FROM TROPICAL WETLANDS TO PASTURES ON THE COAST OF THE GULF OF MEXICO

P. MORENO-CASASOLA[1]*, H. LÓPEZ ROSAS[2] AND K. RODRÍGUEZ-MEDINA[1]

[1]Red de Ecología Funcional, Instituto de Ecología, A.C., Carretera antigua a Coatepec No. 351

El Haya, Xalapa 91070, Veracruz, México. [2]Estación El Carmen, Instituto de Ciencias del Mar y Limnología, UNAM, km 9.5 carretera Carmen-Puerto Real, Cd. del Carmen, 24157 Campeche, Mexico.

*Author for correspondence: patricia.moreno@inecol.mx

SUMMARY

Animal husbandry in Mexico began with the arrival of the Spaniards and the creation of New Spain. It changed significantly in the middle of the 20th century with the introduction of the Zebu breed of cattle and improved pastures. From the beginning, wetlands were used for cattle grazing, and we describe the transformations that occur in grazed wetlands that convert them into flooded pastures. The degree of impact depends on the number of cows, the time they are in the wetland, and modifications to hydroperiod and vegetation. We describe the changes in the level of flooding, the soil characteristics (organic matter, water retention, bulk density, pH, micro- and macronutrients) and floristic composition, and how all this affects the environmental services produced by wetlands. With the introduction of cattle breeds tolerant of tropical environments, mainly Zebu cattle, and of exotic forage grasses that can grow in wetlands, the impact has increased. These grasses drastically alter the environment (water and soil) and can become invasive. Therefore there is a gradient of transformation from wetlands with no cattle impact, to those with slight changes that continue to function as wetlands, and finally to heavily transformed wetlands. Management based on low livestock intensity maintains the functions and environmental services provided by wetlands while constituting a sustainable economic activity that permits these ecosystems to be preserved.

Key words: Cattle ranching, compaction, invasives, sustainability, vertical accretion.

Bases de datos: http://polired.upm.es/index.php/pastos (España), AGRIS (Italia), CAB Abstracts (Reino Unido), CABI Full Text (Reino Unido), Catálogo LATINDEX (México), DIALNET (España), ICYT Ciencia y Tecnología (España)

INTRODUCTION

The most extensive tropical wetlands in Mexico are located along the coastal plains. They include mangroves, freshwater marshes and swamps forming gradients, which differ in their salinity, degree and temporality of flooding. Wetlands are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water (Cowardin *et al.*, 1979). These wetlands are rich in plant and animal biodiversity and provide numerous valuable ecosystem services. These are functions that contribute to human welfare and help sustain the biosphere (Costanza *et al.*, 1997). Thus, wetlands are not only places; they should be considered as entities that benefit society. Their genetic diversity helps to maintain wetland processes such as water storage, sediment trapping and nutrient cycling. Among the most valued services of wetlands are disturbance regulation, waste treatment, water supply, cultural and recreational uses, habitat, food production, and nutrient cycling functions, such as processing nitrogen and phosphorus (Vörösmarty *et al.*, 2005; Mitsch and Gosselink, 2007). In particular, tropical coastal wetlands have been recognized because they increase fisheries (Aburto-Oropeza *et al.*, 2008), are important carbon sinks (Moreno *et al.*, 2002; Campos *et al.*, 2011; Marín Muñiz *et al.*, 2011), store water (Campos *et al.*, 2011), and they function as protective shields—bioshields—against storms and surges (Selvam *et al.*, 2005; Thuy *et al.*, 2012). In a noteworthy study, Costanza *et al.* (1997) estimated that tidal marshes, mangroves, swamps and floodplains produced 4879 trillion dollars in services per year.

Mexico has lost or degraded 62% of its wetlands (Landgrave and Moreno-Casasola, 2012). Wetland degradation is not always obvious as direct physical destruction or alteration. Among the major causes of loss and degradation are both human actions and natural threats. Direct human actions include drainage, dredging and stream channelization, deposition of fill, diking and damming, tilling for crops, levee construction, logging, mining, construction, runoff, air and water pollutants, changing nutrient levels (increased nutrient inputs and eutrophication), releasing toxic chemicals, introducing nonnative species, grazing by domestic animals, and urbanization. Indirect human actions are colmatation and eutrophication in downstream wetlands derived from agricultural runoff and from erosion, respectively, due to deforestation and farming upstream. Natural threats include erosion, subsidence, rising sea level, drought, hurricanes and other storms (http://water.epa.gov/type/wetlands/vital_status.cfm). Some of these natural threats will increase with global climate change (increased air temperature; shifts in precipitation; increased frequency of storms, drought, and floods; increased atmospheric carbon dioxide concentration; rising sea level; and increased salinity in freshwater wetlands). All of these changes could impact species composition and wetland functions. Moreover, these detrimental changes could favor the invasion of exotic species, which are more successful in disturbed, fragmented and/or species-poor environments (Crawley, 1987; Rejmánek *et al*., 2005).

Semarnat (2008) indicates that 56% of the Mexican territory (1.09 millions km^2) is used for cattle ranching and in 2007, there were 23.3 million bovines (INEGI, 2007). In 2002, natural and induced grasslands, as well as livestock areas covered 15% of the territory; thus the remaining 41% of the land used for grazing is maintained in areas covered with natural vegetation (Semarnat, 2008) from arid land, mountainous regions and humid tropical areas, including wetlands. Only 14.7% is used for agriculture. This indicates the importance of livestock production both as an economic activity and with respect to the impact that the management practices associated with cattle ranching have on the environment (Guevara and Moreno-Casasola, 2008). In the state of Veracruz, in the Gulf of Mexico, where we have been developing research on the impact of cattle ranching on wetlands, 43.2% of its surface is used for agriculture and 26.8% for cattle ranching. This region has a broad coastal plain (39% of the territory is under 50 m.a.s.l.). The climate is humid tropical, bordered inland by a mountain range that filters precipitation, which drains as subterranean water into the coastal plain. For the lowlands of the coastal municipalities, an estimated 63.4% of this area is used for cattle ranching and 15.7% for agriculture (Peresbarbosa Rojas, 2005). Wetlands currently occupy 70 476 ha in Veracruz (Figure 1).

THE INTRODUCTION OF CATTLE TO MEXICO

Cattle ranching in Mexico began in the state of Veracruz, along the Gulf coast. When the Spanish conquest began in 1519, Veracruz was occupied by the Totonacapan (*sensu* B. Ortiz E. and R. Jiménez M., see chapter in this volume). Several authors (Heimo *et al*., 2004; Beach *et al*., 2009) report that at that time, raised fields and canals in many of the wetlands of lowland Mesoamerica were manmade and used to produce a variety of crops. The fields bordered the wetlands and were subject to repeated, but shallow flooding. The canals provided access, irrigation water, muck for fertilizer, and fish. It was possible to have several crops per year by managing water levels. During the dry season the lower, more humid parts were used; during the rainy season, the higher, nonflooded parts were cultivated (Siemens, 1998). Even now, there are remains of the elevated terraces that the indigenous people used for agriculture.

In the early 1500s, European settlers, mostly farmers, brought several breeds of *Bos taurus* with them; cattle breeds that over four centuries became naturalized in tropical Mexico (Guevara and Lira, 2006; Guevara and Moreno-Casasola, 2008). Some of these breeds came from the Guadalquivir marshes in Spain (Velasco Toro and Skerritt, 2004). In the terraces described above, it was possible to grow grasses year round, in the lower areas during the dry season and on the upper terraces during the rainy season. Cattle could, therefore, be fed year round and could also browse in the forests, eating leaves from lower branches, seedlings, etc. (personal communication Sergio Guevara). These terraces are still being used for cattle ranching.

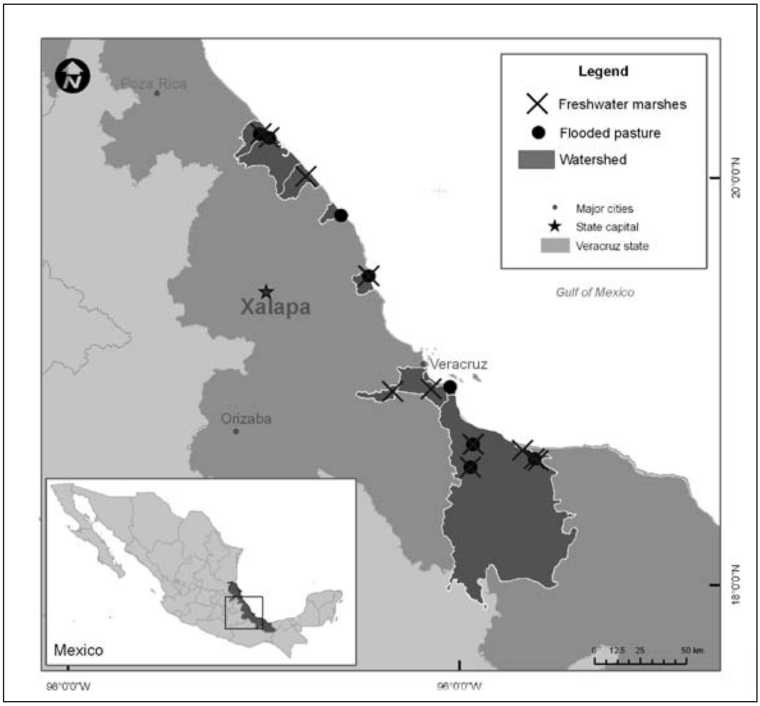

FIGURE 1

Map of the state of Veracruz in Mexico, and the distribution of its coastal wetlands. The locations of the sites mentioned in the text appear on the map. The size of the watersheds upon which the sites depend are shown.

Mapa del estado de Veracruz (México) y la distribución de sus humedales costeros. En el mapa se indican las localidades de los sitios mencionados en el texto. Se muestra el tamaño de las cuencas hidrológicas de las que dependen los sitios de muestreo.

Bovine livestock accounts for 40% of Mexico's domestic meat production and, in rural areas, is mainly used to obtain milk. Production is primarily extensive, low-tech, and disease control is poor. Stocking density of grazing cattle varies from 0.8 ha/head in the warm-humid tropics to 70 ha/head in the driest areas in the north, with a national average of 3 ha; meat production is very low, ranging from 10 to 55 kg per hectare (Toledo *et al*., 1993).

From 1950 on, particularly in the Gulf region and southeastern Mexico, agricultural and livestock production expanded into the territories still covered by forests and wetlands. This was accompanied by a change in livestock breed, with Zebu cattle (*Bos indicus*) replacing the cattle that had been brought by the Spanish (*Bos taurus*) (Guevara, 2001). Beginning in 1870, but especially in the first half of the twentieth century, exotic grasses were introduced in Brazil and the Caribbean, and then Mexico, and these replaced the native grasses. These species still persist and are favored by government authorities and cattle ranchers when they have the means to purchase them. With its bigger, heavier body, Zebu cattle needs open, high quality pastures. Tropical dry and evergreen forests, and tropical oak woodland have been felled and anthropogenic pastures have taken their place. Wetlands have also been used for raising Zebu cattle (Guevara and Moreno-Casasola, 2008). Parsons (1972) and William and Baruch (2000) recount the history of exotic grass introduction to the Americas. African grasses were introduced to the continent in the 17th century, even before they were widely used for grazing (Parsons, 1972). Different regions of Africa are the centers of production of various forage grasses, and the flooded African savannas have numerous species adapted to wetland conditions. Adaptation to foraging by these species is related to their simultaneous evolution with ruminants in their areas of origin during the late Pliocene and Pleistocene (Parsons, 1972; Matthews, 1982; Milchunas *et al*., 1988). As a highly specific, frequent and intense disturbance, foraging can quickly alter the species composition (Huston, 1994). One of the primary adaptations of grasses to foraging is the ability to reproduce vegetatively by producing viable canes that disperse from the parent plant. This is common in grasses from Africa and the Mediterranean region of Eurasia, but is absent in many of the native grasses of America. As a result, the native grasses of America have been largely displaced by invasive Old World grasses (Parson, 1972; Huston, 1994).

Wetlands have been extensively used for raising cattle not only in Veracruz, but all over Mexico and other parts of the Americas, such as Cuba (Caraballoso *et al*., 2011) and in the Pantanal in Brazil (Junk and Nunes da Cunha, 2012). In some locations, cattle have been introduced directly without modifying the plant species composition or the flooding regime though they are moved to drier land during the months when the water level increases. In some places the wetlands have been drained and in others, African grasses, tolerant to flooding, have been introduced. Thus there are several levels of wetland transformation.

The aim of this paper is to integrate and synthesize the information of numerous studies that our research group has done on the impact of cattle herding on tropical freshwater coastal wetlands, focusing on how the soil, the hydrological patterns and the vegetation structure, composition and diversity are affected, as well as any alterations to wetland processes that have been documented. This analysis is based on experience acquired in the analysis of wetlands used for raising cattle in Veracruz, Mexico, by our research group. Some of these results have been published in Travieso-Bello *et al.* (2005), who analyzed biodiversity and soil changes in the flooded pastures of La Mancha, Veracruz, and management practices in the same region (Travieso-Bello and Moreno-Casasola, 2011). López-Rosas (2007), López-Rosas *et al.* (2005 and 2006) analyzed the degree of transformation and the type of impact that the introduction of the African grass *Echinochloa pyramidalis* had on a freshwater marsh, and also ran several experimental trials to eradicate the grass. López-Rosas and Moreno-Casasola (2012) analyzed the results of a competition experiment using different levels of flooding between the grass mentioned above and two native wetland hydrophytes: *Sagittaria lancifolia* and *Typha domingensis*. Moreno-Casasola *et al.* (2010) analyzed the vegetation's composition and structure, as well as the water level fluctuations of thirteen freshwater marshes along the coastal plain of Veracruz, some of them with either native or introduced grass species, and grazing cattle. Rodríguez Medina (2011) and Rodríguez-Medina and Moreno-Casasola (2013) studied the vegetation and soil properties of freshwater marshes in an extensive wetland complex in southern Veracruz and compared areas where cattle had been excluded with those with cattle. Moreno-Casasola *et al.* (submitted) have studied the vegetation, water level fluctuations and soil properties of several flooded pastures along the coastal plain of Veracruz.

WETLAND VEGETATION, FLOODING AND SOILS

Mitsch and Gosselink (2007) developed a conceptual model for describing the fundamental role of hydrology in wetlands, which starts with climate and the geomorphology of the basin. In this model, hydrology (water level, flow, frequency of flooding, etc.) strongly interacts with the physical environment (sediments, soil chemistry, water chemistry, etc.) and biota (vegetation, animals and microbes). Our analysis of flooded pastures is based on this model, thus we will be discussing cattle ranching impacts on hydrology, soils and vegetation.

Flooding and hydroperiod

Tropical Mexican freshwater wetlands can be dominated by either trees that form freshwater swamps, or herbaceous species that form freshwater marshes (Olmsted, 1993; Moreno-Casasola *et al.*, 2010; Infante Mata *et al.*, 2011). They are found on both mineral and organic soils. Wetlands differ not only in the dominant growth forms and species composition, but also in their hydroperiod. This term defines water level fluctuations, i.e. the seasonal pattern in the water level of a wetland, which is like a hydrological signature for each wetland type (Mitsch and Gosselink, 2007). Wetlands are ecosystems whose functioning relies on hydrologic regimes and small variations in flooding pulses or flooding levels may produce massive changes in the local biota.

Figure 2 shows examples of water fluctuation patterns for three sites, using data from three types of wetlands (freshwater forested wetlands, marshes and flooded pastures) present in the same area in Veracruz. The graph shows the flooding behavior for a period of 18 to 24 months (October 2007 to November 2009). Zero represents the soil surface and values above it denote flooding. Flooding behavior is site specific as is the type of wetland, but in general pastures have more pronounced oscillations; that is, during the dry season the phreatic level is lower. All of the wetlands remain flooded for part of the year, except for pastures in Ciénaga del Fuerte. Water rises and saturates the soil where roots are found, but there is no flooding; pastures at the other two sites are flooded for several months of the year. The general picture is that marshes and pastures at the three sites become flooded, thus from the hydrological perspective, these pastures behave similarly to the other wetland types.

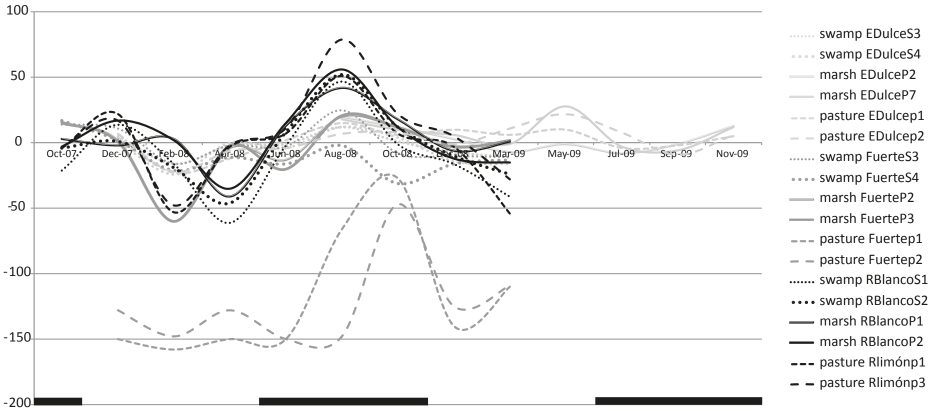

FIGURE 2

Hydroperiod over a year and a half to two years for three types of wetlands (swamps, marshes and flooded pastures) in three sites (Ciénaga del Fuerte, Estero Dulce and Río Blanco-Río Limón) in Veracruz, Mexico. Swamps are indicated with a black continuous line; marshes with a gray continuous line and flooded pastures with a dashed line. Zero is ground level. Zero is ground level and vertical axis is in centimeters. Horizontal lines at the bottom of the figure indicate the rainy season.

Hidroperíodo de un año y medio a dos años para los tres tipos de humedales (arbóreos, herbáceos y pastizales inundables) en tres sitios (Ciénaga del Fuerte, Estero Dulce y Río Blanco-Río Limón) en Veracruz, México. Los humedales arbóreos se indican con una línea negra contínua, los humedales herbáceos con línea gris contínua y los pastizales inundables con una línea discontinua. El cero es el nivel del suelo y el eje vertical está en centímetros. Las líneas horizontales en la parte inferior de la figura indican la época de lluvias.

Vegetation

Both swamps and marshes are being transformed into pastures. In swamps, trees are felled and grasses planted. One group of species is replaced by another and in the new community, tree stumps resprout. In areas that remain flooded for longer periods of time, small differences in topography allow for the presence of patches dominated by marsh species. In marshes, even when exotic grass species are introduced, herbaceous species persist, though with low cover values (López-Rosas *et al*., 2006). Figure 3 shows a dendrogram comparing the vegetation from quadrats sampled in marshes and flooded pastures.

A matrix with 155 quadrats and 113 species from 23 sites sampled in Veracruz was used. The data were taken from 12 herbaceous wetlands and 11 flooded pastures. A cluster analysis was done (program PCOrd -McCune and Grace, 2002) using the flexible β linkage method and relative Euclidian distance as a distance measure. A dendrogram with seven floristic groups was formed, with 1.38 percent chaining. Figure 3 shows the dendrogram, indicating the geographic location of the samples and the dominant species in each group. Most samples from the same site fell into the same floristic group or were with samples from only one or two other sites; only in group 6 are there samples from several sites.

The first major division separates the samples from La Mancha in central Veracruz from the rest. These samples form two subgroups. The first (1 A) is formed of hydrophytes dominated by native broadleaf herbaceous plants that comprise a community known as popal (described in Moreno-Casasola *et al.*, 2010). It is located in a reserve and has been under restoration so there is no influence by cattle. It is dominated by *Sagittaria lancifolia* and *Pontederia sagittata*, among others. The second subgroup (1 B), also in La Mancha, is dominated by the African grass *Echinochloa pyramidalis* which has become an invasive wetland species, and *Typha domingensis*, a tall, herbaceous monocot hydrophyte, locally called tule (a name also used when referring to cattail), which is widely distributed. This site is separated from the others because of the presence of an exotic that has become a wetland invader that has taken over most of the wetland (López Rosas *et al.*, 2005 and 2006). The other major group (indicated by the number 2) brings together the other floristic groups.

This second big group is subdivided into various subgroups that are characterized by wetland species, with cover by invasive species still low. Group 3 consists of several subgroups and group 4 is comprised of samples from five sites from the Papaloapan River Basin, located along the Río Limón and Río Blanco rivers. In this vast area of herbaceous wetlands there are popales dominated by *P. sagittata* and *Thalia geniculata* and tulares dominated by narrow leaved species such as *T. domingensis*, *Cyperus giganteus*, *Eleocharis cellulosa* and *Phragmites communis*; all of which are being used for grazing livestock. Herbaceous wetlands from this area are rich in species and are dominated by *E. cellulosa* (Cyperaceae) and *Leersia hexandra* (Poaceae), both of which are palatable to livestock, the latter a typical native grass and common in wetlands. Group 3 was divided into five subgroups. Group 5 was dominated by *Cyperus giganteus* and the native wetland grass *Hymenachne amplexicaulis*, and to a lesser degree by *Typha domingensis, Limnocharis flava,* and *Thalia geniculata*, among others. These species are distributed in several places both in northern Veracruz (Estero Dulce, Laguna Grande and Chica) and the Papaloapan (Sombrerete and Río Limón).

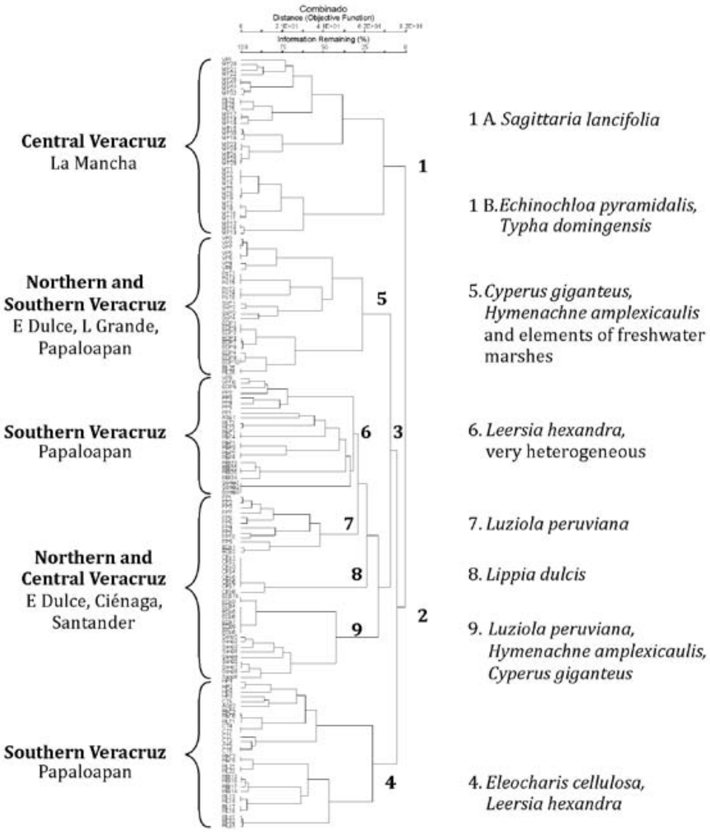

FIGURE 3

Dendrogram comparing the vegetation of marshes and flooded pastures. Data are from López Rosas et al. (2005), Moreno-Casasola et al. (2010), and Rodríguez-Medina and Moreno-Casasola (2013).

Dendrograma que compara la vegetación de los humedales herbáceos y los pastizales inundables. Los datos provienen de López Rosas et al. (2005), Moreno-Casasola et al. (2010), y Rodríguez-Medina y Moreno-Casasola (2013).

Group 6 is dominated by *Leersia hexandra*, which is associated with several species from the herbaceous wetlands, with few representative quadrats. It is a very heterogeneous group present in several sites of the Papaloapan. Group 7 is dominated by native species such as the grass *Luziola peruviana*. The herb *Lippia dulcis* (Verbenaceae) dominated group 8 and only appeared in the north of Veracruz, in Ciénaga del Fuerte and Estero Dulce. Finally, group 9 is dominated by *L. peruviana, H. amplexicaulis* and *C. giganteus*. The dominant species of most of these groups indicates that wetland plant cover at these sites is dominated by native species used by livestock. The most frequent members of the Cyperaceae are *Eleocharis cellulosa*, *Cyperus giganteus*, *Cyperus articulatus* and *Fimbristylis spadicea*.

The data were also analyzed with a Principal Component Analysis, and data were modified with Beals smoothing technique to eliminate zero truncation problems (Beals, 1984), using the same program. Axis 1 and 2 of the ordination account for 38.51% of the variation found. In Figure 4, samples from the different sites can be seen, using different symbols to show the herbaceous wetlands in central and northern Veracruz, those in the Papaloapan Basin, the flooded pastures of the central and northern regions and those in the Papaloapan Basin. Axis 1 shows a regional gradient with both the herbaceous wetlands and the flooded pastures of the Papaloapan communities (the largest wetlands in the state of Veracruz) on the left. The communities located on the northern region appear on the right of the ordination space. Axis 2 shows a gradient of herbaceous wetlands along the upper part of the ordination space and flooded pastures at the bottom. These gradients can also be interpreted as diversity gradients. Both marshes and flooded pastures along the Papaloapan have higher diversity values (Shannon index: 1.949 and 1.250 respectively) than the herbaceous wetlands and flooded pastures in the central and northern regions (1.191 and 0.632 respectively). Thus, both site and management determine some of the properties of these wetlands. The Papaloapan River Basin harbors the most extensive freshwater marshes in Veracruz allowing for a less impacted hydroperiod, with fewer fluctuations over time, and this allows for the conservation of wetland diversity. Cattle stocking rates are also low, with only one or two cows per hectare, though there are cattle throughout the region. These species richness and diversity values together with the area of the wetlands and the numerous aquatic bodies in between the wetlands, probably do not favor the invasion of exotic species. Table 1 lists some of the characteristics of the native and exotic grass species found in the flooded pastures of Veracruz.

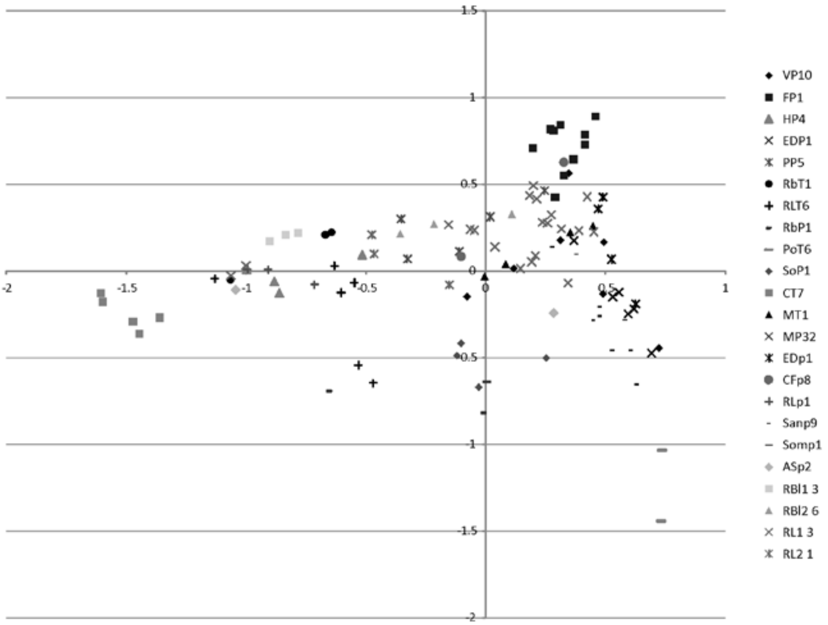

FIGURE 4

PCA ordination in which Axis 1 and 2 account for 38.51% of the variation. Wetlands in the central and northern region of Veracruz are dark circles; wetlands in the Papaloapan Basin, with very low cattle grazing impact, are open diamonds. Flooded pastures in the central and northern region are open triangles and those located in the Papaloapan Basin are gray squares. Along axis 1 there is a geographical gradient, with the samples from the Papaloapan on the left side and samples from the central and northern region on the right. Axis 2 shows a grazing gradient, which is clearest for the central and northern sites, where some wetlands are not used for grazing. These appear toward the upper part of the ordination space. The Papaloapan samples are mixed because there are sites with intensive grazing and others with very low impact, but there are no sites which have not been grazed at all.

Ordenación por análisis de componentes principales (ACP) en donde los ejes 1 y 2 explican el 38.51% de la varianza. Los círculos representan a los humedales de la región centro y norte de Veracruz; los rombos representan a los humedales de la Cuenca del Papaloapan, con muy bajo impacto de pastoreo de ganado. Los triángulos representan a los pastizales inundables en la región centro y norte; los cuadros representan a los pastizales inundables de la Cuenca del Papaloapan. A lo largo de eje 1 hay un gradiente geográfico, en donde los sitios del Papaloapan se encuentran del lado izquierdo y las de la región centro y norte en el derecho. El eje 2 muestra un gradiente de pastoreo, el cual es más claro para los sitio del centro y norte, donde algunos humedales no se utilizan para el pastoreo. Estos aparecen en la parte superior del espacio de la ordenación. Las localidades del Papaloapan son variadas, ya que hay sitios con pastoreo intensivo, otros con bajo impacto, sin embargo no hay sitios totalmente libres de pastoreo o que no hayan sido pastoreados en algún momento.

TABLE 1

Characteristics of the more common native and introduced grass species found in Mexican wetlands.

Características de las especies de gramíneas nativas e intruducidas más comunes que se encuentran en los humedales de México.

Species	Common name English (Spanish)	Some ecological traits	Photo-synthesis	Origin
Arundo donax L.	Giant reed, giant cane (carrizo, arundo, caña)	Perennial, rhizome; sterile seeds, vegetative growth appears to be well adapted to floods, which may break up individual clumps, spreading the pieces, which may sprout and colonize further downstream. Is poisonous to cattle and so cannot be used as forage.	C3[1]	Introduced, Asia
Urochloa mutica (Forsk.) Nguyen (synonym *Brachiaria mutica* (Forsk.) Stapf)	Pará grass (pasto Pará, zacate Pará)	Perennial, creeping stolons, stems reclining at base, rooting at the lower nodes, fodder grass and also one of the worst weeds. Allelopathic abilities allow it to form dense monocultural stands. Reproduces and spreads primarily by stem fragments; can form a stolon mat 1 m or more in depth; sends up floating stems. Tolerates both drought and brackish water .	C4[6]	Introduced
Cynodon dactylon (L.) Pers.	Bermuda grass (zacate Bermuda)	Perennial, stolons, rhizomes, reproduces by seed and vegetatively, widespread, good animal fodder	C4[1]	Introduced, Africa
Echinochloa colona (L.) Link	Jungle rice (arrocillo silvestre)	Annual, considered an agricultural weed, good animal fodder	C4[1]	Introduced, naturalized, Eurasia
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Barnyard grass (pasto alemán, zacate alemán)	Perennial, rhizomes, reproduces vegetatively, very productive and “builds soil” through biomass accumulation	C4[1]	Introduced, Africa
Eriochloa acuminata (J. Presl) Kunth	Southwestern cupgrass	Annual, caespitose, erect or decumbent, sometimes rooting at the lower nodes	C4[2]	Native
Hymenachne amplexicaulis (Rudge) Ness	Foxtail, West Indian marsh grass (azuche, cola de zorra, trompetilla)	Perennial, stolons, stems floating, creeping, or ascending to 1 m, rooting at the lower nodes. Adapted to fluctuating water levels, which allow massive regeneration by seed and ensure persistence after extensive drought. Grows in water up to 2 m deep in periodically inundated wetlands, but not in permanent water	C3[2]	Native, tropical America and Caribbean
Hyparrhenia rufa (Nees) Stapf	Giant thatching grass, jaragua grass (pasto jaragua)	Perennial, forms large clumps, reproduces by seed; medium quality forage grass; fire adapted	C4[1]	Introduced, Africa
Imperata cylindrica (L.) Raeusch.	Blady or cogon grass (alang alang, sujo)	Perennial, rhizomes, spreads through seeds and rhizomes, forms compact tufts	C4[1]	Introduced, Asia

Species	Common name English (Spanish)	Some ecological traits	Photo-synthesis	Origin
Leersia hexandra Sw.	Swamp ricegrass, southern cut grass (pasto lamedor)	Perennial, stolons and small rhizomes, develops rooted, floating culms during the rainy season, spreads vegetatively by rhizomes and stolons and can also reproduce from seed. Sometimes forms floating islands and can grow in water up to 1.8 m deep; animal fodder	C3[1]	Native
Luziola peruviana Juss. Ex J.F. Gmel.	Peruvian watergrass (engordador)	Perennial, stolons.	C3[4]	Native
Oryza latifolia Desv.	Wild rice, broad leaved rice (arrozillo)	Perennial, caespitose, short rhizomes, erect culms up to 2 m.	C3[1]	Native, south of Mexico to Paraguay
Paspalidium geminatum (Forsk.) Stapf	Kissimmee grass, Egyptian paspalidium, Egyptian panic grass	Perennial, mat forming, elongated rhizomes, rooting at nodes	C4[4]	Native, although there are contradictory reports
Paspalum repens P.J. Bergius (syn. *P. fluitans*)	Water paspalum (camalote)	Perennial, stolons, stems grow long and sprawling, spongy and thick, frequently found submersed or floating	C4	Native
Pennisetum purpureum Schumach.	Napiergrass, elephant grass (pasto elefante, p. Taiwan)	Perennial, bamboo-like clumps, spreads by short rhizomes, rooting from lower nodes or falling stems rooting at nodes creating a stolon, reproduces vegetatively or by seed, recovers from fire	C4[1]	Introduced, Africa
Phragmites australis (Cav.) Trin. ex Steud.	Common reed (carrizo)	Perennial, thick rhizomes, spread mainly through vegetative means; rhizome and stolon fragments, producing dense mats, tolerates brackish water, although a native it can become invasive	C3[1]	Native, although there is discussion
Setaria palmifolia (J.Köning) Stapf	Palm grass, Buddha grass	Perennial, rhizomes, forms pure colonies, rhizome mass excludes all other vegetation; reproduces only by seeds, dispersed by wind, animals	C4[1]	Introduced, India
Spartina spartinae (Trin.) Merr.	Gulf cordgrass (esparto)	Perennial, caespitose, no rhizomes, tolerates saline conditions; sprouts are used as animal fodder	C4[5]	Native
Zizianopsis miliaceae (Michx.) Döll & Asch.	Giant cut grass, water millet	Perennial, rhizomes, grows up to 4 meters tall in dense bunches from large, creeping rhizomes. Spreads via functional stolons and vegetative buds that erupt from the stems; tolerates small amount of salt in free soil water	C3	Native

(1) Waller and Lewis (1979), (2) Medina and Motta (1990), (3) Field Guide to Texas Grasses. Robert B. Shaw, Institute of Renewable Natural Resource, (4) Giraldo-Cañas (2010), (5) Ainouche et al. (2004), (6) Williams and Baruch (2000).

Flooding as a plant stressor

Freshwater wetlands are stressful ecosystems for most plants. Flooding or water saturation of the soil decreases the concentration of oxygen available to plant roots. Under these reducing conditions there is an increase in soil microbial processes that produce gases that are potentially toxic to the plant, such as sulfide or methane (Mendelssohn *et al.*, 1981; Ponnamperuma, 1984). Aquatic plants (hydrophytes) have features that allow them to endure or avoid reducing (anaerobic) soil conditions. The flood response varies with plant type, the duration and frequency of flooding, and the flood water characteristics (Kozlowski, 1984). The tolerance of plants to flooding is associated with the resistance of air movement through the vascular *cambium*, the survival of secondary roots, the development of new secondary roots and adventitious roots, accelerated anaerobic respiration, and the oxidation of the rhizosphere (Kludze and DeLaune, 1996). Most hydrophytes develop aerenchyma in their leaves, stems and roots. This tissue has a dual function: (1) transporting oxygen from the atmosphere to the rhizosphere, and (2) diluting the toxic gases out of the plant cells (Crawford, 1987). Plants adapted to flooding capture atmospheric oxygen through their photosynthetic tissue and this oxygen is directed toward the aerenchyma from where it is spread to the roots, creating an oxidized microenvironment around them. This process is beneficial to plants because they oxidize reduced compounds such as iron and manganese ions, which are abundant in flooded soils and are toxic to the roots (Kozlowski, 1984). As flooding is a stressor to plants, the number of species in tropical wetlands is low compared to those in terrestrial environments. Perhaps this is why the exotic hydrophytes are successful invaders in these environments and produce such a negative impact. In the wetlands of the Americas, invasive hydrophytes are one of the main causes, whether direct or indirect, of negative effects. Many of these are reported in the literature, others have not been reported but they are highly likely to be present. For example, *Arundo donax* (giant reed) displaces the trees on the banks of rivers and lakes, reducing riparian diversity (direct impact) and consequently decreases the shade on the water's surface with the result that temperature increases (indirect impact). Another example: invader grasses such as *Echinochloa pyramidalis*, *Brachiaria mutica*, *Pennisetum purpureum* and *Phragmites australis* are aggressive competitors that displace native vegetation (direct impact). They are highly productive species with high water requirements through evapotranspiration, which leads to reduced hydroperiods and accelerates the process of succession (indirect impact) to communities of facultative hydrophytes or terrestrial environments. Table 2 lists the main wetland invasive hydrophytes of the tropical and sub-tropical Americas, and the effects that have been reported in the literature.

Soils

Wetland soils are a key element in the ecological services that wetlands provide to society. Their physico-chemical characteristics are fundamental to water retention during floods and in the storage of organic carbon.

The effect of livestock on wetland soils

Livestock provides an important source of income in a world that increasingly requires more space to feed growing populations. In recent decades, wetlands have been affected as the cattle frontier has expanded into mangroves and freshwater wetlands where the animals can graze during the dry months when forage supply decreases in other pastures (Skerrit, 1992; Moreno-Casasola, 2004). The few studies that have examined the impact of cattle grazing on these ecosystems state that there is some impact on vegetation, the growth of exotic grasses and small plants with short life cycles is favored, and there is a reduction in the richness and abundance of species with large leaves and thick rhizomes, which are characteristic of the native vegetation of herbaceous wetlands (Travieso-Bello *et al*., 2005; Jones *et al*., 2011; Rodríguez Medina, 2011). The impact of livestock on the vegetation is also reflected in the diversity of the fauna. Jansen and Healey (2003) have shown that if large leaves are not available in wetlands, frog communities are markedly reduced. Furthermore, Jones *et al.* (2011) mentioned that waterfowl breeding is adversely affected, mainly that of ducks, because they are more likely to use the large leaves of the emergent vegetation as cover for the nest and when trying to escape.

The type and quality of the vegetation depends partly on the soil, which is one of the basic components of a wetland (Mitsch and Gosselink, 2007). It is critical because that is where the stress is produced by oxygen limitation, which affects both the rate of decomposition and nutrient availability (Úlehlová, 1998).

Currently, there are several studies that report the impact of livestock on the soil of diverse ecosystems such as grasslands, savannas, and agricultural systems. These studies report that trampling by livestock over short periods of time affects mainly the first 15 cm of soil, and significantly increases bulk density and penetration resistance, thus reducing infiltration and porosity (Lal, 1996), and affecting the development of plant roots and their productivity (Pinzon and Amezquita, 1991). Studies on this topic in wetlands are scarce. Travieso-Bello *et al*. (2005) reported that the values of C and N at multiple sites under different livestock handling regimes are explained by a combination of factors including changes in hydrology, the introduction of nonnative species, and the presence of cattle. Higher values of C and N were found in seminatural wetlands with little livestock management (with no draining or species introduction, etc.), and the opposite happened in wetlands where the hydrology had been changed and the stocking rate was higher. They also found that soils had higher organic matter content and retained more moisture when the stocking rate was lower. Rodríguez-Medina and Moreno-Casasola (2013) evaluated the effect of livestock on the soil of four freshwater herbaceous wetlands on the central Gulf coast of Mexico, and reported that where the stocking rate was higher, soil bulk density was also higher and the amount of organic material was low, reducing its total porosity. They also reported that trampling during the rainy season affected the soil and made it more prone to compaction.

Some authors have briefly mentioned the impact of livestock on wetlands, indicating that it affects biodiversity, induces changes in the balance of nutrients because cattle dung introduces nutrients, and reduces the amount of organic matter and soil moisture, among other effects (Coffin and Lauenroth, 1988; Archer and Smeins, 1991; Skerritt, 1992; Trettin *et al.*, 1995; Collins *et al.*, 1998; Baron *et al.*, 2002). Each cow defecates 15 to 20 times per day and its dung can cover one square meter per day (De Elias, 2002).

Despite all of the negative impact on wetland soils caused by raising livestock, Rodríguez-Medina and Moreno-Casasola (2013) mention that if livestock were excluded from these sites during the flooding period for at least six months, and stocking rate were maintained between one and two cows per hectare, the impact on the soil would not be as severe, and important physico-chemical characteristics would be little affected in the long term. Thus low intensity grazing would favor the preservation and maintenance of tropical wetlands. Further work is needed to develop a system that ensures sustainable livestock production with minimal degradation of soil resources (Tian *et al.*, 1999). Junk and Nunes da Cunha (2012) indicate that cattle ranching in the Pantanal in Brazil maintains the dominant herbaceous wetlands and hampers shrub and tree growth.

In the following paragraphs we describe the changes that take place in the soils and the tropical marsh vegetation associated with different management practices: the introduction of cattle, fire, wetland drainage, and the introduction of exotic forage species. The information was compiled from Travieso-Bello *et al.* (2005), López Rosas *et al.* (2005), Escutia-Lara *et al.* (2009), Olsen *et al.* (2011), Wantzen *et al.* (2012), Rodríguez-Medina and Moreno-Casasola (2013) and personal observations.

1. Cattle is introduced into the wetlands, no other management practice is applied

1.1. *Hydrology*

Flooding is kept similar to the natural regime.

1.2. Soil

Organic material (OM). When livestock is present, the layer with OM decreases due to grazing and trampling; however, during the flooded months animals are removed and grazing and trampling stops; the OM layer increases since the process of mineralization decreases. Several wetland species tolerate grazing and resprout.

Water retention. Soils that have a layer with OM retain more water because they have pores of various sizes, resulting from plant residue in various stages of decomposition. These pores fill with water during flooding. Porosity can decrease with cattle trampling.

Bulk density (BD). BD increases because of animal trampling. The soil can regain its porosity and part of its structure when livestock is excluded during flooding. This is possible when the number of cattle is no higher than one or two per hectare.

Micro- and macronutrients. A long period of flooding reduces mineralization and the amount of micro- and macronutrients (C, N, P, K, Mg, Ca, Na) increases.

pH. The soil remains slightly acidic (characteristic wetland soil) because oxidation-reduction processes still occur.

1.3. Vegetation

The species appearing under these conditions are mainly native wetland species: *Sagittaria lancifolia, Pontederia sagittata, Thalia geniculata, Eleocharis cellulosa, Cyperus articulatus, Hydrocotyle verticillata, Nymphaea ampla, Sporolobus virginicus, Lippia nodiflora, Fuirena simplex, Typha domingensis, Ipomoea tiliacea,* and *Bacopa monnieri.* In more flooded areas *Salvinia minima* and *Lemna minor* are dominant. There are few grass species.

2. Cattle is introduced into the wetlands and the hydrological conditions are modified

2.1. Hydrology

Flooding is reduced.

2.2. Soil

Organic material (OM). The layer of OM is reduced because grazing and trampling by livestock occurs year round and directly affects the vegetation. Additionally, the small amount of OM present decomposes very quickly in the absence of anaerobic conditions.

Water retention. In soils where the hydrology has been changed and flooding periods have been significantly reduced, mineralization processes dominate, so there is little OM and thus the soil's water retention capacity is much lower.

Bulk density (BD). In the absence of OM, environmental factors such as wind and rain can more easily erode the soil's surface. If we add trampling to this scenario, the soil structure is modified as stable aggregates are destroyed and begin to clog the air spaces. This produces an increase in BD and lower porosity.

Micro- and macronutrients. Micro- and macronutrients decrease because OM is scarce; there are no long periods of flooding, and therefore mineralization is increased.

pH. The alkalinity at these sites is higher due to the decrease in the flooding periods and lack of anaerobic conditions, which limits the processes that acidify the soil.

2.3. Vegetation

A few native wetland species are maintained, including indigenous wetland grasses such as *Hymenachne amplexicaulis.* Exotic grass species used as forage appear or are introduced: *Echinochloa pyramidalis, Echinochloa colona.* Other accompanying species are *Panicum* sp., *Paspalum* sp., *Hydrocotyle verticillata,* and *Typha domingensis.* Other species commonly found in disturbed areas or associated with human activities are *Cucumis anguria, Acacia cornigera, Ipomoea tiliacea,* and *Solanum campechiense.*

3. Cattle is introduced into the wetlands and the vegetation is burned annually

3.1. Hydrology

Flooding is kept similar to the natural regime.

3.2. Soil

Organic matter, micro- and macronutrients. In general, OM, soil nutrients and water retention decreases with the presence of livestock (see above 1.2 and 2.2) and can further increase with burning. There are reports stating that if both management activities are low impact (few cattle, and removing cattle during the period of high floods), the productivity of a site may increase, and may in fact favor the wetland species and control the spread of exotic and invasive species (López Rosas, 2007; Escutia-Lara *et al.*, 2009; Rodríguez Medina, 2011).

Bulk density. It has been mentioned that livestock increases the value of BD, but when the presence of livestock is combined with a low-intensity burning, this may favor the growth of wetland species. The latter help decrease BD, because the native hydrophytes of these ecosystems have many, much longer and thicker roots (due to aerenchyma), and these increase air space and soil porosity (Davey *et al*., 2011).

3.3. Vegetation

Native wetland grasses and sedges that tolerate grazing are present, such as *Sporolobus virginicus* and *Hymenachne amplexicaulis*, *Eleocharis cellulosa, Cyperus articulatus,* and *Fuirena simplex.* Other hydrophytes are also maintained: *Sagittaria* *lancifolia*, *Pontederia sagittata*, *Thalia geniculata*, *Hydrocotyle verticillata*, *Nymphaea ampla, Lippia nodiflora, Typha domingensis,* and *Bacopa monieri*. In more flooded areas *Salvinia minima* and *Lemna minor* are dominant. The exotic grass *Echinochloa colona* is present. Species associated with disturbance or human activities are *Cucumis anguria*, *Acacia cornigera, Ipomoea tiliacea,* and *Solanum campechiense.*

4. Cattle is introduced into the wetlands, vegetation is burned each year, and flooding time is reduced, sometimes with the introduction of exotic forage species

4.1. Hydrology

Flooding is reduced

4.2. Soil

The impact of livestock in the areas where flooding has been reduced by changes to the hydrology is high, and if the vegetation is burned this management practice may be more harmful to the soil, mainly because the conditions are no longer suitable (mainly the hydrology) for the growth of native wetland species. Fires cause increased soil erosion. The low-impact fires in wetlands that have not been strongly transformed may benefit the growth of native vegetation because temperature in soil is not enough to kill seeds and propagules of hydrophytes; then the gaps can be revegetated with natives (Lin *et al*., 2005). Intense fires are common when the flooding is reduced; those fires kill seeds and propagules in soil surface, then only propagules of resistant species, such as the invader grasses, survive and dominate new gaps (Lin *et al*., 2005) and the process of invasion is reinforced.

4.3. Vegetation

Species richness decreases and few native wetlands species remain: *Hydrocotyle bonariensis, Fimbristylis spadicea, Cyperus articulatus.* Grass species are favored as well as those associated with human activities*: Echinochloa pyramidalis, Echinochloa colona, Panicum* sp.*, Paspalum* sp.*, Cucumis anguria*, *Solanum campechiense*, *Ipomoea tiliacea*, *Acacia cornigera,* and *Mimosa pigra.*

FROM WETLANDS TO PASTURE

The use of wetlands for cattle grazing brings about important environmental changes. The number of cows allowed to graze per hectare is closely related to the degree of the impact, thus forming a gradient from wetlands to flooded pastures, with different species composition and richness, soil characteristics and hydrology. These flooded pastures can be considered wetlands, though when they are invaded by exotic species, or when their hydrology is altered, these transformations impair their functioning, and there is a tendency to lose environmental services and for them to function more like terrestrial systems (Table 2).

TABLE 2

Impact of exotic hydrophytes on tropical and subtropical American wetlands.

Impacto de hidrófitas exóticas sobre humedales de América tropical y subtropical.

Family	**Species**	**Type of Impact**	**References**
Acanthaceae	*Hygrophila polysperma* (Roxb.) T. Anderson	1, 4, 5	Sutton, 1995; Mora-Olivo *et al*., 2008
Araceae	*Pistia stratiotes* L.	1-4, 8	Gordon, 1998
Fabaceae	*Mimosa pigra* L.	1-5, 7, 13-15, 20, 22	Labrada *et al*., 1996; Gordon, 1998; Rejmánek *et al*., 2005
Fabaceae	*Pueraria montana* var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep	1-3, 5	Gordon, 1998; Rejmánek *et al*., 2005
Hydrocharitaceae	*Hydrilla verticillata* (L. f.) Royle	1, 2, 4, 5, 8, 13, 14, 16, 17	Comité Asesor Nacional sobre Especies Invasoras, 2010; Gordon, 1998; Sousa, 2011; Langeland, 1996
Iridaceae	*Iris pseudacorus* L.	1, 6	Pathikonda *et al*., 2008
Lythraceae	*Lythrum salicaria* L.	1-4, 14, 17	Blossey *et al*., 2001; Brown *et al*., 2006; Lavoie, 2010; Rejmánek *et al*., 2005; Zedler and Kercher, 2004
Myrtaceae	*Melaleuca quinquenervia* (Cav.) S.T. Blake	1-4, 6, 7, 13	Gordon, 1998; Mack *et al*., 2000; Rejmánek *et al*., 2005; Zedler and Kercher 2004
Poaceae	*Arundo donax* L.	1, 3-5, 7, 11, 12, 15, 18, 21	Guthre, 2007; Flores Maldonado *et al*., 2008; Comité Asesor Nacional sobre Especies Invasoras, 2010; Rejmanek *et al*., 2005; Yang *et al*.; 2011
Poaceae	*Brachiaria mutica* (Forssk.) Stapf	1, 3-5	D'Antonio and Vitousek, 1992; Parsons, 1972
Poaceae	*Echinochloa pyramidalis* (Lam.) Hitchc. & Chase	1, 5, 6	López Rosas, 2007; López Rosas *et al*., 2005; López Rosas and Moreno-Casasola, 2012
Poaceae	*Imperata cylindrica* (L.) Raeusch.	7, 18, 20	Labrada *et al*., 1996
Poaceae	*Pennisetum purpureum* Schumach.	1, 4, 5, 7, 13, 14	Williams and Baruch, 2000; Cronk and Fuller, 1995; Laegaard and Pozo Garcia, 2004; Schardt and Schmitz, 1991

Family	**Species**	**Type of Impact**	**References**
Poaceae	*Phragmites australis* (Cav.) Trin. ex Steud.	1, 2, 8, 16	Zedler and Kercher, 2004
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	1-6, 8-10, 13-19	Barret, 1989; Labrada *et al*., 1996; Comité Asesor Nacional sobre especies invasoras, 2010; Gordon, 1998; Mack *et al*., 2000; Rejmánek *et al*., 2005
Salviniaceae	*Salvinia molesta* D.S. Mitch.	2, 5, 9, 10, 13, 14, 19	Berret, 1989; Labrada *et al*., 1996; Rejmánek *et al*., 2005
Tamaricaceae	*Tamarix ramosissima* Ledeb.	1-3, 6	Rejmánek *et al*., 2005; Zedler and Kercher, 2004
Vochysiaceae	*Vochysia divergens* Pohl	1-3	Vourlitis *et al*., 2011; Sanches *et al*., 2011

***Environmental impact**: (1) decrease of biodiversity, (2) changes in the chemical composition of soil or water, (3) alteration of hydrology (e.g. excessive water loss through evapotranspiration), (4) obstruction of flow water (stagnation), (5) intercepts light, increasing shade at soil level, (6) vertical soil accretion, (7) altered fire regime, (8) altered food webs, (9) excessive use of oxygen, (10) reduction of dissolved oxygen, (11) increase in the temperature of rivers and water bodies (by reduced shade of trees), (12) erosion of river borders. Social impact: (13) obstruction of navigation channels, (14) obstruction of waterways or hydroelectric plants, (15) accelerated siltation of reservoirs and irrigation canals, (16) reduction in fisheries productivity, (17) reduction of recreational activities, (18) increase in habitat for vectors of human or livestock disease (malaria, dengue fever, filariasis, encephalitis, schistosomiasis, etc.), (19) interferes with the operation of waterworks, (20) aquatic weed in crops (e.g. rice), (21) damage to social infrastructure (bridges, pipes, etc.), (22) interferes with the movement of people and livestock.*

Figure 5 synthesizes in a diagram the information presented in this paper with the changes in the hydrology, soils and vegetation occurring under two conditions. The first occurs when flooded pastures originate from swamps (freshwater forested wetlands), and the second when marshes undergo the transformation. Flooding can either be maintained or reduced. In the first case flooding only remains aboveground for a few months and in the second case it can either be maintained (as occurs on floodplains with extensive wetlands, i.e. Río Blanco in the Papaloapan River basin- Figure 2) or reduced as a result of draining or the introduction of exotic species. Soil properties change, although this depends strongly on the original soil type, i.e. organic or mineral. Vegetation also varies as shown in the classification and ordination figures.

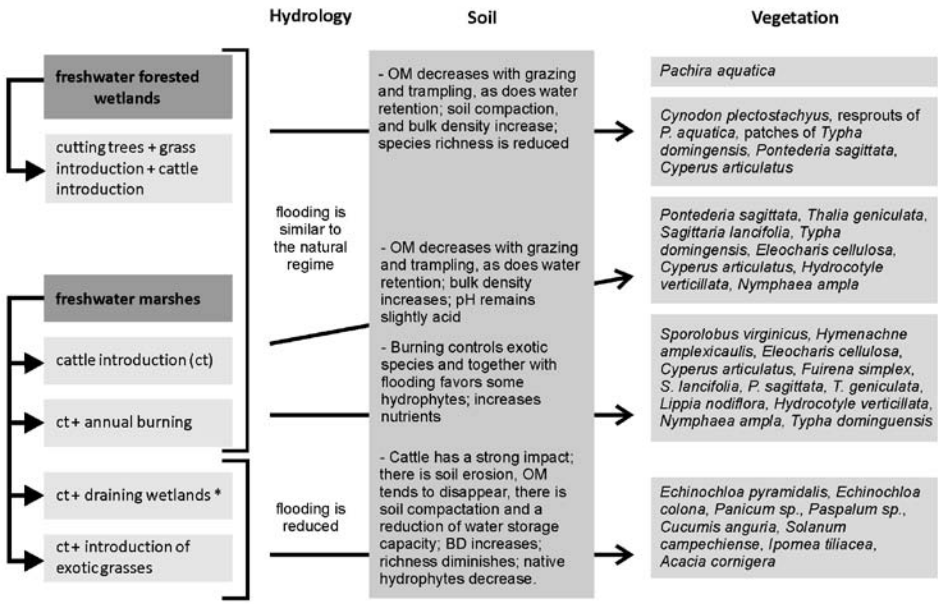

FIGURE 5

Diagram showing changes in the hydrology, soil and vegetation in flooded pastures originating from freshwater forested swamps and from marshes.

Diagrama que muestra los cambios en la hidrología, suelo y vegetación en los pastizales inundables que se originaron a partir de humedales arbóreos de agua dulce y de humedales herbáceos de agua dulce.

Some grass species introduced from the African flooded savannas can tolerate flooding and compete with native wetland plants (López-Rosas and Moreno-Casasola, 2012). Wetlands are particularly vulnerable to invasion processes, where variations in hydrologic regimes may cause changes in community composition and structure and are considered one of the causes that make the incorporation of alien species possible (Kalesnik and Malvárez, 2003). Currently, the most widely distributed grass on the coastal plain of Veracruz is the African grass *Cynodon dactylon*, which tolerates both dry and wet conditions (Travieso-Bello, 2005), but not prolonged periods of flooding. In wetlands, *Echinochloa pyramidalis* is preferred by cattle ranchers, because it “dries the area and builds soil” (Melgarejo-Vivanco, 1980), and because of its high productivity (Andrade *et al.*, 2008; Braga *et al.*, 2008). When exotic species are introduced into wetlands, transformations increase. Some of them are able to modify the hydrology of the particular wetland type, thus initiating a more drastic change in wetland functions.

Figure 6 shows how wetland functions, processes and values are affected by the transformation of herbaceous wetlands into flooded pastures. The following discussion does not apply to swamps that are cut down, because felling trees is, in itself, a major transformation. The degree of transformation of freshwater marshes varies with cattle grazing intensity. Arrows indicate permanence or decrease. Impact is grouped according to the type of environmental and socio-economic impact, based on Table 2 and on the data presented in this paper. The first type of environmental impact is the alteration of wetland structure and interactions, which includes the decrease in biodiversity and the increase in the presence and cover of invasive species (López Rosas, 2007). When exotic species are introduced to allow for more intensive grazing, and the biodiversity decreases, the dominance of a few species is promoted, shading reduces habitat for sun loving wetland species, there are changes to the soil physico-chemical characteristics, and flooding is reduced. Changes in species composition and community structure affect the wetland regulatory functions, habitat functions, production functions and information functions (*sensu* De Groot *et al.*, 2002), thus important ecosystem services decrease. For example, species composition and structure are related to carbon sequestration and water regulation (Campos *et al.*, 2011).

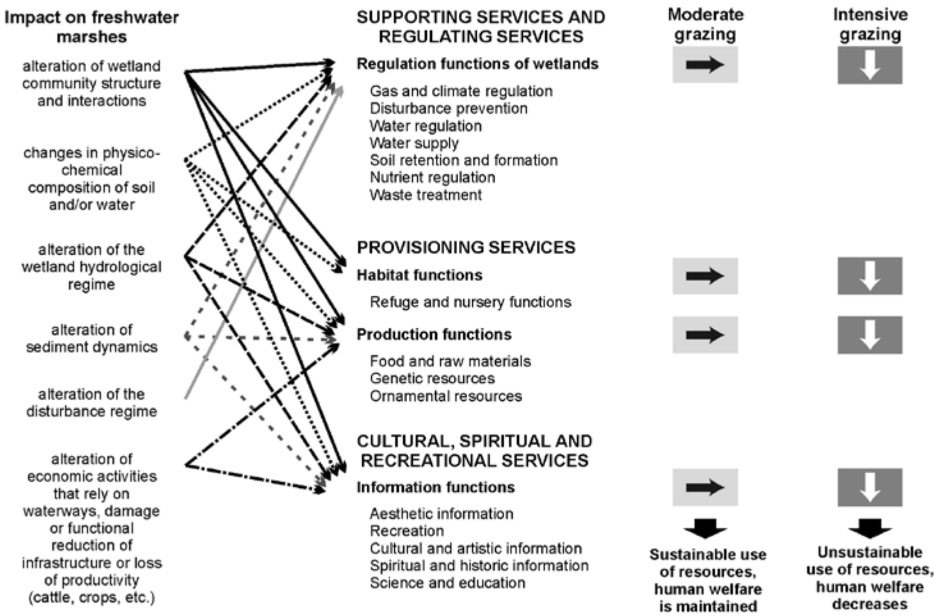

FIGURE 6

Diagram showing the functions and processes affected by the transformation of wetlands into pastures as a result of cattle ranching.

Diagrama que muestra las funciones y procesos afectados por la transformación de los humedales en pastizales para ganadería extensiva.

The second type of impact involves changes in the physico-chemical composition of the environment, which in the case of cattle grazing mainly involves alterations to the chemical composition of either the soil or the water, an increase in the temperature of rivers and water bodies (because of reduced tree shade), the interception of light which increases shade at soil level, and soil compaction produced by trampling. Among the main changes in the soil is an increase in bulk density, reduced pore space, and lower water retention. The organic layer is reduced, there is less aeration, pH becomes neutral, nutrient content decreases, and carbon storage potential is reduced, as is the soil's capacity to store water. These alterations will affect species composition. Important regulatory functions are affected as soils lose many characteristics and become similar to terrestrial soils. Supporting and regulatory ecosystem services decrease. Changes in the soils, one of the fundamental elements of wetlands, has a profound effect on plant composition, thus altering provisioning services.

The third is the alteration of the wetland hydrological regime, which includes the alteration of hydrology, and can result from one or more of the following: excessive water loss through evapotranspiration, obstruction of water flow, changes in topography due to soil accretion, or an increase in sedimentation. Soils remain drier for a longer period of time and organic matter is lost, thus altering the physico-chemical characteristics of the soils. All types of wetland functions are altered as hydrology is the main driver of hydric soil processes and wetland vegetation. There is a general reduction in ecosystem services.

The fourth impact is the alteration of sediment dynamics, which includes vertical soil accretion and the erosion of the river banks. These changes end up altering the hydrological regime, which has the strongest negative influence on wetlands. The main impact is on supporting and regulatory services. Finally, the fifth is the alteration of the disturbance regime, which impacts species composition.

The main type of social and economic impact includes the alteration of income generating activities that rely on waterways when navigation channels are blocked, changes to waterways or the construction of hydroelectric plants, the operation of waterworks, decreased opportunities for recreational activities, and the obstruction of the movement of people and livestock. A second type is the damage or functional reduction of infrastructure, which results in the premature siltation of reservoirs and irrigation canals and damage to social infrastructure (bridges, pipes, etc.). A third type of impact includes a decrease in crop production (i.e. rice), invasion by species that reduce the quality of flooded pastures for cattle grazing (Junk and Nunes da Cunha, 2012), and an increase in the habitat available for the vectors of human and livestock diseases. Local and regional economies are affected, and the final result is a reduction of human well being (*sensu* Millennium Ecosystem Assessment, 2005).

Wetlands that are used for grazing produce milk and meat, and therefore make an important contribution to the family income. Milk in particular, sometimes transformed into dairy products, is part of the everyday diet. Meat (or the live cow) represents capital, or a means of having some savings for difficult times. Considering the myriad benefits provided by wetlands, their conservation and use should be analyzed taking into account the degree of transformation. When wetland ecosystem services decrease or are lost, the price paid is very, very high. When cattle grazing does not alter ecosystem functions, it represents a sustainable use of resources that promotes human welfare. This use is probably linked to wetland size, and according to Junk and Nunes da Cunha (2012) can be achieved "…through modern management plans that reconcile the requirements of environmental protection with the economic needs of the ranchers, who are the owners of most of the Pantanal. The key to any such plan's successful implementation is to consider the Pantanal not as a pristine wetland, but as a valuable cultural landscape". Over the last two and a half centuries, the vegetation over large parts of the Pantanal has been altered due to the presence of cattle ranchers, as it has over most of the tropical wetlands in the Americas. These authors indicate that cattle ranching has maintained the environment's habitat diversity and the multiple services provided to humans and to the environment, including the enhancement of species diversity. Our results indicate that cattle ranching in wetlands with a low density of cattle (one head per hectare) maintains wetland species, hydrological and soil conditions. This was probably the situation when cattle was first introduced to Mexico. The cattle introduced by the Spanish, *Bos taurus*, were small animals, much lighter than Zebu and with smaller hoofs. They occupied extensive areas of wetlands with low densities (Siemens, 1998), thus their impact was moderate, maintaining the functions and environmental services provided by wetlands while constituting a sustainable economic activity that permited these ecosystems to be preserved.

High density livestock rearing or modifying the hydrology reduces plant diversity and results in a loss of wetland functions and services, such as water holding capacity being reduced by soil compaction. This is aggravated by the presence of C4 invasive species that make more efficient use of water than the native C3 species, can photosynthesize more efficiently in high temperatures and are very productive, causing soil accretion and increased shade at the soil level.

Government policies should thus promote the conservation of wetland functions and services, coupled with sustainable cattle ranching. This implies setting limits to the number of head of cattle per hectare in wetlands, rotating cattle so that during the flooding peak the wetland soil and plants can recover, banning wetland drainage practices and the introduction of African grass species. The sustainable practices mentioned above should be promoted in areas where the wetlands are not in a good state of conservation, and that are dedicated to cattle production, thus promoting better management practices for these areas, and ensuring that both wetland processes and the economic activities that are associated with them are maintained.

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POTREROS EN HUMEDALES TROPICALES EN LA COSTA DEL GOLFO DE MÉXICO

RESUMEN

La cría de ganado en México se inició con la llegada de los españoles y la creación de la Nueva España. Se modificó de manera significativa en la mitad del siglo XX con la introducción de la raza de ganado cebú y los pastos mejorados que esta ganadería requería. Los humedales se usaron para el pastoreo de ganado desde el inicio de esta actividad. El trabajo describe las transformaciones que se producen en las zonas inundables usadas para pastoreo y como se van convirtiendo en pastizales inundados. El grado de impacto depende de la cantidad de cabezas de ganado, el tiempo que permanecen en el humedal, y las modificaciones al hidroperíodo y a la vegetación. Se describen los cambios en el nivel de la inundación, las características del suelo (materia orgánica, retención de agua, densidad aparente, pH, micro y macro nutrientes) y la composición florística, y cómo todo esto afecta a los servicios ambientales que proporcionan los humedales. Con la introducción de razas tolerantes a ambientes tropicales, principalmente el ganado Cebú y las gramíneas forrajeras exóticas que pueden crecer en zonas inundables, el impacto ha aumentado. Estos pastos alteran drásticamente el medio ambiente (agua, suelo vegetación nativa) y pueden convertirse en invasoras. Por lo tanto hay un gradiente de transformación de los humedales sin impacto del ganado, a aquellos con ligeros cambios que siguen funcionando como humedales, hasta finalmente transformarse y perder sus funciones. Una gestión basada en un bajo número de cabezas de ganado mantiene las funciones y servicios ambientales que proporcionan los humedales al mismo tiempo que constituye una actividad económica sostenible, que permite que estos ecosistemas se conserven.

Palabras clave: Acreción vertical, compactación, invasión, pastoreo, sostenibilidad.