Experiences in the Restoration of Tropical Freshwater Swamps

Patricia Moreno-Casasola[1], Hugo López Rosas[2], Judith Vázquez Benavides[1], Oscar Sánchez Luna [1], Marco González Nochebuena[1], Laura D. Aguirre[1], and E. Sánchez García[1]

A variety of tropical wetlands is found on the floodplains of coastal regions in Mexico, including mangroves, swamps, and marshes. The first (mangroves) are well known and have received much scientific and social attention, including research, inclusion in blue carbon programs, an appreciation of their role in fisheries, and restoration efforts. However, tropical coastal freshwater wetlands have been neglected, and members of society and government have little awareness of their benefits. Tropical coastal freshwater forested and herbaceous wetlands like the mangroves represent important carbon deposits (Sjögersten et al. 2021), store water and help reduce flood peaks (Campos et al. 2011), are important for fisheries, and produce fibers, wood, and other resources that are used by local people (González-Marín et al. 2012; Vázquez-González et al. 2015), among other environmental services. They are frequently used for raising cattle, while swamps are logged, and grasses are introduced as cattle fodder, some of them exotic African grass species. Marshes feed cattle during the dry season, and aggressive grasses are planted to induce changes in plant composition. Tropical freshwater forested and herbaceous wetlands have also been drained for housing projects, thereby reducing the area of freshwater wetlands, mainly swamps.

While wetlands provide diverse and invaluable ecosystem services, their extent worldwide is decreasing and the condition of many of the remaining wetlands is deteriorating worldwide. Approximately 62% of coastal wetlands have been lost globally (Ramsar 2015). For example, in Mexico alone (the focus of this study), an estimated 7 million ha of herbaceous and forested wetlands have been lost, 33% of which are in coastal municipalities (Landgrave and Moreno-Casasola 2012).

Restoring tropical freshwater swamps is becoming increasing important given continued threats. In this paper we are putting together the results obtained by different members of our working group. We will present a picture

[1] Red de Ecología Funcional, Instituto de Ecología, A.C., Carretera Antigua a Coatepec No. 351, El Haya C. P. 91073, Xalapa, Veracruz, México; corresponding author: patricia.moreno@inecol.mx.,
[2] Academia de Desarrollo Regional Sustentable, El Colegio de Veracruz, Carrillo Puerto 26, Zona Centro, Xalapa, 91000, Veracruz, México.

of the problems encountered and the possible alternatives during the restoration of the freshwater forested wetland of Ciénaga del Fuerte.

STUDY AREA: CIÉNAGA DEL FUERTE PROTECTED NATURAL AREA (CFPNA)

On the Gulf coast, in Veracruz, there once were many swamps (freshwater forested wetlands) - today only a few sites remain. One of them, Ciénaga del Fuerte Protected Natural Area (CFPNA), is in the county of Tecolutla (Figure 1). The climate in the region is wet and warm with three seasons: rainy from July to October, cold with northerly winds and rain from November to February, and dry from March to June (Infante Mata et al. 2012). The mean annual temperature is 24 °C, and the total annual precipitation is around 1450 mm (Figure 1).

While Ciénaga del Fuerte Protected Natural Area is a swamp largely dominated by the money tree (*Pachira aquatica*), it also contains patches of cattail marshes dominated by *Typha domingensis* along with *Cladium jamaicense* (Jamaica swamp grass), and *Cyperus giganteus* (Mexican papyrus), and broad-leaved marshes that include *Pontederia sagittata* (pickerelweed), *Thalia geniculata* (alligator flag), *Sagittaria lancifolia* (bulltongue arrowhead), and *Leersia hexandra* (southern cutgrass or swamp rice grass) (Figures 2 and 3). CFPNA is separated from the coast by a field of low parallel dunes used for cattle ranching.

Different freshwater forested wetlands are distributed along a gradient with changes in the elevation (topography) and duration of flooding. *Pachira aquatica* dominates areas where inundation can last up to six months and water currents are present, while pond apple (*Annona glabra*) is found in depressions where flooding lasts two to four months. Swamps dominated by fig trees are the driest - lowlands with only one to two months of flooding.

Hydroperiod is one of the characteristics that define

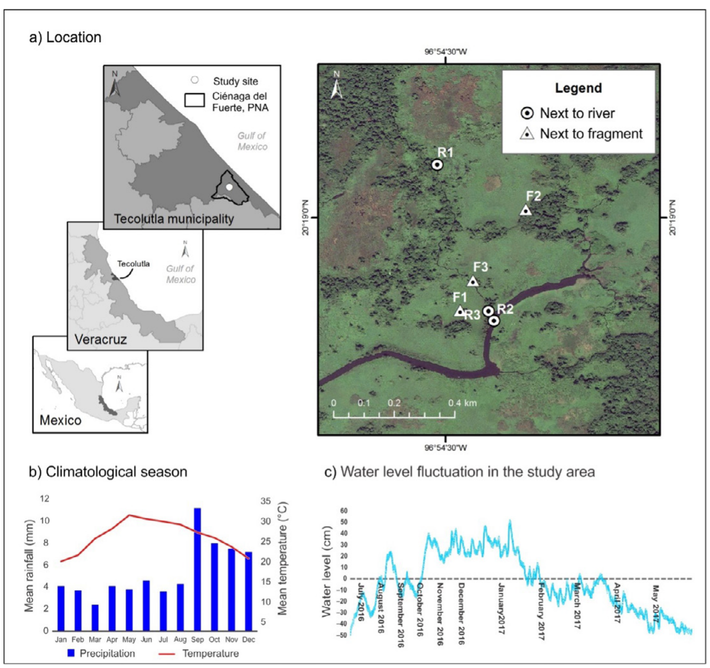

Figure 1. Overview of the study site and its climate and hydrology: a) location of the study site (Ciénaga del Fuerte Protected Natural Area) on the coast of Veracruz, Mexico, on the Gulf of Mexico with an aerial image showing a strip of swamp and several smaller patches immersed in an herbaceous matrix (Source: Google Earth; letters indicate study sites by the river = R and on the border of forest fragments = F), b) precipitation and temperature data for the area, and c) water level fluctuation in the study area - the dashed line represents the soil level and the blue line is the water level. As shown in c) the water level starts rising in August and remains high until the dry season begins in February or March. Note that after the rains in the area stop, the area continues to receive water that slowly flows down the Sierra Madre Occidental mountain range.

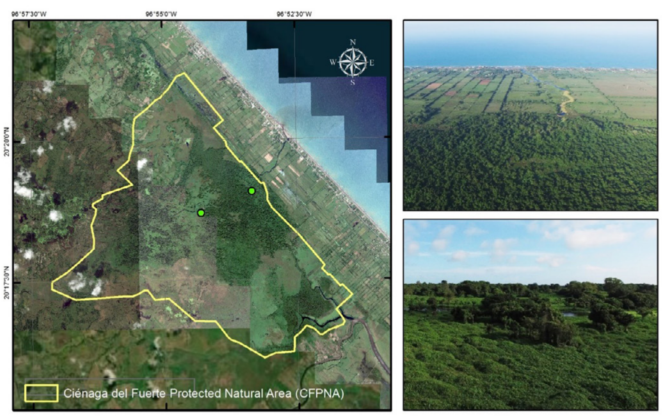

Figure 2. Aerial image from November 2014 showing Ciénaga del Fuerte Protected Natural Area: mostly swamp (dark green area) with considerable marsh (brown and light green areas) on the northern and southern borders. (Source: Pleiades) The upper photograph shows the swamp and the sandy area towards the water. The lower photograph shows swamp patches imbedded in a marsh matrix. (Photos by Roberto Monroy)

Figure 3. Major plants of coastal freshwater wetlands in Mexico. Left to right, top line – marsh plants: *Thalia geniculata, Pontederia sagittata, Cyperus giganteus*; lower line – swamp plants: *Pachira aquatica, Annona glabra*, and *Ficus species*. (Photos by Gerardo Sánchez Vigil)

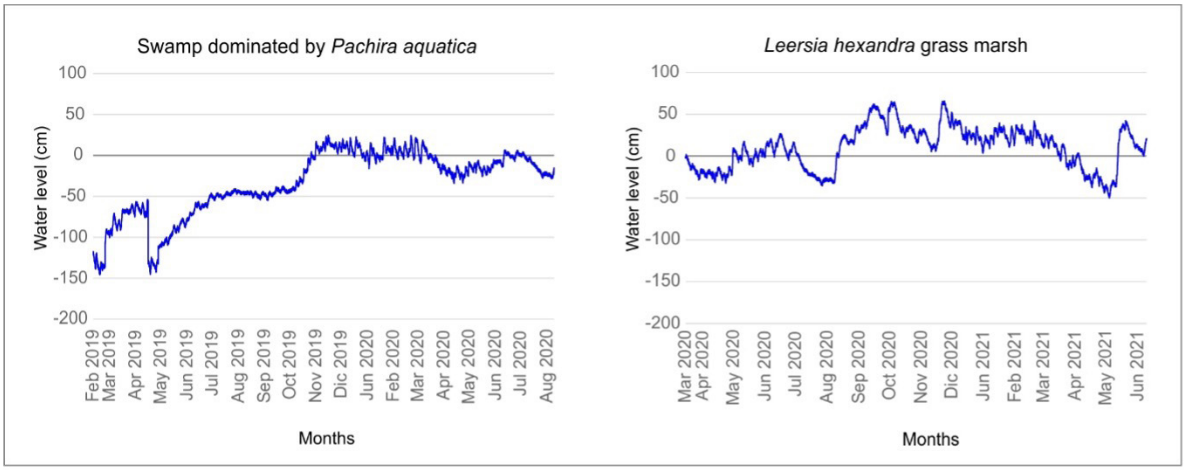

Figure 4. Water level fluctuation in two types of tropical coastal wetlands. On the left is a swamp dominated by *Pachira aquatica* (data from February 2019 to August 2020). On the right side is a *Leersia hexandra* grass marsh (data from March 2020 to June 2021). The latter was flooded longer, had higher levels of flooding, and the roots remained saturated most of the time, whereas the swamp experienced significant drops in the water level during the dry season as in 2019.

wetland types. Mitsch and Gosselink (2000) refer to it as the wetland signature. Figure 4 shows fluctuations in water level graphs for two freshwater wetland types located in the natural protected area of CFNPA: *Pachira aquatica* swamp and *Leersia hexandra* grass-dominated marsh surrounding the swamp.

Direct human impact in the study site includes the expansion of human settlements and productive rural activities (mainly crops and cattle ranching), along with the construction of the Poza Rica-Veracruz coastal highway. These activities have caused changes in the hydrological regime and in the structure and composition of the original vegetation of the protected area (Programa de Manejo 2002). Swamps trees are felled to increase the area for cattle ranching, and ditches are sometimes built to change watercourses and reduce flooding. The highway also acts as a barrier to water flow as there are insufficient water passes, particularly during tropical storms and hurricanes.

Hurricanes have also significantly degraded the site (Robledo 2013). Tecolutla is one of the areas in Veracruz where more hurricanes and tropical storms reach land. Tropical depression Number 11 (October 1999) changed the location of the outlets where water flowed out of the swamp, and Hurricanes Dean (August 2007) and Lorenzo (September 2007) and tropical storm Barry (June 2013) also had significant impacts. Their strong winds knocked down numerous swamp trees, many covered by lianas, thus increasing the damage and connecting the clearings that had progressively resulted from diverse climatic and anthropogenic events in previous years. In these clearings, a species-poor herbaceous community established – one dominated by the grass *Leersia hexandra*, and the herbaceous climbers *Ipomoea tiliacea* and *Ipomoea indica.*

IS THE SWAMP REGENERATING?

We worked in the several swamp forests in Veracruz to understand their floristic composition and variability (Infante-Mata et al. 2011), productivity (Infante-Mata et al. 2012) and carbon storage in the soil (Marín-Muñiz et al. 2014; Moreno-Casasola et al. 2017; Sjögersten et al. 2021). More recently, our work in this tropical freshwater swamp is focused on disturbed areas where the native grass *Leersia hexandra* dominates open areas, creating a grass matrix surrounding patches of *Pachira* swamp forest (Figure 5). *Leersia hexandra* thrives, forming cushions of dry matter that cover the soil, thereby creating a potential obstacle to seed dispersal (Vázquez-Benavides et al. 2020). While grasses (native and exotic) and trees are both commonly found on tropical floodplains, grasses expand very quickly and outgrow tree seedlings. We have seen this in the case of swamps affected by hurricanes, in felled areas transformed to pastures for cattle ranching, and where exotic grasses have been introduced as cattle fodder in wetlands.

METHODS

To understand if there was any possibility for natural regeneration of forest to occur in the *Leersia* matrix, we set up transects in the grass matrix in two zones: close to the river (R) and bordering the tree fragments (F) (Figures 5 and 6). We quantified the seed and seedling presence, survival, and the growth of seeds and seedlings found in

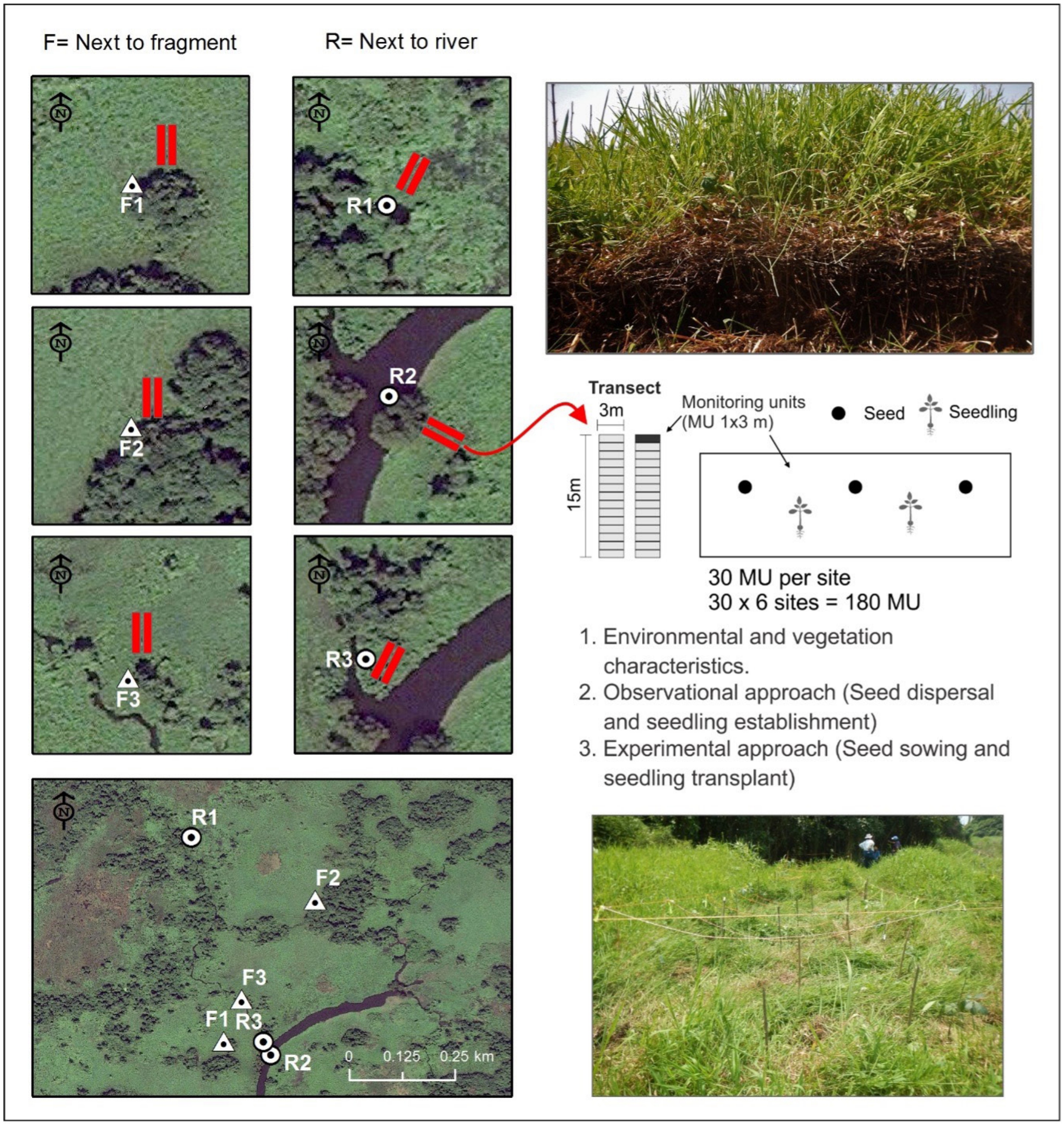

Figure 5. Study sites and field research design. The figure represents the layout of seed dispersal, germination treatments, and the establishment of *Pachira aquatica* seedlings in two zones (R = next to river; F = next to fragment) of the three study sites in each zone (R1, R2, R3, F1, F2, F3). Transect position is displayed as two red bars, and consisted of 3m x 1m monitoring units in which natural arriving seeds and established seedlings were counted. In addition, two seedlings and three seeds were placed in these same quadrats (on the transects) and monitored at different distances from the river (R) and the swamp fragment (F). The photograph shows the cushion formed by *Leersia hexandra*. (Images on the left from Google Earth; Photos by Judith Vázquez-Benavides)

situ and those variables for experimentally introduced seeds and seedlings in the field. We monitored their germination and seedling survival and development, as well as that of the transplanted seedlings. We set up monitoring units along transects in areas close to the river (R) where seeds arrive by currents and in the border of swamp fragments (F) where adult *Pachira* trees are producing seeds (Figure 5).

RESULTS

There was a negative relationship between the number of seeds and established seedlings and the distance to the river or fragment and the grass (Figure 6). West Indian marsh grass (*Hymenachne amplexicaulis*) is more abundant on the river border and does not form a grass cushion. It was present in the first meters of R1 and R2 transects, and

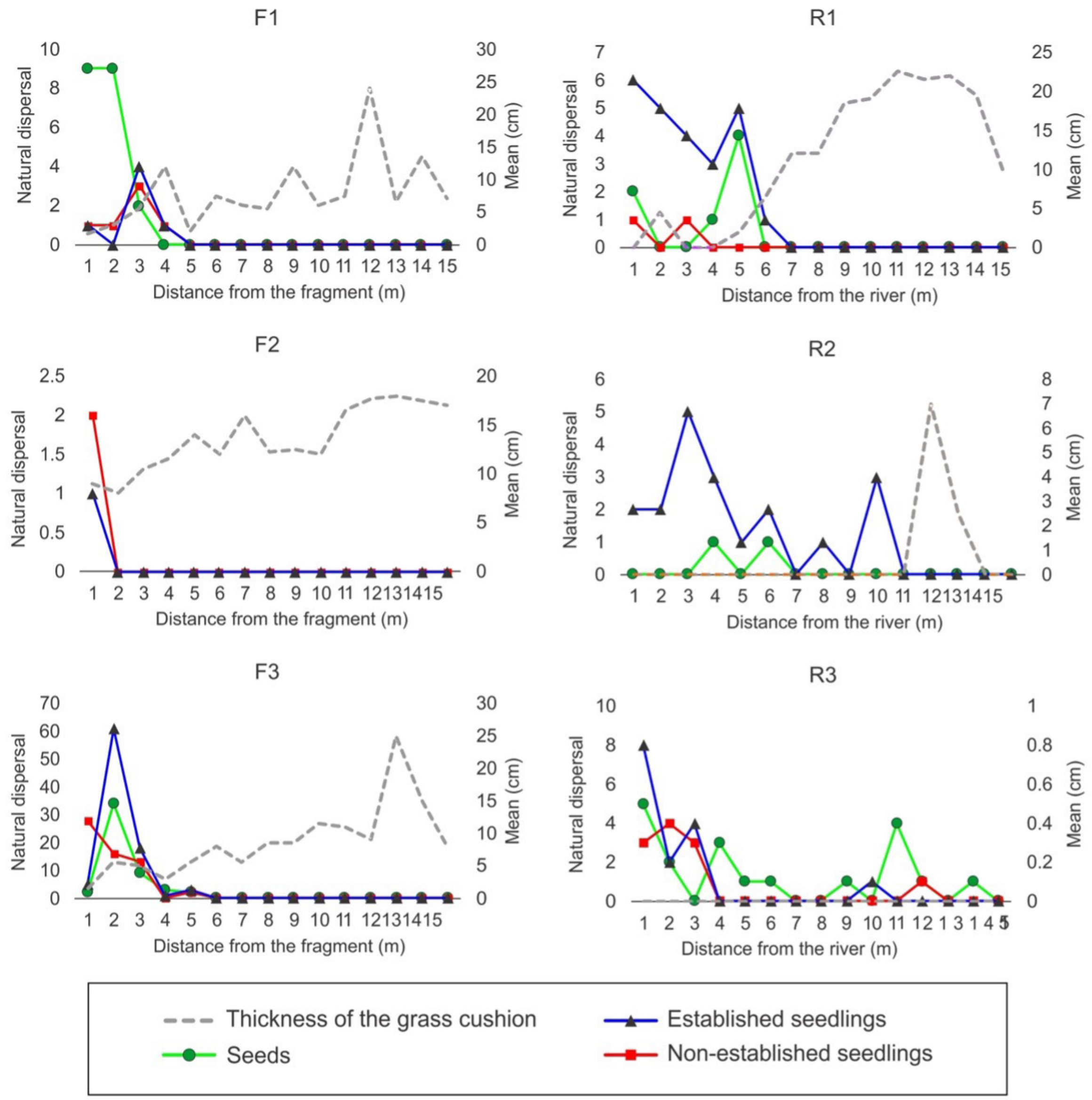

Figure 6. The number of naturally dispersed *Pachira aquatica* seeds, established seedlings (naturally established seedlings), and non-established seedlings (seedlings planted manually) found in the transects (black line) and the average thickness of the grass cushions (gray dashed line) at the sites next to a fragment (F1, F2, F3) and the areas next to the river (R1, R2, R3). See Figure 5. (Redrawn form Vázquez-Benavides et al. 2020.)

dominated R3 transect. *Leersia hexandra* has a different habit and accumulates dead plant material forming a cushion that acts as a barrier to seed dispersal. In R3, the grass cushion was non-existent because of the presence of the grass *H. amplexicaulis,* thus seeds can travel further inland. Thus, in zone R, the presence of the grass cushion was more variable between sites. In the F zone, this cushion was always present. In both zones, the thickness of the grass cushion was a function of distance, from the river and from the forest fragment. Seeds and seedlings were found at a greater distance from the river than in the sites next to the fragments. In the F zone, more seeds and seedlings were found (241), especially in F3 (204), than in the R zone (103), and the seeds and seedlings did not travel more than 5 m, as reported by Vázquez-Benavides et al. (2020).

When seeds were sown after clearing the grass cushion, germination success was high, and the transplanted seedlings had a greater survival rate and final height than the seedlings sprouting from the planted seeds. So, these stages are not limited in the area once the grass has been removed. Seedling survival rates were inversely related to grass cover, showing that seedlings overgrown by grass had low survival rates (Vázquez-Benavides et al. 2020). Thus, *L. hexandra* cover had a negative effect on both types of seedlings.

We can conclude that the native wetland grass *L. hexandra* dominates in open areas and presents an obstacle to *Pachira aquatica* seed dispersal by acting as a physical barrier that traps the seeds in its dry biomass, preventing them from reaching the soil and effectively arresting succession. *Leersia hexandra* also limits their germination and seedling. When seeds are sown on bare soil opening the grass cushion, germination success is high, so this stage is not limited. These seedlings established, grew, and had good survival rates, showing that in general the environmental conditions are suitable for seedling recruitment and survival (Figure 7; Vázquez-Benavides et al. 2020). The same happened with seedlings transplanted directly. However, seedling survival rates were inversely related to grass cover, and seedlings overgrown by grass had low survival rates

CAN PRIOR TREATMENTS HELP RESTORATION?

Planting seedlings is not always effective for ensuring their establishment and survival. Many times, it is necessary to pre-treat the area to reduce the presence of competing plants. In this section, we evaluate the survival and growth *of P. aquatica* seedlings after their planting with and without previous treatments.

METHODS

To evaluate the effectiveness of different treatments to reduce and control herbs and climbers, and to promote the establishment of *P. aquatica* in open areas dominated by the grass *Leersia* spp., we planted *Pachira* saplings in quadrats subjected to different manipulations. We used 20 plots (3 × 3 m each). The vegetation of the corridors surrounding the plots was cut to ground level with a machete and hook, and maintenance was carried out every three months. The herbaceous plants from one plot did not enter another, nor were there any plants from outside of the experimental area. Four *P. aquatica* saplings were planted in each plot, with 20 saplings per treatment (Sánchez Luna et al. 2021). Saplings had an average height of 70.05 ± 9.36 cm at the time of planting.

The treatments we used were: a) Control - the area was covered by the dominant native grasses, with no maintenance (cutting, weeding) or intervention of any kind; b) Cut - herbaceous vegetation in the plot was cut to ground level (with a machete and a hook) prior to planting the saplings and again two days after tree planting. The cut plant material was removed from the plot, but there was no maintenance afterwards; c) Vegetation Mulch - the surrounding vegetation was cut as in treatment b, and the plant material was chopped and piled on the plot, around the sapling, as mulch. After eight months, the cutting was repeated and climbers removed (mainly *I. tiliacea* and *I. indica*) from the trees, d) Plastic Cover - the surrounding vegetation was cut to ground level as in the previous

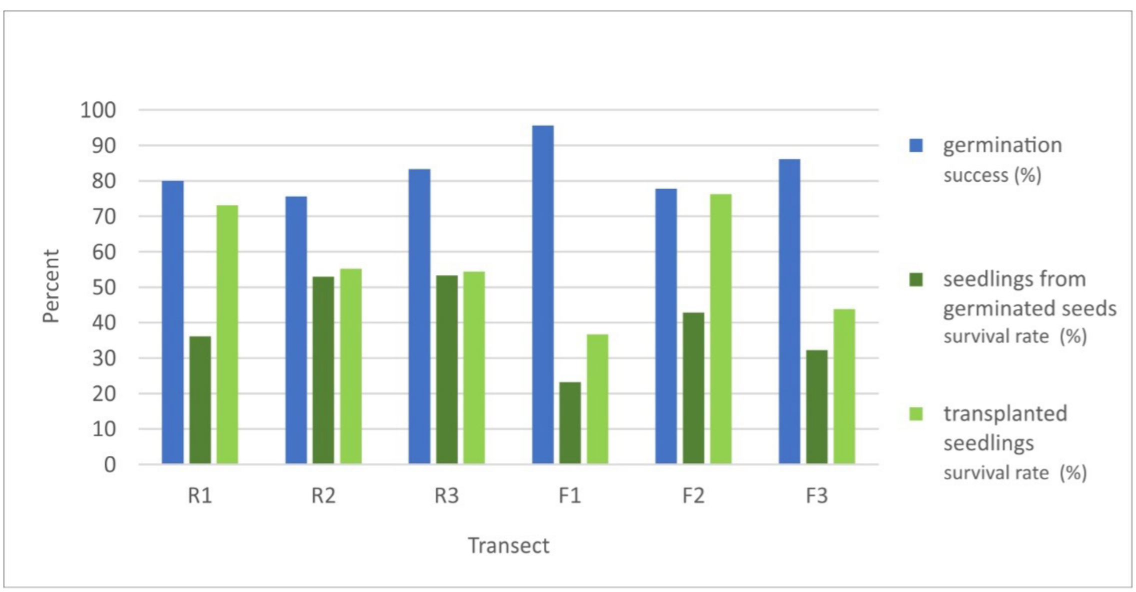

Figure 7. Germination percentage and seedling survival rate (percentage) of seedlings from seeds sown on bare soil and germinating along the transect, and seedlings transplanted directly. Result for transects at the sites next to a fragment (F1, F2, F3) and the areas next to the river (R1, R2, R3) can be seen. In all cases there was seed germination and seedling establishment.

treatments, this plant material was removed, and a black plastic sheet was placed on the ground. After eight months, maintenance was applied once. In all treatments, sapling survival was recorded at the beginning of the experiment and every three months for two years. Tree height, crown cover, and basal diameter (at 5 cm from the ground) were measured right after planting and then two years later. To evaluate the effect of the treatments on the herbaceous vegetation cover in each plot, the number of species, height, and species cover of the herbaceous vegetation was recorded at 12 and 24 months (Sánchez Luna et al. 2021).

RESULTS

Our findings show that herbaceous vegetation can reduce seedling establishment and growth (Table 1). In the Cut and Vegetation Mulch treatments, the herbaceous vegetation took two to three months to recover (one trimester), giving the *P. aquatica* saplings a better chance to survive. In the Plastic Cover treatment, the herbaceous vegetation took even longer to recover. The final height of the herbaceous vegetation was 140 cm in Control, 200 cm in Cut, 90 cm in Vegetation Mulch, and 70 cm in Plastic Cover (Table 2). This means that, to increase the survival of the seedlings, it is necessary that they have sizes of more than 125 cm in height at the time of planting. If seedlings of less than 125 cm are planted, to increase their survival the herbs should be pruned continuously, or the growth of the herbs should be reduced with a padding or by covering with black plastic. While all the treatments had a positive effect on the survival and growth of the *P. aquatica* saplings, the Plastic Cover treatment produced the best results. When the cost-effectiveness is considered, the Vegetation Mulch approach is the best for controlling the herbaceous layer because it gives *P. aquatica* a growth advantage at a lower cost and does not generate waste (plastic) that takes decades to degrade (Table 3). Even though the establishment of *P. aquatica* plantings reduced the cover of the herbaceous vegetation, maintenance, especially the removal of climbing plants, is also essential for the successful establishment of the tree saplings (Sánchez Luna et al. 2021).

ARE CLIMBERS OF THE GENUS IPOMOEA AFFECTING PLANTED JUVENILES OF THE TREE PACHIRA AQUATICA TREES?

Globally, woody and herbaceous climber proliferation is becoming frequent in forest gaps and disturbed forests (Allen et al. 2007; Murphy et al. 2016). At its worst, this phenomenon can lead to the replacement of forest vegetation by a dense layer of climbers that prevents ecological succession, even when active restoration efforts are underway, which is happening in the Ciénaga del Fuerte restoration site. Thus, the removal climbers is considered necessary to improve tree recruitment, growth, and survival (César et al. 2016).

These climbers grow using the trees as supports, and in doing so they both shade and damage the trees (Figure 8), which can be considered as a parasitic structural relationship (Schnitzer et al. 2000; Tang et al. 2012). Aguirre (2019) studied this interaction under restoration conditions by evaluating the regeneration capacity and biomass accumulation of *I. tiliacea* and *I. indica* under contrasting conditions of supports and light availability, as well as the effect of herbaceous vegetation removal as a control strategy.

From that study, it became evident that the planted saplings provided a new source of supports and enhanced the biomass accumulation of climbers. *Ipomoea tiliacea* presents a great challenge because its initial biomass is high in the wetland, and it can take advantage of supports under shaded conditions. When the herbaceous layer is removed at the beginning of the dry season, it is possible to significantly reduce the biomass of both climbers by the end of the dry season, relative to areas where there was no

Figure 8. The climber *Ipomoea tiliacea* covers the young trees, bending them. In reforestation sites, local inhabitants have to carry out maintenance to ensure tree survival and growth. (Photos by Marco González Nochebuena)

Treatment	Initial N	Final N)	Survival (%)	Final height (cm)
Control	20	1	5.0 ± 5.0 c	122.0
Cut	20	7	35.0 ± 12.7 bc	143.8 ± 9.58 a
Vegetation Mulch	20	14	70.0 ± 9.3 ab	161.2 ± 6.02 a
Plastic Cover	20	19	95.0 ± 5.0 a	163.6 ± 1.81 a

Table 1. Survival (mean ± 1 SE), final height and relative growth rate (RGR) of P. aquatica planted saplings in four treatments: 1) Control (planting saplings); 2) Cut (herbaceous vegetation cut and saplings planted); 3) Vegetation Mulch (herbaceous vegetation cut and used as plant mulch, saplings planted); 4) Plastic Cover (herbaceous vegetation cut, plastic cover over soil, saplings planted). Different letters indicate significant differences among treatments with the Holm-Sidak test (*$P \leq 0.05$, ***$P \leq 0.001$, ns = non-significant at $P > 0.05$). Survival is indicated as the mean of survival percentage for each treatment after 24 months. In the Control only one sapling survived in one of the five blocks therefore, the control was not included in the two-way ANOVA for final height. Transformed values were used for statistical comparisons. N = number of sapling per treatment.

Treatment	Initial plant cover (%)	Final plant cover (%)	Species with the highest cover	Final height (cm)	Trimester regrowth of the herbaceous cover
Control	100	94	*Leersia hexandra, Ipomoea tiliacea, Ipomoea indica*	140	Never disappeared
Cut	0	94	*Leersia hexandra, Leersia oryzoides, Ludwigia octovalvis*	200	First
Vegetation Mulch	0	28	*Leersia hexandra, Pistia stratiotes, Leersia oryzoides,*	90	First
Plastic Cover	0	34	*Pistia stratiotes, Leersia hexandra, Ipomoea tiliacea*	70	Second

Table 2. The time that the herbaceous layer needs to recover after each treatment.

Treatment	Activities)	Materials	Total (USD)	Total/ha (USD)
Control	Plant transportation, sapling planting	*P. aquatica* saplings	$8.9	$1,993
Cut	Cutting the herbaceous layer, plant transportation, sapling planting	*P. aquatica* saplings, materials for plant cutting	$15.9	$ 3,551
Vegetation Mulch	Cutting the herbaceous layer, preparing and applying plant mulch, plant transportation, sapling planting	*P. aquatica* saplings, materials for plant cutting	$22.9	$5,106
Plastic Cover	Cutting the herbaceous layer, fixing plastic cover, plant transportation, sapling planting and maintenance	*P. aquatica* saplings, materials for plant cutting, plastic	$44.2	$9,824

Table 3. Cost of activities and materials required for each treatment to control the herbaceous vegetation in Ciénaga del Fuerte, Veracruz, Mexico. The total cost is calculated for one hectare.

herbaceous removal. However, if supports are available, *I. tiliacea* can grow very fast and its biomass accumulation can be very similar to its growth in non-herbaceous removal areas.

The flood level gradient in the wetland was the factor that limited *I. tiliacea* growth. It seems that this species has a low flood tolerance, and its biomass in areas with high flood level areas was very low. Also, high flood levels limit re-sprouting in climbers, which delays both regeneration and growth.

WHAT IS THE EFFECT OF RESTORATION ON THE JICOTEA TURTLE?

Freshwater wetlands are the habitat for a high diversity of fauna such as reptiles, amphibians, and birds. In oviparous reptiles, oviposition is essential to complete their reproductive cycle. Nesting site selection is a characteristic of the female behavior that contributes to the survival and permanence of the species (Kolbe and Janzen 2002). The freshwater jicotea turtle (*Trachemys venusta*, Emydidae family) is a species endemic to southeastern Mexico and Central America. Due to its high nutritional, cultural, and ornamental value, it is one of the most overexploited species (Flores 2009). Its population reduction is also due to the loss and fragmentation of its habitat, and it is currently considered an at-risk species. Therefore, we wanted to see if the environment created by the dominance of *Leersia hexandra* was suitable for this species to nest.

Six sites were selected to search for nests along transects parallel to the riverbank (Note: They are described in Vázquez-Benavides 2019). Data were collected during the dry season of 2017 and twice in 2018 (March and May in both years). Forty-four nests were found, of which 34 had been predated; only ten were active. The site with the highest number of nests was a reforestation site (started in 2013 with *Pachira aquatica* trees). Here the presence of *L. hexandra* grass was low because of tree shading. *Hymenachne amplexicaule* dominated, but this species does not form grass cushions that pose a problem for seed germination so tree re-establishment was unaffected in contrast to sites dominated by *Leersia* (Figure 9).

Since the sites where *L. hexandra* grass dominates have conditions that make it difficult for turtles to enter and dig directly into the ground to lay their eggs, turtles selected areas with less grass cover and less creeping vegetation. Thus, planting saplings of *P. aquatica* favors the recovery of turtle populations by providing suitable nesting sites.

COMMUNITY PARTICIPATION

People in rural communities are very dependent on wetland resources and the environmental services they provide. They are frequently interested in restoration projects. Ten years ago, we worked with local people to organize an ecotourism group to guide people through the swamp. The guides are local farmers who know the area very well and who used to fish in the river that crosses the freshwater forested wetlands, until the catch dwindled to almost nothing. Working as guides in their ecotourism project is a means of earning money and is increasing their knowledge of the ecosystems that surround them and how they function. This activity also expands their awareness of the importance of environmental services and conservation. They are therefore a natural group to support work on the restoration of their environment. They have actively participated in choosing sites, growing plants, maintaining the plantations, and keeping an eye on the whole process (Figure 10). Some of them are very observant and actively contribute to the decision-making process for everyday maintenance and restoration activities. Their help is truly invaluable. They take visitors to the restoration sites and explain the process as part of their guided tours. They are paid wages for their day's work and this benefits them economically – a win-win for local residents and the environment.

CONCLUSION AND RECOMMENDATIONS

It is necessary to control *Leersia hexandra* and *Ipomoea tiliacea* to increase the survivorship of planted trees during the restoration of the Ciénaga del Fuerte swamp. Both are native wetland species but are problematic because they do not allow natural regeneration of floodplain forest, and therefore are an obstacle to restoration. The planted *Pachira aquatica* seedlings should be surrounded by a cleared area, allowing the plantings to grow without competition from these two species for a time long enough for saplings to become well established and eventually to outgrow the grass. So, the first step is to remove the grass cushion to give the saplings an advantage. Once established the saplings grow above the grass and are not greatly affected by it. Since the grass tolerates flooding better than the tree saplings do, the restoration site has to be checked periodically to ensure that saplings are growing sufficiently. The removal of the vines and the grass should be carried out during the weeks before the water level increases above the soil's surface, i.e., from July to August, in order to ensure that the underground biomass of the grasses and vines remains in flooded soils to limit vegetative regeneration for as long as possible. Both will sprout when the water level decreases, while the grass can produce some sprouts under flooded conditions (Vázquez-Benavides 2019). It is important to recognize that cutting and plant removal should be avoided when the dry season begins since the low level of the water table will

Figure 9. Two sites by the river. On the left, a river border with *Pachira aquatica* trees and an herbaceous cover of *Hymenachne amplexicaule* are shown. On the right is a site dominated by *Leersia hexandra*, with its thick cushion of dry organic matter. (Photos by Judith Vázquez Benavides).

Figure 10. Community activities in the restoration process: lifting and removing the *Leersia hexandra* organic matter cushion (first four photographs), collecting young *Pachira aquatica* saplings from the seedling bank, growing plants in the nursery, planting saplings, visiting the sites during high flood levels, and helping set up the experiments. (Photos by Marco González Nochebuena)

favor the growth of both *Leersia hexandra* and *Ipomoea tiliacea*. Shading seems to reduce climber growth, so high sapling densities should be used, and plantings should be done in patches. Areas where *Ipomoea* has not invaded are preferred restoration sites.

Experiments done with *Annona glabra*, another freshwater forested wetland species, show that planting saplings on mounds elevated 30 cm above the soil level increased survival, although the herbaceous layer also had to be removed periodically (Sánchez García 2020). These mounds reduce flooding time and the stress on the plants.

Restoration projects should include a maintenance budget for several years until the *Pachira aquatica* trees have grown a trunk strong enough to not bend and thus survive. The findings reported herein are based on five years of work in Ciénega del Fuerte. More research is needed to understand the biology of the different species involved and their response to both abiotic factors (flooding) and competition. Long-term monitoring of restoration projects should be an important component of any restoration plan. After a few years, the degree of success resulting from the elimination of highly competitive species (*Leersia hexandra, Ipomoea tiliacea*) and the possibility of recovering the forested wetland should be evaluated. Only through monitoring will we be able to determine project success and to improve our restoration techniques.

ACKNOWLEDGMENTS

We thank Roberto Monroy for his help with editing the figures. We thank B. Delfosse for revising the English.

REFERENCES

Aguirre Franco, L.D. 2019. *Regeneración y Crecimiento de Dos Plantas Trepadoras Herbáceas en* Áreas Destinadas *para la Restauración de Selva Inundable en la Planicie Costera del Centro del Golfo de México*. (Master's Thesis). Posgrado en Ciencias Biológicas, UNAM. Morelia, Mexico.

Allen, B.P., R.R. Sharitz, and P.C. Goebel. 2007. Are lianas increasing in importance in temperate floodplain forests in the southeastern United States? *Forest Ecology and Management* 242(1): 17–23.

Campos, A., M.E. Hernández, P. Moreno-Casasola, E. Cejudo Espinosa, A. Robledo, and D. Infante-Mata. 2011. Soil water retention and carbon pools in tropical forested wetlands and marshes of the Gulf of Mexico. *Hydrological Sciences Journal* 56(8): 1388-1406.

César, R.G., K.D. Holl, V.J. Girão, F.N. Mello, E. Vidal, M.C. Alves, and P.H. Brancalion. 2016. Evaluating climber cutting as a strategy to restore degraded tropical forests. *Biological Conservation* 201: 309–313.

Flores, L. 2009. *Valoración y Uso de Tortugas Dulceacuícolas en la Cuenca Baja del Papaloapan, Veracruz*. (Master's Thesis). Instituto de Ecología, A.C. Xalapa, Mexico.

González-Marín, R.M., P. Moreno-Casasola, R. Orellana, and A. Castillo. 2012. Traditional wetland palm uses in construction and cooking in Veracruz, Gulf of Mexico. *Indian Journal of Traditional Knowledge* 11(3): 408-413.

Infante-Mata, D., P. Moreno-Casasola, C. Madero-Vega, G. Castillo-Campos, and B.G. Warner. 2011. Floristic composition and soil characteristics of tropical freshwater forested wetlands of Veracruz on the coastal plain of the Gulf of Mexico. *Forest Ecology and Management* 262 (8): 1514-1531.

Infante-Mata, D., P. Moreno-Casasola, and C. Madero-Vega. 2012. Litterfall of tropical forested wetlands of Veracruz in the coastal floodplains of the Gulf of Mexico. *Aquatic Botany* 98(1): 1-11.

Kolbe, J.J., and F.J. Janzen. 2002. Impact of nest-site selection on nest success and nest temperature in natural and disturbed habitats. *Ecology* 83(1): 269-281.

Landgrave, R., and P. Moreno-Casasola. 2012. Evaluación cuantitativa de la pérdida de humedales en México. *Investigación Ambiental* 4 (1): 35-51.

Marín-Muñiz, J.L., M.E. Hernández, and P. Moreno-Casasola. 2014. Comparing soil carbon sequestration in coastal freshwater wetlands with various geomorphic features and plant communities in Veracruz, Mexico. *Plant and Soil* 378(1): 189-203.

Mitsch, W.J., and J.G. Gosselink. 2000. The value of wetlands: importance of scale and landscape setting. *Ecological Economics* 35(1): 25-33.

Moreno-Casasola, P., M.E. Hernández, and A. Campos C. 2017. Hydrology, soil carbon sequestration and water retention along a coastal wetland gradient in the Alvarado Lagoon System, Veracruz, Mexico. *Journal of Coastal Research* 77(10077): 104-115.

Murphy, H.T., D.J. Metcalfe, T. Forest, and H. Murphy. 2016. The perfect storm: Weed invasion and intense storms in tropical forests. *Austral Ecology* 41: 864–874.

Programa de Manejo. 2002. Programa de Manejo. Área Natural Protegida Ciénaga del Fuerte. Coordinación Estatal de Medio Ambiente, Xalapa, Mexico

Ramsar. 2015. Nota Informativa 7: Estado de los Humedales del Mundo y de los Servicios que Prestan a las Personas. Convención Ramsar, Gland, Switzerland.

Robledo, R.A. 2013. *Análisis de los Servicios Mitigación de Impactos por Tormentas y Huracanes que proporcionan los Humedales de Ciénega del Fuerte para Tecolutla, Veracruz*. (Master's Thesis). Facultad de Ingeniería Química, Universidad Veracruzana. Xalapa, Mexico.

Sánchez García, E.A. 2020. *Germinación y Crecimiento de* Annona glabra *L. Bajo Condiciones Experimentales como Base para la Restauración de un Humedal Arbóreo en la Zona Costera del Centro de Veracruz*. (Master's Thesis). Instituto de Ecología A.C. Xalapa, Mexico.

Sánchez Luna, O., T. Toledo Acevedo, H. López-Rosas, and P. Moreno-Casasola. 2021. Effectiveness of restoration plantings with *Pachira aquatica* in swamps. *Restoration Ecology* e13472. http://doi.org/10.1111/rec.13472.

Schnitzer, S.A., J.W. Dalling, and W.P. Carson. 2000. The impact of lianas on tree regeneration in tropical forest canopy gaps: Evidence for an alternative pathway of gap-phase regeneration. *Journal of Ecology* 88(4): 655–666.

Sjögersten, S., B. Batista de la Barruda, C. Brown, D. Boyd, H. Lopez-Rosas, E. Hernández, M. Rincón, C. Vane, C. Moss-Hayes, J. Hoyos-Santillan, and P. Moreno-Casasola. 2021. Coastal wetland ecosystems deliver large carbon stocks in tropical Mexico. *Geoderma* 403: 115173. https://doi.org/10.1016/j.geoderma.2021.115173

Tang, Y., R. Kitching, and M. Cao. 2012. Lianas as structural parasites: A re-evaluation. *Chinese Science Bulletin* 57(4): 307-312.

Vázquez-Benavides, J. 2019. *Estudio del Pasto Nativo* Leersia hexandra *Sw. y su Efecto en la Dispersión, Germinación y Establecimiento de Semillas y Plántulas de Pachira aquatica Aubl. y como Recurso para la Anidación de la Tortuga Iinta* Trachemys venusta *(Gray, 1855) en el ANP Ciénaga del Fuerte, Tecolutla, Veracruz*. (Master's Thesis). Instituto de Ecología A.C. Xalapa, Mexico.

Vázquez-Benavides, J., P. Moreno-Casasola, and H. López Rosas. 2020. Effect of the grass *Leersia hexandra* on the dispersal, seed germination and establishment of *Pachira aquatica* seedlings. *Freshwater Biology* 65(10): 1702-1717.

Vázquez-González, C., P. Moreno-Casasola, A. Juárez, N. Rivera-Guzmán, R. Monroy, and I. Espejel. 2015. Trade-offs in fishery yield between wetland conservation and land conversion on the Gulf of Mexico. *Ocean & Coastal Management* 114: 194-203.