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The Marceño Agroecosystem: Traditional Maize Production and Wetland Management in Tabasco, Mexico

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Abstract: The *marceño* agroecosystem is based on traditional agriculture in the flooded areas of the alluvial plains of Tabasco, Mexico. In the *marceño* system, the native maize, called "*mején*", is cultivated during the dry season using residual soil moisture. At physiological maturity, *mején* is tolerant to flooding. To estimate the potential area where *marceño* may be implemented, we characterized and defined the areas where it is practiced, using geographic information systems (GIS), and determined the bioclimatic variables of the sites where 16 species of wild plants associated with the management of the *marceño* grow. We also analysed areas of agriculture and livestock in relation to the cyclical floods. This information was used to generate a probability model of *marceño* occurrence through MaxEnt, which was superimposed on an elevation model (LiDAR) geoprocessed with GIS. The *marceño* was observed in 203 localities across eight municipalities of Tabasco (~2% of the state area), at elevations of 1–7 m. The calculated area with potential for implementation of the *marceño* is about 18.4% of the state area. The implementation of this agroecosystem on a wider area might be an alternative for local agriculture development and a strategy for ecological conservation and restoration of wetlands.

Keywords: *mején* maize; Maya Chontal; *Thalia geniculate*; biocultural landscape; agroecosystem; wetland

1. Introduction

Currently, there is a primary need worldwide to develop strategies for agriculture and the adaptation of smallholders to global climate change (GCC), in order to reach the goal of increasing food production by 50% by 2030, as proposed by the Food and Agriculture Organization (FAO) [1]. The adverse effects of GCC will be more severe in regions where millions of people depend on subsistence agriculture and are more vulnerable to food insecurity [2]. The increased frequency of severe weather events will have drastic consequences for agricultural production [2,3]. Lowlands can be highly productive in several countries around the world but require particular attention in order to understand their dynamics and risks, and the ways to prevent and respond to these risks. In Tabasco, Mexico, nearly 62% of people are highly marginalised and 45% have limited access to food, with their economy depending on subsistence farming [4,5]. Promoting productive practices that guarantee sufficient and diversified goods without irreversible deterioration of wetland ecosystems is therefore a priority [2].

Wetlands represent nearly 6% of the ecosystems worldwide [3,6]. Nevertheless, on a global scale, wetlands provide about 40% of global ecosystem services related to protection against floods, storm water retention, water quality enhancement, freshwater fisheries, food chain support, feeding grounds for juvenile marine fish, biodiversity maintenance, carbon storage and climate regulation [7,8]. However, these areas have been damaged by altering the hydrological and ecological watershed conditions of the basins due to agricultural and livestock expansion, as well as the effects of urbanisation on the hydrological system and contamination of water [7]. These activities require drainage of marshes or soil tillage, which result in negative environmental effects. This has increased interest in appropriate wetland management and its restoration [9,10].

Currently, recession agriculture is globally practiced in flooding areas in alluvial river plains, on lake margins and in other wetlands where water level changes are predictable. The overflow of the rivers promotes the seasonal deposition of sediments that increase fertility, which has been used in agriculture at the borders of several rivers such as the Nile, Euphrates, Tigris, Rhine, Danube, Po, Yangtze, Ganges, Mekong, Mississippi, Amazonas, and others. In flood recession agriculture, the water table falls during the dry season, which allows the residual moisture and natural fertility of the soil to be exploited, making high agricultural productivity possible. The crops are harvested before the rainy season, when the seasonal flood cycle of the wetlands starts [7,11]. Flood recession agriculture systems, such as recession sorghum in the Senegal Valley [12], the ponds of Dombes in France [13], and recession rice growing in Madagascar [14], are examples of the traditional use of wetlands for agriculture.

In Mexico, the polyculture (maize–bean–squash) *milpa* system is managed in a variety of environments and topographic conditions involving irrigation or rain-fed agricultural systems [15]. In areas with periodic or permanent flooding dominated by wetland ecosystems, the *milpa* system is practiced in raising fields such as the *chinampas* and the *calal* systems in the Valley of Mexico [16,17], on the flooded banks of the Huazuntlán and Coatzacoalcos Rivers (both in the Coatzacoalcos Basin), where the systems are called *tlapachol* and *chamil*, respectively. They are both situated on the coastal plain of the Gulf of Mexico [18] and in the *tecallis*, on the banks of the Balsas River on the Pacific Coast of Mexico [19,20].

On the alluvial plains of Tabasco in the south-eastern Gulf of Mexico, the farming system *marceño* is a tropical *milpa* system, practiced as a traditional strategy of recessive flood agriculture [21]. The Maya Chontal farmers practice the *marceño* agricultural system as part of a general strategy of natural resource management, but in this study, we focus on the agroecosystem management and its actual and potential importance. This management system aims to modify and domesticate the landscape, without drastically altering the natural hydrological and ecological processes of flood-prone areas [22–24]. The Maya Chontal wetland management of the *marceño* agroecological system has tangible and intangible cultural and natural components, which shape the biocultural landscape of the Tabasco lowlands [25], as well as the food production and ecology of the lowlands in farming units. The alluvial plains of Tabasco are at an elevation of 0–5 m above sea level (a.s.l.), and are drained by numerous rivers, marshes, and lagoons. These plains are regularly flooded, forming temporary swamps and alluvial deposits. The *marceño* (*cultivo de bajiales*) agricultural system is appropriate for such an ecologically dynamic situation. In the Chontalpa region of Tabasco, maize and squash are therefore cultivated in the dry season (March–June) on these saturated wet soils [21,26,27]. Typically, the native maize variety, called *mején*, is cultivated because it is well adapted to germinate in moist soils during the dry season, and it matures in 2.5–3.5 months, evading drought and flooding [27,28]. The *mején* maize yields about 4.5 ton ha^{-1} of grain and about 15 ton ha^{-1} of stems used as fodder [21]. The natural vegetation is associated with emerging hydrophytic plants, dominated by *Thalia geniculata* L. (locally called *popal*, which is 1–3 m in height) (Figure 1).

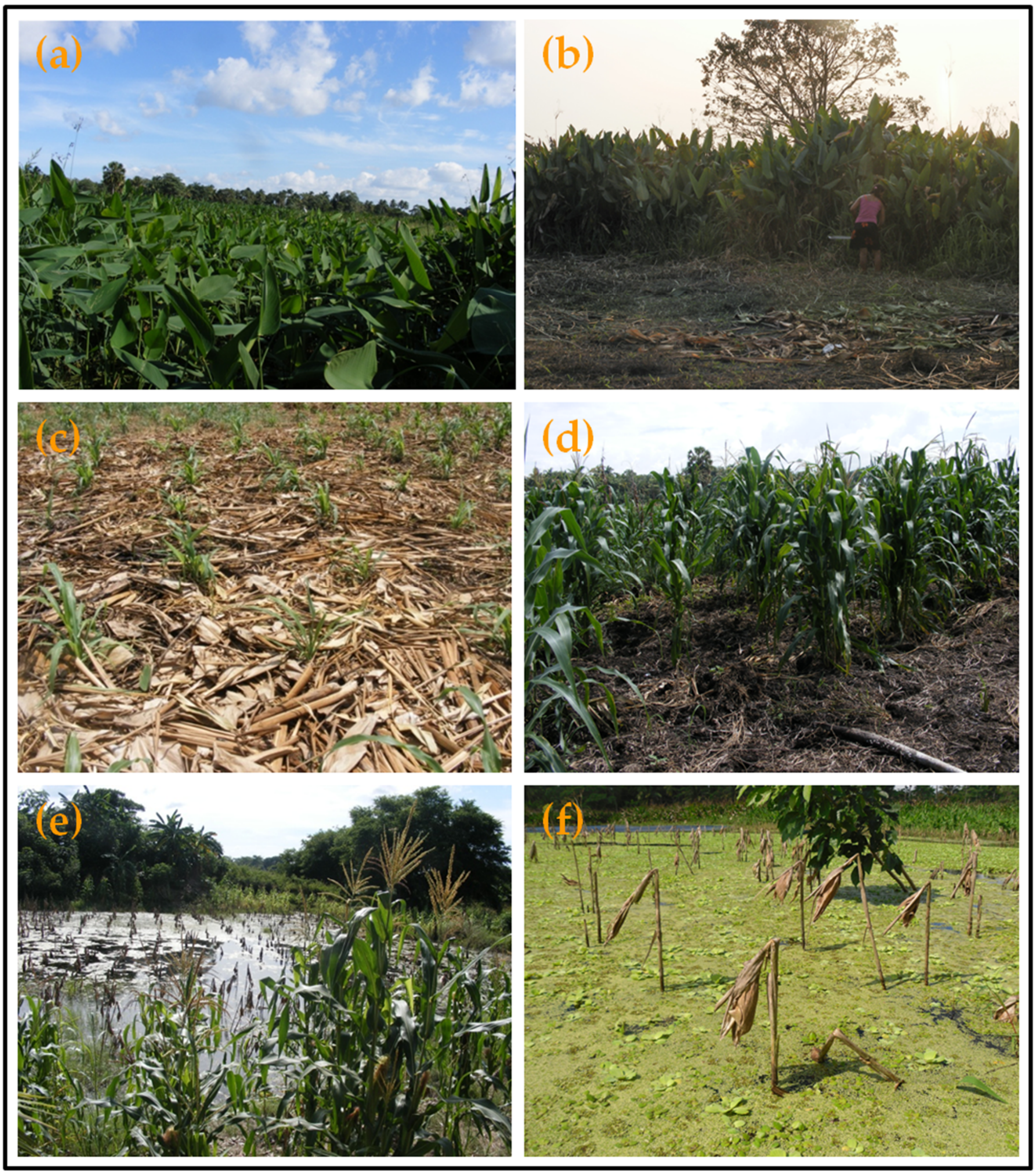

Figure 1. Crop cycle of the *marceño* agroecosystem: (**a**) Popal vegetation dominated by *Thalia geniculata*; (**b**) *T. geniculata* is cut at the beginning of the dry season; (**c**) seedlings of *mején* planted among the *popal* mulch; (**d**) *mején* maize plants; (**e**) corn at physiological maturity of grains (grains full and moist), at the beginning of the rainy season; (f) initial reestablishment of aquatic plants.

To promote the conservation of highly native varieties of maize, beans, and squash in the *marceño* agroecosystem, and to promote the maintenance of wetlands and their ecosystem services, the aims of this research were: (1) To characterize the *marceño* system environment, (2) to identify the localities where the system is practiced, and (3) to estimate flood-prone areas where this agroecosystem may potentially be implemented.

2. Materials and Methods

2.1. Study Sites

This study covered eight municipalities of the alluvial plain of Tabasco, at elevations of −2 m to 15 m a.s.l. that are prone to cyclical flooding: Cárdenas, Huimanguillo, Comalcalco, Cunduacán, Jalpa de Méndez, Nacajuca, Centla, and Jonuta (Figure 2). Tabasco is located in the basin of the Papaloapan, Grijalva-Mezcalapa, and Usumacinta Rivers, in the south of the Gulf of Mexico [26]. They form a complex net of deltaic channels interconnected with lakes, seasonal wetlands and marshes, which are interconnected from September to February. Moreover, 96% of the territory of Tabasco is on the coastal alluvial plains of the Gulf of Mexico [29]. The climate is warm–humid [30], with high precipitation during summer months, and an annual mean rainfall of 1500–2980 mm. Annual mean temperature during the dry season (March to June) is 25–30 °C. Before the middle of the 20th century, the area was about 50% covered by permanent and semi-permanent wetlands [26,28,29] and most of the remaining area was covered by tropical rainforests. Currently, only relics of these ecosystems exist because of anthropic disturbances, such as expansion of the agricultural and livestock frontier and the construction of dams [28,29]. Other relevant vegetation types are flooded rain forest, savanna and mangrove forest [29,31]. The soils in this area are vertisol, gleysol, cambisol, arcisol, luvisol, and fluvisol [32].

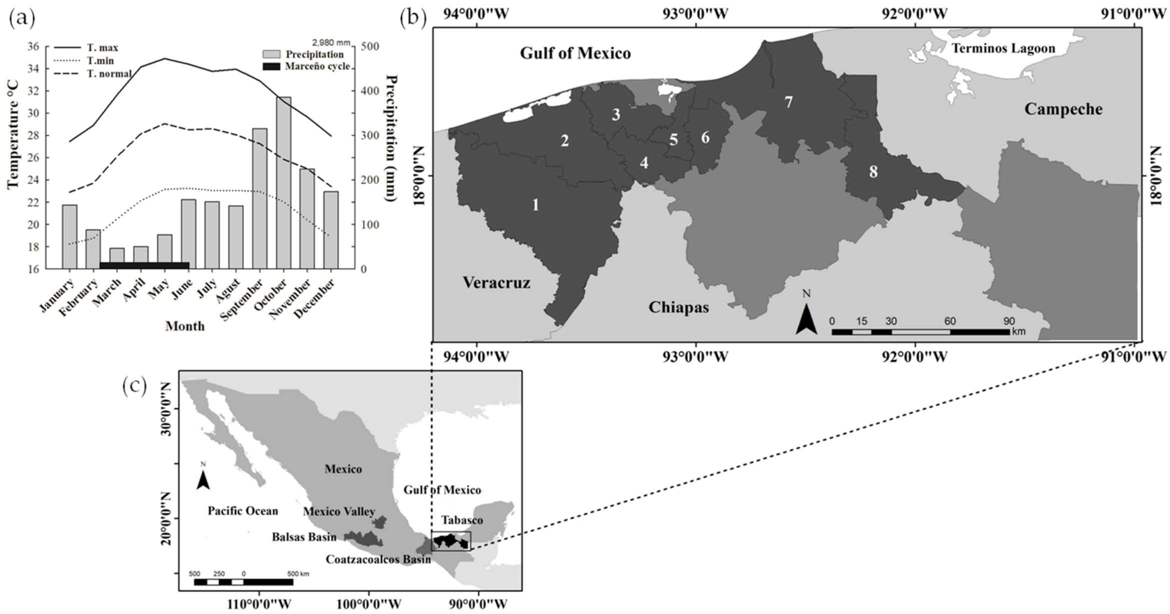

Figure 2. Location of the state of Tabasco: (**a**) Ombrogram of the study area, (**b**) the municipalities studied: 1. Huimanguillo, 2. Cárdenas, 3. Comalcalco, 4. Cunduacán, 5. Jalpa de Méndez, 6. Nacajuca, 7. Centla and 8. Jonuta; (**c**) the Mexico Valley and the Balsas and Coatzacoalcos Basins are also indicated.

2.2. Locating the Localities Where Marceño is Currently Practiced and the Potential Area for Its Implementation in Tabasco

We reviewed the literature about the *marceño* system [21,27,28,33,34], as well as the data from the census of the Department of Agricultural Development of the municipality of Comalcalco and all areas reported that use the *marceño* agroecosystem in the flood-prone areas of Tabasco (Figure 2). To determine the localities that currently practice the *marceño* system, we undertook fieldtrips to identify the plots practising it and characterized the environment around the plots, including aquatic vegetation types, known locally as *popales* and *tulares* (vegetation dominated by *Thalia geniculata* L. and *Typha domingensis* Pers, respectively) [21]. Additionally, we verified the practice of the *marceño* system in 80 plots within eight municipalities (Figure 2). These plots were georeferenced with a Global Positioning System (GPS, Garmin e-trex 30, Kansas, USA). The presence of the *marceño* system was confirmed by the smallholders of the plots, who were also asked about the characteristics of the agroecosystem, particularly the flooding regime of the system.

2.3. Modelling the Potential Distribution of Plant Species Associated with the Agroecosystem Using MaxEnt

A model of the potential distribution of plant species associated with the *marceño* agroecosystem for the coastal plain of Tabasco was built as follows: (1) We included the plant communities associated with the agroecosystem located and georeferenced in the field and the historical occurrence of the 16 most frequent aquatic perennial herbs and tree species, both related to the agroecosystem and to the flood-prone areas of the alluvial plain of Tabasco [21] (Table 1); we also included the plant records for the Pacific and the Gulf coast of these species (a total of 3124 records, derived from the Global Biodiversity Information Facility website [35]). (2) We obtained 19 bio-environmental variables (Table 2) from the Bioclimas Neotropicales website [36] updated for Mexico, which compiles monthly climatic layers for the interval 1910–2009 (Table 2). We elaborated the model using the MaxEnt (Maximum Entropy Species Distributions Modelling, Version 3.33k [37]) algorithm that uses the function of minimum entropy to calculate distribution probabilities [38–40]. In this study, we only included the probabilities calculated for the state of Tabasco.

Table 1. List of species, family and number of occurrences used for the distribution modelling of the *marceño* agroecosystem.

Species	Common Name	Family	Occurrences
Cladium jamaicense Crantz	*Cerillo, sibal*	Cyperaceae	236
Cyperus articulatus L.	*Chintul*	Cyperaceae	377
Echinochloa crus-pavonis (Kunth) Schult.	*Camalote de agua*	Poaceae	65
Eleocharis cellulosa Torr.	*Junquillo*	Cyperaceae	47
Erythrina fusca Lour.	*Colorin*	Fabaceae	10
Haematoxylum campechianum L.	*Tinto*	Fabaceae	485
Hibiscus striatus	*Malva*	Malvaceae	10
Jacquinia aurantiaca W.T. Aiton	*Jaboncillo*	Primulaceae	207
Pachira aquatica Aubl.	*Zapote de agua*	Malvaceae	431
Panicum hirsutum Sw.	*Pelillo*	Poaceae	35
Phragmites australis (Cav.) Trin.	*Carrizo*	Poaceae	10
Sagittaria lancifolia L.	*Cola de pato*	Alismataceae	231
Salix humboldtiana Willd.	*Sauce*	Salicaceae	209
Scleria macrophylla J. Presl & C. Presl	*Navajuela*	Cyperaceae	30
Thalia geniculata L.	*Popal, hojilla*	Marantaceae	406
Typha domingensis Pers.	*Tule, nea*	Typhaceae	335
		Total	3124

Table 2. Climatic variables used in the modelling of the potential distribution of thirteen wild species related to the *marceño* agroecosystem based on Bioclimas Neotropicales [36].

Bioclimate Variable	Units	Bioclimate Variable	Units
B1 = Annual mean temperature	°C	B10 = Mean temperature of warmest quarter	°C
B2 = Mean diurnal range (mean of monthly (max temp—min temp))	°C	B11 = Mean temperature of coldest quarter	°C
B3 = Isothermality (B2/B7) × 100	°C	B12 = Annual precipitation	mm
B4 = Temperature seasonality (standard deviation ×100)	°C	B13 = Precipitation of wettest month	mm
B5 = Max temperature of warmest month	°C	B14 = Precipitation of driest month	mm
B6 = Min temperature of coldest month	°C	B15 = Precipitation seasonality (coefficient of variation)	mm
B7 = Temperature annual range (B5-B6)	°C	B16 = Precipitation of wettest quarter	mm
B8 = Mean temperature of wettest quarter	°C	B17 = Precipitation of driest quarter	mm
B9 = Mean temperature of driest quarter	°C	B18 = Precipitation of warmest quarter	mm
		B19 = Precipitation of coldest quarter	mm

2.4. Generating the Terrain Elevation Model

To generate the digital model of terrain elevation (−2.96 to 1146.25 m) for the state of Tabasco, we processed LiDAR images with ArcMap 10.2.1 Arc Gis Esri (1360 images in GRID format, E-15 region [41]). The horizontal resolution was 5 m. These models did not include infrastructure and vegetation in order to identify the localities that used the *marceño* agroecosystem. We used this model of terrain elevation to locate low elevation areas (0–7 m) in order to determine the areas subject to flooding and with potential to implement the *marceño* system.

2.5. Modelling the Potential Areas for the Marceño Agroecosystem

For this estimation, we included areas with both agriculture and pastures that naturally have floods and are therefore susceptible to productive reconversion to *marceño*.

We used the SIG ArcMap software to geoprocess the following information: (1) To determine the flood-prone areas with elevations from 0 to 7 m, we used LiDAR images of terrain elevation [41]; (2) to identify flood-prone areas with agricultural and cultivated grass pastures, and to discard preserved areas with aquatic vegetation (marshes, mangroves, flooded rain forest, and permanently flooded areas), rain forest areas, natural protected areas, urban areas, infrastructure, and drained areas with elevations of 18–1146 m, we used the layers of soil—gleysol and vertisol (silty-clay with poor drainage and high organic matter content)—and vegetation [32,42]; (3) we used the layer of highest probabilities of distribution of plant communities associated with the *marceño* system (as generated in Section 2.3); (4) we also added a layer with the location of the Maya Chontal population, with the data collected from [43]; (5) we superimposed all five layers to determine the areas with potential to use the *marceño* agroecosystem including the pasture areas with potential for reconversion to agriculture, the ethnic origin of the population and their influence area (biocultural region [25]).

3. Results

Location of the Marceño Agroecosystem in the State of Tabasco

We located the presence of the *marceño* system in the field in 203 localities in the eight municipalities of Tabasco, particularly in Comalcalco, Nacajuca and Cunduacán (Table 3). According to the elevation model of the terrain (LiDAR), these localities are at elevations of 1−7 m with high precipitation (≥2980 mm). This high precipitation causes cyclic floods that maintain the seasonal swamps and other areas used for extensive cattle raising (Figure 3, Table 3, Table 4, and Table A1).

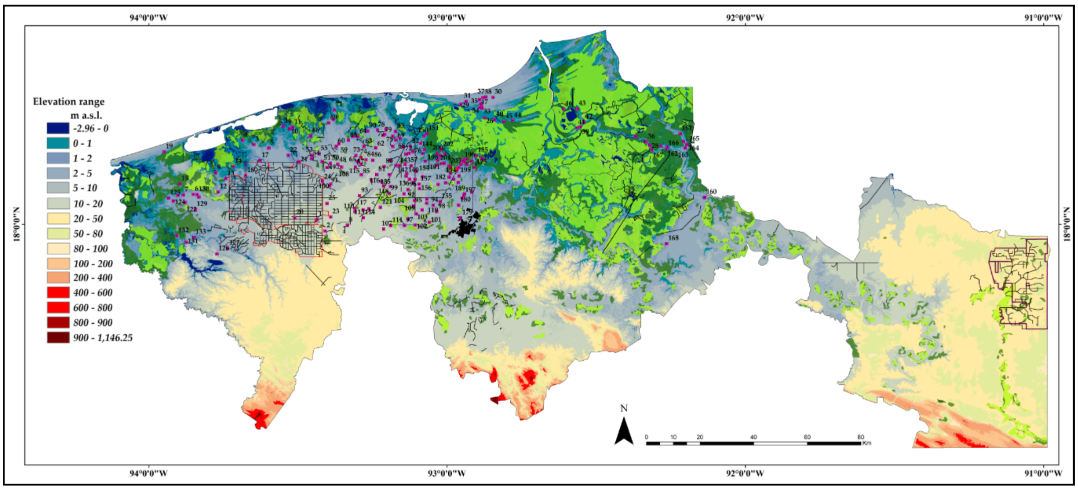

Figure 3. Map of the elevation of the terrain (−2 to 1146.25 m, see Table 4) and locations of the Tabasco localities, where the practice of the *marceño* agroecosystem occurs nowadays (■), aquatic vegetation patches of *popal* (■) and *tular* (■), drain channels (–) with Plan Chontalpa (–) and Plan Balancan-Tenosique (–), Villahermosa city (■).

Table 3. Municipalities, number of localities (L), and elevation range (TER) where the *marceño* was located in Tabasco, Mexico. Total population (TP), indigenous population (IP), and percentage of indigenous population for each municipality (IP%).

Municipality	L	TER (m a.s.l.)	TP	IP	IP%
Cárdenas	25	0−14	22,486	170	0.8
Centla	22	1−11	22,965	5851	25.5
Comalcalco	43	2−11	72,899	390	0.5
Cunduacán	31	3−10	29,823	154	0.5
Huimanguillo	12	6−10	9670	32	0.3
Jalpa de Méndez	23	3−10	34,823	1133	3.3
Jonuta	12	0−11	10,337	640	6.2
Nacajuca	35	2−14	43,631	20,938	48
Total:	203		264,381	47,119	18

Table 4. Elevation range of the terrain in the state of Tabasco, Mexico.

Elevation Range (m a.s.l.)	Areas (km^2)	% Areas of the State of Tabasco
<–2−0	3280.97	13.40
0−1	4455.37	18.19
1−5	5275.40	21.54
5−15	5351.14	21.85
15−20	1376.87	5.62
20−25	869.55	3.55
25−30	700.38	2.86
30−50	3234.04	13.21
50−100	1605.80	6.56
100−500	882.77	3.61
500−1,146	62.52	0.26

Up to 61.6% (15081.9 km^2) of Tabasco is between 0 and 15 m a.s.l. Within this area, 16.6% is drained (2500 km^2) and 13.4% (3280.97 km^2) is permanently flooded (−2.96 to 0 m a.s.l.). We observed that the remaining aquatic vegetation covered 24% of the state (5902.48 km^2). However, most of this area is currently disturbed. We calculated that in Tabasco, 2365.13 km^2 are dominated by *T. geniculata* (*popal*) and 3537.36 km^2 by *T. domingensis* (cattail, *tular*) (Figure 3). Data for each of the studied municipalities are presented in Table 5.

Figure 4 shows the areas with high probability (0.807) for the distribution of plant communities associated with the *marceño* agroecosystem. This model, in conjunction with the terrain elevation model, provided us with information about the areas with potential for productive *marceño* agroecosystems. The area where the *marceño* agroecosystem is currently practiced had the greatest calculated potential (Figure 3, Figure 4b, and Table A1).

Table 5. Livestock and agricultural areas susceptible to cyclical flooding that have potential (very high, high and medium) to be converted into the *marceño* agroecosystem. Areas are shown with flooding potential and percentage, representing each municipality's area.

	Cyclic Flooding Potential						**Area for Reconversion to Marceño**		**Area with Wetland Vegetation Conserved** [(1)]			
Elevation Terrain Range m a.s.l.	**0−2**		**2−4**		**4−6**							
Municipality	**Very High**		**High**		**Medium**		**Cultivated Grass**		***Popal***		***Tular***	
	km^2	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
Comalcalco	158.57	20.7	154.66	20.2	129.93	17	310.86	40.6	49.16	6.4	93.11	12.2
Cárdenas	323.23	15.8	83.59	4.1	133.85	6.5	550.01	26.9	66.27	3.2	161.72	7.9
Cunduacán	0.08	0.01	4.60	0.77	40.63	6.8	85.93	14.4	5.91	1.0	41.97	7.0
Nacajuca	105.78	19.8	62.93	11.8	51.72	9.7	242.80	45.5	106.93	20.0	126.38	23.7
Jalpa de Mendéz	63.39	17.2	67.55	18.3	89.69	24.3	119.19	32.3	43.46	11.8	36.21	9.8
Jonuta	135.35	8.2	211.33	12.9	166.81	10.2	513.49	31.3	226.97	13.8	343.33	20.9
Centla	232.26	8.6	6.12	0.23	0.15	0.01	237.40	8.8	163.00	6.1	1394.78	51.9
Centro	215.32	13.6	150.78	8.8	156.48	9.3	1044.78	61	33.99	2.0	303.33	17.7
Huimanguillo	280.72	7.6	157.96	4.3	145.69	3.9	583.22	15.7	147.02	4.0	151.62	4.1
Macuspana	194.26	8.0	190.13	8.0	90.12	3.7	1522.72	62.8	34.18	1.4	550.73	22.7
Paraíso	63.00	3.0	12.99	0.64	2.30	0.11	53.01	13.0	–	–	30.67	7.5

Notes: [(1)] The areas originally covered by *popal*, were disturbed by clearance for agriculture, fires for turtle hunting, and cattle raising. Vegetation was substituted by aggressively introduced forages and weeds that cover vast areas with cyclic flooding. Additionally, the drainage of wetlands has dropped the phreatic level.

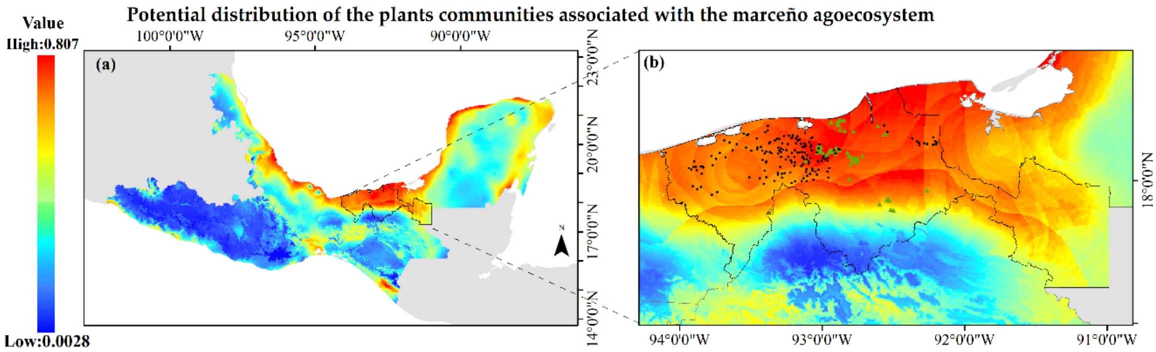

Figure 4. Potential distribution of 16 aquatic plant species reported to be associated with the *marceño* agroecosystem. The model was built for both the Pacific and Gulf Mexico Costal regions to give robustness to the model (Table 1). The colours represent the potential probability of (**a**) the potential distribution model for all the areas included in the MaxEnt analysis; (**b**) the potential distribution model of distribution of the aquatic plant communities found in Tabasco where currently the *marceño* agroecosystem is practiced (●). Current Maya Chontal populations (▲).

The geospatial analysis showed that approximately 1693.71 km^2 has a very high potential for *marceño* (0–2 m a.s.l.). Considering the predictable periodicity of seasonal flooding, only about 1259 km^2 has a high potential (2–4 m a.s.l.) because of its dependence on the severity of inundation. Moreover, approximately 1140.1 km^2 has a moderate potential and 471.3 km^2 has a low potential (4–6 and 6–7 m a.s.l., respectively) because this area is susceptible to flooding in years with atypically high rainfalls. The estimated potential of the *marceño* agroecosystem formed approximately 18.4% of Tabasco's area (Figure 5, Table 6).

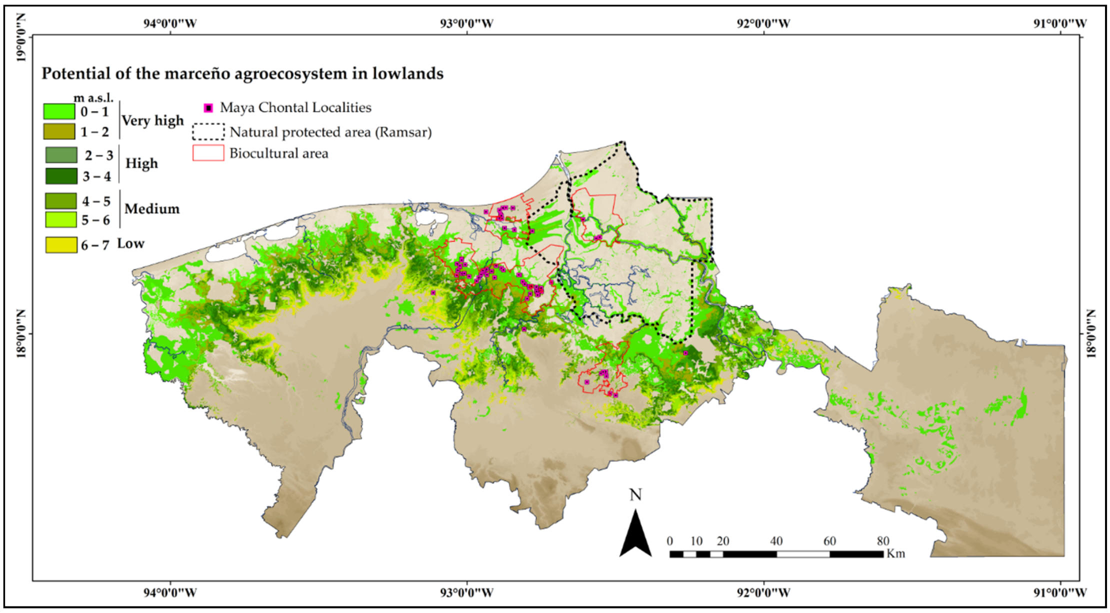

Figure 5. Agricultural and livestock areas in the Tabasco state with potential to be cultivated with the *marceño* agroecosystem. Probabilities of cyclic annual flooding occurrence (areas and elevations in the range −2 to 7 m) are indicated (see Table 6).

Table 6. Potential area for the *marceño* agroecosystem in the lowlands of Tabasco, Mexico.

Potential	Elevation Range (m a.s.l.)	Potential Area (km^2)	Total (km^2)	% Area of the State of Tabasco
Very high	0–1 1–1.5 1.5–2	911.9 420.7 361.1	1693.7	6.85
High	2–2.5 2.5–3 3–3.5 3.5–4	330.3 316.2 307.3 305.2	1259.0	5.09
Medium	4–5 5–6	574.8 565.4	140.1	4.61
Low	6–7	471.3	471.3	1.91
		Total:	4564.2	18.46

4. Discussion

During the fieldwork, we corroborated the presence of the *marceño* agroecosystem in Tabasco's rural communities, many of which have been inhabited by the Maya Chontal since pre-Hispanic times (Figures 3–5; Table 3). These localities are in the range of 1–14 m above sea level and are susceptible to seasonal flooding. Based on the reports of the Food Information Services of Tabasco [44], regarding the area of planted maize during the spring–summer cycle, it can be inferred from our model that, currently, the *marceño* system cover less than 463.52 km^2, which represents approximately 10% of the potential area (Figure 5, Table 3). The presence of *marceño* had been reported in 183 localities previously [33], whereas we found it in 203 localities. However, there might be many other locations in rural areas that use the *marceño* agroecosystem, as it is a current practice in rural areas used by both Maya Chontal and Mestizo people. It is also possible that a greater number of localities practice the *marceño* system in the lowlands and nearby towns of Tabasco, on the banks of the Usumacinta River in the state of Campeche (locality of Palizada), given the cultural similarities of the region.

The model of potential distribution of the plant communities associated with *marceño* allowed an estimation of the areas where the ecosystem is conducive to the implementation of the *marceño* agroecosystem as a rural development strategy in Tabasco. *Marceño* is cultivated predominantly to feed the Maya Chontal population. A total of 59% of this area is currently occupied by primary activities such as subsistence agriculture, mainly in the municipality of Nacajuca [43]. The management of the *popal* by the *marceño* agroecosystem is fundamental to the subsistence of this population. In Tabasco, there are 79694 Maya Chontal people (3.6% of the population) [43], 62% of which live within the "La Chontalpa" biocultural region [25]. This indigenous territory covers about 794.06 km^2 (3.2% of the area of the state), mainly in the municipalities of Nacajuca and Centla. In this study, we found that important areas of wetland vegetation were considered as *popal*. Our results showed that, in this area, 269.93 km^2 (11.4%) and 1521.2 km^2 (43%) are covered with *popal* and *tular*, respectively (Figure 3, Table 4).

It is relevant that approximately 7% of the Mayan Chontal territory is located within the Natural Protected Area of the *"Reserva de la Biosfera Pantanos de Centla"* (3027.06 km^2) [45], one of the priority regions for the conservation of biodiversity and agrobiodiversity. This area has been protected by the Government of Mexico and the Ramsar Convention [46]. For that reason, we only used the areas actually used for cattle, and the *marceño* agroecosystem (using landraces, mainly *mején*), to calculate the potential areas for *marceño*. This conservation area protects against the construction of infrastructure for forced drainage that completely modifies the hydrology and the ecological cycles of wetlands [9,10]. In the *marceño* agroecosystem and other examples of extensive agricultural carried out in the wetlands, the combination of food production and ecosystem services in this area might contribute to the high resilience of both the wetlands and *marceño* system [21,24,27,28], which maintains other ecosystem services such as improving water quality, stopping floods, and maintaining biodiversity [7] and agrobiodiversity [9].

Currently, there are examples of reactivation of pre-Hispanic agricultural systems in wetlands, such as the *waru waru* or *suka kollus* system in Lake Titicaca [47] and the implementation of the "*chinampas chontales*" in Nacajuca, Tabasco, which are similar to the *chinampas* system in the Valley of Mexico [48]. Similarly, the calculated potential areas for the *marceño* agroecosystem represent a viable alternative to produce food for ecological restoration programs of the lowlands of Tabasco and other tropical regions where the traditional cultivation of corn is the basis of the smallholders' diet. Additionally, the *marceño* agroecosystem is recognized by the smallholders for its high soil fertility and good yield of corn crops in flooded areas (actually $\sim$4.3 ton ha^{-1} of grain, including native maize varieties such as *mején*).

The characteristic abundance of *popal* in the hydrophilic vegetation of the landscape and culture of the Tabasco lowlands has been altered by a lack of interest and understanding of its cultural and ecological relevance, as well as a lack of knowledge about its management and productive potential. The *marceño* agroecosystem is part of the local biocultural identity and its maintenance and enhancement may also contribute to the conservation of the Tabasco wetlands and biocultural heritage. Abandoning the *marceño* agroecosystem would represent the loss of a unique agrobiodiversity and a biocultural landscape that represents the important identity of the Tabasco lowlands. On the other hand, the *marceño* might contribute to the tropical subsistence agriculture. This is relevant because the FAO reports that, in Central America, household traditional agriculture farmers produce about 50% of the agricultural production of the region and more than 70% of the foods.

The findings of this study have an important implication for other wetland areas in Mexico and elsewhere in the world, such as the Rhine [49], Danube, and Mississippi [50] River basins. It could also be adopted as a model in agricultural development plans in other tropical regions with cyclical floods and food poverty. This would also allow in situ conservation of agrobiodiversity of varieties of crops that have adapted to high humidity conditions, such as maize *mején*, which represents a genetic reservoir for research on new varieties that are tolerant to waterlogging. *Marceño* represents an opportunity for agroecological studies that allows communities settled in areas susceptible to cyclical floods (61.6% of the state of Tabasco) to develop. This might allow sustainable development, which could be accompanied by ecological restoration programs and the conservation of the biocultural landscape of the Tabasco wetlands.

5. Conclusions

Marceño is relevant for smallholders who produce food for self-consumption in one of the poorest and most vulnerable regions of Mexico. The adoption of practices of sustainable management of natural resources and the retention of traditional agricultural systems by smallholders has been proposed by the FAO as part of a strategy to adapt to climate change, eradicate global poverty and end hunger. The Intergovernmental Panel on Climate Change estimates that agronomic adaptation could improve yields by 15 to 18% [49]. This demonstrates the significance of household agriculture, such as *marceño*, for the food sovereignty of the smallholder communities [50,51]. In Tabasco, the maize crop occurs in the rainy season, but the *marceño* system occurs in the dry season, allowing an additional staggered agricultural cycle during the recession of the flood. This study improves the understanding of the current context of the *marceño* agroecosystem in the lowlands of Tabasco.

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Appendix A

Table A1. Localities indicated in the Figure 3.

Municipality	Id Number and Locality Showed in Figure 3
Cárdenas	1.Arroyo Hondo 1ra. Sección (Santa Teresa A) 2.Arroyo Hondo Abejonal 3.Azucena $2^{da.}$ Sección 4.Azucena $3^{ra.}$ Sección (El Triunfo) 5.Azucena $4^{ta.}$ Sección (Torno Alegre) 6.Buenavista $1^{ra.}$ Sección 7.Buenavista $2^{da.}$ Sección 8.Cárdenas 9.El Capricho 10.El Golpe 11.El Golpe $2^{da.}$ Sección (Los Patos) 12.El Porvenir 13.Ignacio Gutiérrez Gómez (San Felipe) 14.Islas Encantadas (El Zapote y Reyes Heroles) 15.La Trinidad 16.Las Coloradas $2^{da.}$ Sección (Ampliación las Aldeas) 17.Naranjeño $2^{da.}$ Sección A 18.Nueva Esperanza 19.Paylebot 20.Poblado C-28 Coronel Gregorio Méndez Magaña Uno 21.Poza Redonda $1^{ra.}$ Sección 22.Poza Redonda $4^{ta.}$ Sección (Rincón Brujo) 23.Río Seco $1^{ra.}$ Sección 24.Santana $2^{da.}$ Sección A 25.Zapotal $1^{ra.}$ Sección
Centla	26. Buena Vista 27.Chichicastle $2^{da.}$ Sección 28. Chichicastle $3^{ra.}$ Sección 29.Cuauhtémoc 30.El Carmen $2^{da.}$ Sección 31.El Guatope 32.El Limón (De Vicente Guerrero) 33.El Naranjal 34.El Porvenir 35.Gregorio Méndez Magaña 36.Hablan los Hechos (Santa Rosa) 37.Leandro Rovirosa Wade $1^{ra.}$ Sección 38.Leandro Rovirosa Wade $2^{da.}$ Sección 39.Nueva Esperanza de Quintín Aráuz 40.Potrerillo 41.Quintín Aráuz 42.Ribera Alta $1^{ra.}$ Sección 43.Ribera Alta $3^{ra.}$ Sección 44.San José de Simón Sarlat (El Coco) 45.Simón Sarlat 46.Tres Brazos 47.Vicente Guerrero

Table A1. *Cont.*

Municipality	Id Number and Locality Showed in Figure 3
Comalcalco	48.Arena $1^{ra.}$ Sección
	49.Arena $3^{ra.}$ Sección
	50.Arena $4^{ta.}$ Sección
	51.Arroyo Hondo 3^{ra}. Sección
	52.Belisario Domínguez
	53.Carlos Greene
	54.Carlos Greene $1^{ra.}$ Sección Tres (Colonia el Limón)
	55.Carlos Greene $4^{ta.}$ Sección
	56.Chichicapa
	57.Cupilco
	58.Cuxcuxapa
	59.Francisco I. Madero $1^{ra.}$ Sección
	60. Francisco I. Madero $2^{da.}$ Sección
	61.Francisco Trujillo Gurría
	62.Gregorio Méndez $1^{ra.}$ Sección
	63.Gregorio Méndez $2^{da.}$ Sección
	64.Gregorio Méndez $3^{ra.}$ Sección
	65.Guatemalán
	66.Guayo $2^{da.}$ Sección
	67.Independencia $1^{ra.}$ Sección
	68.Independencia $2^{da.}$ Sección
	69.Independencia $3^{ra.}$ Sección
	70.José María Pino Suárez $1^{ra.}$ Sección
	71.Lagartera
	73.León Zárate $1^{ra.}$ Sección
	74. León Zárate $2^{da.}$ Sección
	75.Norte 1ra. Sección (San Julián)
	76.Novillero 4ta. Sección
	77.Occidente $1^{ra.}$ Sección
	78.Occidente $2^{da.}$ Sección
	79.Occidente 3^{ra}. Sección
	80.Oriente $3^{ra.}$ Sección
	81.Oriente $6^{ta.}$ Sección (Los Mulatos)
	82.Paso de Cupilco
	83.San Fernando (Pueblo Nuevo)
	84.Sargento López $1^{ra.}$ Sección
	85.Sargento López $2^{da.}$ Sección (El Chuzo)
	86.Sargento López 3^{ra}. Sección (San Jorge)
	87.Sargento López $4^{ta.}$ Sección
	88.Tecolutilla
	89.Tránsito Tular
	90.Zapotal $2^{da.}$ Sección
Cunduacán	91.Alianza para la Producción
	92.Anta y Cúlico (Santa Rita)
	93.Buenaventura
	94.Buenos Aires
	95.Ceiba $1^{ra.}$ Sección (Jahuactal)
	96.Cúlico $1^{ra.}$ Sección
	97.Cumuapa $1^{ra.}$ Sección
	98.Dos Ceibas
	99.El Palmar
	100.El Tunal
	101.Felipe Galván
	102.General Francisco J. Mújica
	103.Gregorio Méndez
	104.Huimango $1^{ra.}$ Sección

Table A1. *Cont.*

Municipality	**Id Number and Locality Showed in Figure 3**
Cunduacán	105.La Chonita
	106.La Piedra $2^{da.}$ Sección
	107.Laguna de Cucuyulapa
	108.Libertad $2^{da.}$ Sección
	109.Los Cerros
	110.Mantilla
	111.Marín
	112.Miahuatlán (San Gregorio)
	113.Miahuatlán (San Nicolás)
	114.Miahuatlán $1^{ra.}$ Sección
	115.Monterrey
	116.Morelos Piedra $3^{ra.}$ Sección
	117.Once de Febrero (Campo Bellota)
	118.Pechucalco $2^{da.}$ Sección (Las Cruces)
	119.Rancho Nuevo
	120.San Pedro Cumuapa
	121.Yoloxóchitl $3^{ra.}$ Sección
Huimanguillo	122.Benito Juárez $1^{ra.}$ Sección
	123.Benito Juárez $2^{da.}$ Sección (Monte Alegre)
	124.Blasillo $1^{ra.}$ Sección (Nicolás Bravo)
	125.Blasillo $4^{ta.}$ Sección
	126.Huapacal $2^{da.}$ Sección
	127.Paso de la Mina $1^{ra.}$ Sección
	128.Pejelagartero $1^{ra.}$ Sección (Gpe. Victoria)
	129.Pejelagartero $2^{da.}$ Sección
	130.Pejelagartero $2^{da.}$ Sección (Nueva Reforma)
	131.Tres Bocas $1^{ra.}$ Sección
	132.Tres Bocas $2^{da.}$ Sección (El Zapotal)
	133.Zanapa $1^{ra.}$ Sección
Jalpa de Méndez	134.Ayapa
	135.Benito Juárez $2^{da.}$ Sección
	136.Boquiapa
	137.Chacalapa $1^{ra.}$ Sección
	138.Chacalapa $2^{da.}$ Sección (San Manuel)
	139.Hermenegildo Galeana $1^{ra.}$ Sección
	140.Hermenegildo Galeana $2^{da.}$ Sección
	141.Huapacal $1^{ra.}$ Sección
	142.Huapacal $2^{da.}$ Sección (Punta Brava)
	143.Iquinuapa
	144.La Ceiba
	145.La Cruz
	146.Mecoacán
	147.Mecoacán $2^{da.}$ Sección (San Lorenzo)
	148.Nabor Cornelio Álvarez
	149.Nicolás Bravo
	150.Reforma $1^{ra.}$ Sección
	151.Reforma $3^{ra.}$ Sección (El Guano)
	152.San Nicolás
	153.Santuario $2^{da.}$ Sección
	154.Soyataco
	155.Tierra Adentro $2^{da.}$ Sección
	156.Vicente Guerrero $1^{ra.}$ Sección
	157.Vicente Guerrero $2^{da.}$ Sección

Table A1. *Cont.*

Municipality	Id Number and Locality Showed in Figure 3
Jonuta	158.El Cocal 159.Francisco J. Mújica 160.Jonuta 161.José María Pino Suárez (San Pedro) 162.La Bendición (La Tijera) 163.La Candelaria 164.La Concordia 165.Prudencio López Arias 166.Ribera Baja 2$^{da.}$ Sección (Gran Poder) 167.Torno de la Bola 168.Monte Grande
Nacajuca	169.Arroyo 170.Cantemoc 1$^{ra.}$ Sección 171.Cantemoc 2$^{da.}$ Sección 172.Chicozapote 173.Corriente 1$^{ra.}$ Sección 174.Corriente 2da. Sección 175.El Cometa 176.El Zapote 177.Guatacalca 178.La Loma 179.Libertad 180.Lomitas 181.San Isidro 1ra. Sección 182.Taxco 183.Tecoluta 1ra. Sección 184.Belén 185.Chicozapote 186.El Chiflón 187.El Pastal 188.El Sitio 189.El Tigre 190.Guatacalca (Guatacalca 1ra. Sección) 191.Guaytalpa 192.Isla Guadalupe 193.La Cruz de Olcuatitán 194.Mazateupa 195.Olcuatitán 196.Oxiacaque 197.Saloya 1ra. Sección 198.San Isidro 2da. Sección 199.San José Pajonal 200.San Simón 201.Tapotzingo 202.Tecoluta 2da. Sección 203.Tucta

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