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).
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**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 tules (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.            | Colorín       | Fabaceae        | 10          |
| Haematoxyllum campuchianum L.    | Tinto         | Fabaceae        | 485         |
| Hibiscus striatus                | Malva         | Malvaceae       | 10          |
| Jacquinia auranticata 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 poto  | Alismataceae    | 231         |
| Salix humboldtiana Wild.         | Sauce         | Salicaceae      | 209         |
| Scleria macrophylla J. Presl & C. Presl | Navajuela    | Cyperaceae     | 30          |
| Thalia geniculata L.             | Popal, hujilla| 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—gleyso1 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   | 585 | 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   | 113 | 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 (km²) | % 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      | 3.35                           |
| 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 km²) of Tabasco is between 0 and 15 m a.s.l. Within this area, 16.6% is drained (2500 km²) and 13.4% (3280.97 km²) 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 km²). However, most of this area is currently disturbed. We calculated that in Tabasco, 2365.13 km² are dominated by *T. geniculata* (*popal*) and 3537.36 km² 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.

| Elevation Terrain Range m a.s.l. | Cyclic Flooding Potential | Area for Reconversion to Marceño | Area with Wetland Vegetation Conserved (1) |
|----------------------------------|---------------------------|---------------------------------|------------------------------------------|
|                                  | Very High | High | Medium | Cultivated Grass | Popal | Tular |           |
|                                  | km²       | %    | km²    | %              | km²   | %    | km²    | %    |
| 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 Méndez                  | 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.
The geospatial analysis showed that approximately 1693.71 km² has a very high potential for *marceño* (0–2 m a.s.l.). Considering the predictable periodicity of seasonal flooding, only about 1259 km² has a high potential (2–4 m a.s.l.) because of its dependence on the severity of inundation. Moreover, approximately 1140.1 km² has a moderate potential and 471.3 km² 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                                  | 911.9                    | 1693.7         | 6.85                           |
| 1–1.5                                | 420.7                    |                |                                |
| 1.5–2                                | 361.1                    |                |                                |
| High                                 |                          |                |                                |
| 2–2.5                                | 330.3                    |                |                                |
| 2.5–3                                | 316.2                    |                |                                |
| 3–3.5                                | 307.3                    | 1259.0         | 5.09                           |
| 3.5–4                                | 305.2                    |                |                                |
| Medium                               |                          |                |                                |
| 4–5                                  | 574.8                    | 140.1          | 4.61                           |
| 5–6                                  | 565.4                    |                |                                |
| 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 agroecosystem 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 mejín), 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 suká mollus 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 ∼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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Conflicts of Interest: The authors declare no conflict of interest.

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 2da. Sección                    |
|              | 4. Azucena 3ra. Sección (El Triunfo)        |
|              | 5. Azucena 4ta. Sección (Torno Alegre)      |
|              | 6. Buenavista 1ra. Sección                 |
|              | 7. Buenavista 2da. Sección                 |
|              | 8. Cárdenas                                |
|              | 9. El Capricho                             |
|              | 10. El Golpe                               |
|              | 11. El Golpe 2da. 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 2da. Sección (Ampliación las Aldeas) |
|              | 17. Naranjero 2da. Sección A               |
|              | 18. Nueva Esperanza                        |
|              | 19. Paylebot                               |
|              | 20. Poblado C-28 Coronel Gregorio Méndez Magaña Uno |
|              | 21. Poza Redonda 1ra. Sección              |
|              | 22. Poza Redonda 4ta. Sección (Rincón Brujo) |
|              | 23. Río Seco 1ra. Sección                 |
|              | 24. Santana 2da. Sección A                 |
|              | 25. Zapotal 1ra. Sección                   |
| Centla       | 26. Buena Vista                            |
|              | 27. Chichicastle 2da. Sección              |
|              | 28. Chichicastle 3ra. Sección              |
|              | 29. Cuauhtémoc                             |
|              | 30. El Carmen 2da. 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 1ra. Sección     |
|              | 38. Leandro Rovirosa Wade 2da. Sección     |
|              | 39. Nueva Esperanza de Quintín Araúz       |
|              | 40. Potrerillo                             |
|              | 41. Quintín Araúz                          |
|              | 42. Riberá Alta 1ra. Sección               |
|              | 43. Riberá Alta 3ra. Sección               |
| teer          | 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 |
|--------------|------------------------------------------|
|              | 48. Arena 1<sup>ra</sup>. Sección        |
|              | 49. Arena 3<sup>ra</sup>. Sección        |
|              | 50. Arena 4<sup>ta</sup>. Sección        |
|              | 51. Arroyo Hondo 3<sup>ra</sup>. Sección |
|              | 52. Belisario Domínguez                   |
|              | 53. Carlos Greene                         |
|              | 54. Carlos Greene 1<sup>ra</sup>. Sección Tres (Colonia el Limón) |
|              | 55. Carlos Greene 4<sup>ta</sup>. Sección |
|              | 56. Chichicapulco                        |
|              | 57. Cupilco                               |
|              | 58. Cuxcuxapa                             |
|              | 59. Francisco I. Madero 1<sup>ra</sup>. Sección |
|              | 60. Francisco I. Madero 2<sup>da</sup>. Sección |
|              | 61. Francisco Trujillo Gurría             |
|              | 62. Gregorio Méndez 1<sup>ra</sup>. Sección |
|              | 63. Gregorio Méndez 2<sup>da</sup>. Sección |
|              | 64. Gregorio Méndez 3<sup>ta</sup>. Sección |
|              | 65. Guatemala                             |
|              | 66. Guayo 2<sup>da</sup>. Sección        |
|              | 67. Independencia 1<sup>ra</sup>. Sección |
|              | 68. Independencia 2<sup>da</sup>. Sección |
|              | 69. Independencia 3<sup>ta</sup>. Sección |
|              | 70. José María Pino Suárez 1<sup>ra</sup>. Sección |
|              | 71. Lagartera                             |
|              | 72. León Zárate 1<sup>ra</sup>. Sección  |
|              | 73. León Zárate 2<sup>da</sup>. Sección  |
|              | 75. Norte 1<sup>ra</sup>. Sección (San Julián) |
|              | 76. Novillero 4<sup>ta</sup>. Sección    |
|              | 77. Occidente 1<sup>ra</sup>. Sección    |
|              | 78. Occidente 2<sup>da</sup>. Sección    |
|              | 79. Occidente 3<sup>ta</sup>. Sección    |
|              | 80. Oriente 3<sup>ra</sup>. Sección      |
|              | 81. Oriente 6<sup>ta</sup>. Sección (Los Mulatos) |
|              | 82. Paso de Cupilco                       |
|              | 83. San Fernando (Pueblo Nuevo)           |
|              | 84. Sargento López 1<sup>ra</sup>. Sección |
|              | 85. Sargento López 2<sup>da</sup>. Sección (El Chuzo) |
|              | 86. Sargento López 3<sup>ta</sup>. Sección (San Jorge) |
|              | 87. Sargento López 4<sup>ta</sup>. Sección |
|              | 88. Tecolutilla                           |
|              | 89. Tránsito Tular                        |
|              | 90. Zapotal 2<sup>da</sup>. Sección      |
| Comalcalco   |                                          |
|              | 91. Alianza para la Producción            |
|              | 92. Anta y Cúlico (Santa Rita)           |
|              | 93. Buenaventura                          |
|              | 94. Buenos Aires                          |
|              | 95. Ceiba 1<sup>ra</sup>. Sección        |
|              | 96. Cúlico 1<sup>ra</sup>. Sección       |
|              | 97. Cumuapa 1<sup>ra</sup>. Sección      |
|              | 98. Dos Ceibas                            |
|              | 99. El Palmar                             |
|              | 100. El Tunal                             |
|              | 101. Felipe Galván                        |
|              | 102. General Francisco J. Mújica          |
|              | 103. Gregorio Méndez                      |
|              | 104. Huimango 1<sup>ra</sup>. Sección    |
| Cunduacán    |                                          |
|              | 107. Alianza para la Producción           |
|              | 108. Anta y Cúlico (Santa Rita)          |
|              | 109. Buenaventura                         |
|              | 110. Buenos Aires                         |
|              | 111. Ceiba 1<sup>ra</sup>. Sección       |
|              | 112. Cúlico 1<sup>ra</sup>. Sección      |
|              | 113. Cumuapa 1<sup>ra</sup>. Sección     |
|              | 114. Dos Ceibas                           |
|              | 115. El Palmar                            |
|              | 116. El Tunal                             |
|              | 117. Felipe Galván                        |
|              | 118. General Francisco J. Mújica          |
|              | 119. Gregorio Méndez                      |
|              | 120. Huimango 1<sup>ra</sup>. Sección    |
Table A1. Cont.

| Municipality       | Id Number and Locality Showed in Figure 3                                      |
|--------------------|---------------------------------------------------------------------------------|
|                    | 105. La Chonita                                                                  |
|                    | 106. La Piedra 2da. Sección                                                      |
|                    | 107. Laguna de Cucuyulapa                                                        |
|                    | 108. Libertad 2da. Sección                                                       |
|                    | 109. Los Cerros                                                                  |
|                    | 110. Mantilla                                                                    |
|                    | 111. Marín                                                                       |
|                    | 112. Miahuatlán (San Gregorio)                                                   |
|                    | 113. Miahuatlán (San Nicolás)                                                    |
|                    | 114. Miahuatlán 1ra. Sección                                                     |
|                    | 115. Monterrey                                                                   |
|                    | 116. Morelos Piedra 3ra. Sección                                                 |
|                    | 117. Once de Febrero (Campo Bellota)                                             |
|                    | 118. Pechucalco 2da. Sección                                                     |
|                    | 119. Rancho Nuevo                                                                 |
|                    | 120. San Pedro Cumuapa                                                            |
|                    | 121. Yoloxóchitl 3ra. Sección                                                    |
| Cunduacán          | 122. Benito Juárez 1ra. Sección                                                  |
|                    | 123. Benito Juárez 2da. Sección (Monte Alegre)                                   |
|                    | 124. Blasillo 1ra. Sección                                                       |
|                    | 125. Blasillo 2da. Sección                                                       |
|                    | 126. Huapacal 2da. Sección                                                       |
|                    | 127. Paso de la Mina 1ra. Sección                                                 |
|                    | 128. Pejelagartero 1ra. Sección (Gpe. Victoria)                                  |
|                    | 129. Pejelagartero 2da. Sección                                                  |
|                    | 130. Pejelagartero 2da. Sección (Nueva Reforma)                                  |
|                    | 131. Tres Bocas 1ra. Sección                                                     |
|                    | 132. Tres Bocas 2da. Sección                                                     |
|                    | 133. Zanapa 1ra. Sección                                                          |
| Huimanguillo       | 134. Ayapa                                                                       |
|                    | 135. Benito Juárez 2da. Sección                                                  |
|                    | 136. Boquiapa                                                                    |
|                    | 137. Chacalapa 1ra. Sección                                                      |
|                    | 138. Chacalapa 2da. Sección                                                      |
|                    | 139. Hermenegildo Galeana 1ra. Sección                                           |
|                    | 140. Hermenegildo Galeana 2da. Sección                                           |
|                    | 141. Huapacal 1ra. Sección                                                       |
|                    | 142. Huapacal 2da. Sección                                                       |
|                    | 143. Iquiruapa                                                                   |
|                    | 144. La Ceiba                                                                    |
|                | 145. La Cruz                                                                     |
| Jalpa de Méndez    | 146. Mecoacán                                                                    |
|                    | 147. Mecoacán 2da. Sección (San Lorenzo)                                         |
|                    | 148. Nabor Cornelio Álvarez                                                      |
|                    | 149. Nicolás Bravo                                                               |
|                    | 150. Reforma 1ra. Sección                                                        |
|                    | 151. Reforma 2da. Sección (San Nicolás)                                          |
|                    | 152. Santuario 2da. Sección                                                      |
|                    | 153. Santuario 3ra. Sección                                                      |
|                    | 154. Soyataco                                                                    |
|                    | 155. Tierra Adentro 2da. Sección                                                 |
|                    | 156. Vicente Guerrero 1ra. Sección                                               |
|                    | 157. Vicente Guerrero 2da. 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. Ríbera Baja 2da. Sección (Gran Poder) |
|              | 167. Torno de la Bola                   |
|              | 168. Monte Grande                       |
|              | 169. Arroyo                             |
|              | 170. Cantemoc 1ra. Sección              |
|              | 171. Cantemoc 2da. Sección              |
|              | 172. Chicozapote                        |
|              | 173. Corriente 1ra. 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 Sítio                           |
|              | 189. El Tigre                           |
|              | 190. Guatacalca (Guatacalca 1ra. Sección) |
|              | 191. Guayalta                           |
|              | 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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