them to the input data (species occurrence records and environmental variables) and to the work's objectives. ENMeval automates Maxent runs in a range of FC and RM's configurations defined by the user and evaluates them using six different evaluation metrics, including the Akaike Information Criteria corrected for small samples (AICc). Although there is no consensus on an ideal evaluation metric, it has been commonly used by several authors to compare several models with each other (Warren and Seifert, 2011; Fitzpatrick et al. 2013), since, in comparison with other evaluation metrics, it consistently allows to find those models that better balance the complexity of parameters and the goodness of fit to the input data. Test models were run with 0.5 to 4 RM in 0.5 intervals and with the following combinations of FC: L, LQ, H, LQH, LQHP, LQHPT. The obtained results from the multiple models run with the mentioned combinations of FC and RM show that the configuration of RM value of 3.5 and all the available was the one with the lowest values of delta AICc (watch figure A5.2).

Modeling

The models were elaborated by using the Maxent Java interface version 3.4.1 with the configuration that was determined to be optimal (RM of 3.5 and all FCs allowed). The models were run using four cross-validation runs. Cross-validation allows all records to be used at least once to train models and a second one to evaluate them. The chosen type of output that Maxent provides is the most recent one, called 'cloglog'. This new type of output allows interpreting results directly as probability of occurrence (Phillips et al. 2017). The models were fitted using the defined background polygon and then projected to the whole extent of the Mexican territory.

Reclassification of continuous probability predictions in four levels of climatic suitability

In order to more clearly delineate the regions of climate adaptation by establishing discrete zones, although without losing as much information as in the case of binary reclassification, the original continuous prediction was reclassified in four levels of probability: Regions with 0 to 0.25 values were considered as marginal probability, 0.26 to 0.5 as low probability, 0.51 to 0.75 as average probability, and above 0.75 as high probability.

The 0.25 value was a reference due to the following reasons: the common way of transforming continuous probability results to binary probability, that is, to predict the presence or absence as of the original continuous values, is through the use of threshold values. Among the contained results in the Maxent output are threshold values determined under various criteria so that the user can choose amongst some of them. One of the laxest threshold criteria is the so-called 'minimum value of training presence', which corresponds to the minimum given value of probability in some pixel with presence record. Another threshold value, fairly strict, is the one called '10 percentile presences of training', and corresponds to the minimum probability value in 90% of the records with the highest probability values, i.e., the probability values are discarded from 10 of records with lower probability and the value which is taken as threshold is the one at the upper limit of that 10%. In the first threshold criterion, Maxent delivered a 0.067 value, in the second criterion: 0.361. Given the above it was decided that the 0.25 threshold value was convenient since it would allow reclassifying the continuous probabilities (with continuous values from 0 to 1) in four categories of equal amplitude, at the same time its value stands between a lax criterion and a moderately strict one.

The final models were projected to the Universal Transverse Mercator coordinates system with Datum WGS 1984 in order to obtain km^2 areas.

5.3. Results

The Maxent generated model had an area under the receiver operative curve (AUC-ROC) value of 0.89 (Fig. 5.3) and the variables that mostly helped to explain the distribution of *M. mexicana* were the annual precipitation and the precipitation of the driest month. On the response curves of the most relevant variables, it can be observed that *M. mexicana* has affinity for conditions relatively arid: the highest presence probability occurs in 300 mm approximately values of annual precipitation. As for the precipitation of the driest month, the maximum probability occurs around 5 mm values. This would correspond with the drier areas of warm-dry forests. Figure 5.4 shows the response curves of the referred variables for the final models (means of the 4 runs of cross-validation).

Figure 5.5 shows the regions of marginal, low, medium and high probability of occurrence of *M. mexicana* for the whole Mexican territory and table 2 shows the area occupied by the probability categories for the Mexican territory. Most of the areas with medium (0.51 - 0.75) to high (>0.75) occurrence probability (which altogether correspond to 10,41% of the Mexican territory) are coincident with the distribution of warm-dry tropical forests in Mexico, except for its coastline. Some regions with non-marginal probability of occurrence are also found in the ecotones of the warm-dry tropical forest with temperate mountains ranges.

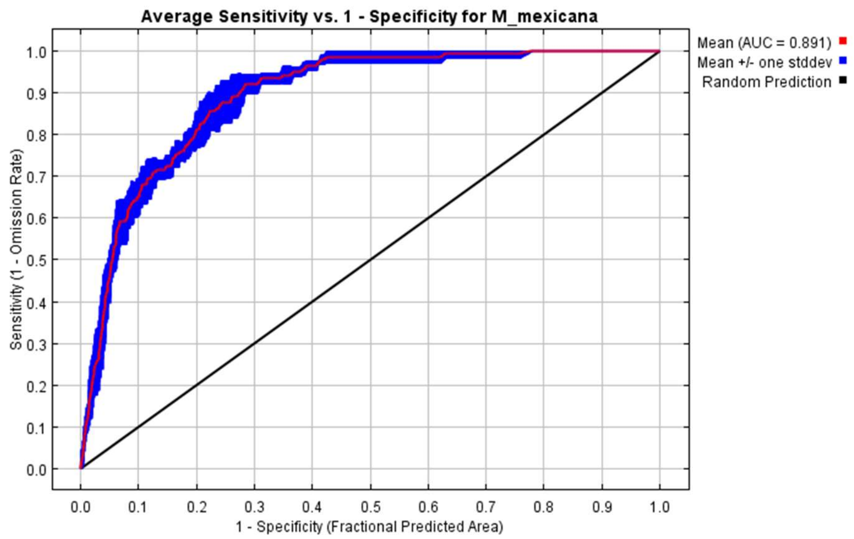

Figure 5.3. Plot of the AUC-ROC for the averaged four cross-validation Maxent runs

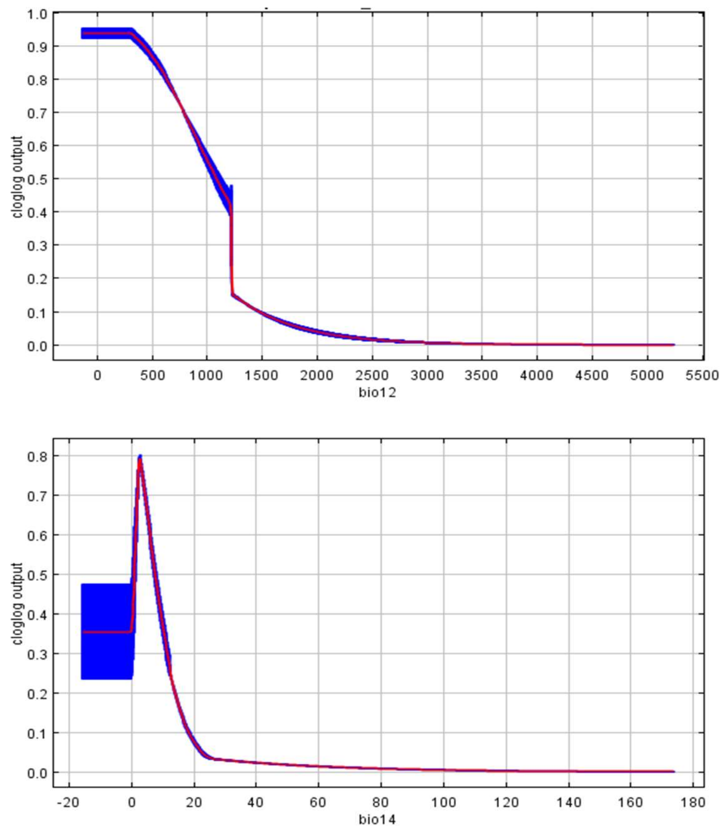

Figure 5.4. Response curves of annual precipitacion (above) and precipitation of the driest ninth (below)

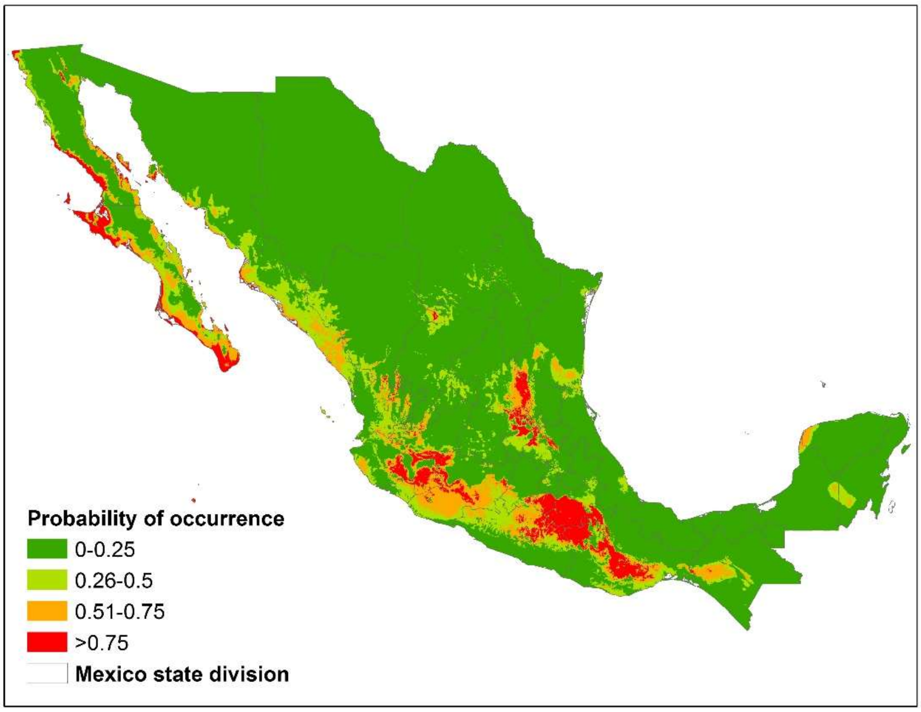

Figure 5.5. Levels of distribution probability of *Malpighia mexicana* Juss for the model projected to the whole Mexican territory

The physiographic region with the most extensive areas of medium and high (0.51 - 0.75 and > 0.75 respectively) probability of occurrence is the Balsas River basin, in southern Mexico. The high probability area extends towards the south to the region of the central valleys of Oaxaca and towards the west to the southern region of the State of Jalisco where areas with warm-dry tropical forests converge with oaks and coniferous forests in the Neovolcanic Transverse Axis. The Balsas River basin, the central valleys of Oaxaca and Western Mexico support high probability areas intercalated with patches of medium probability such that when taken as a unit they would represent a single continuous, encompassing almost the entire South and West of Mexico (excluding its coastline), which can be assumed as the estimated distribution area for *M. mexicana*. Figure 5.6 shows a closer view of the larger continuous areas of higher occurrence probability.

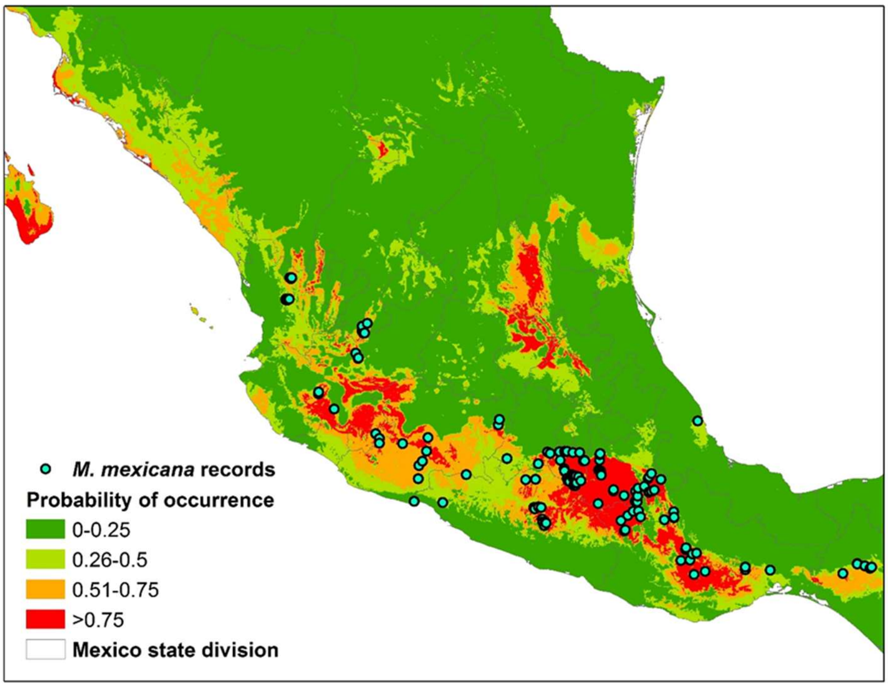

Figure 5.6. Close-up to the largest continuous areas of medium to high occurrence probability of *Malpighia mexicana* Juss in southern Mexico along the Balsas River basin.

Another region with an important extension of medium and high probability areas occurs towards northeastern Mexico, on the center-east of the State of San Luis Potosí, northeast of Guanajuato, the center of Queretaro and some patches that extend to the central zone of the State of Hidalgo. On those areas, temperate forests and warm-dry tropical forests prevail. Another zone with high occurrence probability of *M. mexicana* is the west coast and southern end of the Baja California peninsula where arid vegetation and warm-dry tropical forest, respectively, are the dominant vegetation types, although there are no reference specimens for these areas. Other regions with medium and high occurrence probability but of reduced extension are located in southern Mexico the Central Depression of Chiapas, which is occupied by warm-dry tropical forests; towards western Mexico in the area of canyons shared between the north of the State of Jalisco and the south of the State of Zacatecas; and right in the southernmost portion of the Sierra Madre Occidental at its confluence with the Neovolcanic Transverse Axis, which is also occupied by warm-dry tropical forests.

Considering the whole extension of the Mexican territory, it is the areas of marginal and low probability of occurrence of *M. Mexicana* that occupy the largest extension, accounting for approximately 90 % of the country.

It is worth emphasizing that we identify a marked tendency for the zones of greater probability to coincide with the warm-dry tropical forests of Mexico. Of the total area of warm-dry tropical forests ecoregion (318 313,54 km^2) (INEGI et al. 2008), 166 602,16 km^2 (52,64 %) correspond to areas with more than 0.25 occurrence probability of *M. mexicana* presence. The map that shows the distribution of the occurrence probability categories and the distribution of the warm-dry tropical forests is in the Annex (see Figure A5.3). Table 5.2 shows the areas of each category of occurrence probability for the nationwide analysis.

Table 5.2. Surface's categories of probability in Nationwide and Barranca del Río Santiago

Category	Occurrence probability	Nationwide surface's		BRS	
		Area (km$^{2)}$	Percentage	Area (km$^{2)}$	Percentage
1. Marginal	0 - 0.25	1 570 517,81	79,95	146,12	20,20
2. Low	0.26 - 0.5	189 365,75	9,64	337,38	46,64
3. Medium	0.51 - 0.75	122 184,13	6,22	207,18	28,64
4. High	>0.75	82 307,31	4,19	32,70	4,52

Regarding the focal area of study in the BRS, the largest proportion of its surface (79,8%) corresponds to areas with over 0.25 probability. Figure 5.7 and table 5.2 show that 46,6% of the surface presents low probability (0.26 - 0.5), 28,68% presents medium probability (0.51 - 0.75), and only 4,52% of the study area corresponds to extensions of high probability (> 0.75). Areas of higher probability are located in the eastern and northern sections, limiting with the Sierra Madre Occidental. These are difficult access zones in which the presence of the species could not be verified. Table 5.2. shows surface to each category of probability for the Canyon of the Río Santiago (BRS) analysis.

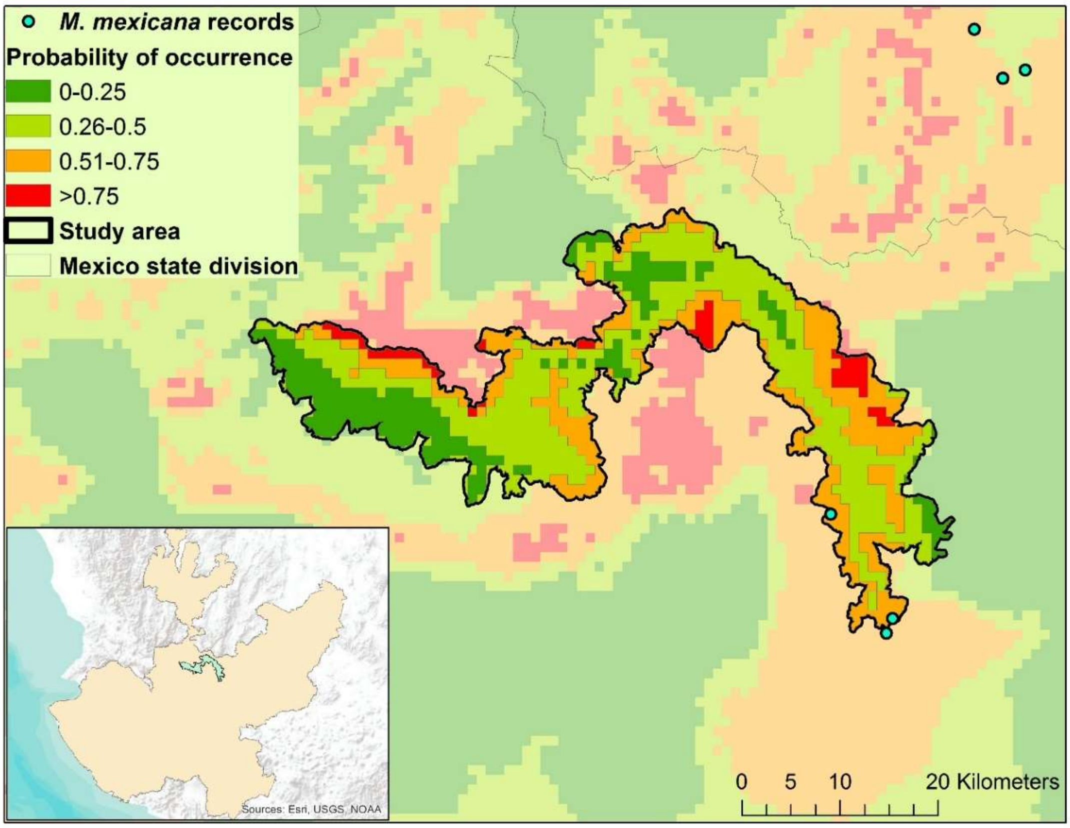

Figure 5.7. Probability levels of distribution of *Malpighia mexicana* Juss in Barranca del Río Santiago

5.4. Discussion

We accept the above-stated hypothesis in the sense that the potential distribution in Mexico of *Malpighia mexicana* is determined by the distribution of warm-dry forests, according to the map of terrestrial ecoregions of INEGI et al. (2008). In Mexico, the study and conservation of phytogenetic resources for food has focused on crops with high economic value, leaving aside the marginalized crops and wild species that supply rural populations with important sources of food. These resources are also being forgotten by the peasants whose diet is now disrupted by the current models of consumption. *Malpighia mexicana* is renowned for its edible fruits (Chávez et al. 2009; Martinez-De La Cruz, et al. 2015) which are sold seasonally in local markets (Díaz et al. 2011) and which have been characterized through bromatological analyses (Chávez et al. 2009; Maldonado-Peralta, 2016a). Moreover, the viability of its seeds (Maldonado-Peralta et al. 2016b; 2018) and its assisted reproduction (Maldonado-Peralta et al. 2017a; 2017b) have been studied, its leaf anatomy (Bárcenas-López et al. 2019) as well as cases of hyperparasitism occurring in its fruits (Jarquin, 2007). These seem as few if we compare them with the number of studies published on industrially produced species of Malpighia (Acerola). Since its production as an industrial crop began in the 1980s different works related to its processing, vitamin C content and germplasm banks creation, which have allowed the development of varieties adapted to the environmental conditions of production areas and market requirements (Musser et al. 2004; Carpentieri-Pipolo, et al. 2002).

Compared to acerola species, *M. mexicana* has a better taste, size, and fruits quality to be eaten fresh. These characteristics give the species a high alimentary and commercial potential, but more research on its nutritious properties, domestication and extensive cultivation (Maldonado-Peralta et al. 2016a). It is important to mention that *M. yucatanea*, one of the 12 endemic species of *Malpighia* in Mexico is considered a rare species and possibly extinct in the wild (Avilés-Peraza, 2016).

Recently, the public availability of botanical and climatic data in addition to the development of modeling algorithms that correlate species occurrence records with environmental coverages have fostered the development and application of ecological niche models and species distribution models (Soberon et al. 2017) which has provided an approach to increase the knowledge on species biogeography regarding its current, potential and future distribution when considering the effects of climate change.

However, there are no known specific studies of its distribution or niche analysis of *M. mexicana*. This study contributes to the knowledge of its potential distribution, whit the largest continuous areas of high probability of occurrence of the species coinciding notoriously with the distribution of the drier zones of the warm-dry tropical forests of Mexico.

Apart from the ecotones with temperate mountain ranges, other areas of high probability are found in arid ecoregions of the country such as Deserts of North America and Southern Semiarid Elevations (*sensu* INEGI et al. 2008), which were not included in the background used as calibration area, so that, despite the affinity shown by *M. mexicana* towards areas with low rainfall (300-500 mm), it is necessary to cautiously interpret the predictions in these regions.

We should bear in mind that the use of records of presence come from heterogeneous sampling efforts, so it is possible that they are environmentally biased. Systematic botanical surveys in these regions could confirm or dismiss the presence of *M. mexicana*.

Since this species is only grown as a backyard crop, or with ornamental and medicinal purposes, it is necessary to carry out the required studies to determine the potential that it represents as a new cultivar or to improve acerola's existing ones, developed from species related to *M. mexicana*.

This is highly significant if we take into account that the estimated value of acerola in the world market by the end of the year 2026 is of US $ 17,500 billion; this only considering their fruits' vitamin C content (Future Market Insights, 2016), but could be increased through the development of functional foods, extraction, and processing of drugs, and ornamental applications among others. The role that this plant could play in its communities of origin is not minor, it has potential as food, traditional medicine, in the development of agroecological projects or in the restoration of ecosystems and environmental services. Therefore, we do not doubt that the management of wild populations and its cultivation in the warm-dry tropical forests of Mexico can be a viable option for economic development, especially considering its apparently low water requirements.

Although there were 21 sites of occurrence in the BRS they were not used to fit the models, excepting three records located in the eastern end of the BRS, very close to the city of Guadalajara, in areas of medium probability (0.51 - 0.75). This means that, according to the used procedure (Varela et al. 2014), the rest of the discarded points of the BRS would have similar climatic conditions in line with the climatic variables considered in the model.

Most of the sites where the presence of the species was confirmed are located in areas with medium and low probability, so one might expect that *M. mexicana* is present in 79,8% of the BRS's area. However, based on the confirmed occurrences in the western part of the study area, which has a marginal probability of occurrence according to the model, we could suggest that the totality of the BRS is suitable for the development of the species.

According to the response curves of the most significative variables (annual precipitation and precipitation of the driest month), it seems that the species has a preference for arid zones, hence the model classified the wetter zones of the western portion of the BRS as regions of marginal probability. In this area, the southern slope of the ravine is more humid than the northern part, according to the perception of the informants and our own observations.

The analysis of the foliar structure of *M. mexicana* reveals this species as a mesomorphic species with some xeromorphic traits that allow adaptation to variation in temperature and precipitation. At the same time, the stem has tracheas with morphological traits that allow them to adapt to dry environments (Bárcenas-Lopez, 2018; Barcenas-López et al. 2019), which may be an advantage to tolerate climatic changes. The estimation of its potential distribution and description of response curves herein presented agree with these works, as they show that the species tends to prefer the dryer areas in the warm-dry tropical forests and in the rest of ecosystems it inhabits.

This work represents a first approximation to the potential distribution of *M. Mexicana*. We consider this species worth of being promoted in Mexico due to its economic potential (because of its vitamin C content) and particularly in the BRS as, in addition to potential economic benefits, it provides other environmental services such as water and soil conservation, biodiversity fostering, preservation of aesthetic and cultural values and the provision of traditional alimentary resource. This potential can only be realized if communities in suitable areas for their cultivation work together to develop agricultural and commercial schemes.

However, and as mentioned above, most of the observed or collected individuals had serious phytosanitary problems, a situation which did not exist 40 years ago, and that would need to be evaluated in the future if this condition is related to changes at a climatic and ecological level.

5.5. Conclusions

Besides being a first approximation to the distribution of M. *mexicana* in Mexico, it also shows its presence in the BRS, where is popularly known as 'manzanita'. In Mexico as well as in the BRS the typical association of *M. mexicana* with warm-dry tropical forests was verified, which provides support to its potential use as a viable crop for regions with this ecosystem. Within warm-dry tropical forests, *M. mexicana* has a higher affinity for the drier areas, so it can be assumed that it could persist in drier environments than in those in which is currently found in the event of climate change. Understanding the distribution potential of *M. mexicana* is of great benefit in view of the need to delve into the knowledge of the species, in pursuit of generating optimal cultivars for the ascorbic acid industry and for the consumption of fresh and processed fruits, as well as in the elaboration of functional foods. Due to its presence and consumption background by the inhabitants of the BRS, and the nutritional potential it represents, the revaluation of the species is necessary along with research and characterization of its populations to its reincorporation in the diet of the dwellers; we should also consider its planting in ecological restoration programs and in the generation of agroecological practices for commercial cultivation purposes.

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Annex 5

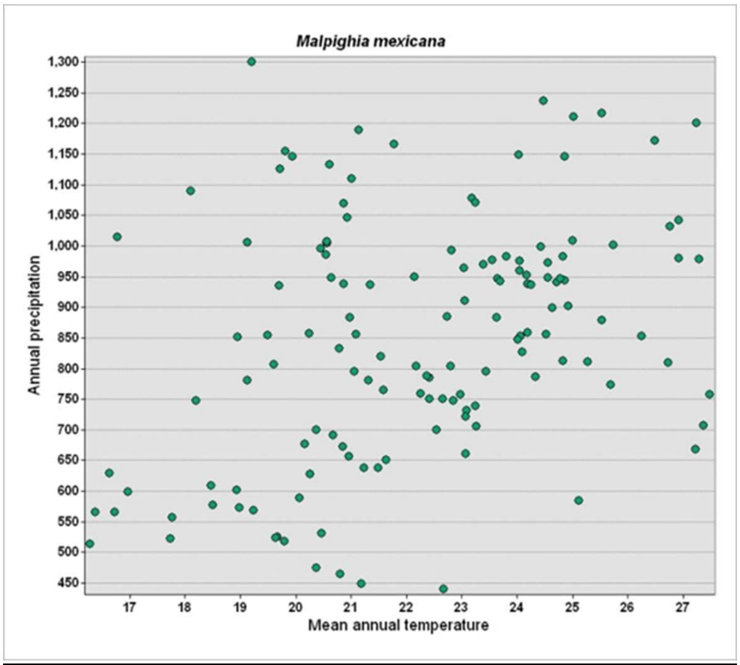

Figure A5.1. Dispersion of *M. mexicana* debugged records on the variables of mean annual temperature and annual precipitation.

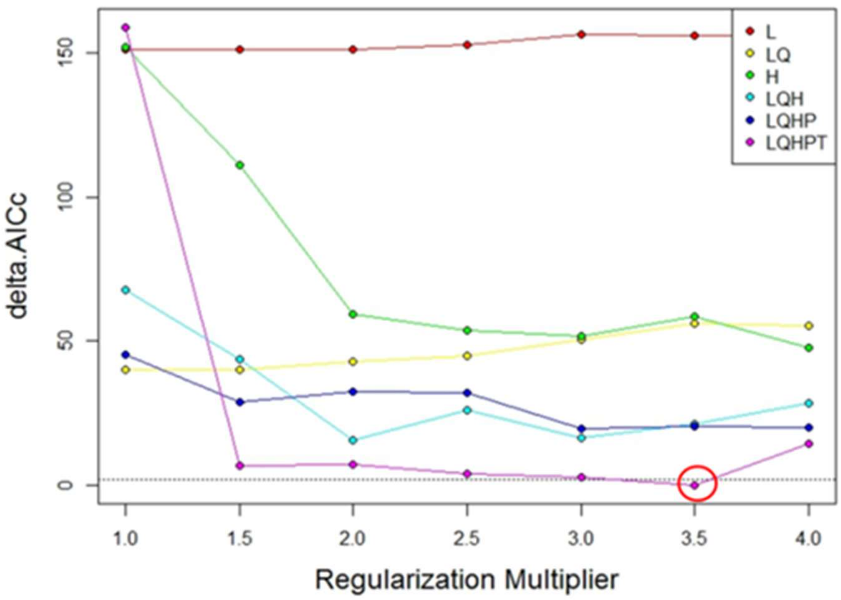

Figure A5.2. Results of the multiple evaluation runs generated by ENMeval. The red circle indicates the configuration which obtained minimum AICc

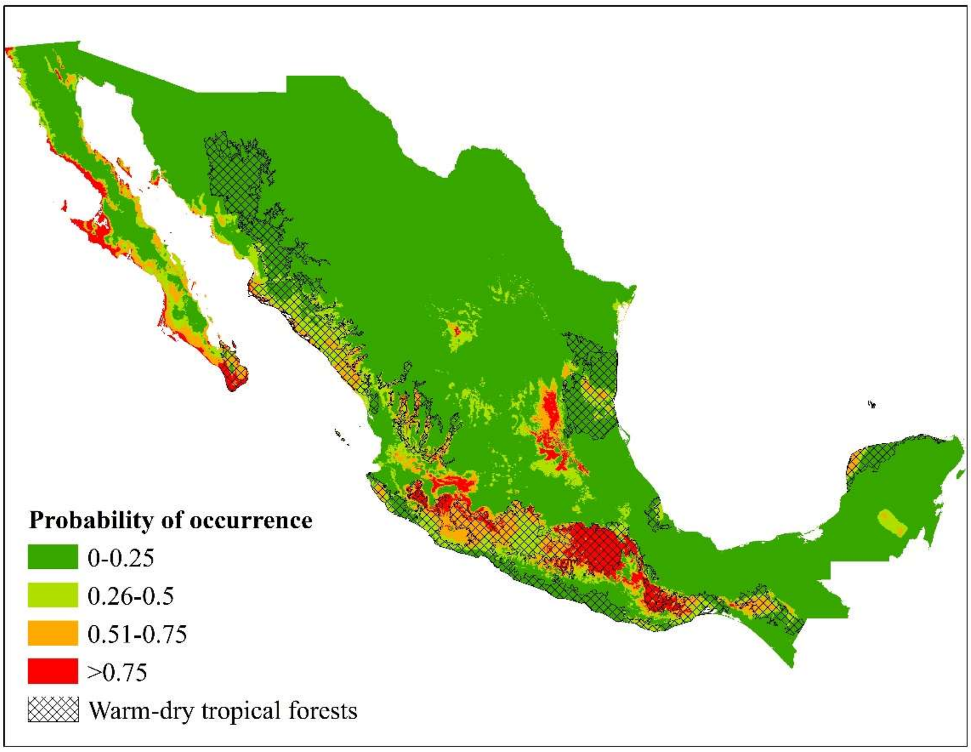

Figure A5.3. Distribution of the warm-dry tropical forests of Mexico over the categories of occurrence probability of *Malpighia Mexicana*.

Table A5.1. Series of mathematical transformations of the values of the environmental variables to account for the species' complex ecological responses to the environment that Maxent acquires.

Quadratic (Q)	The values of each variable are squared. Ecologically it approaches the tolerance of the species to the versatility of variables.
Product (P)	Multiply each of the values of the variables by each of the values of all the others. It addresses the interaction between the variables.
Threshold (T)	It allows different responses of the species to the variables when certain threshold values are exceeded. Ecologically it addresses situations in which the species respond abruptly to limits that define thresholds, such as, the freezing temperature.
Hinge (H)	It allows combining different types of responses to variables, that is, the response curve can have linear response sections, other sections responding to the threshold values, quadratic or other values. Ecologically, it addresses the fact that the response of the species to the variables may not be equal in the inhabited diversity of sites.
Linear (L)	It is not really a FC, since it uses the values of the untransformed variable (Elith *et al*., 2011)

Chapter 6.

Agroclimatic characterization of *Agave tequilana* Weber cultivation in the Barranca del Río Santiago

Abstract

Agave plants have played a key role in the cultures of Mexico, not only because they contain 75 percent of the total registered species in their territory, but because they have been used since ancient times to cover different needs of the population, significantly highlights the nutritional use of its sap (such as mead and pulque), but even more the distillation of its ferments to make the representative beverage of Mexico, tequila. The industrial production of tequila has its origin in the ancestral knowledge of the magueyes and the elaboration of the drink, which was initially produced from different species of the same genus, but over time Agave tequilana Weber displaced the others species for presenting better characteristics for their cultivation and for the use of their honey. Although the origin of the species is located in the state of Jalisco, the distribution of the cultivar has been determined (for use in the production of tequila) by the designation of origin of the drink, so it is currently distributed in different Mexico regions. The climatic requirements reported for the species, indicate that the determining factor for the optimal development of the plant and the accumulation of sugars for the production of tequila, is the temperature; even though the Santiago River Canyon does not present frosts that limit the establishment of the crop, the high temperatures that occur during the summer reduce the daily assimilation of CO2, compared to moderate temperatures in temperate zones which are favorable for accumulation of reducing sugars, which are those that give quality to the raw material; this situation is not seen as a limitation by the producers for the establishment of agave plantations inside the ravine. The main problem that exists for the establishment of plantations and any other agricultural activity, is the change of the use of land in the steep lands in which more than 50% of the agave is sown, which causes the loss of soil and the contamination with agrochemicals to the ecosystem of the ravine, which is promoted by the declaration of the agave landscape as a cultural heritage of humanity.

Keywords: *Agave tequilana* Weber, Barranca del Río Santiago, Agroecology, Tequila.

6.1. Introduction

The possibility to obtain food, drink, protection, shelter, tools, fiber and a wide variety of natural products from the agave plant was an important contribution to the development of great civilizations in the center and south of Mexico. Among most widespread uses of agave there is the preparation of two types of drink: one is sap, extracted from the stem of the plant and consumed directly as *aguamiel*; the other is *pulque*, a fermented drink. There is another type: *licor de agave*[17] (agave liqueur), made from the fermentation and distillation of the juice extracted from the stems or the cooked heads (Gentry, 1982). Even though different pieces of the agave plant have been used as food, the ability to accumulate sugar in their stems and at the base of their leaves was determinant to provide the first Mesoamerican settlers with water and food in periods of scarcity.

According to Gutiérrez (2003), there is little information about the beginnings of tequila and its agroindustry to be contrasted with first-hand sources (archival documents); consequently in most of the written texts about its history there are some «facts» that lack sustenance. The lack of original sources is attributed to the prohibition imposed during the Colony by the Spanish authorities to prevent it from competing with Spanish wines and spirits. The «Account of the day» (*Relación de la jornada*) by Don Francisco Sandoval Acazitli,[18] who accompanied Visorey Don Antonio de Mendoza in the conquest and pacification of the Chichimeca indians in Xuchipila in 1541, is a historic document that well reflects the importance of *magueyes/mescales* (agave plant) to the natives of the region of *Nueva Galicia*,[19] and of how their heads or *piñas* were cooked in barbecue (Jiménez, 2008).

Meanwhile, in his «Description of the New Galicia» (*Descripción de la Nueva Galicia*) Domingo Lázaro de Arregui refers in 1621 to mescal as one of the plants of the region used to prepare a drink from the roast of the stems, which were squeezed to extract a must that

[17] Depending on the used type of agave, it receives the name of tequila, mezcal or bacanora. «Mescal» is also the name assigned to the agave plants.
[18] *Cacique* (cheftain) and *Señor natural* (Natural Lord) who departed from the town of Tlalmanalco, in the province of Chalco.
[19] *Nueva Galicia* (New Galicia) was the assigned name —in Colonial times, to the former Viceroyalty territory witch included the current states of Jalisco, Colima, Aguascalientes and neighboring parts of the states of Nayarit, Durango, Zacatecas, Guanajuato and Michoacán. Region selected by Rogers McVahugh (1909-2009) to carry out his floristic study.

was later fermented and distilled: a drink of the natives «lighter than water and stronger than spirits»; it was prohibited by the Spaniards until the year of 1637, when the establishment of an *Estanco* (State monopoly) in the city of Guadalajara was authorized for its sale and consumption. The analysis of the «Account of the chieftain of Tlalmanalco» (*Relación del cacique de Tlalmanalco*) and of the claims of Lázaro de Arregui and other documentary collections, as well as the oldest physical evidences, shows the native's knowledge of the plant *mescal* and its cultivation intended to produce spirits; we can infer that the plant was indeed cultivated. Documentary evidence shows that the origin of mescals planting and marketing was already common in 1726 in Amatitan; in fact this town was recognized in 1769 as the leading manufacturer of *vino mezcal* (mezcal wine) (Jimenez, 2008). Van Youg (cited by Gutierrez, 2003) gives an account of how José Prudencio Cuervo —established in the region of Tequila, contributed to the expansion of this agroindustry selling mescal plants on credit to other landowners; between 1787 and 1812 he managed to position itself as the area's most important entrepreneur in the distilling industry getting nearly an 800 % increase in his mescal farmlands. In his «Study on the maguey called mescal in the State of Jalisco» (*Estudio sobre el maguey llamado mezcal en el estado de Jalisco*), Perez (1987) mentioned that several kinds of agave plants (more than nine different types) were grown to produce mescal wine; which was also mentioned in the first *Norma Oficial de Calidad para Tequila* (Official Quality Standard for Tequila) in 1949; this situation changed in 1964 to designate that tequila can only be made with plants of *Agave tequilana* Weber var. *Azul*,[20] cultivated in the State of Jalisco (*Norma Oficial de Calidad para Tequila* 1949, 1964) . Subsequent amendments allow nowadays the tequila production of feedstock in 181 municipalities of five states (Consejo Regulador del Tequila, 2017).

More than 200 species are included in the genus *Agave*; three-fourths are found in Mexico, so we can consider this country as its center of origin. Of the cited number, a minimum of 74 species and 28 infraspecific *taxa* have been documented as human food, raw material to produce fermented and distilled drinks, as well as source of fiber and fodder (Colunga-GarcíaMarín, et al. 2007). Knowledge of the genus *Agave* in Jalisco is based on

[20] This cultivar was selected by *mescaleros* (agave farmers) since the 19th century because it was precocious in achieving a greater sugars concentration after cooking, and for producing a large number of shoots (Blanco, 1906).

the work of Gentry, published in 1982. Even though to date numerous botanical explorations have abounded in the knowledge of these plants, they are considered to be scarce ecological quantitative analyses (Vázquez-García, et al. 2007a). In the Table 6.1 presents the reported information in literature about the richness of agave species to different regions of the western part of Mexico.

Table 6.1. Number of *Agave species* reported in literature in the western part of Mexico

Author, Year	Region	Number of *Agave species*
Gentry, 1982	West of Mexico / Jalisco	31/16
McVahugh, 1989	New Galicia / Jalisco	17 /13
Cházaro, et al. 2004	North of Jalisco and adjacent areas	20
Hernández, 2007	Jalisco	23
Vázquez-García, et al. 2007a	Jalisco	28
Vázquez-García, et al. 2007b	West of Mexico	37

Own elaboration

At the present, tequila has reached high levels of acceptance in international trade. 788.9 thousand tons of agave was used in 2015 in Mexico for the preparation of 228.5 million liters of tequila, of which 80% was sold abroad. In 2016 the sales amount reached an estimated value of 1 203 million dollars, and its export has been increasing during the last eight years (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, 2016; 2017).

Like other exploited crops on an industrial scale and linked to the international market, cultivation of *Agave tequilana* is marked by the caused deterioration to agroecosystems where it is sown as monoculture and there is a high amount of agricultural inputs usage in order to obtain largest yields. Among other vicissitudes, this entails a loss of genetic diversity, crop vulnerability to pests and diseases, intensive use of agrochemicals, soil erosion, pauperization of agave's day laborers and farmers, and environmental pollution. In addition to being the source of tequila —emblem of national identity along with the *mariachi* and the *charro*, the plant of *A. tequilana* has also become known worldwide as a result of UNESCO's Agave Landscape Ancient Industrial Facilities of Tequila declaration to recognize it as cultural heritage of humanity in the category of Cultural Landscape (UNESCO, 2006).

The niche and distribution models of wild species allow determining their presence on a large scale, since they synthesize the relations between the species and the environmental variables that would be difficult to interpret or even to appreciate in another way (Mateo, et al. 2011). However, when it comes to cultivated species of commercial interest, not only does it matter that the species can thrive in a region or not, but that it finds the favorable conditions for it to express its productive potential to the maximum. Spatial and time characterization of the climatological and edaphic information available for a particular region allows us to understand the type of management that farmers give to their crops and permits the assessment of their restrictions and possible effects on production (Alcaraz, 2011; Collazo, et al. 2011). The use of these data is even more relevant if we consider that seldom is it possible to take advantage of more than 10% of the information contained in the basic cartography (Alcaraz, 2011).

The general objective of the work is to study the current and potential distribution of *Agave Tequilana* Weber in Santiago River Canyon based on the following specific objectives: (1) Inventory the land where it is grown, (2) generate an environmental database of the ravine and (3) from the use of a geographic information system to carry out the agroclimatic characterization of the land where it is cultivated and estimate its cultivation potential inside the ravine.

6.2. Material and methods

6.2.1. Study area

At this point I refer to the chapter one of this thesis, where the stretch of Santiago River Canyon (Barranca del Río Santiago) chosen as the study area (BRS) is described. The western side of this area comprises the river crossing trough the municipalities of Amatitan and Tequila, where different types of agave were used to produce mescal wine. It was there were the process of selection and domestication of *Agave tequilana* started, in part due to the fact that the area has ideal field characteristics both for its land management as well as to carry out the industrial process (Valenzuela-Zapata 1997; 2003; Pérez, 1887).

Initially, mescal was grown in more or less steep slopes, rarely in flat lands —as it is done now. Its cultivation in the valleys facilitates farming methods and also promotes the scenic attraction of the cultivated fields with agave, which gave rise to the aforementioned 2006 agave landscape's declaration.[21] BRS includes 7 745,23 ha in its core area and 10 382,2 ha in the buffer zone, as shown in Figure 6.1. The remaining BRS has been used for mescal cultures —where the topography allows it, at different times, particularly when there is an excess demand for tequila's feedstock.

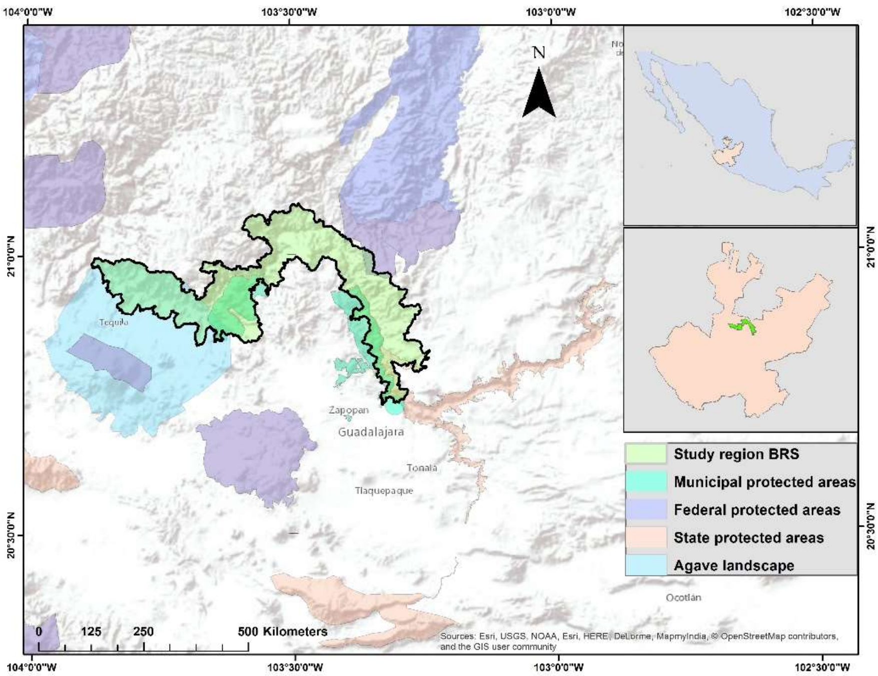

Figure 6.1. Location of Barranca del Río Santiago (Santiago River Canyon) study area and adjoining protected natural areas by jurisdiction.

[21] The declaration *Paisaje agavero y las antiguas instalaciones de Tequila* (Agave Landscape Ancient Industrial Facilities of Tequila) considers two core zones, one with 34 658 ha corresponding to the agave plantations, and another with 360 ha related to the archaeological area of *Guachimontones*, which is surrounded by a buffer area of 51 621 ha.

6.2.2. Distribution of *A. tequilana*

The existing botanical records of *A. tequilana* correspond mainly to cultivated plants for tequila production within the considered territory of the Denomination of Origin for Tequila (DOT), although it is also planted for other industrial or ornamental purposes inside and outside the covered area by the DOT.

Denomination of Origin for Tequila (DOT) only allows the use of *A. tequilana* plants cultivated in the indicated and endorsed territory by the Official Mexican Norm (Norma Oficial Mexicana), emanated from commercial interests more than a natural, historical or cultural criteria. After several modifications, the DOT's territory is now integrated by the total municipalities in the State of Jalisco (125) and some municipalities of the states of Michoacan (30), Guanajuato (7), Nayarit (8) and Tamaulipas (11), with a total of 181 municipalities and an approximate area of 10 182 694 ha.[22] In 2013 the DOT's planted surface was of 100 154 ha and the planted area outside the DOT was of 5280 ha. Although the DOT's area is very broad, most of the *A. tequilana* cultivation and tequila production have always been concentrated in the State of Jalisco, specifically in two zones: the most cultivated and oldest region is in the valleys of Amatitán and Tequila (in the central part of the state, west of Guadalajara) whose background are traced to the beginning of the XVII century; the other zone is the region of «Los Altos» (Highlands) of Jalisco (Valley of Arandas) whose agro-industrial activity began at the end of the 19th century (Luna, 1991).

6.2.3. Distribution of *Agave tequilana* in BRS

Exploratory tours were conducted (2013-2015) in the study area and the GBIF.org database was consulted (2018) in order to locate the species presence.

The location of agave cultivated lands in BRS was elaborated from: (1) a database of geo-referenced plots provided by the regulatory Council of the Tequila (Consejo Regulador del Tequila - CRT), which contains only a fragment of the cultivated lands, since not all agave producers register their plantations to the CRT; (2) various field trips to geo-reference the agave cultivated plots, which were later digitized to know their location and surface, drawn from the located points in the field and the use of Google Earth high resolution satellite

[22] Own estimate elaborated from the geographic information of the State of Jalisco and other states municipalities.

images, the ArcMap V10.3 program, and the Universal Transverse Mercator (UTM) coordinate system for zone 13 of the northern hemisphere.

6.2.4. Selection and preparation of the agro-ecological requirements for *A. tequilana* layers.

Unlike cosmopolite crops, there are few references in literature regarding agro-ecological requirements of *A. tequilana*; however there is substantive information generated from areas where a traditional growing takes place (Ruiz-Corral, et al. 2002; 2013) and from experiments conducted under controlled conditions in laboratory, greenhouse, or bioclimatic chambers (Nobel, et al. 1998, Pimienta-Barrios, et al. 2006).

Coinciding with some of the established criteria in similar works (De Leon, et al. 1991; Ruiz-Corral, 2007; Tinoco, et al. 2010; Collazo, et al. 2011), we selected fifteen environmental variables as predictors of the agro-ecological conditions in which the cultivar develops within BRS: eleven climatic, two topographical and two edaphic (Table 6.2).

The existing layers of climatic cartography for the Mexican mainland were used, with a reference period from 1961 to 2010, in raster format and geographic projection coordinates by using the 1984 World Geodetic System Datum (WGS84), with a resolution of 30 arch seconds (949 m) generated from the work of Medina-García, et al. (2016). The layers for minimum temperature, average temperature, maximum temperature, precipitation, evapotranspiration and photoperiod for each month of the year were changed from RST format to TIFF, with a 151 meters resolution so that the edges of the focal study area could be preserved in a truthful manner at the time of conducting the later extractions from the study area. Average annual temperature layers and photoperiods (arithmetic media of the values of the twelve months of the year) were generated, as well as precipitation and annual-monthly accumulated evapo-transpiration layers. The annual daytime temperature average and its corresponding night temperature were calculated from the values of each month of the year according to the suggested procedure by Tinoco, et al. (2010) and Collazo, et al. (2011). The temperature annual oscillation was calculated by means of the suggested formula by WorldClim for generating the BIO_7 variable (Fick & Hijmans, 2017).

Table 6.2. Variables considered for the agro-ecological characterization of the Santiago River Canyon and the cultivation of *Agave tequilana* Weber

Variable (Unit of measurement)	*Origin*	*Product*
Climate type (Unit)	García, 1998	Map (Fig. 6.2-A)
Annual minimum average temperature (°C)	Medina, et al. 2016	Map (Fig. 6.2-B)
Annual average temperature (°C)	Medina, et al. 2016	Map (Fig. 6.2-C)
Annual high average temperature (°C)	Medina, et al. 2016	Map (Fig. 6.2-D)
Annual daytime average temperature (°C)	Generated	Map (Fig. 6.3-A)
Annual night-time average temperature (°C)	Generated	Map (Fig. 6.3-B)
Annual temperature oscillation (°C)	Generated	Map (Fig. 6.3-C)
Annual cumulative precipitation (°C)	Medina, et al. 2016	Map (Fig. 6.3-D)
Available humidity - humid months (mm)	Generated	Map (Fig. 6.4-A)
Annual cumulative evapo-transpiration (mm)	Medina, et al. 2016	Map (Fig. 6.4-B)
Photoperiod (Number of light hours)	Medina, et al. 2016	------
Altitude (masl)	Generated	------
Slope (° deg)	Generated	Map (Fig. 6.4-C)
Type of soil (Unit)	INEGI, 1982	Map (Fig. 6.4-D)
Soil texture (Unit)	Sánchez, et al. 2018	------

The available humidity in the soil (when the precipitation is larger than the potential evapo-transpiration) was calculated for each month of the year; a layer of the wettest season of the year (June - September) was also generated. Once these variables were generated, we proceeded to extract the corresponding portion of BRS area using the vector layer of BRS as a mask; the layers were reprojected to UTM Z13N system in order to calculate the surface values in metric units. Additionally we used the climates charter in raster format, scale 1:1 000 000, generated by Garcia (1998) available at the National System on Biodiversity Information (Sistema Nacional de Información sobre Biodiversidad - SNIB).

Regarding topographic variables were developed from the digital elevation model by INEGI (2013) with a resolution of 30 m pixel size, from which the coverage of BRS was extracted to produce layers of **altitude** and **slope**, subsequently vectorized. Edaphic variables, the **soil types** were obtained from the pdf format edaphological charts, scale of

1:50 000 (INEGI, 1982), from which the area corresponding to BRS was digitized. The soil **texture** layer was extracted from vectorial information produced by Sanchez, et al. (2018).

Finally, categories were defined for each variable based on its range of values and surfaces were calculated both for the study area as for each of the *A. tequilana* cultivated lands.

6.3. Results

6.3.1. Distribution of *A. tequilana* in BRS

68 records of *A. tequilana* found in the database of Gbif and 55 collections recorded at the National Herbarium Leeds-Herbarium of the Biology Institute of UNAM (MEXU-Herbario Nacional del Instituto de Biología), correspond to collections from botanical gardens or plantations located within the area of denomination of origin for tequila. During the field trips in BRS, isolated individuals of *A. tequilana* were found occasionally, thriving in lands where agave was previously planted; likewise the presence of other species of the genus Agave, mainly *A.* americana*, A. angustifolia*, *A. filifera*, *A. guadalajarana* y *A. vilmoriana* were noted. The cultivation of *A. tequilana* in BRS is partly determined by the accessibility to the plot to carry out the different labors that cultivation requires and to transport mescal heads to factories. A great part of canyon's topography limits the development of production activities.

A total 1 017,58 ha within BRS (72 338 ha) are grown with *A. tequilana*, mainly located in the western portion of the study area, in the municipalities of Tequila and Amatitan. These municipalities are based inside the considered area of origin of the crop and the tequila industry, and are also numbered in the declaration of Agave Landscape. The location of the *A tequilana* cultivated plots in BRS are shown in the following figures.

6.3.2. Agroclimatic characterization

Subhumid hot **climate** Awo predominates in larger part of BRS (72,39%); sub-humid warm (A)C(w_o) and (A)C(w_1) climate types are present in the rest of the canyon's surface: 14,96 % and 12,51 % respectively; and an insignificant 0,14 % portion of temperate climate C(w_o).

(Figure 6.2-A). 97,95% of the 1 017,58 ha of the planted with agave in the study area is under the Aw_o warm climate regime.

The **temperature** varies at the interior of BRS depending on: (1) the depth of the canyon (500 m in general); (2) the area of influence of the riverbed of the river and Santa Rosa dam; (3) the decline of the river (1000 masl at the beginning and 570 masl at its end). The ravine is a frost-free zone; the **minimum temperature** values in most of the ravine (89,2%) oscillate between 12 and 16°C; the lowest range (from 9 to 11°C) occurs in a small part of the surface (10,8%) at the limits with the mountains (Figure 6.2-B). 78% of agave cultivated surface is found in places where the minimum temperature is between 14 and 16°C; 20% of the cultivated area is in the 12 to 13°C range and, only 2% of this surface presents the lowest minimum temperatures reaching 9°C.

Annual average temperature values vary between 17 and 25°C inside the ravine; 86,5% of this temperature is within the range between 21 and 25°C; the remaining surface (13,5%) maintains a range between 17 and 20°C (Figure 6.2-C). The major portion of agave cultivated area (84%) has the highest range of annual average temperature (23-25°C), 14% has a 21-22°C range; and only 2% of the lowest range is found in the canyon with 17-20°C. **Annual high temperature** in BRS vary from 24 to 34°C, although 91% of its surface (Figure 6.2-D) is in the medium range between 27 and 32°C; the lowest extreme values (24°C) and the highest (34°C) occur in 9% of the remaining surface. 89% of agave cultivation in BRS is in the range of high temperature ranging from 30 to 32°C; 5% is in the range of 27 to 29°C and only 6% in the range of 33 to 34°C. The calculated **annual daytime average temperature** for BRS (Figure 6.3-A) is between 27 and 30°C in 57% of its surface, while 40% is in the range of 24-26°C, and the lowest range (21 to 23°C) is found in the remaining 3% of the ravine's surface. Almost the entirety of the agave sown area in BRS (91%) has a range of 27-30°C of annual daytime average temperature; only 9% is in the range of 24-26°C. On the other hand the **annual night average temperature** inside BRS (Figure 6.3-B) shows little variation. 70% of its surface is between 16 and 18°C, and 23% has a higher night temperature of 19 and 20°C; cooler temperatures are between 13 and 15°C and only occur in 7% of the canyon. The largest acreage with agave in the canyon (58%) presented the highest night-time temperature in BRS: 19 and 20°C, followed by 41% of the surface with records between 16 and 18º C. **Annual thermal oscillation** values in BRS (Figure 6.3-C) are between 22 and 27°C. 51% of BRS's surface **annual temperature** ranges between 24 and 25°C; in terms of cultivated surfaces with *A. tequilana*, 68% of it is in the range of 26-27°C annual thermal oscillation, while 31% is in the range of 24-25°C.

Analysis of BRS **accumulated precipitation** raster layer displays (figure 6.3-D) a tendency to less rain in the deep parts of the canyon (71% of its surface area), with values falling between 822 and 900 mm per year; while in the periphery, in areas of higher altitude, higher values are obtained even if they do not exceed the 965 mm of annual precipitation. 70% of agave cultivated farms are in a range of 857 to 900 mm precipitation, 12 % of the surface is below this range (822 to 856 mm), while 18% is above it (901 to 965 mm). **Available humidity** in the study area (Figure 6.4-A) occurs during most of the rainy season (June to September, 122 days), when the precipitation values are higher than those of evapo-transpiration. Available humidity range in 92% of BRS surface is between 160 and 327 mm; in this same range is 98% of the agave cultivated farms in BRS. BRS presents cumulative potential **evapotranspiration** (ETo) values between 1350 and 1849 mm (Figure 6.4-B), well above precipitation values (between 822 and 965 mm). In general terms the highest values (between 1678 and 1849 mm) are observed in the last third downstream of the river bed, which represent 13,4% of the study surface. The largest agave cultivated surface (70%) is between 1445 and 1600 mm of ETo; 12% of it is in the lower range of 1350-1444 mm, while the highest values of ETo ranging from 1601 to 1849 are located in 18% of the cultivated area. The annual average **photoperiod** in BRS is 12 hours, with fluctuations lesser than two hours throughout the year.

6.3.3. Edaphic and physiographic variables

Altitude in the study area varies between the 637 and 2146 masl. 47% of agave plantations have altitudes between 637 to 933 masl; 35% between 934-1136 msnm; and 10% between 1137-1350 masl; the remaining 8% has a range between 1351-2146 masl. Given the topographic configuration of BRS, 21% of its surface presents slopes ranging from 1 to 10° (Figure 6.4-C), housing 48% of *A. tequilana* cultivated farms. 26% of the canyon's surface manifests 11 to 20° slopes, were 33% of agave cultivated surface is found. 53% of the canyon presents more than 20º inclination slopes, where 19% of the planted agave is found.

Three types of soil predominate in BRS, which together cover 97,3% of the ravine's surface (Figure 6.4-D). The most abundant **soil** type in BRS is litosol (57,5%) covering the steep slopes in the river margins: they are thin soils with less than 10 cm deep. Next are feozem type soils with 28,5% of land cover presenting a dark superficial layer, rich in organic matter and nutrients. The following type is luvisol soil (11,3%): these are red or yellowish soils with clay accumulation and high susceptibility to erosion. Finally, 2,7% of the remaining area is comprised of small portions of cambisols, regosols and vertisol soils. Agave cultivation in BRS is found almost at the same proportion: 42% of feozem and luvisol soils, and 16% of litosol soil. 90% of the soil in BRS has a medium **texture**, with some areas (8,4%) of fine texture, mainly located to the east of the study area, and a minimum portion (1,6%) of thick texture soil. 97% of agave cultivated surface is found in soils with medium texture; the remaining portion has fine textured soils at the limits of the ravine with the valley.

6.4. Discussion

The State of Jalisco stands out nationally as a result of its richness of agave species; 28 species represent 20% of the reported species in Mexico and 13% of reported species for the genus. The largest number of species within the State of Jalisco was found in the physiographic province of the Transverse Neovolcanic Axis, in the forest habitats formed by the oak groves and deciduous tropical forest; the municipality of Tequila is one of the locations with greater species richness. 24% (six) of the species in Jalisco are endemic and the Santiago river basin is the area with the highest endemism for the *Agave* genus in Jalisco. Vázquez-García, et al. 2007a).

Since archaic times several of these species have developed in BRS, on account of its warm climate and dry forest vegetation; in fact, this canyon is regarded as the place of origin of *Agave tequilana* Weber, the selected species among others also used (Pérez, 1887) over one hundred years and more to produce tequila, due to its rapid growth, better features for its industrial exploitation and because, compared to others, it generates more stems (Valenzuela-Zapata, 1997; 2003).

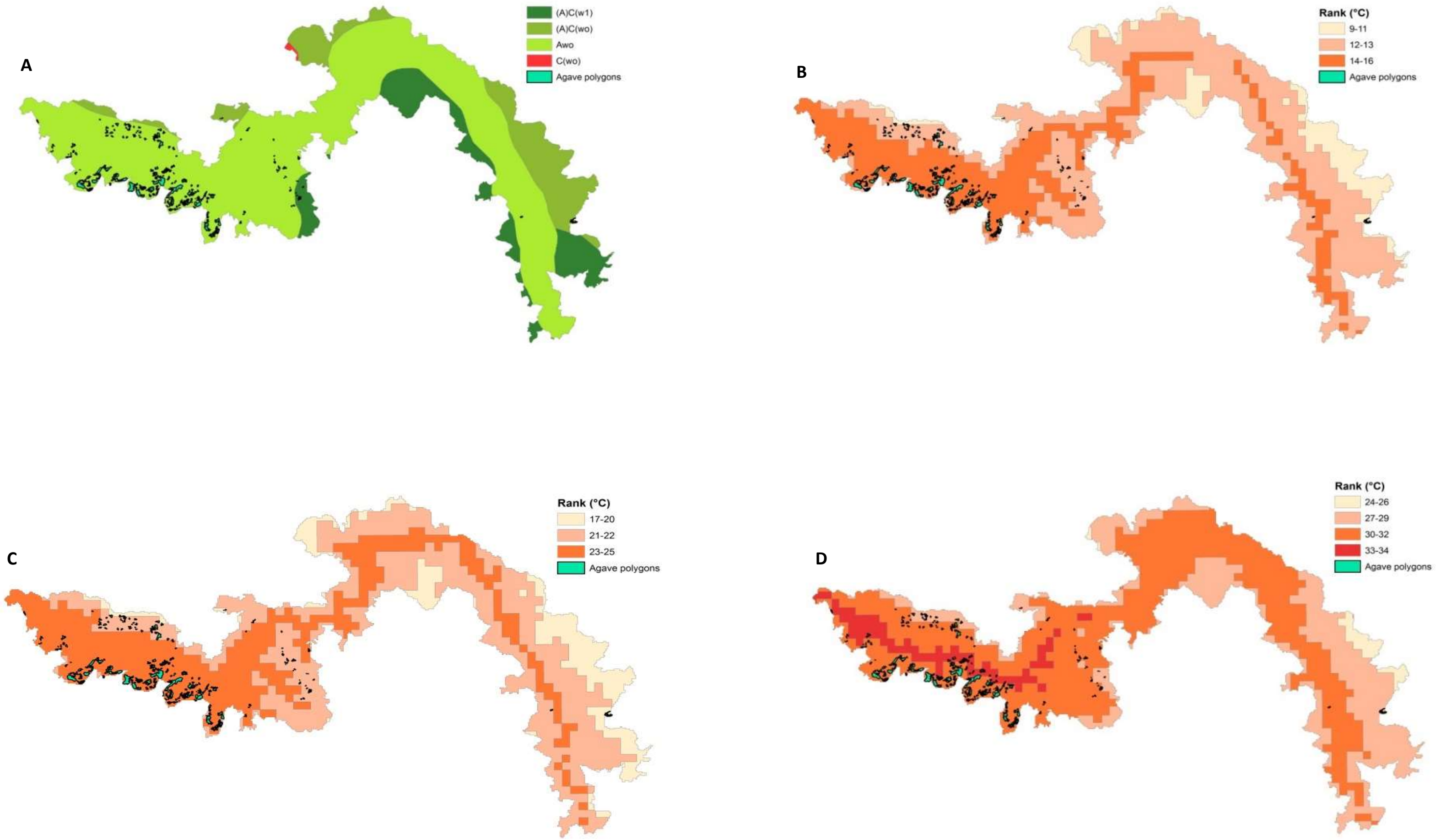

Figure 6. 2. Variables distribution in BRS-SA and cultivated plots of *A. tequilana*: A) Climate type, B) Annual minimum average temperature, C) Annual average temperature, D) Annual high average temperature.

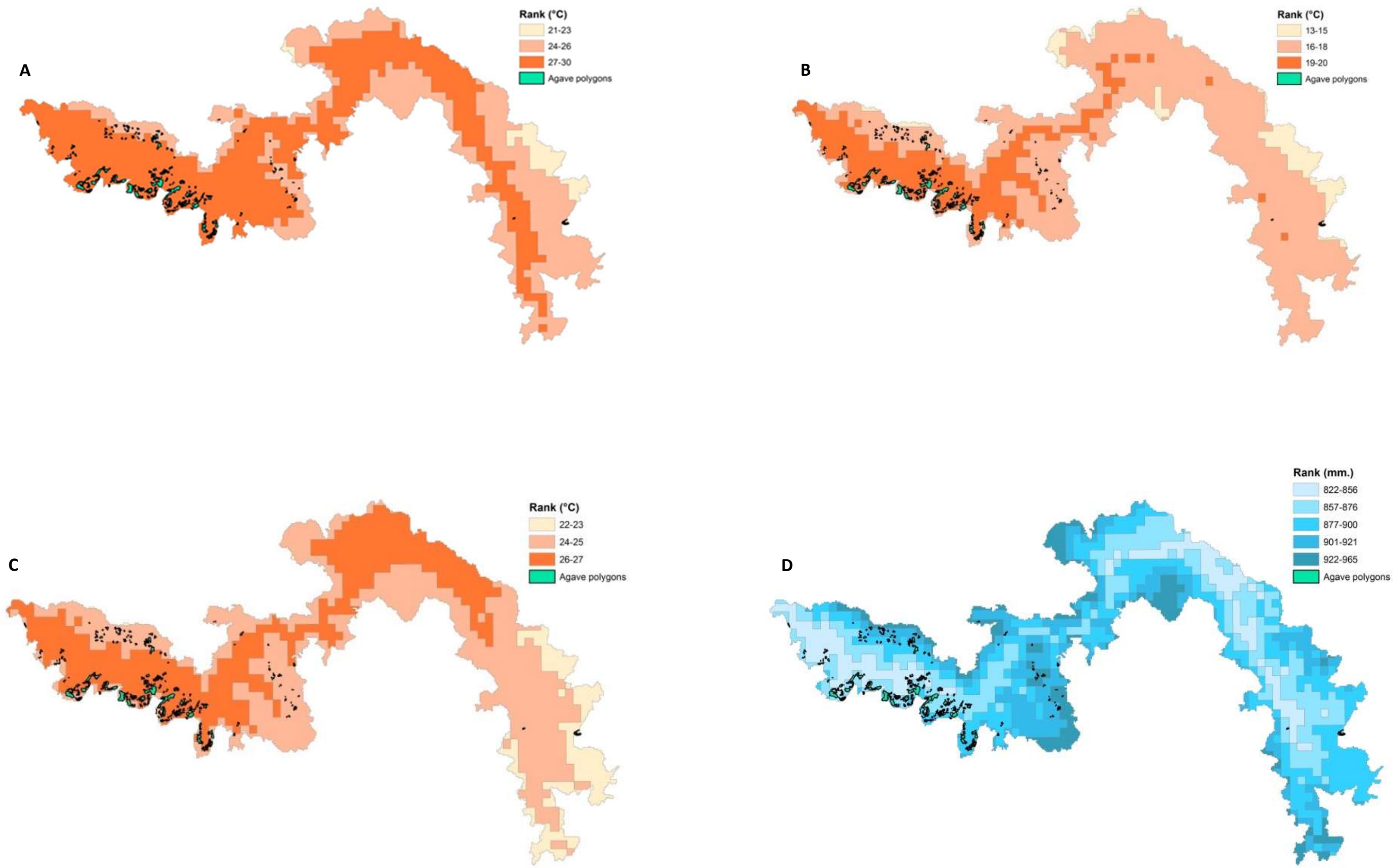

Figure 6.3. Variables distribution in BRS-SA and cultivated plots of *A. tequilana*: A) Annual daytime average temperature, B) Annual night-time average temperature, C) Annual temperature oscillation D) Annual cumulative precipitation.

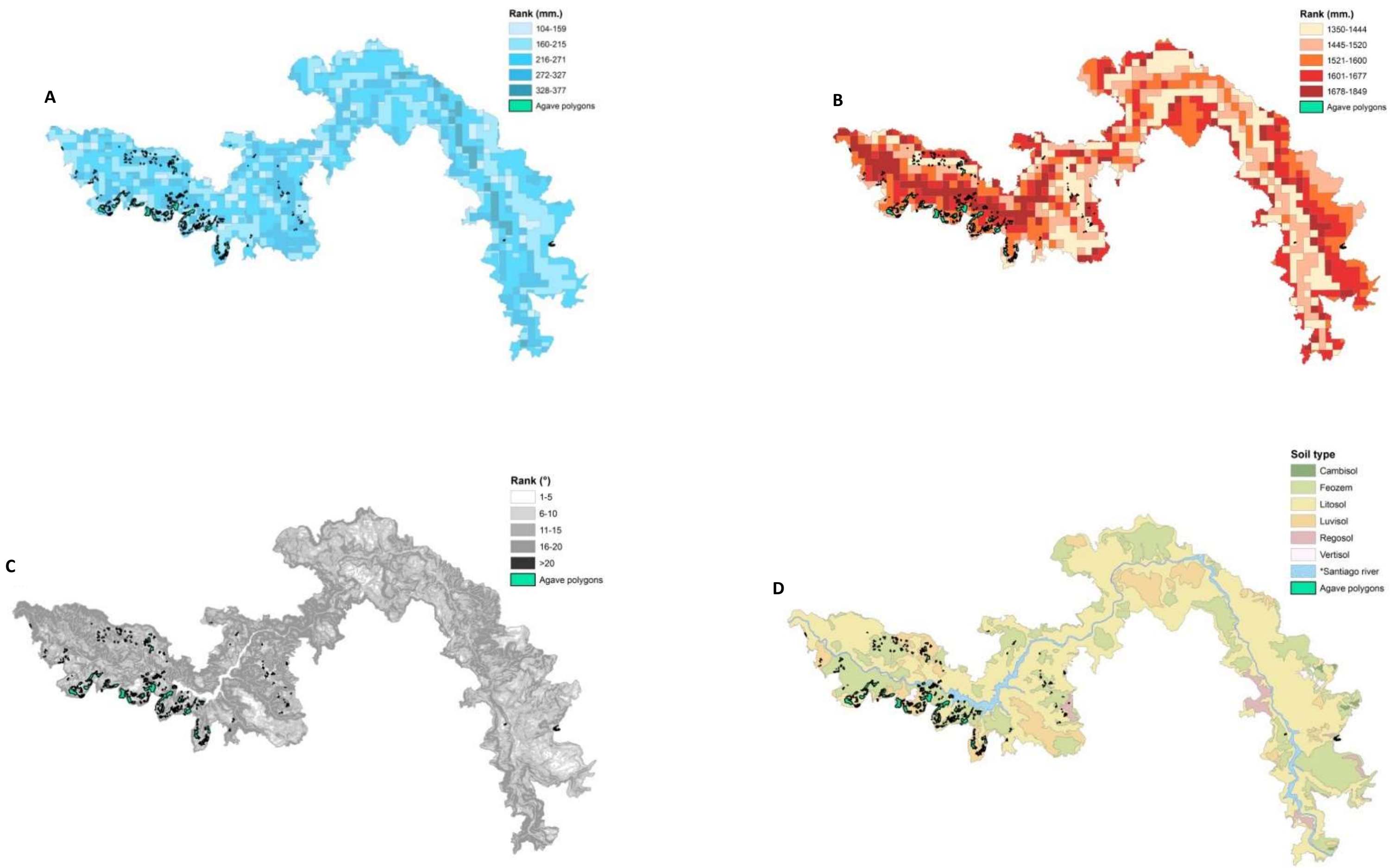

Figure 6.4. Variables distribution in BRS-SA and cultivated plots of A. tequilana: A) Available humidity, B) Annual cumulative evapo-transpiration, C) Slope D) Type of soil.

6.4.1. Distribution

According to SIAP data (2013) (Servicio de Información Agrolaimentaria y Pesquera), 59% of the 20 052 ha of agave nationally harvested in 2013 were from Jalisco. 25,7% of the state production was generated in the most cultivated and oldest region, the valleys of Amatitán and Tequila —where our study area is located; and 13,6 % in the region of «Los Altos». The rest of the harvested area corresponds to different regions in the State of Jalisco, the same ones that started the production of agave in the last two decades. Even though there are marked climatic differences in the two regions with the largest agave tradition, particularly the maximum and minimum monthly average temperatures (Pimienta-Barrios, et al. 2006), they have been used as reference by different authors to establish the thermal requirements of the species (Ruíz-Corral, et al. 2002; Ruíz-Corral, et al. 2013).

In the end of the 1990s, the national agave planting and tequila production was limited to the already mentioned regions of the State of Jalisco; Nobel, et al. (1998) investigated on young agave plants that grew in controlled environment cameras how extreme temperatures influence the optimal areas for the establishment of the crop, and how the temperature significantly influences the absorption or loss of daily net CO_2.[23] They conclude that the regions of Tequila, Amatitan and Arandas all coincide with no minimum temperatures below - 4º C or maximum temperatures above 36°C.

For their part, Pimienta-Barrios, et al. (2001) evaluated the field conditions to which the agave plantations in Tequila-Amatitán (with subtropical climate) and in Arandas (with mild —temperate— weather) are subjected; they considered the response from cultivated plants to seasonal variations in air temperature during the day and night, the water content in the soil and irradiation. They have determined that the high temperatures during the summer reduce the daily assimilation of CO_2; however the moderate temperatures in the temperate area favor the daily net assimilation of CO_2.

As agave cultivation in Jalisco was expanding and in order to contribute to its planning, Ruíz-Corral, et al. (2002) used the seasonal photosynthetic response reported in the work of Pimienta-Barrios, et al. (2001) —in which they made a thermal stratification of

[23] It is important to note that agave plants have the type of photosynthesis of crassulacean acid metabolism.

Jalisco's surface, thereby helping avoid the risks due to occurrence of frosting and allowing to identify areas with fresh day and night temperatures to favour *A. tequilana* photosynthesis. The cited investigation concludes that the night temperature is the most limiting environmental variable for the potential culture of *A. tequilana* and for establishing plantations. Ruíz-Corral (2007) also analyzed the agroecological requirements and the productive potential of *A. tequilana* in the DOT area, in addition to considering nighttime temperature as the most important variable; they integrated frost probability, altitude, soil's slope and annual rainfall variables. Using a geographic information system they also defined areas with agave cultivation potential in the five states included in the DOT.

In addition to the thermal limitations indicated in previous paragraphs, the compendium of agroecological requirements of crops by Ruíz-Corral, et al. (2013) notes that the agave plant adapts to semi-arid and sub-humid regions with sunny days. It prefers medium-textured soils such as loam-clay or loamy-sandy soils even in areas with steep hills that are not considered suitable for agriculture. Under these conditions soil and water conservation practices must be carried out to ensure a favorable environment for the crop. In flat land there is a risk of flooding problems, which is detrimental to the cultivation.

Almost all of the 1 018 ha (96%) grown with agave in BRS are located in the municipalities of Amatitan and Tequila, which along with the municipalities of El Arenal, Magdalena and Tehuchitlan, share surface territory of the core denominated zone of the agave landscape; the rest of the agave cultivated surface is located in the municipality of Zapopan. This is due to the fact that Amatitan and Tequila are part of the crop originary region, maintaining its place as the most important production area of *A. tequilana* in the country, which in 2013 represented 15% of the national harvested area and 25,7% of the harvested surface in the State of Jalisco; this entity contributed more than half (59%) of the *A. tequilana* harvest in Mexico that year (SIAP, 2017).

6.4.2. Climatic variables

According to Ruíz-Corral (2007) the plant of *A. tequilana* adapts to semi-arid and sub-humid subtropical regions with a semi-warm or warm thermal temperate regime, while the suitable considered climates are those with a thermal regime going from warm to semi-warm (Ruíz-Corral, et al. 2002; Valenzuela, 2003; Ruíz-Corral, et al. 2013). The area of the valleys and canyons in the municipalities of Amatitan and Tequila —the oldest in the planting of agave and tequila production (location of the **FAO's** declaration on the agave landscape as cultural heritage of mankind) has a subhumid climate which varies from semi-warm in the region of the valleys (A)C(w_o) to warm Aw_o in 72% at the interior of the canyon, so 97,95% of the 1 017,58 ha sown with agave within the BRS is under this climate regime. According to the literature the canyons and ravines where warm temperatures prevail most of the year are considered marginal for *A. tequilana* cultivation, since these reduce photosynthesis because that temperature increases respiration thereby consuming high amounts of the produced carbohydrates during the photosynthetic process (Ruíz-Corral, et al. 2002; Pimienta-Barrios, et al. 2006). Even though in 28% of BRS's surface semi-warm and temperate climate — considered as optimal for the cultivation of mescal, are present, they are located at the margins of BRS (shallower areas), which are untapped because they are hardly accessible. It is important to note that even when spring high temperatures can inflict stress on the agave, plantations within BRS develop satisfactorily; its surface has even increased in a significant manner in recent years. The majority of farmers pinpoint valleys —as opposed to the canyon, as better places to grow agave; they know from experience that the plants develop well but that agave heads accumulate smaller amount of sugars.

Among 19 agave species studied, *A. tequilana* showed the lowest tolerance to low temperatures (Nobel, 1988; Nobel, et al. 1998). The plant stops developing at 11°C; Valenzuela (2003) mentions that in the growing regions the minimum temperature is between 3 to 10°C, and the probability of frosts is considered as a limiting condition for the establishment of crops (Pimienta-Barrios, et al. 2006). Low temperatures do not represent a problem for the existing agave plantations in BRS were minimum temperature does not fall below 9°C. 77,7% of the agave sown area does not fall below 14°C; 20% drops to 12°C. In the agave regions of the State of Jalisco the average temperature is considered to be 30º C (Valenzuela, 2003); the average temperature in BRS is favorable for the crop: 84% of the surface with agave maintains a temperature between 23 and 25°C. Even though agave leaves tolerate high temperatures up to 55°C (Nobel et al. 1998), extremely hot environments are considered limiting conditions for cultivation since they reduce photosynthesis due to the increase in respiration (Pimienta-Barrios, et al. 2006); the **maximum temperatures** in the agave cultivated regions oscillate between 30-34°C (Valenzuela, 2003). The **optimum night temperature** determined for *A. tequilana* is 11 to 21°C; -1 to 11°C is suboptimal, 21 to 28°C supra-optimal, and less than -1°C or higher than 28º C is considered marginal (Ruiz-Corral, 2007). Considering that the values generated for BRS range from 13 to 20°C, these are within the determined optimum night temperature range. About 60% of the agave cultivated surface inside the ravine presents the highest temperature values (19-20°C) which could be a disadvantage against 40% of the remaining area were slightly cooler night temperatures (16-18°C) occur, if we consider that during the summer the presence of cool temperatures at night facilitates a better net assimilation of CO_2. The absence of frost in BRS could also be corroborated, which favors the presence of the crop.

Thermal oscillation throughout the year inside BRS can vary from 22 to 27°C, which does not represent an inconvenience for the cultivation of the agave, since the difference between the maximum and minimum temperatures occurs within the thermal margin of the dominant warm climate in the area. Even considering that the *A. tequilana* plant has adapted to conditions of extreme aridity (Pimienta-Barrios, et al. 2006) less than 500 mm rainfall in the humid season produces poor quality crops and more than 1000 mm rainfall require well-drained soils in the growing regions of *A. tequilana* (Valenzuela, 2003). Average rainfall in the production areas varies from 600-700 to 1000-1200 mm per year (Valenzuela, 2003, Ruíz,et al. 2013). In view of the above, *A. tequilana* plantations in BRS receive adequate precipitation favoring the crop's development, since the range of precipitation varies between 822 and 965 mm. During the 120 days of months June to September in which precipitation values are higher than evapo-transpiration ones, **available humidity** values range from 160 to 327 mm in 98% of BRS cultivated area, which is undoubtedly favorable for the plant development, having greater soil moisture to be stored in their tissues to survive dry seasons.

Obtained classes of **evapo-transpiration** values for the BRS are mapped into small portions of a few square kilometers because of the environment of the dam and the river, but also due to orographic heterogeneity and the level of human intervention in the canyon. The duration of the day (**photoperiod**) in agave growing areas is between 10.5 and 13.6 h.; it is a plant that prefers sunny days. BRS finds itself in intermediate status at a longitudinal length. The photoperiod in the study area is 12 + -2 h. It is evident that in most of the plots the presence of any other stratum or vegetation that shades the crop is avoided, whether these are wild or cultivated species.

6.4.3. Edaphic and physiographic variables

Most of the agave cultivated in BRS is found below 1000 masl, possibly the reason why some plantations do not obtain heads with the required sugar amount. Only 8% of the cultivated lands have favorable altitude conditions for the crop. Terrain's slope degree is a predominant criterion to determine potential areas to establish A. tequilana plantations; this was the most restrictive variable in determining the potential surface for the DOT (Ruiz-Corral, 2007). Indicated optimal slopes for the crop go from 2 to 8% (5° approx.), which facilitates and avoids problems of puddling; lands with slopes greater than 45% (24,23°) are considered marginal for the crop (Ruíz-Corral, 2007). In lands with more than 2° slope it is recommended to plant in contour lines and other practices for soil and water conservation, depending on the slope degree (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación - SAGARPA, 2015). When in the field we noticed that the farmers prefer to cultivate the slopes of the hills and not in the peaks, because the first ones better drain the moisture excess.

According to FAO, cited by Ruiz-Corral (2007) and Ruiz-Corral, et al. (2013) agaves can be grown on thin or deep soils, preferring medium-textured soils, for example, loamy, and loamy-sandy or loamy-clay soils. Although in areas with low rainfall, agaves prefer soils with higher moisture retention, i.e. heavy textured soils, such as clayey or clay-loam, they can develop adequately in thin or deep soils. In the State of Jalisco agave is cultivated in luvisoles, cambisoles and lithosols soils, which have a red to ocher coloration (INEGI, 1994); although lithosol soil prevails in the ravine in 57,5% of the surface, only 16% of this surface is grown with agave; it is the feozem and luvisol soils type that cover about 82% of the cultivated surface in the ravine.

Medium-textured soils are preferred to cultivate agave, for example, loamy, sandy-loam or clay-loam soils. While in areas with low rainfall agaves prefer soils with higher moisture retention, i.e. heavy textured soils, such as clayey or clay loam (Ruiz-Corral, 2007). Soils of BRS in general feature average **texture**, so almost all of the cultivated lands (97%) have this characteristic. Even when *A. tequilana* adapts to a wide altitudinal range, it seems to favor the interval ranging from 1000 to 2200 / 2400 masl (Ruiz-Corral, 2013). The initial development of the crop at altitudes below 1000 masl is rapid and promising, hence sites with these characteristics have plant production potential, but not so for the production of the agave head, since even when it can acquire a considerable volume it generally does not gain the sugar concentrations required by the industry. Development speed of the crop is significantly reduced at altitudes higher than 2200 masl, and the risk of damage by low temperatures and/or frost increases significantly (Ruiz-Corral, 2007).

6.5. Conclusions

The distribution of the *Agave tequilana* cultivar for tequila production is delimited by regulations in force at national and international levels. Because it is a recent crop (just over 200 years old) and because it is limited to a specific region, there is little information in literature about the agroecological requirements of the crop in comparison with others. As a result of these investigations it was determined that temperature is the determining factor for the development of the *A. tequilana* crop, and that the canyons where the cultivar and its industry originated are considered marginal regions, due to the warm temperatures that prevail throughout the year, which reduce net photosynthesis due to the increase in respiration. Notwithstanding the foregoing, there is evidence on the farmers part to regard BRS good for the production of agave, because the land is not cold, the agave develops sooner, although it has the disadvantage to store less reducing agents, while still obtaining a good percentage per kilo of agave; at the end and following the laws of the market is not bad to produce agave in BRS.

Climatic conditions are not considered a limiting problem by peasants of BRS to establish agave plantations; the main problem —not only for this crop but for the development of any productive activity in BRS is the ground slope: rough terrain and steep slopes predominate in the canyon's orography. It is necessary to move from the industrial cultivation system of *A. tequilana* to an agrosilvopastoral system in BRS to harmoniously integrate the ecological processes involved in the production of the raw material of tequila.

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Chapter 7. Tequila, Heritage and Tourism: Is the Agave Landscape Sustainable?[24]

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Abstract

Reflects on the origin of the raw material for the production of tequila, the production of the drink and its appellation of origin, and the declaration made by UNESCO that certified the Agave Landscape and the Old Industrial Facilities of Tequila as elements of the Cultural Heritage of Humanity in the category of cultural landscapes. Different aspects of the biocultural heritage of a region where the Barranca del Río Santiago is included are shown, can disproportionately benefit a few individuals to the detriment of many others; considering that tourism can be a trigger and play an important role in transforming the social environment series of proposals are added to improve tourist activities from a sustainable perspective that contribute to the conservation of the plant genetic resources of the region.

7.1. Introduction

In these pages, we briefly describe the origins of tequila, Mexico's most emblematic alcoholic beverage, before going on to analyse the current state of the tequila industry. Both aspects are considered in relation to the tourist potential of tequila in light of the declaration made by the United Nations' Education, Science and Culture Organization (UNESCO) that certified the Agave Landscape and the Ancient Industrial Installations in Tequila, Jalisco as elements of the Cultural Heritage of Humanity in the category Cultural Landscapes. Our observations conclude with a series of proposals that hopefully, will broaden and enhance the quality of tourist-related activities around the artisanal production of tequila and the Agave Landscape from a perspective of sustainability.

7.2. The Agave plant

The genus *Agave L.* includes over 200 species, three-quarters of which exist in Mexico, the country that can be considered the birthplace of these plants. Of these species, at least 74, together with 28 infra-specific *taxa*,[25] have been documented as forming part of human diets,

[25] Taxa (plural of taxon) is the taxonomic unit of any hierarchy.

as the raw material for elaborating fermented and distilled drinks, and as well as a source of fibre and forage (Colunga-García Marín et al. 2007). In the state of Jalisco, specifically, 23 species of the genus Agave have been registered (Hernández et al., 2007), many of which have developed from archaic times, especially in the Santiago River Canyon (Barranca) north of the city of Guadalajara, the state capital, where they are favoured by the warm climate and dry forest vegetation.

Industrialized tequila production originally used various types of agave (Pérez, 1887),[26] selected for their short stems and tough fibers commonly known as *piñas* or *cabezas*. Those stems and the bases of the leaf (called pencas) contain high concentrations of polysaccharides and are very palatable. In fact, the area around this Canyon is considered the birthplace of the species *Agave tequilana* Weber, which was selected over a hundred years ago for tequila production be- cause it grows relatively quickly, has properties suitable for industrial exploitation and generates more offshoot (pencas) than other species (Valenzuela-Zapata, 1997; 2003).

The first Official Quality Norms for Tequila (NOM, 1949) defined this beverage as an alcoholic drink elaborated from *Agave tequilana* and other species of that genus. But those terms were modified in new Norms issued in 1964, which specify *Agave tequilana* Weber var. *Azul* exclusively, though no justification was given for introducing this change. This measure provoked the marginalization of other species that had been widely used to produce the drink called *mezcal* –tequila's original name– to such a degree that supplies were depleted, and some types may have become extinct in the study zone after falling into disuse (Valenzuela-Zapata 1994; 1997).

In this regard, it is worth noting that no wild populations of *Agave tequilana* or *Agave angustifolia* Haw have been found recently in the Santiago River Canyon, the area where agaves developed archaically, as mentioned above.[27] The reason for it could be that the study area lies on the margins of the natural distribution zone of those species, it might also be due to their extinction in this zone, in contrast with areas in southern Jalisco where the

[26] «There are several classes of this precious Mexican plant that are cultivated for the liquor industry of a drink called *mescal* […]. Their names are: *chino*, *azul*, *bermejo*, *sigüín*, *mo- raneño*, *chato*, *mano larga*, *zopilote*, *pie de mula*, etc.»

[27] A species related to *Agave tequilana* that is also used to produce agave distillates.

introduction of *Agave tequilana* and the development of the tequila industry has been less intensive. In this latter region, distilled drinks are produced from over 20 types of cultivated agaves (Colunga & Zizumbo, 2007).

7.3. Tequila production

Like many other crops exploited on an industrial scale, many of them linked to international markets, *Agave tequilana* is known to cause the deterioration of local agroecosystems because it is monocropped and requires huge investments in agricultural inputs to obtain high yields. This induces the following pernicious effects, among others that could be mentioned:

Loss of genetic diversity. Because agave cultivation depends on the abundant asexual propagation of ofshoots, monocropping reduces the genetic variability of populations (Hurtado, 2008). This, in turn, increases the plants' susceptibility to plagues while reducing their ability to adapt to the environment (Abraham-Juárez *et al.* 2009).

Vulnerability to plagues and diseases. Planting the same species of agave (mono-cropping) over broad extensions, which is highly-characteristic of the Agave Landscape, contradicts the principles of agroecology since, as this method of cultivation is well-known to foster the development of plagues and diseases.[28] To give but two examples: in 2007, one-fourth of the 120,000 hectares of cultivated agave were affected by diseases and plagues,[29] while for over two decades –between 1990 and 20107[30]– agave farming suffered a phytosanitary crisis that severely affected plantations.

Intensive use of agrochemicals. High-density, monocrop plantations require ever-greater dosages of fertilizers and biocides, whose application contaminates soil and water. This has caused devastating changes in local ecosystems and damaged the health of nearby populations. The latter occurs because most of the farm workers who carry out activities are

[28] The most common diseases that affected agave were: anillo rojo *Erwinia* spp., stem rot *Fusarium oxysporum*, and shoot rot *Erwinia* spp. (Vicente, 2002).

[29] Ulises Zamarroni (correspondent): «Agoniza la producción de agave azul, alertan». *El Universal, Sección Estados*, August 9th, 2007

[30] Javier Trujillo Arriaga, Director General de Sanidad Vegetal, Servicio Nacional de Sanidad. Discourse at the I Foro de Discusión Fitosanitaria en el Cultivo del Agave Azul Tequilero, May 31st, 2011.

of a low socioeconomic level who do not adequately handle agrochemical products because they rarely receive the necessary training and qualified technical assistance is not usually available. Furthermore, a particularly common practice consists in keeping agave fields free of other types of vegetation that could compete for environmental resources, though this entails applying enormous quantities of herbicides and glyphosate, a particularly toxic pesticide (Seneff, Swanson & Li, 2015; Watts et al. 2016).

Soil erosion. Mezcal cultivation takes place in various environmental niches (topoforms) that make up the Agave Landscape, including: *a*) the slopes of the Tequila volcano; *b*) plains in the El Arenal, Amatitán and Tequila valleys; and *c*) the banks of the Santiago River Canyon. This latter zone has suffered a significant loss of the fertile layer of soil because the furrows formed for planting run parallel to the downward slopes, soil conservation practices are notably absentdespite the fact that fields are quite steepand the intensive application of herbicides eliminates other types of vegetation cover.

Agave growers. The method of *Agave tequilana* cultivation (i.e., quality, attention and management) largely depends on the kind of producer involved, but above all on the per-kilo price of the product on the market. The first group of growers consists of large companies that cultivate some of the agave they require in their own fields. Second, come producers who have sufficient access to capital to specialize in agave production, either on their own fields or rented land, in order to sell their harvest directly to industries that produce tequila. In third place, we find small producers who practice more diversified agricultural activities. Their agave fields rarely exceed one hectare in size, and they of- ten plant in one or more agroecosystems, including under the following conditions: rain-fed fields, irrigated fields, sloped fields shared with corn, squash and beans in different proportions, and plantings in fallow fields that may or may not have irrigation. These producers are usually active in other economic practices, such as commerce or as paid agricultural labourers on other farms. Finally, a fairly high proportion of these growers produce their own tequila, or negotiate contracts with taverns to process their agave plants.

Here, it is important to note that, strictly speaking, growers are not obliged to register their agave plantations with the Tequila Regulating Council[31] (Consejo Regulador del Tequila, CRT), which exists, in part, to guarantee product quality. This is because when agave is scarce, available volumes can easily be traded at attractive prices, but when supplies of *Agave tequilana* dwindle, «tequila» production is maintained by expressing the juice from other species of agave and distilling it, even if those plants were harvested outside the boundaries of the certified «region of origin». Sometimes, immature plants may be boiled and pressed to obtain the raw material for tequila production. Although they do not contain all the sugars required to produce alcohol, they do contribute to the typical 'tequila flavour'.

Agave crises. Shortages of raw material for tequila production have frequently occurred. One key cause of scarcity is the poor health of plantations. In the mid-19th century, a disease called «gangrene», or «drying» (secazón) damaged agave production to such a degree that in 1868 a reward was offered to anyone who succeeded in eradicating the terrible scourge. Another outbreak of this dis- ease occurred in the late 20th and early 21st century, when much broader extensions of land had been sown with agave (Valenzuela-Zapata, 2003).

Another important and recurring aspect that affects how agave is produced and commercialized nowadays involves situations of excessive supply and it's opposite, severe shortages. These oscillating periods can cause enormous economic losses for producers and represents a particularly contentious issue since growers are limited in their ability to manage these conditions because Mexico's Department of Agriculture, Cattle-Raising, Rural Development, Fishing and Alimentation (*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación*, sagarpa), National Chamber of the Tequila Industry (*Cámara Nacional de la Industria Tequilera*, CNIT), and the aforementioned Tequila Regulating Council (CRT) can neither prohibit agave production, nor oblige farmers to plant agaves. Clearly, existing technology for the instantaneous diffusion of data would allow these organisms to continuously generate and disseminate information on supplies of this raw material and so forecast supplyand-demand

[31] The Consejo Regulador del Tequila, A.C. is the organism in charge of verifying and certifying compliance with the NOM for tequila. It also oversees the quality, culture and prestige of this drink. It is an inter - professional institution that since 1993 has brought together all the producing actors and agents linked to tequila production. 'Actors' and 'agents' can also be understood as large tequila distilleries.

for the tequila industry in any given period. Unfortunately, these practices have not been implemented.

When growers decide to undertake agave cultivation, like any other economic agent they are motivated by the high per-kilo price that this product can demand in the market (up to 17 Mexican pesos), and by the —often— illusory hope that this will continue sine die. Obviously, these conditions can generate overproduction of this raw material[32] with the consequent rapid price decreases that can go as ridiculously low as 30 or 40 *centavos* per kilo. As Tena, Ávila and Jiménez (2015) point out, fluctuations between periods of scarcity and overproduction of mescal plants can be traced back to one basic fact: that the market is determined by *buyers*, not *producers*. Some observers argue that periods of abundant raw material are induced deliberately by industrialists who offer high per-kilo prices for agave to increase cultivation, well aware that this will eventually generate overproduction that will automatically force prices to fall, perhaps drastically; obviously, to their advantage.

Other important factors that determine prices and orient agave commercialization are the presence of intermediaries (called *coyotes*) who operate between producers and industrialists and usually end up obtaining the highest profits from this part of the tequila production, and the fact that the nom for tequila authorizes mixing agave sugars with those extracted from other plants —especially sugarcane— in proportions as high as 49 per cent. This occurs especially when agave is more expensive than other sugar-producing plants and can be used as a substitute for agave up to almost 50 per cent.

The tequila industry. Once mature agaves are harvested (jimado)[33] in the field, they are transported to a tequila distillery, where the ball-shaped hearts (called piñas or cabezas) of the plants are cleaved into pieces, roasted in ovens, and then crushed in order to extract their substances (mieles in Spanish) that are then fermented in huge vats to transform the

[32] We should point out that mezcals must be harvested once they mature, a process that takes, on average, about eight years from the time of planting.

[33] In Mexico, especially in traditional tequila-producing areas, *jimar* refers to field labors where men (*jimadores*) cut the leaves (*pencas*) off the heart of the agave, which is the part of the plant used to produce tequila.

agave's sugars into alcohol.[34] Finally, a double distillation method in stills produces the separation and con- centration of the degree of alcohol desired for the drink in question. As in the production of sugarcane alcohol and similar distilled drinks, tequila production generates huge amounts of bagasse that —if not suitably disposed of— represent a serious problem of environmental contamination. In the specific case of tequila production, this problem has not been dealt with adequately and is still far from being resolved.

Producing one litre of tequila requires 7.5 kilos of mature mescal, but 40 per cent of the weight of this raw material must be disposed of after extracting the sugars. This amount to 3 kilos of bagasse per litre of tequila elaborated. But the depicted distillation process also produces a second waste product, called vinasse, which has a negative impact on the biota of the ecosystems where it is discarded. The amount of vinasse produced per litre of tequila varies from 7 to 11 litres (Cedeño, 1995; Ibarra et al. 2010).

In the so-called Agave Landscape, properly-speaking, there are 50 registered companies devoted to tequila production. Unfortunately, the volume of waste products that they generate is unknown, as is their final destination.[35] But what is visible is the perennial and increasing contamination of streams and aquifers, a reality that has caused water scarcity for human use in the area, as well as the disappearance of orchards and gardens that require irrigation. Finally, environmental norms demand that tequila distilleries dispose of their waste products adequately, but only the largest companies have the economic capacity to support the investments that compliance requires. In reality, the few industries that apply those norms do not necessarily follow environmental dictates to the letter; that is, they fall short of 100 per cent compliance.

7.4. Artisanal tequila production

Tequila production originally took place in taverns established on lands around the Santiago River Canyon so that producers did not have to transport their mezcals outside the area. Also,

[34] A second procedure for obtaining sugars from agave plants consists in splitting the hearts and injecting high-pressure steam. This technique makes extraction more efficient.
[35] Response to the request for pertinent information submitted by the authors to the Department of the Environment and Territorial Development of the State of Jalisco (SEMADET), supported by the «Policy of Transparency of the State of Jalisco»; file 3s96/2017, 19 September 2017.

the zone had abundant supplies of the good-quality water that elaborating distillates required. But another reason for this modus operandi was to keep production in clandestine conditions to avoid paying taxes to the fiscal authorities.

Though in past decades those small taverns were harassed by the State and tequila entrepreneurs, now that «this tradition is back in style» and consumers enjoy distillates made from other agaves, the few taverns that survived inside or on the outskirts of the Agave Landscape still operate 'clandestinely', but apparently problem-free. Indeed, some are employed to promote and disseminate the origins of tequila production.

Today, most small tavern-operators who are devoted to producing agave distillates also perform other typical farming activities, sometimes on lands close to their homes, and not so much on the places where their tavern lies. But because of the volatility of agave prices, very few produce tequilas year-round, since it is not economically viable to depend on one sole productive activity. In fact, most continue distilling simply because they enjoy it, while others never lose hope that their business will one day produce profits and «pull them out of poverty…»

These tavern-owners usually learned their trade from a relative —father, father-in-law, uncle, etc.— or by working as young men in taverns in their hometown or nearby villages in the surrounding sierra, where they learned the art of distillation, though not through any kind of formal instruction. They often refer to their masters (maestros) as men who had extensive experience and the ability to produce unique, special, distillates. Though they learned as best they could, they feel they cannot match their maestros' achievements because they never learned what they call «the secret». They cannot distil tequila like those men did, though they do asseverate that their products are «more-or-less» the same.

The smallest taverns, those with limited production volumes, are not significant competitors for the large, long-established tequila-distilling companies, so they market their products on a small scale, usually selling in bulk to relatives and friends. Thus, for example, numerous small operators may be contacted to sell their products —always at prices below those of the formal market— when people organize family parties or neighbourhood festivities, which always involve small budgets. However, some tavern-owners (surely, a small minority) who enjoy broad recognition in the trade have been sponsored, semiofficially, by promoters of 'agave culture' to demonstrate the roots and history of tequila production. They may succeed in commercializing their products at prices that rival those of the best distillates sold by the large, commercially- consecrated companies.

Although these artisanal producers usually ply their trade individually or perhaps with family labour, some occasionally hire neighbours or friends to help with the tasks involved in the distillation process. This provides jobs (though usually temporary) and a modest monetary remuneration, which in rural areas of Mexico are rarely unwelcome. Through these processes, some artisanal distillers produce considerable quantities of tequila and so decide to establish their own small-scale businesses, though this does require registering their operations with the CRT and receiving authorization to distil special editions of tequila requested ex profeso, or perhaps to elaborate certain agave products for other companies on a by-order basis (called maquila). There are even cases of growers who, like landowners of the past, have set up their own small taverns where they can produce and consume their favourite tequilas, extracted from their own agaves production, or others that might not belong to *Agave tequilana*. For example, they may incorporate agave masparillo *Agave guadalajarana* Trel., or a species called sigüín *Agave angustifolia*, which grow wild in the sierra beyond the borders of the Santiago River Canyon. Even more, these tavern-owners may be hired to process agaves that are transported from far-off places, like semi-desert zones of Zacatecas.

As in other cases of artisanal production, it is the price of the raw material (agave) that determines the activity of the more traditional tavern-owners. Thus, when agave is cheap, those who possess some stocks prefer to invest a modest sum of money to give their harvests added value, instead of selling at low prices, so they distil their agaves themselves or pay to have them processed. Likewise, other tavern-owners, meanwhile, try to take advantage of such circumstances by taking the risk of buying agave at the low price and having it distilled, in the hope of turning a high profit. But when agave price is high, they stop purchasing it because they would almost have to sell their taverns just to acquire enough raw material.

It is important to emphasize that the knowledge of the agave distillation process that characterizes the traditional tavern-owners is quite broad. For example, they recognize the properties of the different types of agave that can be used as raw material and, although many insist that *Agave tequilana* is the best species for elaborating tequila, they are quite familiar with the knowhow and techniques required to produce distillates from other agaves.

Our final point regarding these producers is that because of the low level of tequila production they achieve and maintain, the discarded bagasse does not impact the environment to any great degree, as it is simply incorporated into surrounding agricultural soils.

7.5. The denomination «region of origin» of tequila

Up to 1940, tequila production in Mexico was largely a domestic operation, but around that time some economic actors made applications to the Mexican government to protect the name of this alcoholic beverage –which, in reality, derives from the town of Tequila, where tequila production and commercialization has been concentrated throughout history– and so obtain exclusive rights to use the label 'tequila' (CRT, 2007). Their arguments centred on the long history that associate the town of Tequila with the production of this Mexican spirit, on the region of origin, and on the fact, that, by that time, tequila was being considered Mexico's «national drink». Through their efforts, as mentioned above, in 1949 the Official Mexican Norm (Norma Oficial Mexicana) for tequila was established to describe the process that tequila producers had to follow, and the characteristics of the drink itself in terms of body, flavour and aroma. This Norm stipulated that for a product to be legally labelled «tequila» it had to be produced with Agave tequilana and other species of the same genus cultivated within the boundaries of the state of Jalisco. This meant that only agaves so identified could be used to produce this alcoholic drink, and that no other sugars could be added to enrich it.[36] In addition, striving to complete this original protection, the Norm specified the criteria for bottling, labelling and transporting tequila once it was distilled (Norma Oficial de Calidad para Tequila, dgn. R9-1949).

Despite the solid argumentation just outlined, the declaration of Region of Origin of tequila formulated years later and published in the Official Bulletin of the Mexican Federation (*Diario Oficial de la Federación Mexicana*) on March 12, 1964, recognizes as tequila only the alcoholic beverage exclusively made with *Agave tequilana* Weber var. *azul*, while omitting

[36] In those years, the tradition dictates that the elaboration of tequila only used the hearts of agave plants as raw material, so no denomination that ensured its use at 100 per cent was necessary.

consideration of all other species. Moreover, it allowed tequila to be enriched with sugars from oth- er sources, up to a maximum proportion of 30 per cent,[37] broadened the geographical area to include other states of Mexico in the Region of Origen, and authorized its exportation in bulk to be bottled and labelled abroad.

These developments seem to justify the argument that the area now included in the Region of Origin of tequila has been moulded in accordance with the interests of the tequila industry. In this process, the declaration abstracted its norms from the ecological, historical and cultural evidence that should have constituted its formal basis. This scientific perspective has been argued by Pérez, Villa and Balderas (2012), revealing the contradictions involved in including municipalities in the state of Tamaulipas within the Region of Origen of tequila, since they have no antecedents in tequila production whatsoever. Indeed, it is well-documented that those municipalities use agaves from the state of Jalisco to produce tequila and, worse yet, only bottle tequila distilled in that state.

In this new context, we find that 9 of the 10 leading brands of tequila in terms of quality, price, prestige and age are now the property of foreign companies (Olmedo-Carranza, 2010) that, therefore, are the principal beneficiaries of the natural and cultural conditions (read: patrimony) of the Region of Origin of tequila and of the official Mexican norms that rule its production.

7.6. The Agave landscape

Heritage (or patrimony) is the legacy obtained from the past that is lived in the present and will be transmitted to future generations. Cultural and natural heritage is an irreplaceable source of life and inspiration, our touchstone, our point of reference, our identity (UNESCO, 2008a). In 2006, the UNESCO declared the Agave Landscape and the old industrial installations in Tequila, Jalisco, Cultural Heritage of Humanity in the category Cultural Landscapes. Their decision was justified by the argument that their peculiarities provide

[37] Since then, the declarations of 'region of origin' in 1974 and 1977, as well as the changes made to the official norms for tequila production in 1970, 1976 and 1978 permit the incorporation of other sugars up to 49%, while also broadening and reducing the zone of the 'region of origin' of the plant, according to the interests of the large companies.

evidence of a harmonious and sustainable adaptation of the use of the soil in a natural context that should be recognized in order to preventing modifications of their traditional essence.[38]

The environment now known as the Agave Landscape consists of a nuclear zone that covers some 34 658 hectares located between the Tequila volcano and the Santiago River Canyon. These lands include the scenarios proper to, and characteristic of, agave cultivation. A second, much smaller nuclear zone (only 360 hectares) includes the Los Guachimontones archaeological zone. These two areas are surrounded by a buffer zone of 51 621 hectares where some of the old industrial installations that once produced tequila, the Tequila volcano itself, and the Santiago River Canyon are located.[39] Gómez (2008) mentions that this latter zone conserves, intact, a natural wildlife corridor where over 800 vegetation species have been identified.[40] Today, we would say that fulfilment of the goals of the management plan for the Agave Landscape is a simulation, at least in the following regards:

- The balance among the natural, agricultural and urban environments required to improve the quality of life of the area's inhabitants is still far from being achieved.
- The water used by tequila industries, which inevitably becomes contaminated, has reduced the availability and quality of this vital liquid for large numbers of inhabitants. The Santiago River Canyon, especially, receives residual waters from towns upstream, as well as the vinasse generated by agave processing, while various sites in the zone have been transformed into sanitary landfills. As a result, the Santa Rosa Dam, which forms part of the Santiago River system, has reports of high indexes of pollution and is a focus of infection and fetid odours, especially in the dry season.
- Few rural towns have adequate health services.
- There are no sustainable development projects that foment traditional agricultural systems.
- Outside the administrative head towns (cabeceras municipales) and the Los Guachimontones archaeological zone, signs that identify the Agave Landscape are scarce;

[38] La Crónica.com: «Patrimonio Mundial: Paisaje agavero e instalaciones de Tequila»; published on July 12th, 2006.

[39] It is important to note that the *Los Guachimontones* archaeological zone, the Santiago River ravine, and the Tequila volcano functioned as tourist attractions in the study area long before the declaration of the Agave Landscape and the development of tourism programs like the «Route of Tequila» and «Tequila, a Magic Town».

[40] Unfortunately, the author does not cite the source of the number of species mentioned.

many have been destroyed or are deteriorated, while the most striking aspect of tourism infrastructure may well be its absence.

- Only some old tequila-producing haciendas in municipal head towns are open to visitors. Those farther away rarely have efficient access roads, or are simply closed to the public.
- Many tourism services, including helicopter and hot-air balloon rides over the Agave Landscape, are too costly for low-income families. All jewellery stores are high-end, as are the spas, gymnasiums and hotel boutiques; while practicing extreme sports and horseback-riding are also prohibitively expensive for most visitors.
- The expansion of tourist activities around the Agave Landscape, though modest, has increased the cost of basic products significantly for local people.
- Agricultural fieldworkers, whose manual labour sustains agave cultivation, earn low wages and are denied other work-related benefits. Also, they are hired in the outsourcing modality, so they do not enjoy seniority or other fundamental rights.

7.7. Heritage and Sustainable Tourism

Over the past five decades, as the aperture and improvement of means of communication have enhanced mobility in the valley region territory around the town of Tequila, residents of neighbouring municipalities and of the town itself have become frequent visitors to numerous natural sites in the recently-recognized Agave Landscape, including the Tequila volcano and the Santiago River Canyon. In the canyon, they enjoy natural spas and orchards that dot the countryside and provide a wide variety of fruits typical of tropical zones. Of course, the main attraction there has long been the opportunity to purchase, at reasonable prices, a few decilitres of the famous beverage. And this practice continues to give travellers a good pretext to stop along the Pan-American Highway that passes by Tequila to taste these celebrated spirits —despite doubts about their quality— and perhaps purchase a bottle or two of this prestigious distillate of the agave plant.

Because of its clear potential for attracting tourism, in 2003 Tequila was incorporated into the Mexican government's tourist program called Magic Towns (Pueblos Mágicos), which allows them to apply for federal government funding so that local authorities can carry out projects to enhance the image of their hometowns, especially urban zones. In the case of Tequila, the application for public funds was not initiated by local government (Ayuntamiento), but by the owners of leading brands of tequila: Cuervo, Sauza and Herradu-ra (Hernández, 2009). The UNESCO declaration of Tequila as Cultural Heritage of Humanity in 2006, mentioned earlier, is also a result of this process. That announcement helped formalize and consolidate tourism activity in the region, while also providing access to more public resources to stimulate tourist activity and establish better-quality businesses, especially for the main tequila entrepreneurs.

As noted previously, the UNESCO declaration with respect to Tequila and its surrounding area entails implementing specific in situ intervention programs that include a plan for a territorial ecological organization; in this case, of the zone where agave and the drink derived from it are produced. Addition- al commitments stemming from the declaration are elaborating an inventory of local flora and fauna to aid in their conservation, and a project to re-establish previously altered habitats, which means ameliorating conditions for the species that live there (Gómez, 2008). To date, however, evidence of efforts in these directions is scant.

In this respect, it is worth mentioning that the deterioration of the bio- cultural heritage of the Santiago River Canyon has continuously worsened. Significantly, much of the biodiversity of the different ecosystems it harbours has been lost, including various edible species of fish and crustaceans that once inhabited the river and its permanent tributaries, as well as numerous edible plants, birds and mammals that used to live in the deciduous forest that covered the slopes of the canyon.

Traditional methods of appropriating and producing foods have succumbed almost entirely to this onslaught, especially the now-predominant mode of industrial production. This not only limits the material possibilities of residents, but also has forced many people to migrate to large urban centres, especially the metropolis of Guadalajara.

In light of the phenomena described herein, it is of utmost importance to rethink the actions included in the current management plan for the Agave Landscape in order to correct the current, ‘simulated’ recovery of the tradition of tequila production that benefits primarily large companies with global economic interests. This reorientation is required to guarantee observance —to the letter— of the principles of the Declaration of Cultural Heritage of Humanity granted by the UNESCO, which privileges sustainable tourism.

According to the definition of the World Tourism Organization,[41] sustainable tourism is the form that takes into account «the current and future economic, social and environmental repercussions [of the sociocultural environment in question], in order to satisfy the needs of visitors, industry, environment and host communities». Thanks to the diversity of relations included in sustainable tourism it has the potential to act as a catalyst of social change, since it can help fight hunger and poverty, while promoting peace and safety and as well as stimulating local economies.[42]

In this regard, the original aim of the Agave Landscape management plan was to foster sustainable development, but it turns out that only micro-tourism excursions in the zone around the Tequila Volcano have been fomented. The same is true for hiking, and tours on horseback or bicycle, which are not the services most often requested by tourists. Given the scenic richness of agave plantations, we would recommend enlarging installations that would allow visitors to enjoy the visual and natural sights that characterize the Santiago River Canyon. These could be complemented by descriptions and explanations by guides on the local physiography. By the same token, the modest efforts at tourism promotion that emphasize sedentary activities like eating and drinking could be broadened and enriched. For a greater impact and success of the Agave Landscape management plan, the promotion of tourism initiatives focused on sustainable development should be implemented in order to benefit local people and not only the global economic interests that develop in the shadows of tequila production.

In addition, it would be of paramount importance to promote visits to traditional taverns, where visitors could witness the early forms of tequila production. It would also be interesting and important to inform visitors and travellers, as well as the general population, of the different types of agave that can be used to obtain distilled beverages. Promoting knowledge of the distinct varieties of agave could be a nucleus that leads to the establishment of true ethnobotanical gardens based on scientific and cultural knowledge.

[41] See: http://sdt.unwto.org/content/about-us-5
[42] See: https://www.biospheretourism.com/es/blog/22-beneficios-del-turismo-sostenible/94

It is important to understand that plants are the most conspicuous el- ements of ecosystems; indeed, they constitute their very basis. This consideration is of the greatest importance in the case under study, because the following studies, research and activities could be fomented from botanical, ethnobotanical and alimentary culture perspectives: analyses of the plants that sustained the Mesoamerican alimentary system, of the plants that, aside from agave, contributed to the identity of the Agave Landscape, of the consumption of edible, wild plants, of recipes of traditional cooking, of the applications of medicinal plants, and of horticulture and the commercialization of ornamental plants.

In the same vein, it is key to improve our understanding of the ecological value of the 'dry', or deciduous, forest; a habitat that produces numerous plants that are utilized in Mexico and, more specifically, in the area examined herein. Such studies could be complemented by research on forest fauna. Similarly, we need to determine the diversity of species managed by farmers in the agroecosystems of the Santiago River Canyon, and the nature of their rain-fed or irrigated orchards and gardens, where a great variety of wild and cultivated plants can be found whose potential is not yet exploited. Finally, it would be worthwhile to collect edible, wild and medicinal plants that are native to these sites, as such initiatives would be of great pedagogical, gustative and culinary value.

Without question, the potential of a declaration granting the status of Heritage of Humanity –in our case, the Agave Landscape cultural landscape– presents many more aspects than just the disproportionate and discarnate economic benefits that may accrue to a few individuals, to the detriment of many others. Clearly, identifying and then promoting these other perspectives is feasible in the case analysed in this article.[43]

[43] NB. *A proposal*. The results of the author's research project on phytogenetic resources for alimentation in the Santiago River ravine include a database with 197 species of marginal wild and cultivated plants, grouped in 50 botanical families that represent 13 per cent of all alimentary species that exist in Mexico, according to estimates. Of these 197 species considered edible, over half (93) are trees and bushes, the most conspicuous part of the vegetation. These results can be incorporated into proposals for sustainable tourism projects, as mentioned (Tena et al. 2019)

7.8. References

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Capítulo 8 Discusión General

Capítulo 8. Discusión General

En las cuencas hidráulicas del centro y occidente de México, durante el periodo preclásico o formativo, el primer sedentarismo se dio a partir de las condiciones locales tales como: la presencia a corta distancia de nichos abundantes de pesca, caza y recolección, aunada a la de una condición hidrológica favorable a propiciar cuidados a los cultígenos proveedores de proteínas, el maíz y el frijol. Pequeños sangrados a los ríos, pequeños drenes, el riego a mano, ataron al cultivador a la tierra, lo obligaron a prescindir del itinerario estacional, a encontrar fórmulas para atraer y supeditar a los nómadas en el intercambio (Boëhm de Lameiras, 1998). En la zona centro del Estado de Jalisco, fueron los lagos y los ríos los que marcaron las rutas por las que viajaron las manufacturas, las materias primas, los conocimientos y las ideas, donde el Rio Santiago y sus afluentes jugaron un importante papel (López-Cruz, 2016; Cabrero, 1985; Cabrero, 2007).

La biodiversidad para la alimentación y la agricultura de una manera u otra contribuye a la producción agrícola y alimentaria, además de las especies domesticadas incluye a sus parientes silvestres y otras especies silvestres recolectadas para la obtención de alimentos y otros productos, y lo que se conoce como "*biodiversidad asociada*". La biodiversidad para la alimentación y la agricultura está disminuyendo, por lo que es necesario mejorar los conocimientos sobre la *biodiversidad asociada*, en particular sobre los servicios ecosistémicos que prestan (FAO, 2019).

El presente trabajo de investigación tiene como objetivo registrar los recursos fitogenéticos para la alimentación presentes en uno de los cañones del Occidente de México, la Barranca del Río Santiago (BRS). Hace apenas unas décadas el ecosistema de la Barranca del Río Santiago proveía de una dieta variada a los pobladores de la barranca, en el rio Santiago y sus afluentes permanentes se encontraban diferentes tipos de peces y crustáceos, el bosque proveía de una amplia variedad de productos alimenticios y en las parcelas agrícolas se obtenían maíz, frijol, chile y calabaza y diferentes tipos de quelites que enriquecían la dieta tradicional.

En esta Tesis, se tomó en cuenta el estado que guardan tanto los recursos silvestres que inciden principalmente en el Bosque Tropical Caducifolio (BTC), así como, los cultivares tradicionales con larga presencia en la región. Además de realizar el inventario de los recursos se evaluó la importancia de las especies silvestres en términos de su valor ecológico, económico y social; se modelo la distribución de *Malpighia mexicana* a nivel nacional y en particular para la BRS. Se realizó la evaluación agroecológica de dos cultivos de tradición centenaria en la zona de estudio, el cultivo de marginal *Spondias purpurea* y el cultivo industrial de *Agave tequilana*; vinculada a esta misma especie se analizó la actividad de la industria tequilera y el paisaje agavero en términos de sustentabilidad para la región.

8.1. Los recursos silvestres y cultivares tradicionales para la alimentación en la Barranca del Río Santiago

El inventario de los recursos fitogenéticos para la alimentación (RFA) realizado en la BRS permitió reconocer el alto potencial de la BRS en la producción de alimentos, reflejo de ello son los 196 taxones registrados, los cuales se encuentran por arriba del número de registros obtenidos en otras regiones afines (Rendón y Núñez, 1999; Gispert y Rodríguez, 1998; Lascurain, et al. 2010), cantidad que representa el 13% de las 1500 especies posibles con usos alimenticios estimados para todo el país (Casas, 2010), lo cual refiere al alto nivel de conocimiento que mantiene la población ranchera sobre los mismos.

En los registros obtenidos sobresalen 164 especies nativas del ámbito de la BRS (el Occidente Mesoamericano), de las cuales el 70% son silvestres, 24% son cultivadas y el 6% restante corresponde a taxones que comparten ambas categorías. Las especies introducidas son 32 y solo representan el 16% de los registros totales, de estas, tres cuartas partes corresponden cultivares introducidos desde épocas remotas y una cuarta parte corresponde a plantas asilvestradas.

La flora alimenticia están representadas 53 familias, sobresalen aquellas que son representativas del BTC de acuerdo con Pennington et al. (2000); Trejo (2010); Lot y Atkinson (2010); el mayor número de taxones comestibles corresponden a Fabaceae o Leguminosae, la cual que se caracteriza por poseer un gran número de plantas con alto valor nutricional (Caballero y Cortés, 2001). Las herbáceas silvestres nativas (22,8% del total) se reconocen como alimenticias desde tiempos remotos, mismas que han estado asociadas a los cultivos originarios que constituyen la base del sistema alimentario mexicano: maíz, frijol, calabaza, chile, nopales, agaves, ciruela mexicana. En la BRS estén presentes 25 de las 33 plantas que han sido reportadas por Zizumbo-Villareal, et al. (2014) como parte del Sistema

Alimentario durante el periodo formativo mesoamericano. El 16% de los RFA en la BRS corresponde a especies introducidas, la mayoría son frutales tropicales las menos son malezas acompañantes; la larga tradición de cultivo de *Cannabis*, en la zona como estupefaciente, podría ser útil ahora que en México se pretende utilizar las bondades de este cultivo para su uso en la industria textil, farmacéutica, cosmética y alimenticia.

El estado de conservación de estos recursos en la BRS es muy bajo para las especies silvestres debido a la eliminación de la vegetación original, en algunas zonas ha desaparecido: *Malpighia mexicana, Casimiroa sapota* y *Mastichodendron capiri*; el bosque de galería abundante en el río y sus afluentes han sido substituidos por huertas de mango y de otros frutales introducidos, eliminando a: *Brosimum alicastrum*, *Peperomia campylotropa, Piper auritum, Sideroxylon persimile,* entre otros. El estado de los RFA se relaciona con el manejo que dan los rancheros a los diferentes entornos de la BRS, uno de los más importantes es sin duda el huerto familiar, venido a menos por su conversión a espacios habitacionales y la escases de agua, este es atendido principalmente por las mujeres y aunque predominan en ellos las plantas ornamentales, se registraron 37 tipos de cultivares con uso alimenticio, una mezcla de plantas aromáticas introducidas y especies locales (chiles, nopales, y árboles frutales).

El cauce de río y las cañadas que forman sus afluentes representan un oasis durante la época seca y un remanso térmico durante el invierno, situación que los pobladores han aprovechado a lo largo del tiempo para el establecimiento de huertas de riego. En ellas se registraron 35 cultivares, de los cuales 18 son introducidos (plátano, mango, cítricos, café, entre otros) mezclados con 11 cultivares americanos (mamey, zapotes, aguacate, anonas, etc.). Desde tiempos pasados se ha reconocido a los magos barranqueños por sus cualidades organolépticas, anteriormente su producción abastecía diferentes poblaciones de la región y del país, ahora ante la competencia que ejercen otras zonas productoras muchas de las huertas se han abandonado o están siendo sustituidas por otros cultivos.

Los informantes reportaron que las plantas adventicias (ruderales y arvenses incluidas) se utilizan cada vez menos, se reportaron 23 especies, la mayoría son nativas y corresponden de manera general a aquellas especies consideradas como "quelites", consumidas desde tiempos inmemorables como parte de la dieta de los pueblos mesoamericanos. La diversidad en las huertas de secano se reduce a 16 especies casi la mitad de las huertas de riego, en estas prevalecen uno o varios cultivares de *Spondias purpurea*, dependiendo de la región se pueden encontrar otros cultivos perenes alimenticios como el *Agave tequilana*, *Bromelia plumieri*, *Opuntia* spp, y plantas silvestres como *Leucaena* spp., *Pithecellobium dulce* y *Mastichodendron capiri*.

El monocultivo de secano sólo se realiza en algunos escalones de la barranca donde existen terrenos planos (8% del total de la superficie) donde es posible utilizar tracción mecánica o animal para cultivos de 16 cultivares diferentes, prevalecen los de alto valor comercial como el *Zea mays* (para forraje) *Agave tequilana* y *Opuntia ficus-indica*, mismos que tienen altos costos de inversión, lo cual es una limitante para la mayoría de los agricultores.

Se registraron 10 taxones en el *cuamil* (sistema de cultivo tradicional), aun cuando los agricultores utilizan los mejores sitios para cultivar maíz, se trata por lo general de terrenos pedregosos con pendiente pronunciada, la siembra en conjunto de la triada alimenticia mesoamericana (maíz, frijol y calabaza) la realizan muy pocos campesinos. Se cultiva principalmente maíz para autoconsumo y para la venta de excedentes, sobre todo, cuando se trata de variedades locales (morado, pozolero) de amplia aceptación en el mercado local (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2010). Aun cuando los campesinos utilizan semillas mejoradas proporcionadas por programas de asistencia, una gran parte de los campesinos utiliza su propia semilla seleccionan en sus parcelas. Algo evidente en este tipo de ambiente es la reducción o casi eliminación de *quelites* debido al uso de herbicidas, lo cual priva a los campesinos de una fuente importante de alimento en las épocas previas a la cosecha; por otro lado el trabajo físico que requiere y el poco rendimiento económico que se obtiene, hace que este sistema ceda espacio al monocultivo de *Agave tequilana*.

El monocultivo de riego se realiza en terrenos planos donde se aprovechan los escurrimientos del río y sus afluentes, por ser predios de tamaño reducido no se pueden establecer plantaciones extensivas, en la zona de estudio son un par de cientos de hectáreas. En este sistema sólo se registraron siete recursos fitogeneticos con alta aceptación en el mercado como *Cucurbita pepo*, *Zea mayz* var. Elotero, *Capsicum annuum*, *Physalis philadelphica* y *Solanum lycopersicum*.

8.2. Árboles de la Barranca del Río Santiago para la alimentación y la sustentabilidad

Los bosques estabilizan el clima, apoyan y protegen la biodiversidad y mantienen a las comunidades. Las soluciones para proteger y gestionar los bosques, así como para restaurar tierras degradadas y deforestadas, pueden hacer que los bosques sean más valiosos para las personas y el planeta (UICN, 2019).

Los árboles silvestres representan una excelente fuente de nutrientes que puede contribuir a reducir el hambre y la desnutrición, no sólo durante periodos de escases (sequía, malas cosechas y escasez estacional de alimentos), si no también, pueden contribuir de manera proactiva a las necesidades dietéticas de las personas. Los arboles pueden ser una fuente importante en la producción de forraje para el ganado, cuando existe poca humedad en el suelo sus raíces profundas pueden extraer agua del suelo, reduciendo los impactos adversos ocasionados por el cambio climático (World Agroforestry, 2019)

En nuestro estudio se identificó en la BRS a las especies leñosas (árboles y arbustos) como el grupo de RFA más representativo (52% del total de registros) en comparación con las plantas herbáceas y otras formas de crecimiento con presencia escasa, lo que confirma el hecho de que los árboles son la expresión más conspicua de la vegetación y que estos son dominantes en el ecosistema de BTC. Es significativo que la mayoría de los árboles y arbustos registrados producen frutos comestibles de consumo directo por los humanos, al mismo tiempo que son ricos en proteínas con hojas y frutos comestibles para el ganado, y pueden usarse como suplementos forrajeros de alta calidad (Op. cit.).

La restauración mediante el uso de árboles es una de las estrategias más efectivas para la mitigación del cambio climático. Si no se cambia la trayectoria actual la cobertura potencial mundial del dosel puede reducirse en ~ 223 millones de hectáreas para 2050, con la mayor parte de las pérdidas en los trópicos; se tiene la oportunidad de mitigar el cambio climático a través de la restauración global de árboles de manera urgente (Bastin, et al. 2019). Es urgente detener la deforestación, estabilizar las fronteras agropecuaria y forestal, gestionar los bosques de manera sostenible y restaurar los bosques degradados (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2019).

Treinta de las especies arbóreas y arbustivas registradas con uso alimenticio presentes en la BRS, son consideradas por la FAO y la Comisión Nacional Forestal (2012) como especies prioritarias para la reforestación en México, de acuerdo a su importancia económica, ecológica y social; el 60% de estas son importantes desde el punto de vista ecológico y social por el valor social o servicio ambiental que representan, mismo que va desde el valor estético de la planta, la sombra que proporciona, la preservación del suelo y agua en zonas de recarga, recuperación de suelo, barreras vivas y barreras contra el viento, mejora de la fertilidad y preservación de la biodiversidad. El 73% de las mismas puede también contribuir a la seguridad alimentaria por sus frutos, semillas y otras partes comestibles, tienen usos medicinales, forrajeros, melíferos y se utilizan para producir fuego; al mismo tiempo que el 22% puede ser útil para reducir la pobreza debido a que se utilizan en la construcción rural, producen madera aserrada, aceites esenciales o gomas.

8.3. Potencial agroecológico de un cultivo marginal para el desarrollo y conservación de la Barranca del Río Santiago

El estado de Jalisco se ha consolidado en los últimos años como el gran productor de alimentos de México; alimentos básicos de consumo masivo en el país y alimentos y derivados de alta demanda en los mercados internacionales. Jalisco es sin duda el Gigante Agroalimentario de México (Padilla, 2017). No obstante que México es reconocido como centro de origen y de diversidad genética de un gran conjunto de plantas de importancia para la agricultura y la alimentación (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2019), y que específicamente el occidente de México es una de las áreas del origen genético y domesticación de *Spondias purpurea* (Miller and Schaal, 2005; Fortuny-Fernández et al. 2017; Zizumbo-Villarreal et al. 2014), esta especie se mantiene como un cultivo marginado pese a que se considera un frutal promisorio por ser una especie rustica adaptada a la sequía y ha suelos pobres (Cuevas, 1992).

Este trabajo cubre en parte la falta de información que existe sobre el cultivo de ciruela (871 ha) en una de las zonas productoras más importantes del país, en cuanto a su distribución actual y potencial al interior de la BRS y las condiciones agroclimáticas en que se encuentra, estas además de ser coincidentes con las reportadas por la literatura, son vinculantes con los aspectos siguientes: A) El occidente de México es centro de origen y de domesticación de la especie (Fortuny-Fernández, et al. 2017). B) El hábitat nativo de los progenitores silvestres de *S. purpurea* cultivado, son los bosques secos mesoamericanos

(Miller y Knouft, 2006). C) *S. purpurea* es considerado como un componente del estrato dominante del BTC (Rzedowski y Mc.Vaugh 1966; Rzedowski y Rzedowski 1999; Pennington y Sarukhán 2005).

Aun cuando toda la barranca reúne las condiciones óptimas para el cultivo, la experiencia de los agricultores les permite seleccionar los mejores sitios para el establecimiento de los siete cultivares registrados en este estudio para la BRS; la rusticidad de los árboles de ciruela permite a los campesinos. A diferencia de otras zonas del país este cultivo marginal esta poco estudiado en el occidente de México, es evidente la falta de asistencia técnica y la necesidad de generar información para mejorar las prácticas de cultivo, el manejo postcosecha de los frutos, dar valor agregado a la producción y establecer mejores canales de comercialización, ya que la mayor parte de los campesinos se encuentra a merced de los intermediarios.

El cultivo de ciruela Mexica en la BRS se encuentra amenazado por la agricultura intensiva la agroindustria del tequila, y por cambios en los hábitos alimenticios de la población de la barranca y de los centros urbanos donde se comercializa la fruta, ya que estos se encuentran abarrotados de frutillas (berries) importadas o producidas localmente con altos costos económicos y ambientales.

8.4. Un recurso silvestre nativo con potencial agrícola

Entre los 196 recursos fitogenéticos para la alimentación registrados en la BRS destaca *Malpighia mexicana*, una especie silvestre con una amplia tradición de uso alimenticio, medicinal, ornamental y como combustible; forma parte del grupo de arbustos tropicales de origen americano que producen frutos rojos comestibles, conocidos como Acerola (*M. glabra* y *M. emarginata*), la cual se considera la fuente natural más importante en el mundo de ácido ascórbico para la industria de los alimentos, cosmética y farmacéutica (Johnson, 2003).

Aun cuando *M. mexicana* es conocida desde tiempos prehispánicos (UNAM, 2009), esta no ha sido estudiada por completo, en comparación con sus especies afines, de las cuales existen variedades comerciales mejoradas. Se conoce que *M. mexicana* se distribuye en México en el bosque tropical deciduo (Rzedowsky y Mc. Vaugh, 1966) y que la planta crece silvestre en climas templados y es cultivada fuera de su área de distribución (Maldonado et.al. 2016; Ecosur, 2015), también se encuentra como cultivo marginado. De acuerdo con los pobladores de la BRS *M. mexicana* abundaba y se consumía ávidamente en épocas pasadas, incluso se comercializaba en la ciudad de Guadalajara; razón por la cual se estudió su distribución actual y potencial en México y en la BRS. El modelo de distribución mostró una clara preferencia de la especie por los bosques tropicales secos, siendo la depresión del Balsas y la región de los valles centrales de Oaxaca las zonas más extensas y con los valores más altos de probabilidad de presencia de la especie, en la región occidente aunque con menor superficie también se presenta los valores altos de probabilidad, como es el caso de la región de los cañones del río Santiago que se encuentran cubiertos de BTC.

Al igual que en el resto de las Selvas Secas del Pacífico Mexicano en la BRS la ganaderización (conversión a praderas), la conversión del BTC en sistemas agrícolas de temporal, la extracción irracional de productos y, la creación y crecimiento de asentamientos humanos, son las principales amenazas del habitat de *M. mexicana* (Maass et al. 2010).

8.5. Potencial agroecológico de un cultivo industrial nativo en la Barranca del Río Santiago

Aun cuando la distribución del cultivo del *Agave tequila,* que se utiliza para la elaboración del tequila, se encuentra acotada por la denominación de origen de la bebida, la mayor parte de la producción de la materia prima se produce en el estado de Jalisco, la zona con mayor antigüedad corresponde a los municipios de Amatitán y Tequila, los cuales cubren casi la totalidad (96%) de la superficie (1,017.58 ha) cultivada con *A. tequilana* en la BRS.

Entre los requerimientos agrologicos considerados como óptimos para el cultivo se encuentran los climas templados a semi-cálidos (Ruíz-Corral, et al. 2002; Valenzuela, 2003; Ruíz-Corral, et al. 2013), el clima cálido que prevalece en el cañón convierte a éste en una zona marginal para el establecimiento del cultivo (Pimienta-Barrios, et al. 2006). No obstante lo anterior, la declaratoria de la UNESCO del Paisaje Agavero como Patrimonio Cultural de la Humanidad, incluye más de 18 mil Has de la BRS.

Al tratarse de un cultivo industrial se utilizan gran cantidad de agroquímicos en una zona de alta fragilidad ambiental como es la BRS, por lo que es necesario transitar a un sistema agroecológico que contribuya a la sustentabilidad del ecosistema barranqueño. De igual manera deben de rescatarse o ser reintroducidas las distintas especies o cultivares de agave utilizados en antaño para la producción de mezcal, lo cual ampliaría la oferta de destilados y se rescataría el conocimiento biocultural sobre los mismos.

8.6. Patrimonio, sustentabilidad y turismo del paisaje agavero

Dadas las características orográficas de la BRS las actividades productivas viables para desarrollar son: praticultura limitada y moderada en el 47% de su superficie y, praticultura intensa y actividad agrícola de manera moderada e intensa en el 8%; el 45% restante debe de dedicarse a la conservación de la vida silvestre (INEGI, 1974), incluyendo las actividades productivas que sean compatibles con este propósito. Contrario a lo anterior, el BTC (vegetación dominante), fue trasformado por la ganadería y las actividades agrícolas a vegetación secundaria arbustiva en un 31,7% de su superficie, el 12,1% cambio a pastizal y el 11,4% cedió ante la agricultura de temporal permanente, quedando solo el 27,5% de la superficie original de este tipo de vegetación (INEGI, 2016). Tomando en cuenta lo anterior y el hecho de que la zona de estudio, está inmersa en la zona de origen de la industria del tequila y del potencial turístico del paisaje agavero, resulta pertinente la mejora de la calidad de la oferta turística desde una perspectiva sostenible.

De acuerdo con la definición de la Organización Mundial del Turismo,[44] el turismo sostenible es aquel que tiene en cuenta «las repercusiones actuales y futuras, económicas, sociales y medioambientales para satisfacer las necesidades de los visitantes, de la industria, del entorno y de las comunidades anfitrionas». Gracias a la diversidad de relaciones implicadas en tal actividad, el turismo sostenible tiene la capacidad de actuar como catalizador del cambio social: por medio de él se puede combatir el hambre, promover la paz y la seguridad, así como propulsar a las economías locales.[45]

Por lo que los estudios, investigaciones y actividades productivas podrían fomentarse desde las perspectivas de la cultura botánica, etnobotánica y alimentaria; se podrán abordar desde la arqueología y la historia la fundación del sistema alimentario mesoamericano y su transformación hasta nuestros días; incursionar en las bebidas alcoholicas no destiladas (pulque, tejuino, vino de ciruela, tepache); incluir como parte del paisaje agavero aquellas

[44] Véase http://sdt.unwto.org/es/content/definicion
[45] Véase http://www.biospheretourism.com/es/blog/22-beneficios-del-turismo-sostenible/94

plantas que destacan por ser: arboles majestuosos (Higueras, parotas, capomos), por ser plantas comestibles, medicinales u ornamentales.

8.7. Situación General de los recursos fitogenéticos para la alimentación en la Barranca del Río Santiago

La diversidad biológica de México sorprende por el número de especies y el numero endemismos, la variedad de sus ecosistemas y el hecho de ser uno de los centros mundiales de domesticación de especies y de contar con un gran patrimonio biocultural se manifiesta en el uso tradicional de siete mil especies vegetales de las cuales unas 1000 a 1500 tienen uso alimenticio (Caballero 1987, Casas, 2010).

En la BRS predomina el BTC que es el tipo de ecosistema tropical mejor representado en México, el cual es una variante del gran bioma que son las selvas tropicales, el cual alcanza su distribución mundial más norteña en el Occidente de México (Dirzo y Ceballos, 2010), en el Estado de Jalisco el 21,8% de su superficie corresponde selvas cálido secas (INEGI, 2019), este tipo de vegetación proporciona a los pobladores de la BRS diferentes servicios ecosistemicos, prueba de ello son los 196 registros obtenidos en el presente estudio que representan una posibilidad para que los pobladores de la misma obtengan algún tipo de alimento.

Al ser la BRS una zona marginal de bajo potencial productivo por su topografía escabrosa, la desigualdad en el tamaño de los predios (la propiedad social es pequeña y la privada es grande) y la falta de créditos, constriñen a muchos de sus pobladores a practicar la agricultura de subsistencia, a la par que trabajan como jornaleros o realizan otros trabajos temporales fuera de la barranca; las actividades agropecuarias propician la expoliación de los recursos naturales y del conocimiento que tienen la población de los mismos. La existencia de áreas naturales protegidas y la declaratoria por parte de la UNESCO del Paisaje Agavero y las Antiguas Instalaciones Industriales de Tequila, como patrimonio cultural de la humanidad, no significan beneficio alguno en términos de la sustentabilidad de los ecosistemas, por el contrario, se han contaminado las aguas, se propicia la ganadería extensiva, y la sustitución de cultivos marginales de larga tradición por cultivos industriales que utilizan una gran cantidad de agroquímicos.

Por otro lado se reconoce que la investigación agrícola se ha enfocado a nivel mundial en aumentar los rendimientos de solo algunos cultivos que son los principales proveedores de calorías, poniendo poca atención para proporcionar micronutrientes cruciales, los cuales son abundantes en las plantas silvestres comestibles y en los cultivos huérfanos o marginados, los cuales están bien adaptados a los entornos y culturas locales, son nutritivos y ricos en vitaminas, minerales esenciales y otros micronutrientes importantes para dietas saludables (Jamnadass et al, 2020). En ese sentido en la BRS destaca la presencia especies silvestres con alto potencial, tales como *Brosimum alicastrum* y *Malpighia mexicana*, la primera sobresale por ser una especie promisoria por su alto valor nutricio, además de ser medicinal, maderable y forrajera; la segunda se considera también una planta subexplotada con un promisorio valor económico ya que sus frutos contienen cantidades similares de vitamina C al de cultivares afines.

La causa más importante de transformación y pérdida de la diversidad biológica, ha sido a lo largo de la historia la producción/obtención de alimentos para los humanos, por lo que, las políticas y las formas en que se decidan obtenerlos /producirlos en las siguientes dos o tres décadas, definirán el grado de conservación –ó destrucción− de los ecosistemas naturales (Sarukhán, 2018).

La vocación natural de la BRS solo permite desarrollar la praticultura y la protección de la vida silvestre (INEGI, 1974) para los cual son de primera importancia las 93 especies de árboles y arbustos registradas para la BRS como especies alimenticias, 30 de las cuales son consideradas como prioritarias para la reforestación del 32% de la barranca para favorecer el restablecimiento del BTC.

Tomando como punto de partida lo anterior y considerando el uso de suelo y vegetación reportado por el INEGI (2016), los resultados de la presente investigación podrán ser utilizados para recuperar el 72,5% de la cobertura original del BTC de la BRS; en la superficie (31,7%) transformada por la ganadería y las actividades agrícola en vegetación secundaria arbustiva y en aquella utilizada para el establecimiento de pastizales (12,1%) se podrían implementar practicas agroecológicas con enfoques agro-silvo-pastoril donde se incluyan arboles con uso alimenticio para la población y para los animales, que ayuden a la conservación del suelo y su fertilidad, que proporcionen sobra al ganado y que sean utilizados como cercos vivos (*Acacia farnesiana, Brosimum alicastrum, Enterolobium cyclocarpum,* *Guazuma ulmifolia, Leucaena esculenta*, *L. leucocephala, Mastichodendron capiri, Prosopis laevigata, Spondias spp)*.

A la par con las acciones de remediación y de recuperación del entorno natural, la actividad productiva en general debe de ser retomadas en el marco de la sustentabilidad a partir de los ejes siguientes: 1) La belleza escénica del paisaje barranqueño 2) la riqueza biológica de la barranca y, 3) La cultura del estilo de vida ranchero. Debe de manejarse el pago de servicios ecosistémicos que presta la barranca y promover de manera conjunta con la población local unidades de manejo ambiental para protección de la vida silvestre, para la caza y la pesca sustentable, el senderismo y la observación de la naturaleza; así como el turismo rural basado en la gastronomía autentica de la región, la producción de bebidas fermentadas y destiladas, la herbolaría.

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Capitulo 8. Conclusión General

CAP. 8. CONCLUSION GENERAL

1. Esta investigación ha logrado los objetivos generales señalados en los objetivos específicos de cada capítulo, aportando información original con respecto al *conocimiento tradicional y la situación en que se encuentran los recursos fitogenéticos para la alimentación en la Barraca del Río Santiago*, por lo que este trabajo es un referente importante para el reconocimiento del patrimonio biocultural del estado de Jalisco.

2. Se confirma la hipótesis de que las poblaciones rancheras (mestizas) en el occidente de México poseen al igual que las comunidades indígenas (donde más han prosperado los estudios etnobiologicos en México), una visión propia de su entorno natural, rico y diverso con respecto a los recursos fitogenéticos para la alimentación.

3. En la zona de estudio (72,338 ha), existe un importante deterioro ambiental ocasionado por la sustitución del bosque tropical caducifolio y la contaminación de la cuenca del Río Santiago, a pesar de ello, en este trabajo se registra la presencia y el reconocimiento que la población local hace de 196 vegetales como recurso alimenticio. Estas especies contribuyen a mantener de manera sustentable una dieta diversa y saludable.

4. 30 especies son cultivos marginales que pueden significar un papel importante para la preservación de los ecosistemas y la mejora de la economía de las comunidades rurales de la zona de estudio.

5. El hecho de que el 52% de las plantas registradas sean árboles y arbustos nativos respaldan la vocación que tiene la barranca para ser utilizada para la conservación de la vida silvestre y el aprovechamiento de recursos forestales no maderables, así como el desarrollo de actividades agrícolas con perspectiva sustentable.

6. Al menos 30 especies leñosas se encuentra reconocidas por la literatura como prioritarias para la reforestación, lo cual se considera como una de las estrategias más efectivas para contrarrestar el cambio climático.

7. La ciruela mexicana *Spondias purpurea*es es la especie arbustiva con mayor antigüedad de uso en la Barranca del Río Santiago, y su cultivo tradicional es considerado como marginal (autóctono, huérfano, subutilizado). De acuerdo con la caracterización agroclimática realizada, la Barranca cubre de manera amplia los requerimientos agroclimáticos de la especie, en esta se producen desde hace décadas entre el 60 y el 85% de la producción estatal. Un aporte adicional de este trabajo es el registro de 7 cultivares en la zona de estudio que requieren ser caracterizados y conservados en bancos de germoplasma, también se detectaron graves problemas de plagas, de manejo de postcosecha y comercialización.

8. Se registró durante la exploración etnobotánica la presencia y consumo tradicional de los frutos de *Malpighia mexicana*, los cuales contienen cantidades de ácido cítrico similares al cultivo de la acerola, por lo que se considera a esta especie como un excelente candidato para su estudio y promover su uso y conservación. Ante la falta de trabajos relativos a su distribución, pudimos determinar que a nivel nacional la mayor probabilidad de ocurrencia corresponde a la distribución de las selvas cálido secas en la depresión del Río Balsas y que en el occidente de México las probabilidades altas se intercalan con zonas de probabilidad media, estas coinciden de manera puntual en la Barranca del Rio Santiago, lo cual se pudo corroborar con observaciones y colectas realizadas durante el trabajo de campo.

9. Existen altas probabilidades de que el cultivo tradicional de *Agave tequila* y la elaboración del tequila pudo haberse originado en el interior de la barranca, razón por la cual se incorporaron 18127,43 ha de la zona de estudio a la declaratoria otorgada por la UNESCO de *El Paisaje Agavero y las Antiguas Instalaciones de Tequila*, lo que ha propiciado el cultivo industrial al interior de la barranca. El estudio agroecológico realizado de la Barranca, demuestra que la Barranca no reúne las condiciones térmicas óptimas para lograr altos rendimientos en la producción de los azucares necesarios que se requieren para la elaboración de la bebida; no obstante los agricultores consideran que el cultivo es productivo dadas las condiciones del mercado.

10. Entre los campesinos de la zona de estudio y de los valles colindantes, existe una percepción vaga y superficial del significado de la declaratoria de la UNESCO, desconocen sus límites territoriales y consideran que son pocos o nulos los beneficios obtenidos de la misma. Aunque el propósito de la declaración incluye preservar y demostrar la transformación de un paisaje natural como es la Barranca del Río Santiago a un paisaje modificado por el hombre mediante la siembra de agave y el patrimonio industrial de las antiguas fábricas de tequila. Lo que se tiene a 14 años de la declaratoria, es un ambiente natural degradado y transformado en un sistema de producción industrial, insostenible en cuanto a la perdida de la biodiversidad y la contaminación de los campos de cultivo y de las aguas superficiales por el uso excesivo de agroquímicos y el depósito de desechos urbanos e industriales. La actividad turística se limita a la oferta que generan y concentran las grandes industrias, dejando poco espacio para los emprendedores locales.