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Palm use and social values in rural communities on the coastal plains of Veracruz, Mexico

R. M. González-Marín · P. Moreno-Casasola · R. Orellana · A. Castillo

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Abstract Palms are a resource of great importance in the tropics and are found in a variety of ecosystems, including the wetlands of the tropical coastal plains. In order to recover wetland ecosystems, we studied the traditional uses of wetland palms, by conducting interviews in the communities of four municipalities on the Gulf of Mexico coast. We found that people use five species of palm: *Cocos nucifera, Sabal mexicana, Attalea liebmannii, Roystonea dunlapiana* and *Acrocomia aculeata*. Main uses for the five species were for food and construction materials. Although palms are still used, traditional knowledge is declining in the younger generations, likely as a result of various social, cultural and economic factors. It is important to recover and promote the traditional use and value of palm trees, especially for the native species, because of both the economic benefits and the environmental services they provide. More participatory work with the inhabitants is needed to initiate palm breeding programs to assist in the recovery of wetland ecosystems.

Keywords *Attalea liebmannii* · *Roystonea dunlapiana* · *Sabal mexicana* · Conservation · Traditional use · Wetlands

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R. M. González-Marín · P. Moreno-Casasola (✉)
Red de Ecología Funcional, Instituto de Ecología, A.C.,
Carretera Antigua a Coatepec No. 351, Congregación El Haya,
91070 Xalapa, Veracruz, Mexico
e-mail: patricia.moreno@inecol.edu.mx

R. Orellana
Unidad de Recursos Naturales, Centro de Investigación Científica de Yucatán,
Calle 43 No. 130, Colonia Chuburná de Hidalgo, 97200 Mérida, Yucatán, Mexico

A. Castillo
Centro de Investigaciones en Ecosistemas, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701 Col. Ex-Hacienda de San José de La Huerta, 58190 Morelia, Michoacán, Mexico

1 Introduction

Palms are tropical flora elements of high economic value to humans, providing raw materials and food (Leiva 1999). However, some palm species have little economic value, even though they are potentially useful in the modern world, and many species have not been well studied or conserved. Palms are found in different types of ecosystems such as tropical forests, savannas, coastal scrub and tropical wetlands (Quero 1994; Henderson 2002; Ellison 2004; Infante et al. 2011).

In the coastal wetlands of the Gulf of Mexico, palm swamps are an important component of forested flooded wetlands (Infante et al. 2011). Several palm species are tolerant to flooding and are found in these environments, mainly *Attalea liebmannii* (Becc.) Zona, *Roystonea dunlapiana* Allen and *Sabal mexicana* Martius, which form monospecific patches or are mixed with other palm or tree species. *Acrocomia aculeata* (Jacq.) Lodd. Ex Mart. tolerates flooding but prefers drier areas. Hereafter, these species are referred to as *Attalea, Roystonea, Sabal, Acrocomia*, respectively. An introduced species, the coconut palm, *Cocos nucifera* L. (hereafter referred to as *Cocos*), has been planted in sandy areas both along the coastal plain and on sand dunes. It is one of the most common crops in the humid tropics and in the region (Granados-Sánchez and López-Ríos 2002). Forested wetlands, including palm swamps, provide important environmental services to the people living in the settlements on the coastal plain: they function as barriers against wind and hurricanes, they filter water, offer shelter for wildlife, shade for livestock, they are a source of food for people and animals and provide material for construction (Kahn 1988; Gardiner 2006; Millennium Ecosystem Assessment 2005).

Two of the most important environmental services offered by forested wetlands are their ability to sequester carbon as organic carbon in the soils and water retention, which reduces damage from flooding (Chmura et al. 2003; Campos et al. 2011). Carbon captured by photosynthesis is stored in the trunks, leaves, roots and soil, but the incessant expansion of the agricultural frontier is resulting in the release of green house effect gases, such as CO_2. Palm trees are burned to make way for pastures and crops, releasing carbon and, instead of cleaning the atmosphere, end up polluting it (Richards and Stokes 2004). Furthermore, logging and the use of fertilizers for farming enhance the effect of these gases (Walther et al. 2007).

Unfortunately, over the last 50 years, humans have changed ecosystems more rapidly and extensively than during any other period in our history, mainly to satisfy the demand for food, water and wood, etc. (Batllori-Sampedro et al. 1999) and have thus altered other ecosystem services (e.g., climate regulation, erosion control). These demands are increasingly growing and challenge us to understand the connections between different management systems (provisioning and non-provisioning), the use of resources by and the customs of people, ecosystem structure and the endowment of various types of ecosystem services (Millennium Ecosystem Assessment 2005; Bennett and Balvanera 2007). Arriving at this understanding and its corollary, proper management would ensure the resilience of wetland ecosystems (Folke and Gunderson 2006) and continuity in the services they provide.

Traditionally, palms have met many needs: food and seasoning, and home decoration (Johnson 1996; Pérez-García and Rebollar-Domínguez 2008), among others. Their use is widespread in rural areas. Unfortunately, knowledge about the traditional uses of palms is scarce. Research and the dissemination of results is needed to preserve this part of the culture, as it offers knowledge and social values, which can support present-day development in rural communities (Braun and Delascio 1987).

This study focuses on palms in recognition of the great importance they still have in some rural communities on the coastal plains of Veracruz. The sites we studied have been subjected to floods that have affected property, livelihoods and livestock and have even taken human lives. Local inhabitants are becoming increasingly vulnerable because wetland transformation has reduced ecosystem services. In addition, it is important to conserve palms, since several of them are considered threatened species (Barrow et al. 2005).

Ethnobiological information about palms growing on the coastal plain of the Gulf of Mexico is scarce. The aim of this study was therefore to document the traditional uses of palms in rural communities, where wetlands are abundant. The recovery and revaluation of traditional knowledge could drive its readoption and the recovery of ecosystem services such as flood contention. Knowing the way in which palms are used by people and the level of interest the inhabitants have in the wetlands can be used to design and implement integrated ecosystem management strategies that promote sustainable development, not only locally but regionally.

2 Methodology

2.1 Study area

This study was conducted in rural communities located close to wetlands on the coastal plain of the Gulf of Mexico in the state of Veracruz. The settlements are located in the municipalities of Alvarado, Jamapa, Tecolutla and Tuxpan (Fig. 1, "Appendix 1").

2.2 Introduction to communities and sample selection

We focused on families living in houses made with materials obtained from palms, and contact was initially made by explaining the research project. We used the "snowball" sampling method (Mejía and Sandoval 2003) in which the family that was being interviewed then recommended another family to be interviewed, and so on. Initially, we found that older women had the most complete information on the uses of palms and their products (especially for food); both sexes had information on construction materials.

2.3 Research methodology and techniques

We used a qualitative research methodology that allows one to understand how people give meaning to social and natural phenomena (Denzin and Lincoln 2000). Open interviews, participant observation and discussion groups were used (Taylor and Bogdan 1984; Tarrés 2004), allowing us to talk with informants and document the ways in which they perceive themselves and their environment, under specific circumstances, realities and problems.

The questionnaire used for interviews had three thematic sections: (1) personal data about informants; (2) the traditional uses, benefits, importance and abundance of palms as a resource, and peoples' perception of the palm species found close to wetlands, including factors influencing the use of palms; and (3) questions about each of the palm species that the interviewees cited as important. Topics included the local name of the palm, the plant parts used and the products obtained. The family interviews lasted about 1 h, depending on the flow of the conversation and the interest of interviewees. We used a tape recorder during the interviews.

Interviews were stopped when the information became repetitive among families; recognized as saturation of data (Law et al. 2007). However, and in order to match sample

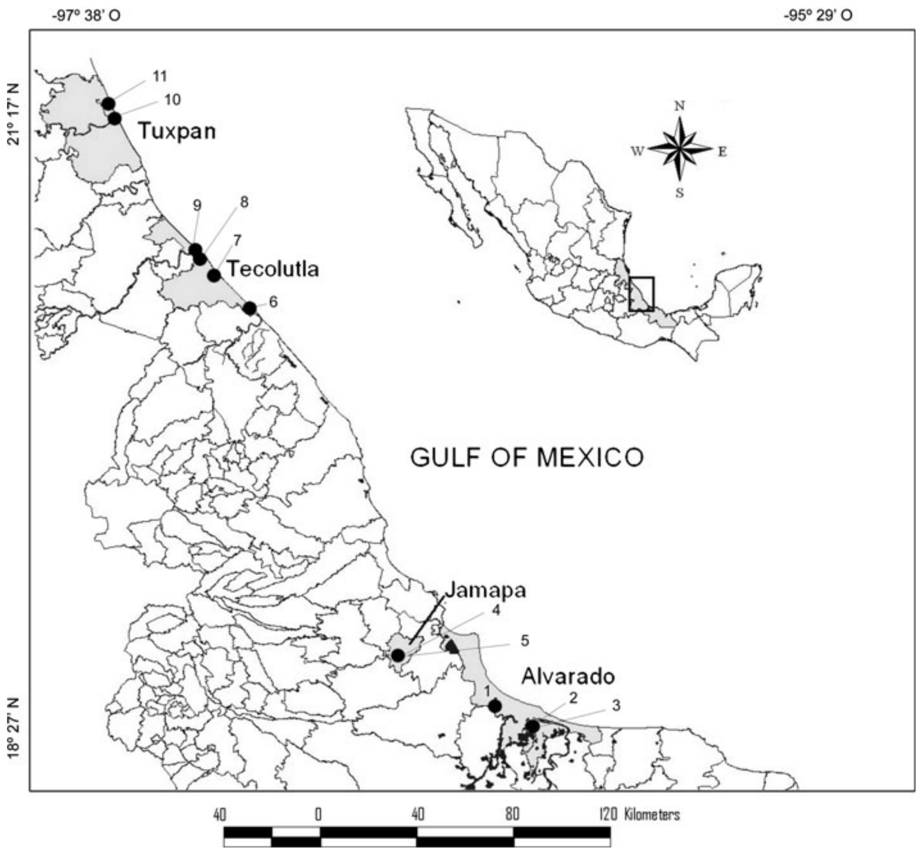

Fig. 1 Location of the municipalities (*gray*) and communities interviewed (*dots*) on the coastal plain of Veracruz, Gulf of Mexico. (1) Costa de San Juan, (2) Nacaste, (3) Pajarillos, located in the municipality of Alvarado (18°46′24″N-95°45′35″W); (4) Piñonal, (5) Matamba, Jamapa municipality (19°02′29″N-96°14′29″W); (6) Casitas, (7) Ricardo Flores Magón, (8) Tecolutla, (9) Cruz de los Esteros, Tecolutla municipality (20°28′46″N-97°00′36″W); (10) La Mata de Tampamachoco, (11) Golfo de Barra de Galindo, Tuxpan municipality (20°57′51″N-97°24′16″W)

size among municipalities, 15 interviews were conducted per municipality (total, 60 interviews). Also, participant observation was conducted in each community and the information recorded in field notes (Taylor and Bogdan 1984). We worked in Alvarado (six families interviewed in the town of Costa San Juan, five in Nacaste and five in Pajarillos), Jamapa (nine in Piñonal, six in Matamba), Tecolutla (four in Casitas, five in Ricardo Flores Magón, three in Tecolutla, four in Cruz de los Esteros) and Tuxpan (seven in Golfo de Barra de Galindo, eight in La Mata de Tampamachoco).

All open interviews were transcribed and analyzed following the qualitative analysis procedures of Taylor and Bogdan (1984) as follows:

(1) All interviews and field notes were examined line-by-line; (2) the texts of the interviews and field notes were coded, creating categories from the data; (3) categories were listed according to the number of times they were mentioned (Levin 1979), and then used to develop interpretative texts (the frequency or number of times a category was mentioned is given within brackets). For example, in Alvarado, "*Cocos*" was the most

frequently mentioned palm (15 times). “Food” is the most frequently mentioned type of use (15 times). Among the factors affecting the use of palms, “cutting palms to clear the land for cattle ranching” was mentioned the most (56 times); (4) Observations collected in the field were used to verify the answers and establish a broader social context for the usefulness and perception of people about palms; (5) Discussion groups were held to verify the results of the data analysis.

3 Results

3.1 Palm species used in the wetlands of Veracruz

Five palm species (four native and one cultivated) are used by people, and these are distributed throughout the four municipalities, although the use made of them depends on their abundance in the area (Table 1). The most frequently mentioned were *Cocos* and *Sabal,* both of which were mentioned in all four municipalities surveyed (Fig. 2). In Jamapa, people use more palm species and this is the only place where informants mentioned using *Roystonea* (mentioned 10 times). Fewer palm species were used in Tuxpan (Fig. 2).

3.2 Traditional uses of palms

Food and construction were the most frequently mentioned types of use (Fig. 3). Table 1 shows the different types of use, the parts used and the products obtained from each species. Palm fruits, fronds and stems are most commonly used.

Coconut fruit is the part that is most used (45 times) for food, followed by *Attalea* (24 times), from which the endosperm is used for human food and livestock feed. *Sabal* and *Attalea* fronds (31 and 25 times) are preferred for roof thatching. *Roystonea* stems are used for making boards to build walls (10 times). The least mentioned palm species in all municipalities was *Acrocomia;* the only use of which is that its endosperm is consumed (Table 1; Fig. 3).

3.3 The importance of palms in the coastal wetlands of Veracruz

Families mentioned that palms are important and are considered a resource from which they benefit and obtain mainly supplies. Perceived importance or value varies between species and is mainly determined by the economic benefit and products they provide to people. For example, *Sabal* is highly appreciated for its fronds (31 times), while *Acrocomia* is much less appreciated because its spines make it difficult to handle. Few of the families surveyed are aware of the environmental services provided by palms; although in Jamapa (6 times) and Alvarado (8 times), some families perceived environmental benefits from palms, such as regulating temperature and providing shelter for birds and mammals.

3.4 Factors currently affecting the use of palms

People mentioned that the use of palms has decreased compared to the use of palms by their ancestors. The reasons, in order of frequency of mention, are the following: (1) cutting palms to clear the land for cattle ranching (mentioned 56 times), (2) the decrease in the availability of palms (50 times), (3) increase in the cost of palm material (33 times), (4)

Table 1 Palm species, parts used and products obtained from palms in four municipalities in coastal Veracruz, Mexico

Species	Local names	Municipality	Uses	Parts used	Products obtained
Cocos nucifera L.	Palma de coco, coco, cocotero	Alvarado^{+++}	Human food	Fruit	Sweets and drinks
		Jamapa^{+++}	Animal feed	Fruit	Food
		Tecolutla^{+++}	Construction	Fronds and stem	Ceilings and tables
		Tuxpan^{+++}	Crafts	Fruit	Ornaments and jewelry
			Medicinal	Root	Remedies
Sabal mexicana Martius	Marachao, apachite	Alvarado^{+++}	Human food	Palm heart	Food
		Jamapa^{+++}	Construction	Fronds, sheath, petiole, stem, rachis	Ceilings, walls, fences, beams
		Tecolutla^{++}	Craft	Sheath	Utensils to store food or to cover food
		Tuxpan^{+}			
Attalea liebmannii (Becc.) Zona	Palma de coyol real, palma real	Alvarado^{+}	Human food	Fruit, palm heart	Seed, *atole**, tortillas, *gorditas**, candy, stews
		Jamapa^{++}	Animal feed	Fruit	Food
		Tecolutla^{++}	Construction	Fronds, stem, sheath, petiole and rachis	Ceilings, boards for walls, fences
		Tuxpan^{+}	Crafts	Pinnae and sheath	Hats and utensils
			Religious	Pinnae	Ornaments
Acrocomia aculeata (Jacq.) Lodd. Ex Mart.	Palma de coyol redondo	Alvarado^{+}	Human food	Fruit, palm heart	Seed, *atole*, stews.
		Jamapa^{++}	Animal feed	Fruit	Food
		Tecolutla^{++}	Crafts	Pinnae, fruit	Hats, ceremonial decorations
		Tuxpan^{+}			
Roystonea dunlapiana Allen	Palma de yagua, yagua	Alvarado^{+}	Human food	Palm heart	Stews
		Jamapa^{++}	Construction	Stem, sheath and petiole	Boards for walls, fences
		Tecolutla^{+}	Crafts	Sheath	Utensils to store or cover food
		Tuxpan^{+}			

* *atole* is a warm, thick drink; *gorditas* are thick tortillas used as a base for savory toppings

$^{+++}$ Abundant in certain areas

$^{++}$ Relatively abundant, + not abundant

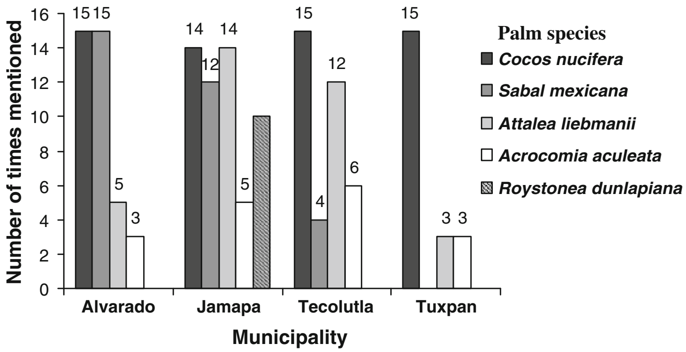

Fig. 2 Frequency with which the five different palm species were mentioned in four municipalities on the coast of Veracruz, Mexico. In Tuxpan only three species were mentioned

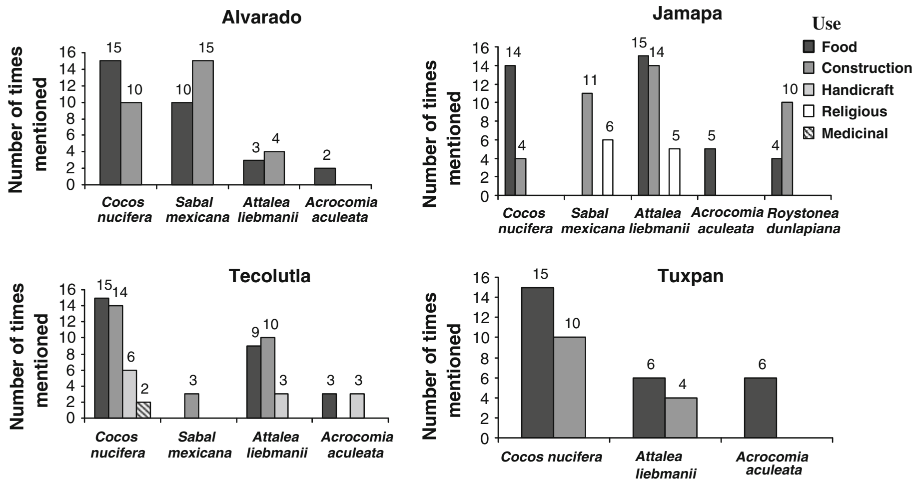

Fig. 3 Number of times each type of use is mentioned per palm species in four municipalities on the coast of Veracruz, Mexico

the selective management of plant species (15 times) and (5) cultural changes (8 times). These factors are related to each other and are discussed in the next section.

4 Discussion

The results of this research allow us to appreciate that palms are of great importance in the wetland communities on the coastal plain of Veracruz, as they are used for meeting various human needs.

4.1 Palm species used in wetlands of Veracruz

The most widely used palm species in communities along the costal plain of Veracruz is *C. nucifera*. This Asiatic species (Zizumbo-Villarreal 1996) was rapidly incorporated into the local culture and has displaced some of the native species of tropical America (Orellana and Ayora 1993). It has changed the natural landscape of the coastal strip, subsistence practices and the customs involving local palms. This species has come to be widely used most likely because it produces clusters of large fruit throughout the year (McKillop 1996), and these are used for food and beverages around the world ("Appendix 2"; Granados-Sánchez and López-Ríos 2002). Native palm species produce smaller fruits and only seasonally, but they do have many traditional uses that are mainly known by native groups of people (Caballero and Cortés 2001; Cob-Uicab et al. 2003). Their use has declined as people have changed their habits and customs in response to the arrival and settlement by groups of people from other regions and with them, the introduction of different species (McKillop et al. 1980).

The fronds of several species of the genus *Sabal* are desirable for building rural and touristic housing owing to their strength, flexibility and the cool temperatures they impart; qualities that make them highly suitable for roofing houses in the tropics ("Appendix 2"; Pérez-García and Rebollar-Domínguez 2008; Martínez-Ballesté et al. 2006).

Attalea is used as raw material for construction, the same way other species of this genus are used in tropical America (Calle-Díaz and Murgueitio 2008). In Jamapa, there is a strong tradition of using this species (fronds, stem and fruits), but its abundance is rapidly decreasing. Fifty years ago, Hernández-Xoloctozi (1947) found that Veracruz and Tabasco had huge commercial plantations of this palm. At that time, *Attalea* was one of the most economically important forest resources in Mexico because of the oil and soap industry. He estimated that the production potential of the Papaloapan River Basin was approximately 3,000 tons of seeds/year. This highlights the major changes that the use of palms has undergone and also the great economic potential that this species had and could have again in the future.

Roystonea is mentioned as a scarce species in the region. Its current situation is precarious, because its populations have declined due to factors such as the decrease in rainfall, the disturbance and drainage changes in wetlands and the construction of levees. Changes in environmental conditions are reducing palm populations because it grows in areas that remain flooded for a longer period than the areas where other palms grow (Bonadie 1998; Infante et al. 2011). It is also possible that sapling establishment is being affected by changes in land use, because they require shade that is not common in livestock pastures (Gonzalez-Marin unpublished data). *Roystonea dunlapiana* is currently classified as under special protection by Mexican law (NOM-59 ECOL-2001).

Acrocomia is rarely used in the area and its natural populations are the ones that are most often destroyed for changes in land use because it has very spiny stems and is difficult to handle. In contrast, in other areas of Mexico (e.g., Yucatan Peninsula), it is considered economically important, since its fruits are used for food for people and animals and for jewelry and crafts (Ly et al. 2005; Pérez-García and Rebollar-Domínguez 2008).

Palms are still traditionally used by the residents of the rural communities who live along the coastal plain of Veracruz, especially in the communities of Jamapa. However, some types of use are mainly preserved by the older women in the community, particularly when used as food, and by both sexes for building houses. Unfortunately, traditional knowledge has declined markedly in recent generations. In most of these wetlands, traditional palm roofs are gradually being replaced by artificial materials, such as foil, cardboard asbestos and cement. A similar situation is occurring in other parts of the Mexican tropics, such as the Yucatan Peninsula (Caballero-Nieto et al. 2001).

4.2 Factors currently affecting the use of palms

Several factors were mentioned as affecting the current use of palms; mainly felling them to make way for cattle farming. People cut palm trees to clear the land and this causes a decrease in their populations. In addition, the cultural changes resulting from migration to globalization (Caballero-Nieto et al. 2001; Bennett and Balvanera 2007) also affect the use of palms, because as the younger generations move elsewhere in search of employment opportunities some traditions are lost, resulting in changes in the materials used for building houses, and the use of commercial food (Gonzalez-Marín unpublished data). The demand for *Sabal* and *Attalea* fronds for thatching commercial buildings such as restaurants along the coastal plain of Veracruz reduces availability of these materials to the locals and increases its cost for rural construction, especially where the resource is scarce and must be transported from other places.

The preference for other, faster growing crops is also affecting resource availability and prices. For example, the fronds of *Attalea* are only ready to harvest after 6–7 years. *Roystonea* reaches its commercial height more slowly, after about 15 years. In the study area, people do not plant palms, but they do plant other trees that grow faster and can be harvested in less time or that have commercial value, i.e., mangoes. Moreno-Casasola and Paradowska (2009) mentioned some reasons why people do not cultivate plants in this region, and two of them are applicable to this study. One is the lack of a local market and affordable prices for useful species. Purchase among neighbors is not a common practice today. Occasionally, fronds are sold when there is a great demand for raw material or poles. Another reason given is that today the knowledge of traditional uses is being lost and only remains in the memories of the elders.

The establishment of sugar cane plantations (*Saccharum officinarum)* has resulted in the drainage and modification of wetlands and has caused an alarming decline in the populations of native plant species, such as palms. In addition, livestock has caused changes in land use, and a concomitant loss of biodiversity in tropical regions (Villafuerte et al. 1997; Rzedowski 2006).

4.3 The importance of native palms in the coastal wetlands of Veracruz

Wetland recovery is a fundamental goal of sustainable management, and it is necessary to establish priorities with respect to the environmental services wetlands provide. Not all wetlands are functionally equivalent. A wetland that only has a few livestock animals (Travieso-Bello et al. 2005) and has populations of palms, and other trees will facilitate water drainage, flood contention and offer sites for recreation, food and construction materials (Kahn 1988; Gardiner 2006). Such a wetland is quite different from one that has been converted to extensive pasture for livestock and is only focused on producing a single product (beef cattle). Restoration efforts should initially focus on raising people's awareness of the environmental services and supplies that the natural vegetation provides—especially native palms—and, once peoples' interest has been engaged, actions leading to the reforestation of the wetlands can be taken.

The current frond yield of *Sabal* and *Attalea* is not sufficient to satisfy the commercial demand of the growing tourist market because there are no official or private reforestation programs. The management of wild populations of palms (e.g., *Attalea* and *Sabal*) for the purpose of obtaining products could contribute to increasing the economic value of the degraded soils that are currently used for livestock (Kahn 1991). This way, palm management could help to increase the perception of the positive value of wetlands to the locals, who would then be motivated to conserve these ecosystems.

Linking traditional uses and the current needs of the tourism industry with conservation and restoration projects would make it possible to recover customs and practices and would encourage an appreciation for wetland services.

4.4 Some conservation and management recommendations

Management and conservation recommendations include the promotion of traditional uses and conservation of native palms through projects for restoring natural populations, introducing marketing strategies for meeting the demands of the commercial market and the needs of the communities, as well as environmental education programs as strategies to ensure the sustainable use of palms.

The extreme flood damages from Hurricanes Karl and Matthew are examples of the serious consequences of transforming and destroying wetlands (Milenio Newspaper 2011). The destruction of flooded forests (including palm swamps) and their replacement with pastures or human settlements reduces the buffer capacity against phenomena such as hurricanes (winds and flooding). Only the restoration of floodplain forests can offer a partial solution to such problems and is a strategy that would be applicable in many countries (Costanza et al. 1997). In this sense, native palms have a great potential for reforestation: they can tolerate the hydroperiods that occur in wetlands (Kahn 1991; Infante et al. 2011), they are resistant to lethal yellowing caused by *Phytoplasma* and are less susceptible to pests (Harrison and Elliott 2008) and people are interested in them. Wetland soils are considered poor for agriculture and could, alternatively, be used for palm crop diversification (Kahn 1988).

Propagation programs for *Attalea*, *Sabal* and *Roystonea* are necessary to encourage people to restore wetlands. These species can also be used sustainably in the medium term, either for construction, food or for making handicrafts. It is also necessary to promote the use of *Acrocomia* in crafts given that this species, though underused on the Veracruz coast, has significant potential.

Initiatives carried out with the local inhabitants are necessary to promote an environmental culture that creates pride of ownership for resources in a conscious and responsible way. It is also important to increase the participation of the locals in programs for restoring wetland ecosystems. The creation of nurseries for wetland reforestation with palms and for harvesting fronds would be beneficial in both ecological and social terms. The organization of groups to make handicrafts from seeds, palm fronds and other plant parts would provide the local inhabitants with economic alternatives. Fair markets should be also established so that this production can be sold to tourists and benefit the locals. This could provide a number of benefits to families: income, consolidation of the social unit and improved environmental awareness. Finally, further studies of wetlands are essential in order to plan the long-term care and maintenance of this beautiful, important ecosystem.

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Appendix 1

See Table 2.

Table 2 Comparative synthesis and main characteristics of the study sites

Municipality, towns and approximate number of inhabitants	Wetland type and vegetation (Infante et al. 2011)	Main productive activities	Housing type (material)	Education	Degree of isolation
Alvarado: Costa de San Juan (100) Nacaste (30) Pajarillos (15)	*Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa* mangrove *Pachira aquatica*, *Sabal mexicana*, *Attalea liebmannii*, *Acrocomia aculeata* flooded forest *C. nucifera* is cultivated	Fisheries (shrimp and fish) Clam farming	Mangrove wood, palm fronds, bricks, asbestos sheets for roof	Mostly elementary school or illiterate	They have no access to shops or others products in their area. Must travel by boat 40 min to get to Alvarado, the closest city
Jamapa: Piñonal Matamba (500–1,000 between both towns)	*P. aquatica*, *Ficus* spp., *S. mexicana*, *R. dunlapiana*, *A. liebmannii* flooded forest. *Typha domingensis*, *Thalia geniculata*, *Pontederia sagittata* marsh *C. nucifera* is cultivated	Raising livestock Cultivation of fruit trees Planting corn and beans Raise animals in backyard	Bricks and asbestos sheets. Kitchen and other parts of the house are made of different species of palms	Elementary and junior high school	They are 2 h by road from the Port of Veracruz. They have some access to shopping and a variety of products

Table 2 continued

Municipality, towns and approximate number of inhabitants	Wetland type and vegetation (Infante et al. 2011)	Main productive activities	Housing type (material)	Education	Degree of isolation
Tecolutla: Casitas (2,024) Ricardo Flores Magón (1,000) Tecolutla (4,523) Cruz de los Esteros (<100)	*P. aquatica, Ficus* spp., *S. mexicana, Roystonea dunlapiana, A. liebmannii* flooded forest *T. domingensis, T. geniculata, P. sagittata* marsh *R. mangle*, *A. germinans*, *L. racemosa* mangrove *C. nucifera* is cultivated	Fishing (shrimp and fish) Raising livestock Cultivation of oranges, watermelon, lemon, coconut, corn, beans, grapefruit, pepper, banana and pumpkin Laborers (planting grass seed) Travel services (hotels, restaurants, sale of handicrafts) in nearby towns	Bricks and asbestos	Elementary school or illiterate	A tourist area with access to shops and a variety of products
Tuxpan: Golfo de Barra de Galindo (75) La Mata de Tampamachoco (2,000)	*R. mangle*, *A. germinans*, *L. racemosa, C. erecta* mangrove *A. aculeata*, *A. liebmannii* flooded forest *C. nucifera* is cultivated	Fishing (shrimp and oysters) Casual work as employees in oil and thermoelectric industry. Travel services (rent beach huts, selling food and drinks).	Most are brick with an asbestos roof, but in Golfo de Barra de Galindo some are built with mangrove wood and coconut palm	Mostly elementary school or illiterate	The inhabitants of Golfo de Barra de Galindo need to travel approximately 40 min by a sand road to reach the city and buy products. La Mata is very close to the city of Tuxpan

Appendix 2

See Table 3.

Table 3 Some examples of use of the palms in others parts of Mexico and America

Species	Uses	Parts used	Location	Authors
C. nucifera	Ornament for streets and tourist areas	Palm tree	Border of México-Belice; Amazon and Isthmus of Panamá	Pulido-Salas 1993, Haynes and McLaughlin (2000), Granados-Sánchez and López-Ríos (2002), Sosnowska and Balslev (2008)
	Drink fresh and fermented	Fresh fruit (endosperm)		
	Food in regional dishes, sweet or bread flour	Endocarp		
	Medicinal (combat amoebiasis, leishmaniasis)	Embryo, endosperm and roots		
S. mexicana	Human food and animal feed	Fruits and palm hearts	Peninsula of Yucatán in Mexico; Southeast of Texas in USA	Orellana and Duran (1992), Haynes and McLaughlin (2000), Pérez-García and Rebollar-Domínguez (2008)
	Making crafts and hats	Young fronds		
	Roofing	Mature fronds		
A. liebmannii	Shade for cattle	Palm tree	Peninsula of Yucatan in México	Orellana and Duran 1992
	Human and animal feed	Fruit and seed		
A. aculeata	Human food and beverages (prepared in syrup or fermented) and animal feed	Fruit and seed	Border of México-Belice; Yucatán and Tamaulipas in México; Costa Rica	Orellana and Duran 1992; Pulido-Salas (1993), Haynes and McLaughlin (2000), Sosnowska and Balslev (2008)
	Food dishes	Palmito or heart		
	Shade for cattle	Palm tree		
	Medicinal treatment of diabetes	Roots		
R. dunlapiana	Obtaining oils	Seeds	Southeast of Florida, Caribbean, South and Central America, Peninsula of Yucatán in Mexico	Orellana and Duran (1992), Haynes and McLaughlin (2000)
	Ornaments of streets	Palm tree		
	Construction	Stem		

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ORIGINAL ARTICLE

Regaining the traditional use of wildlife in wetlands on the coastal plain of Veracruz, Mexico: ensuring food security in the face of global climate change

Rosa María González-Marín[1] · Patricia Moreno-Casasola[2] · Alejandro Antonio Castro-Luna[1] · Alicia Castillo[3]

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Abstract Wetlands play important roles that benefit social-ecological systems. They are threatened by climate change and human activities, i.e., raising livestock and wildlife hunting. The latter is essential for subsistence and for the food security of rural communities. To understand the traditional uses of wildlife, we examined the use of wildlife among people living within and outside of, but close to wetlands, in the communities located in four municipalities of Veracruz, Mexico, using open-ended interviews. We also analyzed the socioeconomic factors and environmental problems associated with the use of wildlife, and how these affect food security. People, especially those living within the wetlands, use wildlife mainly for food and trade. Wildlife is mainly used as food but also as pets, ornaments and medicine. The most useful species were black-bellied whistling duck (*Dendrocygna autumnalis*), nine-banded armadillo (*Dasypus novemcinctus*) and Meso-American slider (*Trachemys venusta*). People living within the wetland make more intensive use of wildlife. The main problems causing decreasing wildlife populations were water pollution, hunting practices and deforestation. Local communities were aware of the importance of wetlands, their degradation and the need to preserve them. More research focused on socioecological systems is required to address both the need for biodiversity conservation and food security. Also, good local management plans that incorporate current knowledge about key species have to be drawn up with the participation of government and scientific institutions, citizens and local stakeholders.

Keywords Hunting · Wetland loss · Management · Rural areas · Traditional use · Veracruz

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✉ Patricia Moreno-Casasola
patricia.moreno@inecol.mx

Rosa María González-Marín
rosy.gonzalez.marin@gmail.com

Alejandro Antonio Castro-Luna
alcastro@uv.mx

Alicia Castillo
castillo@cieco.unam.mx

1 Instituto de Biotecnología y Ecología Aplicada (INBIOTECA), Universidad Veracruzana, Av. de las Culturas Veracruzanas 101. Col. Emiliano Zapata, 91090 Xalapa, Veracruz, Mexico

2 Red de Ecología Funcional, Instituto de Ecología, A.C. Carretera Antigua a Coatepec 351, El Haya, 91070 Xalapa, Veracruz, Mexico

3 Instituto de Investigaciones en Ecosistemas y Sustentabilidad, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701 Col. Ex-Hacienda de San José de La Huerta, 58190 Morelia, Michoacán, Mexico

Introduction

The wetland ecosystem: importance and threats to climate change

Wetlands are among the most productive ecosystems on the planet. They provide important environmental services such as flood control, water filtration and microclimate stabilization and diverse benefits for people, such as water, food, construction materials, and areas for recreation (MEA 2005). They are important in the conservation of biodiversity due to their high levels of organic material and humidity, both of which favor the diversity of plants and animals, both resident and migratory (Costanza et al. 1993). Although freshwater habitats represent less than one one-hundredth of one percent of the Earth's water, rivers, lakes and wetlands harbor up to 12 % of the world's biodiversity (Ramsar Convention Secretariat 2007). Over the past 50 years, we have transformed ecosystems more rapidly and extensively than at any other time in human history, primarily to meet our growing demand for the services provided by them (MEA 2005). Unfortunately, wetlands are one of the most threatened ecosystems and also one of the most vulnerable to climate change (Botello et al. 2010), which increases the risk of species extinction, especially for those species restricted to certain habitats and whose population numbers are low. As ecosystems are transformed, many of the essential services they provide and consequently peoples' livelihoods will be affected (Halsnæs and Trærup 2009).

Dams, diversion of water, invasive species, overharvesting and pollution are degrading wetlands. Climate change may exacerbate impacts of these threats through predicted reductions in rainfall and increased temperature, decreasing flow and altering timing and variability of flow regimes (Kingsford 2011) although not all wetlands will be equally affected. Vulnerability of wetlands dependent primarily on discharge from regional ground water flow systems are the least vulnerable to climate change, because of the great buffering capacity of large ground water flow systems to climate change (Winter 2007). In Mexico, 62.5 % of the wetlands have been lost or are degraded (Landgrave and Moreno-Casasola 2012). In Alvarado (with wetlands covering 66,485 ha), Jamapa (not assessed but <5 % of the surface), Tecolutla (8831 ha) and Tuxpan (14,897 ha), 50, 9 and 13 %, respectively, have been lost or transformed. In our study areas, the main drivers of wetland change are transformation into flooded pastures for cattle growth, wood extraction, urbanization, port and energy industries and pollution (Moreno-Casasola 2008); they are all fed by ground water systems.

Climate change and food security

Climate change is worsening the living conditions of farmers, fishermen and those who live in the wetlands, many of whom are already vulnerable and under conditions of food insecurity. Rural communities, especially those located in fragile environments such as wetlands, face an immediate and increasing risk of crop and livestock loss and reduced availability of marine, forest and aquaculture products. Increasingly frequent and extreme weather events have a negative impact on food availability and access to it and decrease the stability of the food supply and its use, in addition to affecting goods and the opportunities for making a living in both rural and urban areas. Poor people run the risk of food insecurity because of the loss of their property as a result of disastrous events resulting from the impact of climate change and the lack of adequate insurance coverage. The capacity of the rural population to live with the impact of climate change depends on the cultural context, existing policies and socioeconomic factors of each place. People, plants, livestock and fisheries are exposed to new pests and diseases that flourish only at certain temperatures and humidity conditions and that bring new risks for food security, food safety and human health (FAO 1999).

To better understand the concept of food security and insecurity, we used Ford's (2009) and the FAO's (1999) definitions. Food security exists "when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Thus, individuals and households must be able to rely on food access, nutritious food must be available in sufficient quantities, and it must be of an acceptable quality. Food availability refers to the existence of sufficient food. For example, for an animal or plant to be part of food security, it must be available to all (i.e., there should be enough food for the whole community). Food access refers to the ability to access adequate resources for a nutritious diet. In this case, the place an animal lives must be accessible to users and it should be economically viable for people to go to these sites. Food quality concerns the existence of safe food with sufficient nutritional and cultural value, i.e., animals or plants must be in pollution-free sites, to ensure the safety of meat or fruit. Food insecurity occurs when food systems are so stressed that food is not accessible, available, and/or of sufficient quality (Ford 2009). This can happen when an ecosystem is greatly transformed by human activities, as has been occurring in many wetland ecosystems.

The impact of climate change on food safety has been studied with an emphasis on water and crops, but there are very few studies focusing on wildlife (Jiménez et al. 2010). One of the few studies focused on wildlife use was done by Ford (2009), who developed a conceptual model to illustrate how the climate-related conditions interact with the Inuit food production systems, traces the pathways through which these processes affect food systems based on its susceptibility (exposure sensitivity) or adaptive capacity. It takes into account the social context, government policies, traditions and store components of the Inuit food system, as well as the temporal dimension, identifying and explaining the presence of vulnerable groups to climate change.

The traditional use of wildlife to ensure food security

Wildlife is an important natural resource for humans as a source of protein, medicine, clothes and recreation (Naranjo et al. 2004). It has provided food security since time immemorial mainly in rural communities. The study of the traditional use of tropical wildlife has focused largely on tropical forests (Robinson and Redford 1991; Ojasti 1993) and on indigenous communities (Enríquez-Vázquez et al. 2006), with only a few studies on the traditional use of wildlife in wetlands (Desbiez et al. 2011) and none focused on mestizo people, the main inhabitants of a large proportion of rural land in Latin America.

There are many forms of traditional wildlife use, which reflect local economic, cultural and social differences, as well as diverse ecological conditions (Ojasti 1993), so it is essential to understand the role of wildlife in people's lives to guarantee food security through the sustainable management of natural resources (Ziervogel et al. 2006). Many people live beside and make use of wetlands, and this cannot be overlooked when planning conservation and development strategies and trying to ensure food security. In a previous study, González-Marín et al. (2012) analyzed the use of wetland palms along the coastal plain of Veracruz, Mexico. The fruits of *Attalea liebmannii* were used as a food source for both people and animals. The participation of the local inhabitants in conservation and natural resource management has proved to be extremely important because they are the main users of these resources (Robinson and Redford 1991), even more so as part of an effective adaptation strategy to face climate change.

The aim of this study was to document the traditional uses of wildlife by the mestizo people living within wetlands and those living close to, but outside of wetlands, to ascertain whether they differ in how they use these resources. We also examined how social, economic and environmental factors can affect the traditional use of wildlife and breach food security. Management strategies and wildlife conservation are proposed to ensure food security; therefore, this information can serve as the basis for developing the environmental education projects, restoration plans, population biology studies and breeding programs that are needed to ensure wildlife permanence and recovery, and so it continues or can once again become an important dietary protein complement for local rural people and an incentive for wetland conservation.

Study area

This study was conducted in Veracruz, Mexico, which has one of the highest levels of population marginalization of Mexico (fourth place, CONAPO 2010), with 58 % of the population living in poverty (17.2 % of them in extreme poverty) and where the average annual income of its population is 4.923 USD (INEGI 2014). The educational level is among the lowest; levels of overcrowding (40 % of the population) are among the highest in the country. Moreover, 73 % of households in Veracruz are in a category of food insecurity (mild, moderate or severe), a figure that rises to 82.2 % in rural communities (ENSANUT 2012). We chose rural communities located close to wetlands on the coastal plain of the Gulf of Mexico, in the municipalities of Alvarado, Jamapa, Tecolutla and Tuxpan, all of which are on the coast, except Jamapa which is 20 km inland (Fig. 1—see González-Marín et al. 2012). These wetlands are on floodplains and include extensive freshwater swamps and marshes; the coastal wetlands also include mangroves (Infante et al. 2011). They are the same localities studied in González-Marín et al. (2012).

Table 1 (see González-Marín et al. 2012) describes the main features of the localities studied. Poverty is high, with three municipalities with more than half their population under poverty conditions, except Tuxpan, which has 47.4 % in poverty. In Tecolutla, 77 % of population is considered poor and 29.8 of these living in extreme poverty. Degree of marginalization of each town is shown, and most of them have high marginalization, except Tampamachoco. Towns are close to Ramsar sites or state-protected areas, and the ones in Alvarado are located within a Ramsar site.

The inhabitants of these rural communities were divided into two groups to reflect the location of their homes and activities with respect to wetlands: (A) Internal users live in communities located within the wetlands themselves and carry out most of their daily activities within this ecosystem (residents of Alvarado), and (B) external users live in communities near wetlands and the majority of their productive activities take place outside the wetland (residents of Jamapa, Tecolutla and Tuxpan). For example, the communities of Alvarado are the most geographically isolated and its inhabitants are mainly engaged in shrimp and fish extraction, as well as clam farming. Jamapa communities have road access to the Port of Veracruz, the largest city in the region, and the main activities of its population are livestock, agriculture and the raising of backyard animals. Tecolutla communities work in fishing and agriculture, but are also engaged in tourist services, as they are in a touristic area known as "Costa Esmeralda"; thus, they have access to various products. Finally, Tuxpan communities are focused on marine fishing and oyster collection; temporarily, they are also employed in industries and tourism services (Table 1).

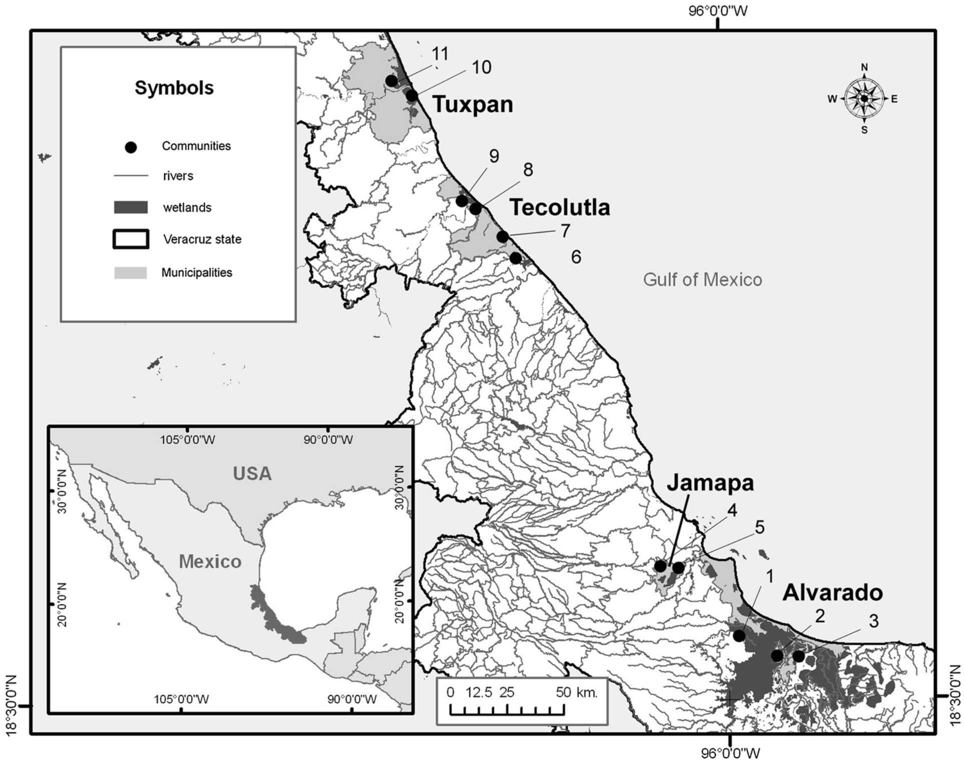

Fig. 1 Location of the municipalities (*gray*) and the communities studied (*dots*) on the state of Veracruz, Gulf of Mexico. *1* Costa de San Juan, *2* Nacaste and *3* Pajarillos, municipality of Alvarado (18°46′24″N–95°45′35″W); *4* El Piñonal and *5* La Matamba, municipality of Jamapa (19°02′29″N–96°14′29″W); *6* Casitas, *7* Ricardo Flores Magón, *8* Tecolutla and *9* Cruz de los Esteros, municipality of Tecolutla (20°28′46″N–97°00′36″W); *10* La Mata Tampamachoco and *11* Gulf of Barra de Galindo, municipality of Tuxpan (20°57′51″ N–97°24′16″W). ArcView 3.11 was used to create the map

Materials and methods

The methodology used was described in González-Marín et al. (2012) and was based on qualitative research methodology (Denzin and Lincoln 2000), with open interviews, as well as participant observation and discussion groups (Taylor and Bogdan 1984; Tarrés 2004). It allowed us to talk with informants and document the ways in which they perceive wildlife and the environment.

Introduction to communities and sample selection

All the communities under study are close to wetlands, and this was the main criterion for choosing them. Another selection criterion that we used was the interest and availability of the people to participate in the wetlands conservation. To get a general idea of what people knew about wildlife, we conducted a workshop in each of the four municipalities (8–12 people). Participants included young and old, local men and women; key people were identified as those who because of their status in the community, had more information. We used pictures of the birds, mammals and reptiles known for the region as support material to enhance our dialogue with participants. After the workshops, we worked directly with families in their homes. Family selection depended on whether or not a member was aware of regional wildlife. Generally, in each family there was a person with more information (usually the family head: father, mother, grandparent), who more frequently left the house to work in the field. They were those who had more information on wildlife and therefore used to participate more than the other family members. However, all the family was involved in this activity, because they often complemented the knowledge that we were documenting. To locate more informants, we used the "snowball" technique where one family would recommend another that they thought might have information regarding the topic and so on until the information provided became redundant, indicating that the sample was complete (Taylor and Bogdan 1984).

Interviews

The questionnaire used for interviews had also three sections (González-Marín et al. 2012), but the latter two were focused

Table 1 Main characteristics of the study sites

Municipality (degree of moderate and of extreme poverty), towns and approximate number of inhabitants and degree of marginalization	Main productive activities	Degree of isolation and legal wetland status	Problems affecting the abundance of wildlife populations
Internal users			
Alvarado (40.3 and 13.1 %) Costa de San Juan (100)-high El Nacaste (30)-very high Los Pajarillos (15)-high	Fisheries (shrimp and fish) Clam farming	They have no access to shops or other manufactured products in their area. Must travel 40 min by boat to get to Alvarado, the closest city, where they acquire products for their daily lives. The three towns form part of the Alvarado Ramsar wetland	Water pollution caused by agrochemicals, industrial wastewater (e.g., sugar mills), sewage and garbage (organic and inorganic matter) Exploitation of wildlife (especially of birds and turtles) Cattle ranching and obstruction of water flows to dry land
External users			
Jamapa (42.9 and 11.3 %) El Piñonal-high La Matamba-high (both have more than 500 but less than 1000)	Livestock Cultivation of mango Planting corn and beans Raising animals in backyard (chicken, turkeys, pigs)	Proximity (1 h by road) to the Port of Veracruz (ca. 550,000 inhabitants) They have some access to shops and diverse products. Wetlands unprotected, although a marine reserve is 25 km away	Water pollution due to agrochemicals and garbage (organic and inorganic matter) Poaching and wildlife sports Immoderate tree felling (habitat loss)
Tecolutla (47.2 and 29.8 %) Casitas (2024)-medium Ricardo Flores Magón (1000)-medium Tecolutla (4523)-high Cruz de los Esteros (< 100)-high	Fishing (shrimp and fish) Livestock Cultivation of oranges, watermelon, lemon, coconut, corn, beans, grapefruit, pepper, banana and pumpkin Day labor (planting grass seed) Travel services (hotels, restaurants, tours, sale of handicrafts) in nearby towns	A tourist area with access to shops and diverse products. Wetlands form part of a state reserve (Ciénaga del Fuerte). R.F. Magón is 500 m away, and Tecolutla, the farthest, 17 km	Exploitation of wildlife Cutting of mangroves and swamp trees, and disturbance from hurricanes (habitat loss) Water pollution because of industrial wastewater (e.g., sugar mills and bottling companies of fruit juice)
Tuxpan (37.5 and 9.9 %) El Golfo Barra de Galindo (75)-high La Mata de Tampamachoco (2000)-very low	Fishing (shrimp and oysters) Casual work as employees in the oil and thermoelectric industry Travel services (rent beach huts, selling food and drinks)	The people of Barra de Galindo need to travel approx. 40 min by a sand road to reach the city and buy products. La Mata is very close to the city of Tuxpan (2–3 km). Both are on the border of the Ramsar site Manglares y Humedales de Tuxpam	External and internal pollution from industrial wastewater (a thermoelectric plant) and drains from hospitals and urban centers Siltation of the lagoon Exploitation of wildlife (parrots)

Degree of marginalization taken from CONAPO (2010)

on wildlife instead of palms and their uses: (1) personal data about the informants; (2) a list of useful animals and their availability according to peoples' perception of the wildlife species found in wetlands; (3) questions about each wild animal species that the interviewees cited as useful. Topics included the local name of the animal, the animal parts used, type of use, their eventual marketing and price. We also documented socioeconomic factors that could influence the use of wildlife and the problems associated with its use. When the information became repetitive among families, the interviews ended; a level of saturation of data was reached (Law et al. 2007). A total of 60 interviews, 15 per municipality, were conducted and tape-recorded to analyze transcripts in detail. Also, in each community, participant observation was developed, recording all information through field notes. We worked in Alvarado (six families interviewed in the town of Costa San Juan, five in Nacaste, five in Pajarillos), Jamapa (nine in Piñonal, six in Matamba), Tecolutla (four in Casitas, five in Ricardo Flores Magón, three in Tecolutla, four in Cruz de los Esteros) and Tuxpan (seven in Golfo Barra de Galindo, eight in Mata de Tampamachoco).

All interviews were transcribed and analyzed following the procedures suggested by Taylor and Bogdan (1984) and González-Marín et al. (2012): (1) Interview transcripts and field notes were examined line by line; (2) a code was used to recognize relevant ideas for the research, allowing us to establish categories from the data; (3) these categories were listed according to the number of times they were mentioned and used helping us to develop interpretative texts using the number of times a category was mentioned, e.g., the most frequently named bird species was *Dendrocygna autumnalis* (37 times); (4) observations collected in the field were further used to verify the answers and also to establish a broader social context for the usefulness and people's perception of wetland wildlife; (5) discussion groups were held to verify results that coincided with those given by the groups and also to supplement information.

Results

Wildlife was mainly used as food; however, other traditional uses were also mentioned. The use categories were as follows: (A) food: hunted exclusively to supplement the diet of the hunter and his family; (B) trade: capturing animals to obtain cash and get other products; (C) pet: live wildlife used for exhibition or recreation; (D) medicine: parts of the animals provide a remedy; (E) ornamentation: some parts of wild animals are used as personal accessories and to decorate homes (Fig. 2).

Wildlife species used in the wetlands

In all four municipalities, 32 (94 %) of the 34 bird species shown in pictures are used by people. Of these, 25 species are used as food, six for trade, five as pets and three as ornamentation. The most frequently mentioned species was black-bellied whistling duck (*Dendrocygna autumnalis*, 37 times). Of the 17 reptile species shown in pictures, 15 (88 %) were mentioned. Of these, 14 are used as food, seven for trade, three for medicine, three as pets and three as ornaments. The most frequently mentioned was Meso-American slider (*Trachemys venusta*, 45 times). Of 20 mammal species, 12 (60 %) were mentioned; nine used as food, six for trade, four as pets, two for medicinal and one for ornamental purposes. The most frequently mentioned species were nine-banded armadillo (*Dasypus novemcinctus*, 47 times).

Traditional use by internal and external users of wetlands

In the communities of Alvarado (internal users), people use wild animals more frequently and more often dedicate time and effort to capturing them because wildlife is more accessible. These communities live in the wetland, and using wildlife is one of their subsistence activities. In the communities of Jamapa, Tecolutla and Tuxpan (external users), the use of wildlife is casual (Electronic Supplemental Material 1) with animals usually caught during other activities (e.g., fishing, farming, tending livestock).

Alvarado

In Alvarado's communities, birds were mentioned the most (17 times), especially migratory ducks. On a hunting trip, up to 20 are caught. Reptiles are the second most used taxa for food, especially freshwater turtles (Electronic Supplemental Material 1 and 2). A single family can consume 15–20 turtles of different species (mainly *T. venusta*) per year. Wildlife—mainly ducks, turtles and iguanas—is traded when caught by a member of the community who sells the animal to neighbors or in nearby communities. The use of wild mammals is rare, except for *P. lotor* and *Nasua narica*, which are hunted for food. Otter pelts (*Lontra longicaudis*) are sold because of their value in the local fur industry. Some families mentioned that there are manatees in the area (*Trichechus manatus*) and people used to consume their meat; however, informants said that they no longer hunt it because it is protected by Mexican law and there are very few of them nowadays.

Jamapa

Most respondents said wildlife is used infrequently, although some mentioned hunting rabbits for food. Armadillos and squirrels are only rarely captured for food, being mostly terrestrial animals. Of the reptiles, iguanas are consumed often (*Iguana iguana* and *Ctenosaura similis*), and some turtles occasionally (e.g., *Staurotypus triporcatus*, *T. venusta, K. leucostomum*; Electronic Supplemental Material 1). The main bird species used as food is *D. autumnalis*, while parrots (*A. autumnalis* and *A. nana*) are usually caught for trade and pets. The skunk (*Conepatus semistriatus*) is used medicinally, as the meat is thought to

Fig. 2 Common uses of wildlife in the communities studied. **a** Pet (*Amazona autumnalis*), **b** food (*Staurotypus triporcatus*), **c** food (*Trachemys venusta*), **d** ornaments (*Dasypus novemcinctus*)

cure some skin problems (acne and blemishes; Electronic Supplemental Material 2).

Tecolutla

The most used taxa are the reptiles, mainly *T. venusta* and *C. moreletti* (Electronic Supplemental Material 1). The most frequently mentioned mammals are *D. novemcinctus* and *P. lotor*, which are used for food (Electronic Supplemental Material 2). Participation in the pet trade is common with parrots (e.g., *A. autumnalis* and *A. nana*) and squirrels (*Sciurus aureogaster*) seen in homes, hotels and restaurants. The villagers also mentioned that *T. venusta* and *S. triporcatus* turtles are occasionally exchanged for fish and other seafood.

Tuxpan

The inhabitants of La Mata de Tampamachoco make little use of wildlife, in contrast to the Gulf of Barra Galindo where the elderly commonly mentioned *P. lotor* and *D. novemcinctus* as food species (Electronic Supplemental Material 1 and 2). Reptiles are rarely hunted, though the turtle *T. venusta* was frequently mentioned. Some parrots (*A. autumnalis* and *A. nana*) and squirrels (*S. aureogaster*) are sold as pets. Some interviewees also mentioned that *Didelphis marsupialis* and *C. semistriatus* have medicinal uses (Electronic Supplemental Material 2).

Socioeconomic factors influencing the use of wildlife in municipalities

The use of wildlife is closely linked to the main economic activities of each location and their degree of isolation with respect to major urban centers (Table 1). The inhabitants of Alvarado are isolated by numerous waterways and lagoons. They must travel by boat to a city to acquire merchandise, so they use wildlife frequently and dedicate time exclusively to hunting. In contrast, people from Jamapa raise livestock and grow fruit trees and have road access to urban centers, so they usually capture wildlife species while doing these activities. In Tecolutla, wildlife is often used as pets because this municipality includes one of the most important tourist destinations in the region (Costa Esmeralda). In Tuxpan, people depend on finfish fisheries, shrimp and oysters, so wildlife use is secondary (i.e., capturing parrots for sale). However, in the Gulf of Barra Galindo, which is a rustic, isolated community, people sometimes hunt wild mammals and migratory ducks in addition to eating fish and marine crustaceans.

Another factor determining wildlife use in wetlands is the origin of the inhabitants. In the municipalities of Tecolutla, Jamapa and Tuxpan, most of the people are mestizos who arrived during the Agrarian Reform implemented by the Mexican government between 1920 and 1940, during which land was distributed. The communities of Alvarado are the exception; their villagers are Afrodescentants who colonized mangrove areas from villages surrounding the wetland and therefore consumed wildlife as part of their heritage from centuries of living in wetlands. Wildlife trading also provides an additional source of money and resources for people living in wetlands; some earn extra money by selling animals and their parts, also allowing others to benefit from acquiring animal protein at a more affordable price than that available in shops and supermarkets (Electronic Supplemental Material 2).

Problems currently affecting wildlife populations

From the perspective of the residents of Alvarado, the population size of migratory birds, reptiles and medium-sized mammals has decreased owing to causes originating outside of the wetlands. The most cited factors were water pollution (mentioned 15 times) and excessive hunting (10) (see details in Table 1). For the villagers of Jamapa, wildlife is becoming scarce and the biggest problem is hunting, mainly by outsiders and guided by local villagers interested in making some extra money (15), though turtle carcasses were spotted in a few homes. People also mentioned that deforestation (12) and water pollution (9) affect wildlife. In Tecolutla, respondents said that the overexploitation of natural resources (plants and animals) (13 times) and water pollution (8) are the main factors affecting wetland wildlife; hurricanes were also mentioned as causing the loss of wildlife or their habitat (4 times). Water pollution was also the most mentioned (15) in Tuxpan.

It is important to clarify that people who mentioned the problem of water pollution perceive it as both waste pollution by organic matter from human activities and that caused by stagnant water, produced by high temperatures. These, in turn, are associated with wetland desiccation by different human activities, including the tree felling to make way for pastures and house construction.

Discussion

Wildlife species used in the wetlands

Our results reveal that people generally use more species of birds and reptiles than mammals, probably because they are the most diverse and abundant taxa in the wetlands (Weller 1999); therefore, according to what the people mentioned in Electronic Supplemental Material 1, the frequency of use of the species is consistent with their availability in the wetland. People living both inside and close to wetlands used wildlife mainly as food, demonstrating that this is a basic need even nowadays. However, traditions and customs also have an important role in the study area. People use wildlife for pleasure, and there is a tradition of consuming wild meat. Similar results have been observed in indigenous communities living in tropical forests (Robinson and Redford 1991; Naranjo et al. 2004). Also, the market price of wild meat reported by the respondents (Electronic Supplemental Material 2) was noticeably lower than the price per kilogram of chicken (3.93 USD), pork (5.2 USD) and beef (8.34 USD) (PROFECO 2013). Thus, wildlife meat is a more accessible resource to poor people. Furthermore, by selling meat, skin or live specimens of wildlife, they can earn an extra income, allowing them to purchase commodities.

Traditional use by internal and external wetland users

Those living in wetlands used more wildlife species and did so more frequently than external users. This may be because: (1) there is a greater diversity and abundance of birds and reptiles in Alvarado, and (2) people living in wetlands are more likely to capture wildlife. Regarding the first point, the Alvarado wetland is the largest and is located further south, lying biogeographically in the Neotropical region and within the distribution range of more animal species (e.g., turtles, Ippi and Flores 2001). In contrast, Tecolutla and Tuxpan are located further north, where there are fewer species. The proximity and ease of access to hunting sites can facilitate hunting success (Naranjo et al. 2004), because people can locate their prey easily and know more about wildlife habitats and behavior (internal users), which helps them capture and use more species, compared to external users (Shively 1997). However, these characteristics also make communities more dependent on natural wetland resources, and therefore also more vulnerable to food insecurity.

In the communities of Jamapa, there is a lot of poaching pressure on wildlife, mainly to sell the animals and earn extra money as guides for poachers, similar to the exploitation of turtles in the Brazilian Amazon (Schneider et al. 2011). In this region, turtle, especially that of *T. venusta*, has been heavily exploited (González-Marín, unpublished data). It is worth noting that many of Jamapa's wetlands have been replaced by cattle pastures, degrading wildlife habitat (Andrén 1994; Loreau et al. 2003), though this was never mentioned by the interviewees; in fact, the respondents perceive turtles as a common resource in the wetlands.

In Tecolutla and Tuxpan, people use wildlife occasionally. According to those interviewed, the consumption of wildlife has also declined because of the laws protecting them, and because of increased patrolling in the area due to the proximity of Tuxpan, an important seaport on the Gulf of Mexico. However, the decrease in fishing resources (e.g., shrimp) and the lack of jobs have made some people start capturing wild animals illegally (e.g., parrot chicks), for sale or personal use. Worldwide the illegal wildlife trade has an estimated value of 7.8–10 billion dollars (GFI 2011) and persists due to the high demand for exotic species in big cities or some countries (e.g., China, USA and Germany), where large amounts of money are paid to have a live specimen of a rare or endangered species or their parts (e.g., up to 23,068 USD for a yellow-headed amazon). Moreover, there is a big difference between the prices that are handled locally and those that can reach the products in national and international markets; for example, an armadillo can be sold at 5.83 USD in the study area, but can achieve ten times this value in Mexico City. Unfortunately, irresponsible wildlife trade and overexploitation are threatening this resource, and those most affected tend to be the poorest people because they depend directly on wildlife for consumption and as a way of earning cash.

In the coast of Veracruz, illegal trading results from the regional demand for wildlife, its aesthetic value and popularity with tourists. In fact, the use of wildlife as an attraction is a common practice in many tourist destinations worldwide, even though the negative impact on several species has been demonstrated (Orams 2002). The economic crisis in rural areas and people's need to acquire products, among them food, is therefore having an impact on the populations of the wildlife species that are overexploited in the absence of any restocking program or conservation policy. Schneider et al. (2011) report that overexploitation from illicit trade can cause the rapid local extinction of species, since in the process of capturing and transporting the animals, several of them die, requiring the poachers to capture even more animals.

With regard to the above, environmental policy in Mexico is not about adopting a "no-take" approach. Mexican law gives priority to the use of the resource in a sustainable manner, which can be extractive (hunting, commercial, subsistence, for rites and ceremonies, based on restocking and research) or non-extractive, as with certain protected species and those under some degree of threat (ecotourism, environmental education and research). In some cases, even though the species are protected (e.g., some freshwater reptiles, terrestrial mammals and certain plants), commercial exploitation is possible when controlled, continuously monitored, and with the possibility of devising compensatory measures such as stocking or reforestation (Zamorano de Haro 2009). However, our results show that people are not aware of the available options for the use of their resources provided for by environmental policies as legal alternatives, or perhaps they find them complicated and so cannot benefit from them. Thus, many make use of wild animals in a surreptitious manner. Also, the overuse of some wetland resources is the result not only of people meeting their basic needs, but also of external factors (Velayudan 2007), such as proximity to big cities (Guiling et al. 2009). People in cities buy wildlife as pets, and some even commission the acquisition of some species.

Socioeconomic factors influencing the use of wildlife

In this study, we found that the degree to which wildlife is used is determined by factors such as people's main economic activity, the degree of isolation of a community, the origin of the population in each community, their traditions and customs (associated with people's origin, Lion and Hardesty 2002) and the need for additional sources of income and resources. All these factors are closely linked to geography, economy and culture (Conway-Gomez 2008). On the Veracruz coast, the disappearance of the indigenous cultural influence left a void in the centuries following the Conquest. During the eighteenth and nineteenth centuries, and with the Agrarian Reform, the region was slowly populated by new groups of settlers, mostly mestizos who had lived in other parts of Mexico (González-Jácome 1999; von Bertrab 2010) with ecosystems completely different from wetlands (Hoffman 1994). Alvarado communities differ from those located in other municipalities under study, because its inhabitants are descendants of African slaves brought to Veracruz by the Spanish between 1590 and 1640 (Hoffmann 2010), and when mixed with indigenous dwellers, adopted part of their traditions and knowledge, so actually they make a greater use of wetland resources compared to those settlers who arrived in the last hundred years. Also, living within the mangroves and marshes favors these activities.

The use of wildlife as an extra source of money and resources is still a common practice in the rural areas of Mexico: The meat of wild animals is usually cheaper than poultry, pork or beef, because the price of the latter includes their production cost (Apaza et al. 2002). Finally, the consequences of governmental programs subsidizing extensive agriculture and livestock have a negative effect on natural resources and promote the loss of wetland ecosystem services (Botello et al. 2010). In this sense, the Veracruz coast is one of the Mexican regions with the largest area used for livestock, an activity that is the main threat to wetlands (Moreno-Casasola et al. 2012). The above implies the loss of habitat for wildlife (e.g., birds and mammals) and a decrease in their populations, causing wild meat be gradually replaced by that provided by domestic animals. As a final result, both the society and the economy of rural communities, particularly those who are living in extreme poverty are severely affected (Restrepo 2012).

Problems currently affecting the availability of wildlife populations

The problems mentioned in our results are directly related to socioeconomic conditions, land change policies and climate change (e.g., water pollution, deforestation; Halsnæs and Trærup 2009). Climate change is affecting biological systems worldwide and modifying species distribution, animal population size, breeding seasons, and the routes and timing of migration (Case et al. 2009). Thus, today, many of the services and food sources provided by ecosystems have decreased, severely affecting rural peoples' way of living and ability to make a living. Food security is currently a top priority worldwide, especially in developing countries, and as such, is affected by the practices associated with economic growth and those that contribute to climate change (Jiménez et al. 2010).

Pollution, from both urban waste and agricultural runoff, has damaged these ecosystems. Deforestation also affects both the environment and wild animal populations, particularly for those species strongly dependent on trees. With deforestation, many environmental services are lost, affecting wildlife populations and the food security of rural inhabitants.

The factors mentioned in this study affect wildlife, its accessibility, availability and quality (seen as food; Ford 2009). Programs to ensure food security should address these issues to provide viable alternatives and ensure both the availability and quality of wildlife to the community (Ford 2009).

This study helps lay the basis for guaranteeing food security strategies that include the traditional use of wildlife, wetland conservation and restoration. However, further study is essential, with an emphasis on the quality of the food and the nutritional support that wildlife represents for rural people. Likewise, if we preserve the integrity and functions of wetland ecosystems, the negative impact of climate change can be mitigated, especially for the resources that ensure food security (e.g., wildlife). With this strategy, we would also be better prepared for the natural disasters that are exacerbated by climate change such as droughts, floods and hurricanes (Woodrey et al. 2012) and would suffer fewer social and environmental losses.

Management implications and proposals

The ecological integrity of wetlands depends on coordinating watershed management with the use and conservation of flora and fauna. This implies many types of use and stakeholders (Junk 2002), not all of which are directly associated with wetlands. Some activities in wetlands (e.g., raising livestock) alter wetland dynamics and jeopardize food security by affecting the availability of wildlife as a source of food for people (Turbay et al. 2000). The design and implementation of plans, programs and guidelines for the sustainable management of wetland resources is a priority. Communities must be involved in the entire process and in decision making, because the success or failure of management plans depends at least in part on people's commitment to, and their attitudes and prejudices about the environment. The different bodies of knowledge, traditions and practices of the stakeholders need to be acknowledged to develop new ways of interacting with wetland resources.

It is difficult to prevent people from using wildlife because these practices are deeply rooted in their culture and also increase their income. However, to mitigate the impact of unregulated extraction, it is necessary for villagers, as well as governmental officials, conservationists and scientists to accept the need for changes or adjustments to the ways ecosystems are used. There is an urgent need for sustainable forms of land use, infrastructure and management strategies for livestock production, production system designs, the incorporation of local knowledge, participatory strategies and scientific advances that will make adaptation to climate change possible. Climate change is already having consequences, and as the mean global temperature continues to rise, it will be necessary to develop adaptation strategies for people and for wildlife species. Ensuring food security is a fundamental adaptation strategy that must be addressed.

In Mexico, the establishment of wild animal production units known as UMAs (units of management and sustainable use, *Unidad de Manejo y Aprovechamiento*, a legal instrument issued in the Mexican law), for their sustainable consumption is considered and has been vital for many species, including turtles, iguanas and rabbits, which has been useful in some cases and social sectors, for example, when breeders of wildlife have the financial resources to pay for technical advisors and infrastructure (González-Marín et al. 2003). In this study, some of these were used for food and management techniques for their reproduction have been developed (Aguirre and Cázares 2002). The legal breeding of wild species, together with wetland restoration and conservation actions to protect specific areas would help to secure food for local families and thus reduce the pressure on natural resources, giving wetlands time to regenerate.

Conclusion

In this study, we report that despite the loss of coastal wetlands in Veracruz, traditional use is still being made of wildlife in rural communities, mainly to meet basic needs (food and goods). Although use varies among communities because of the degree of isolation, economic activities and the origin of the population, it is clear that wildlife comprises an important resource for people and one that can be managed adequately to ensure the continuous availability of food under different climate change scenarios.

This research has shown that the use of natural resources should be considered in conservation planning and management, to make sure the needs of rural people are taken into account and to ensure their food security.

Mexican legislation on wildlife has legal figures and instruments for the sustainable use of wildlife; the main problem is that there are no human or financial resources to implement them. Besides the above, there is little knowledge of the laws and legal procedures, especially in the most marginalized communities. Thus, registering a UMA or obtaining a permit to make some kind of exploitation of wildlife involves a series of procedures that these people (some of them unable to read or write) simply can not follow, at least without having some professional guidance, so the hunter only has two options: break the law or starve their families. In order to change this situation, several things are necessary: more research on socioecological systems to address the need for both biodiversity conservation and also food security; good communication and coordination, and constant interaction between the government and scientific institutions, as well as the members of society to develop local management plans that incorporate current knowledge about key species (e.g., ducks and turtles), the interest of stakeholders, technical support and the dissemination of information, all of which would ensure the success of programs designed to both benefit people and conserve wetlands.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Green Rural Enterprises: guidelines for empowering local groups towards sustainable ventures

Adi Lazos-Ruíz[a], Patricia Moreno-Casasola[b] & Eduardo Galante[a]

[a] Centro Iberoamericano de la Biodiversidad (CIBIO), Universidad de Alicante, Carretera de San Vicente del Raspeig, s/n 03690 San Vicente del Raspeig, Alicante, Spain.

[b] Departamento de Ecología Funcional, Instituto de Ecología, A.C., Carretera Antigua a Coatepec 351, El Haya, Xalapa 91070, Veracruz, Mexico

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Adi Lazos-Ruíz[a], Patricia Moreno-Casasola[b]* and Eduardo Galante[a]

[a]*Centro Iberoamericano de la Biodiversidad (CIBIO), Universidad de Alicante, Carretera de San Vicente del Raspeig, s/n 03690 San Vicente del Raspeig, Alicante, Spain.*; [b]*Departamento de Ecología Funcional, Instituto de Ecología, A.C., Carretera Antigua a Coatepec 351, El Haya, Xalapa 91070, Veracruz, Mexico*

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In developing countries rural communities frequently face conditions of economic poverty, yet these areas are often rich in natural resources and biodiversity. We propose the concept of Green Rural Enterprise (GRE) and a methodology for its assessment by scoring 38 indicators based upon: (1) wise use of natural resources, (2) territorial rural development, (3) local rural groups and (4) sustainability-driven enterprise. Three cases of the auto-evaluation of community-based ecotourism groups are presented, where self-assessment is emphasised as an empowering tool. This method is useful for NGOs and funding agencies to compare and evaluate conservation ventures and to facilitate joint-work between them.

Keywords: rural entrepreneurship; sustainability indicators; community-based ecotourism; Mexico

1. Introduction

Although rural areas in developing countries are frequently plagued by economic poverty, they are often rich in biodiversity and natural resources. Therefore, it is important to orient rural development towards sustainability. The developmental strategy of combining the conservation of natural resources with the proposed economic growth of rural areas is supported by numerous organisations (i.e. state governments and NGOs). This strategy is embodied by our concept of a Green Rural Enterprise (GRE), a sustainability-oriented economic venture that makes a wise use of natural resources, holds a territorial approach to rural development and involves local groups in its management. One example addressed in this paper is community-based ecotourism, defined as ecologically-friendly tourism developed and managed by local people for their own benefit (Norris, Wilber, and Morales-Marin 1998).

Although many studies suggest the importance of community participation in conservation ventures, the practical actions required to achieve and evaluate such participation have seldom been articulated (Okazaki 2008, Kumar and Inoue 2008). Many authors argue that it is essential that ecotourism conserves local resources, involves the community and generates income, especially when business and economic development are prioritised over conservation (Scheyvens 1999; Barkin 2003). Yet community members participating in ecotourism ventures often encounter operational difficulties, such as lack of education and business experience, which may increase the transaction

*Corresponding author: Email: patricia.moreno@inecol.mx

costs and maintenance (Okazaki 2008). This is especially true in developing countries, where Zeppel (2006) found that the majority of ventures are supported and funded by NGOs and other development agencies. These ventures are often considered as business alternatives to extractive land uses, instead of community, family or individual ventures. Considering the amount of resources that are invested in such enterprises, it is necessary to establish a method that can evaluate whether or not the enterprise is sustainable.

Efforts to define sustainability have led to disagreements about its defining indicators, yet some form of measurement is necessary in order to evaluate the effects of different strategies (Stevenson and Lee 2001). Ideally, sustainability indicators provide valuable information for decision makers at all levels of organisation – local, state and national (Yli-Viikari, Risku-Norja and Aakkula 2012). We are interested in small enterprises in rural areas of developing countries, where primary extraction and transformation of natural resources is the most common way of sustaining the local livelihood (Toledo 1997).

The design of sustainability indicators is subjective, where stakeholders (including researchers) often define indicators in terms of their own values (Bell and Morse 2008). Therefore, some authors (Stevenson and Lee 2001; Bell and Morse 2008; Njuki *et al.* 2008) have referenced the need to involve a wide range of stakeholders in the process of defining indicators. However, defining indicators at the local level would probably limit the possibility of extending the methodology to other situations. The bottom-up approach, where local stakeholders actively participate in the decision-making process, is likely to result in indicators that better reflect local realities versus using the traditional top-down approach, where decisions are made by external institutions or authorities (Roberts and Tribe 2008). It is necessary to consider local people's knowledge and opinions (Cantrill 2012), where indicators should not be conceptualised as isolated facts but also as expressions of underlying processes (Turcu 2012).

Several methods exist for assessing the sustainability of rural enterprises. One example is the Framework for Assessing the Sustainability of Natural Resource Management Systems (MESMIS, the acronym in Spanish) (Speelman *et al.* 2007), which was developed in Mexico for the evaluation of agro-ecosystems and has been applied in several different Latin American countries. The International Fund for Agricultural Development (IFAD 2003) also promotes a methodological framework for project evaluation, which is guided by key questions and matrices of change over time. This analysis is complex and relies mostly on external evaluators, and even though the local participants are considered, the language and process may be too technical for them. Scheyvens (1999) proposed another framework to empower community-based ecotourism ventures, where the assessment includes an array of economic, psychological, social, and political indicators, although they are not measured quantitatively.

We propose the model of the Green Rural Enterprise (GRE), where the adherence of an enterprise to this model is measured by 38 specific indicators. The assessment of a GRE is carried out by the involved participants as a means of empowerment. This allows the group to detect deficiencies in enterprise operations in order to develop strategies to address problems and orient future growth towards the model of a sustainable rural enterprise. This paper focuses on the self-assessment of three community-based ecotourism enterprises in Mexico, using GRE indicators.

2. Categories and indicators of the GRE

This study adopts 38 indicators divided into four categories for assessing the sustainability of GREs. Considering the concepts outlined in Figure 1, we explain the

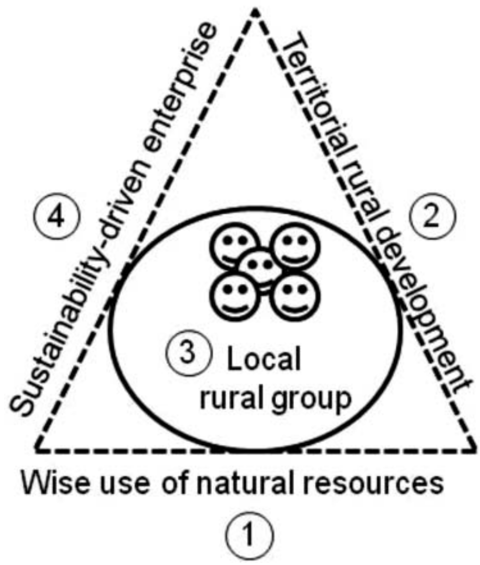

Figure 1. Sustainability triangle sustaining the Green Rural Enterprise based on the wise use of natural resources (1), territorial approach to rural development (2), a local group running the enterprise (3), and sustainability-driven entrepreneurship (4).

rationale for each of the four broad categories and the indicators associated with each of them (see Table 1, Table 2, Table 3, and Table 4 respectively). The indicators were designed based on an extensive review of relevant literature and on empirical experience working with organised rural groups (Webster 1999).

(1) *Wise use of natural resources*. This forms the basis of the proposed system, where use of natural resources is considered sustainable if it fosters ecosystem functioning (González *et al*. 2008; MEA 2005) (see Table 1).

(2) *Territorial approach to rural development*. A territorial approach takes into consideration the functional, sociological and cultural context of rural areas. These rural landscapes are shaped by natural resource use and the interactions between different ecosystems (Guevara and Laborde 2008). Within a territorial context of development it is important to appraise territorial resources, give an added value to territorial and local production, and establish relationships and boundaries with other territories of the world (AEIDL 1999; Gómez *et al*. 2010) (see Table 2).

(3) *Local groups running the enterprise*. It is essential that the local population benefits from the enterprise and is in charge of its management. The internal characteristics of the local group managing the GRE are important to evaluate in order to identify weaknesses and strengths that serve as indicators so that the group may fully develop its potential (see Table 3).

(4) *Sustainability-driven entrepreneurship*. Sustainability-driven entrepreneurship might be the analogue of the traditional 'economic' pillar of sustainability, but we stress the importance of seeing the enterprise and its income as a means of perpetuating natural resource availability and maintaining the quality of long-term ecosystem functions (Parrish 2010) (see Table 4).

Table 1. Wise use of natural resources. GRE indicators: their definition, sources and guidelines for assessment.

Indicator	Description	Source	Assessment guidelines
1.a. Awareness of the importance of conservation	The group recognizes the need to maintain the functioning of natural resources in the long term.	Bookchin 1978, Gudynas and Evia 1991, González *et al*. 2008	1: There is no awareness of the importance of conservation. 10: There is a deep understanding of ecosystem functioning and the value of conserving it, as well as the capacity to defend this point of view and to transmit it persuasively. Application of this knowledge in daily activities.
1.b. Local knowledge about the environment	The knowledge of the group concerning ecosystem functioning, uses of plants and animals and the state of their populations.	Sillitoe 2006, Sola 2005, Zhou and Jiang 2004	-1: Irrational application of knowledge bringing about more degradation (e.g. overexploitation of medicinal plants or animals). 1: There is no knowledge of the environment. 10: Local knowledge is used in all of the pertinent activities of the project, and is applied in the management plan for the area.
1.c. Clear conservation objectives in the project	Priority is given to conservation objectives; natural capital is considered the foundation of the enterprise.	González *et al*. 2008	1: There are no conservation objectives. 10: Project objectives include expressed, high priority conservation aims, as well as proposed actions to reach them.
1.d. Environmental education	Education in environmental care, conservation, changes in behaviour toward better ecological awareness.	Fuks 2004, Freire 2005, Zanotti and Chernela 2008	1: There is no environmental education program and/or no involvement of the group in an environmental education program. 10: There is active environmental education within the group and the members constantly share their knowledge, especially with the rest of the community and visitors.
1.e. Ecological monitoring and restoration by the community	Participation of the group in environmental research, restoration activities, monitoring local environmental conditions to understand its functioning and its effects on the community.	Deutsch *et al*. 2005, Paré *et al*. 2008	1: There is no monitoring or restoration program and/or no involvement of the group in these programs. 10: The group participates in ecological monitoring (e.g. fauna census, water quality assessments) and identifies changes that need further specialized analysis. The group actively participates in the restoration of the ecosystem (e.g. reforestation, cleaning water bodies). The group understands the importance and benefits of restoration.

(*continued*)

Table 1. (*Continued*)

Indicator	Description	Source	Assessment guidelines
1.f. Decrease in pollution and energy consumption	The quantity of residues and energy consumption resulting from the activities and elaboration of products of the enterprise.	Frosch and Gallopoulos 1989, De Carlo and Drummond 1998, Iribarren *et al*. 2010	-1: Producing the product or service generates more untreatable residues than before the enterprise started operating (e.g. residues that cannot be recycled or reused or that pollute a lot), introduction of new contaminants, dangerous waste, and/or invasive species. 1: Producing the product or service generates untreatable residues, equivalent to those generated before the enterprise started operating. 10: The enterprise endeavours to reduce the generation of waste and/or convert them into their least polluting form. Actions such as environmental education, recycling, prevention of poaching. Actions result from an analysis of life-cycle, carbon footprint estimation, the use of eco-technologies and decreased energy consumption.

Table 2. Territorial approach to rural development. GRE indicators: their definition, sources and guidelines for assessment.

Indicator	Description	Source	Assessment guidelines
2.a. Management Plan	The strategy of land use management used for the development of the region, with human development and natural conservation as its heart.	Aquino *et al*. 2006	1: There is no Management Plan in the area of influence of the enterprise. 10: There is a Management Plan in the area and it truly promotes the conservation of the region; the group participates in its preparation.
2.b. Heritage inventory	The list of elements that constitute the cultural and environmental heritage of the region.	Arango and Rivera 2010	-1: The information about the heritage of the region is used to the detriment of the resources (e.g. poaching in strategic sites). 1: There is no information about the cultural and environmental heritage of the region. 10: There is an inventory of the heritage of the region and it is continuously updated.
2.c. Law	Legal framework for the enterprise.	Steck 1999, Pinson 2008	-1: The endeavours of the enterprise fall outside the framework for legal activities. 1: It is not known what legislation applies to the enterprise. 10: The enterprise is legally registered, has a clean record and is regulated by ethical principles.
2.d. Land tenure	Legality of land rights.	Steck 1999, Sola 2005	1: Fragile and changing land use or tenure is a source of conflict. 10: The group has its own land and ownership is clear and protected.

(*continued*)

Table 2. (*Continued*)

Indicator	Description	Source	Assessment guidelines
2.e. Presence in socio-political circles	Capacity of the enterprise to establish networks and participate in different social and political spaces, with the highest ethical principles.	D. Díaz, pers. comm., Scheyvens 1999	-1: Government institutions and other organizations (e.g. universities, NGOs) know of the enterprise, but it has a poor reputation (e.g. corruption, poor management). 1: Other organizations are not aware of the enterprise. 10: Different organizations know about the enterprise, which has earned respect and an excellent reputation (e.g. transparency, quality). These organizations are allies of the enterprise.
2.f. Impact in the community	The assemblage of effects brought about by the enterprise in the rural community where it is located.	Gibbs 2009, Lazos-Ruíz 2010, Scheyvens 1999	-1: There is a negative impact on the community. 1: The community does not perceive any effect from the enterprise. 10: The community benefits from the enterprise even if they are not members of the group. The enterprise carries out conservation and social actions in the community.

Table 3. Local group running the enterprise. GRE indicators: their definition, sources and guidelines for assessment.

Indicator	Description	Source	Assessment guidelines
3.a. Empowerment	The members of the group take the enterprise on as their own, and take care of it.	D. Díaz, pers. comm., Scheyvens 1999	1: The group does not regard the enterprise as its own. 10: The group considers the enterprise its own and is interested in fighting adversity when necessary.
3.b. Economic independence and independence in resource management	The capacity of the enterprise for self-maintenance in terms of human and financial resources.	Speelman *et al*. 2007, Ohl-Schacherer *et al*. 2008	1: In order to operate, the enterprise depends exclusively on transient agents (e.g. students, volunteers, government employees). 10: The group is able to manage all its resources by itself or hires professionals (e.g. project preparation, reinvestments), and has access to healthy financing.
3.c. Initiative	The action of starting the enterprise from the conception of the idea to proposing the participation of a community group.	Ulloa-Rivera 2007, Ohl-Schacherer *et al*. 2008	1: The initiative of the project was external to the group and it is very possible that the project will finish when those who started it leave. 10: The initiative of the project originated with a community group or the initiative was external but the group has made the project its own and if those who started it leave the project will continue in the long run.
3.d. Motivation	The reason that moves the group to continue with the enterprise with interest and diligence.	Scheyvens 1999	-1: The group has become discouraged and is not able to build up self-motivation. 1: Motivation is very low. 10: The group is motivated and enthusiastic about the project even in times of adversity.
3.e. Leadership	Ability to be recognized as the legitimate head of the group.	Sola 2005	1: The group does not recognize a leader. 10: The group recognizes a legitimate leader who has a clear vision of conservation and keeps the group strong. Different areas of leadership are recognized based on abilities and talents.

(*continued*)

Table 3. (*Continued*)

Indicator	Description	Source	Assessment guidelines
3.f. Internal harmony of the group	An atmosphere of cordiality within the enterprise.	Quintero, Africano, and Faría 2008	1: There is frequent unpleasantness and conflict in the group that the members are unable to solve or work as a group. 10: Everyone respects the diversity of opinions and each other's personalities.
3.g. Gender focus	Equal opportunities for women and men.	ODM 2008, Scheyvens 1999	1: There is no gender focus. 10: Women have the same opportunities to work, receive fair payment and to be trained, occupy decision-making positions, and allowances are made when they are pregnant.
3.h. Training	Transmission of knowledge for the development of capacities for the group and for the enterprise.	Scheyvens 1999	1: There is no access to training. 10: All of the members of the group are trained in diverse areas and share their knowledge with each other. They move from theory into practice; look for training according to practical needs; conduct self-learning, and learn from these when needed.
3.i. Level of technical knowledge and homogeneity	Level and uniformity of the knowledge of the group's members when delivering the product or service offered by the enterprise.		1: The members of the group do not have the knowledge to develop or deliver the product or service. 10: All members have a solid base of abilities and knowledge to develop, deliver and improve the product or service.
3.j. Active integration	The number of members that participate actively in the tasks of the enterprise.		1: Even when the group has several members, less than 50% of the membership participates regularly and the proportion is decreasing. 10: The majority of the members of the group participate actively (90-100%).
3.k. Innovation	Creative capacity of the group members applied to improving the enterprise and its services.	D. Díaz, pers. comm.	1: Nobody is interested in making changes in the enterprise. 10: The creativity of the group is encouraged all the time; new products and services are invented, innovations are constantly applied. The group responds actively to these creative spaces.

Table 4. Sustainability-driven entrepreneurship. GRE indicators: their definition, sources and guidelines for assessment.

Indicator	Description	Source	Assessment guidelines
4.a. Business Plan	The planning document of the enterprise containing information such as market study and promotion objectives; useful for estimating economic feasibility.	Pinson 2008	1: There is no business plan. 10: There is a business plan known by all the members of the group; it is used and constantly updated.
4.b. Internal accounting	System that allows an account of the assets and duties of the enterprise, it shows the financial condition of the enterprise.	Pinson 2008	1: There is no internal accounting. 10: Internal accounts are impeccable. The financial statements are used in decision making and favour transparency.
4.c. Economic feasibility	Capacity of the enterprise to cover its own expenses, generate capital and have healthy finances.	Scheyvens 1999	1: The enterprise loses money or uses the members' personal money for maintaining the enterprise. 10: Profits are distributed among all members of the group.
4.d. Quality	The set of conditions that makes the service or product worthwhile.	Quintero, Africano, and Faría 2008, Gutierrez-Pulido 2010	-1: The product or service is of low quality and is progressively getting worse. 1: The product or service sporadically attains acceptable levels of quality. 10: The high quality of the product or service is recognized and is continuously improving.
4.e. Competitive price	The amount of money required to buy the final product or obtain the service.	AEIDL 1999	-1: The price that can be obtained for the product or service does not cover the entire cost of production, and/or the price is competitive, but the social and ecological costs are high. 1: The price barely covers the cost of production for the product or service, limiting profit. 10: The price of the product or service covers all expenses incurred (including labour) and yields some profit; the target public is willing to pay this price.

(*continued*)

Table 4. (*Continued*)

Indicator	Description	Source	Assessment guidelines
4.f. Respect for the rules within the group	Following the norms that regulate the group and the enterprise for its proper functioning.	North 1993, Ostrom 2000, Lambí-Insua and Pérez-Correa 2007	-1: There are rules, everyone knows what they are and approved them. However, when they are broken there is no sanction or consequence; the rules have totally lost their legitimacy. 1: There are no rules or the group does not know what they are. 10: All members respect all the rules all the time and if there is an omission it is discussed or penalized; the rules are only rarely broken.
4.g. Collective decision making	How decisions for the enterprise are made as a group.	Ostrom 2000, Scheyvens 1999	1: The group is not consulted about matters requiring decisions. 10: There is room for the open expression of opinions and decisions are taken collectively.
4.h. Transparency	Access to enterprise information is open to all the members of the group.		-1: Poor management of resources. 1: Management of resources is not reported systematically, and/or the report is not openly available to the whole group, and/or the group does not trust the information that is given. 10: All members have open access to reports that systematically present information on the management of resources, and they trust them.
4.i. Equity	The fair distribution of benefits derived from the enterprise.	Whitaker and Shenoi 1997, Scheyvens 1999	1: Benefits are not fairly distributed, only a few are favoured. 10: The distribution of benefits is fair (according to the work done) and the group recognizes this.

(*continued*)

Table 4. (*Continued*)

Indicator	Description	Source	Assessment guidelines
4.j. Type of participation	The way in which members get involved in the enterprise.	Pretty *et al*. 1995, Marín, Criado, and Bravo 2005, Speelman *et al*. 2007, Scheyvens 1999	1: Passive participation level: people listen to what is going to happen. The information belongs to professional outsiders. 10: Self-mobilization level: People take the initiative to change systems, independently of external agents.
4.k. Impact on the natural environment	The set of effects in nature caused by the enterprise's actions over time.		-1: The enterprise has had a negative impact on the ecosystem. 1: The enterprise has neither a positive nor negative impact on the natural environment. 10: Degradation of the ecosystem has decreased since the enterprise started.
4.l. Perception of material benefits	The recognition of material benefits such as infrastructure and equipment, derived from the enterprise.		1: Material benefits are not perceived. 10: Material benefits are perceived and acknowledged.
4.m. Perception of intangible benefits	The recognition of nonmaterial benefits such as knowledge, experience and new abilities, derived from the enterprise.	Lazos-Ruíz 2010, Asquint, Vargas, and Wunder 2008, Scheyvens 1999	1: Intangible benefits are not perceived. 10: Benefits such as new knowledge, abilities and increased self-confidence are acknowledged.
4.n. Perception of extra income	Recognition that working in the enterprise brings in extra income.		1: There is no extra economic benefit. 10: There is an extra economic benefit that increases family incomes.
4.o. Strategic evaluation	Mechanism for evaluating the performance of the group and the enterprise in order to design better strategies for its functioning.	Margoluis and Salafsky 1998, IFAD 2003, Waltner-Toews and Kay 2005, Pesci, Pérez, and Pesci 2007.	1: There is no evaluation of the enterprise's performance. 10: Continuous and systematic evaluations are carried out to help the enterprise stay on target with respect to its objectives.

The list of indicators has been revised, summarised and shortened when possible. Some indicators seem to be similar, but each was carefully selected and defined to stress the importance of that particular indicator. We consider that if the criterion is too general, then subtle differences may be overlooked.

While local participants in our study did not design the indicators, we took into account their ideas as expressed in workshops and group conversations. For example, the indicators of presence in socio-political circles (Table 2, Indicator 2.e.), empowerment (Table 3, Indicator 3.a.) and innovation (Table 3, Indicator 3.k.), were suggested as important by participants. The incorporation of local participation in the overall process was given a high priority through the process of self-evaluation.

3. Description of the sustainability metric

The GRE methodology allows for the identification of problems in the operation of the enterprise and helps to establish priorities and guidelines for strategic actions to remedy identified problems. The indicators are not only a list of items to tick off, as proposed by some authors (Becker 2010), but rather as Yli-Viikari, Risku-Norja, and Aakkula (2012) noted, each indicator needs to provide guidelines to reach the desired sustainable state. Criteria that are too abstract or technical might be difficult to pose as a simple question; thus we tried to propose clear and simple definitions. The phrasing of the indicator can also affect its interpretation (Becker 2010), yet the definitions of the elements belonging to each indicator may be adjusted depending on local language use and conceptualisation.

The method proposes that people from the local community involved in the operation of the rural enterprise (at least 50% plus one participant) should function as the evaluators. Commonly perceived problems and their accepted solutions are often discovered via collaboration (Okazaki 2008) and collective action (Jones 2005). External evaluators, or people who do not belong to the group, can also apply the same evaluation, but the focus of this paper is on the process of internal evaluation.

The assessment is based on assigning a number to each indicator on a scale from 1 to 10, where 1 is the least sustainable and 10 is the most sustainable. The guidelines for each indicator provide a framework for assigning a score. It is possible to score a -1 for critical cases where a scenario exists that could potentially bring the enterprise to a breaking point, similar to the signs of disempowerment as proposed by Scheyvens (1999). These critical cases were defined using a Failure Mode and Effect Analysis (FMEA) (Cortés and Gutierrez 2001), where potential failures were assessed for each indicator with respect to potential effects, severity of the failure, cause of the failure, possibility of occurrence and degree of risk.

The initial assessment was based on a scale from 1 to 3, but after a trial was changed from 1 to 10, where -1 is associated with the aforementioned risk. This change was made because internal evaluators were more familiar with a scale from 1 to 10, as it is often used in regional schools. We observed that for illiterate people evaluating on a scale from 1 to 10 is difficult, so in some cases it might be recommendable to apply an oral evaluation with a scale ranging from harmful to excellent.

This method gives the same weight to each indicator, although it is evident that some indicators may be more important than others (Sarandón and Flores 2009). Each case of evaluation will reflect the degree of experience of the group, the development stage of the enterprise, as well as the context, cultural background of the participants, and many other variables. Thus, each evaluation will generate findings and data that are specific to the nature of that project (IFAD 2003). In addition, an indicator that identifies a problem at the beginning of the process has the potential to later be converted into a strength, depending on the historical movement of the enterprise (helicoid *sensu* Pesci, Pérez, and Pesci 2007). Due to this variance in group dynamics, we consider that weighting the different indicators would be a complicated and subjective task. Instead, we consider that the evaluators themselves will signify through their scoring which indicators result in being more relevant to their specific situation. The points obtained for a given indicator would determine the degree of urgency for which that issue should be addressed. Indicators that received a score of -1 to 0 are classified as urgent, or the indicators most in need of being addressed to avoid collapse of the enterprise. Indicators rated from 1 to 4 are considered high priority. A rating of 5 to 6 is considered medium priority. Indicators with a rating of 7 to 8 are of low priority. Finally, indicators rating from 9 to 10 are considered satisfactory and indicate the best performance.

The application of the method requires a trained person to act as a moderator that possesses the following abilities: (1) able to fine-tune the moderation style; (2) offer an optimal and objective explanation of the indicators so that the evaluators have a common understanding of what is being assessed; (3) deal with struggles that might arise as rural participants and external evaluators may have their 'own language' and interpretation; (4) record data and carry out simple analysis in a database software (i.e. Microsoft Excel); (5) understand the importance of maintaining reliable results; and (6) report the findings to the group and suggest possible strategies to follow. This person could be a member of the local group, although he or she may need training from an external organisation that promotes this type of self-evaluation. An external evaluator can also offer support with the processing of the results, as long as consideration and respect is given to the process of the self-evaluation.

Once the indicators have been scored the information is processed. For each indicator, the number of times it was scored as urgent, high priority, medium priority, low priority and satisfactory is recorded. The most relevant indicators for the group would be those classified as urgent or high priority, which would denote weaknesses within the enterprise, as well as satisfactory, which would signify group strengths. In addition, indicators with heterogeneous responses across all intervals are also considered important, since this indicates difference of opinion or conflict among group members. The following dynamics can be assessed to determine future strategy: (1) identify the perceived strengths and weaknesses of the enterprise; (2) determine group priorities; (3) detect differences among internal evaluators; (4) find differences between internal and external evaluators; (5) compare different assessments over time; and (6) compare results between enterprises. For the comparison analyses we recommend using a radial graph as a visual aid to represent and quantify indicators and assess the extent to which the objective – in this case achieving the defining characteristics of a GRE – have been reached (Brink, Hosper, and Colijn 1991).

The environment in which the evaluation is carried out should foster an atmosphere of trust, allowing the evaluators to freely and democratically express their opinions so that everyone has a chance to participate in the discussion. Major differences in opinion among the evaluators can result from multiple factors such as (1) interpreting the concepts under evaluation differently; (2) existing inequity or power conflicts; (3) hiding information from the moderator; (4) idealising or underestimating the capacity of the enterprise; (5) carrying out evaluations at different times; and (6) gathering data from only a few members of the group or the leader. The evaluation should be carried out in a group setting and include all members of the enterprise in order to allow for a

Figure 2. Map showing the location of the study area along the coast of Veracruz, Mexico.

deeper understanding of the group's organisation. The ideal is that the enterprise would adopt this exercise as a systematic way of obtaining feedback and making decisions as part of a cyclical process that would strengthen the group (Lagunas-Vazquez *et al*. 2008).

4. Context

We selected three communities located in key coastal wetland areas in the Gulf of Mexico (Figure 2), where community-based ecotourism enterprises have been promoted since 1998 as means of diversifying the local economy, which is largely based on primary extraction and production (Moreno-Casasola 2004, 2006). Although a variety of interests and objectives exist for those participating in the ecotourism venture, in each case the founding vision was oriented towards the conservation of wetlands. The studied enterprises are run by groups of local people, mainly farmers, cattle ranchers, fishermen and housewives, who have been trained by several organisations but mainly by the Institute of Ecology, A.C. (a public research institute). The groups were trained in workshops about the practical importance of conservation, how to organise groups, accountancy, first-aid and other subjects. They received support in order to achieve legal representation and to participate in calls for funding from various public dependencies, such as the National Forestry Commission and the Ministry of the Environment and Natural Resources, which have been their main source of funding. The local people involved have invested time and effort into training and working together as a group and have established, in some cases, land-trusts and institutional agreements in order to set up a community enterprise.

The three enterprises are organised in an assembly with an executive board composed of a president, secretary, treasurer, oversight committee, education committee and admission committee. The assembly was in charge of defining their own rules for the functioning of the enterprise in which the main goals were providing economic benefits for their members and for the community, as well as conserving natural resources.

5. Area of study

The most common economic activities in the areas of study have traditionally been agriculture (sugar cane, mango, corn), raising livestock and small-scale fishing. Many locals arrived in the area in the 1950s hoping to acquire a tract of land during the time when new *ejidos* were being formed. *Ejido* land arrangements are unique to Mexico and are tracts of land that have a community tenancy and management. All of the enterprises make use of the *ejido* communal land during ecotourism activities, such as guided tours. The majority of the inhabitants have only a primary school education. Rates of emigration to the US are high, and many young generations are beginning to leave the traditional rural way of life and are starting to lose contact with agricultural activities (Paradowska 2006).

6. Application

The methodology was applied to three rural community-based ecotourism enterprises (A, B and C) within the context described above. Groups A and B were created three years ago, and Group C has more than 12 years of experience. We had 7 (out of 12), 14 (out of 16), and 9 (out of 12) participants respectively, representing more than 50% of each group. One potential drawback to this approach is that the sample was self-selected and only respondents taking an active part in the operation of the enterprise were included, while 'difficult to reach' (non-active) respondents were excluded (Turcu 2012). The first author, who has been working directly and indirectly with these groups for more than two years, was the moderator. Data were collected over three sessions (one for each group) during which the respondents were given a printed version of the indicators, with space to write their numerical assessment. In our trials, reviewing each indicator and giving a verbal explanation to the whole group of participants was more efficient and better understood than individual reading, due to low levels of reading comprehension. During the session, participants could ask as many questions as required to understand the indicator concept, but discussion about personal points of view was not allowed so that bias would not be introduced by group leaders. It was explained that the participants' point of view had to be reflected in the evaluation as a number on a scale from 1 to 10. The evaluations were completed anonymously so that respondents would feel free to express their true opinions.

7. Results

Only the highest and lowest rated indicators are presented in the results. Group A (Figure 3) showed a satisfactory response to the initiative indicator (3.c.), where the homogeneity of responses demonstrates the common vision of the group and capacity to survive in the long term. Taking collective decisions (4.g.) was also recognised as satisfactory. The rating of transparency (4.h) was more divided, as 70% of the respondents stated that this indicator was satisfactory, while a minority stated that this indicator was an issue of urgent priority. The three lowest rated indicators received a score of urgent, although by only one person. Meanwhile, the indicators of local knowledge use (1.b), strategic evaluation (4.o) and respect of the rules within the group (4.f.) received heterogeneous scores and were divided between low and high priority.

Group B (Figure 4) (the group with the highest number of participants) gave a satisfactory rating to collective decision making (4.g.), internal accounting (4.b.) and

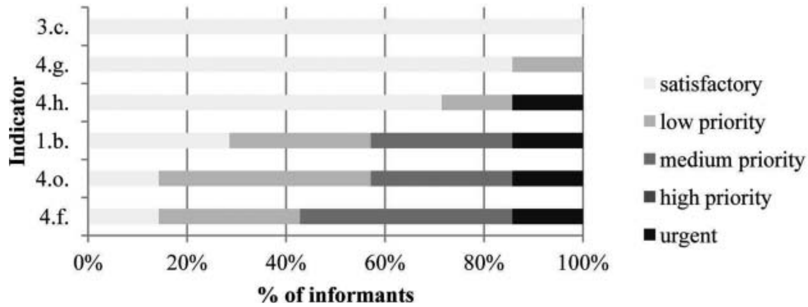

Figure 3. The three highest and lowest rated indicators in Group A.

notable participation (4.j.). In contrast, environmental education (1.d.) received the lowest rating, although the scores were divided among the evaluators. Other low rated indicators were those of having a management plan (2.a.) and a decrease in pollution and energy consumption (1.f.).

Group C responses (Figure 5) were more heterogeneous than the previous two groups. The highest rated indicators were perceived as intangible benefits (4.m.), presence in socio-political circles (2.e.), and empowerment (3.a.). The lowest rated indicators included land tenure (2.d.), respect for the rules within the group (4.f.) and internal accounting (4.b.).

8. Discussion

The scores received on the GRE indicators give insight into group dynamics, strengths and weaknesses, which allow for specific recommendations tailored to each group. This method should stimulate internal discussion, clarify perceptions among group members and prioritise the most important indicators to address for future group dynamics. For Group A the initiative indicator (3.c.) signifies that the group momentum is well established and will continue if founding members leave, and may be considered as one of the great strengths of the enterprise. On the other hand, it is necessary to understand why one participant indicated a transparency problem. It is evidence that one of the group members has probably been excluded from the group process. The three lowest rated indicators received at least one score of urgent, and although these indicators were rated as urgent by only one evaluator it nonetheless requires consideration. It is

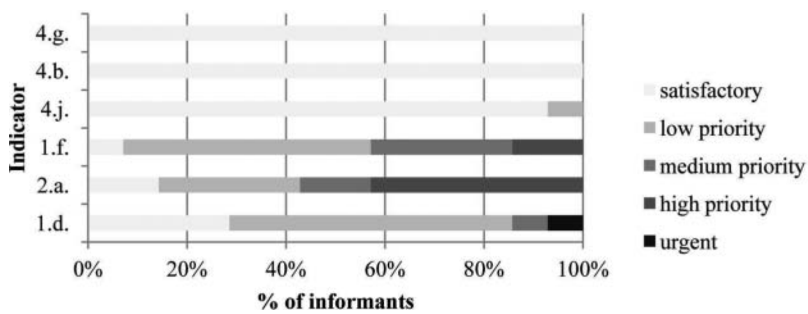

Figure 4. The three highest and lowest rated indicators in Group B.

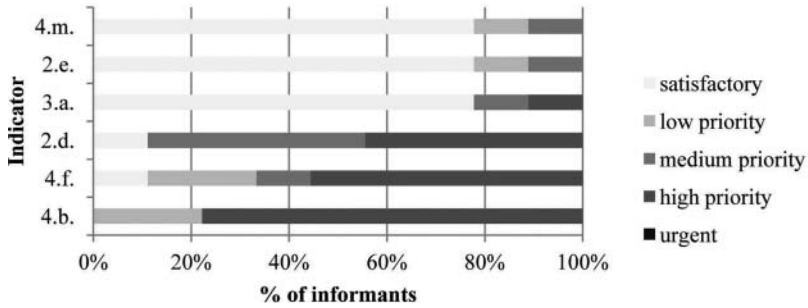

Figure 5. The three highest and lowest rated indicators in Group C.

necessary for the group as a whole to discuss these points and attend to indicators rated as urgent.

For Group B the highest rated indicators reflect an inclusive and participative organisation with good management of financial resources. In the specific case of internal accounting indicator (4.b.), and given the characteristics of the executive board of this enterprise, part of the high score may be accredited to the group having a good treasurer. A strategy that addresses the lowest rated indicators should start with the formulation of a management plan with conservation aims that include environmental education and actions for decreasing pollution and energy consumption.

The responses of Group C are reasonable considering that this enterprise has the most experience. The development of strengths within groups requires time; for example, group members in Group C have a history of participation with different organisations (socio-political circles) and have gained positive recognition. Due to their experiences they have acquired knowledge, experience and new abilities that can only come from working in the enterprise for several years. The problems identified were lack of respect for the rules within the group and internal accounting, which seem to be rather basic for such an experienced group; even so, guided actions to remedy these difficulties could greatly benefit the enterprise. Land tenure problems are delicate and can take a long time to solve, and their solution does not depend solely on the group. Internal accounting was an identified strength for Group B but a weakness for Group C, so one possible action is to promote an exchange of experiences between these groups. Group C could implement a new and more effective internal accounting system that would probably include the proper training of the treasurer. Lack of respect for the rules was also a significant problem for Group A. Following the suggested guidelines, one way to address this problem would be to develop a penalty system and apply it objectively and firmly (see Ostrom 2000). This indicator is even more problematic when the rules have lost their legitimacy, and it is clear that the whole group needs to break away from this vicious cycle. New actions must be taken to solve this situation if the enterprise wishes to continue, that is, be sustainable over time.

Our results have also shown that GRE assessment completed by internal evaluators can also provide useful hints about performance to external evaluators. For this paper we have only presented the three highest and lowest rated indicators, but there is more detailed information that can be obtained and analysed considering the results of the 38 indicators. It is difficult to decide which indicators best flag a sustainable GRE (see justification of weighting of indicators in the 'Description of Sustainability Metric' section). Although it is worth mentioning that the indicators are not fixed and may evolve according to new conditions, each enterprise can also adopt the method and adapt it to their own needs. This methodology is meant to evaluate established enterprises but can also be considered as a guideline in the planning of new enterprises.

Several other evaluations of ecotourism ventures in Mexico have been applied in different scenarios. Fernández, Castillejos and Ramírez (2012) used a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and business management indicators to assess five ecotourism enterprises in Oaxaca. Information was obtained through semi-structured interviews. The main finding was that the lack of business skills and management was one of the principal problems plaguing the enterprises. Barbosa *et al.* (2010) used six evaluation categories with different weighting, proposing a quantitative evaluation done mostly by external evaluators who interviewed participating locals. Analysing interview data is always done based on the criteria of the interviewer, which may allow for some bias. Our GRE methodology shares the objective of evaluation, but also provides a means for summing indicator scores and thus allowing for quantitative analyses. In addition, the method helps to identify priorities and guide steps to reach GRE ideals. Another difference of GRE in comparison to other methods is that it has a strong orientation towards the wise use of natural resources and defends the use of self-evaluation of local entrepreneurs as a means of empowerment. It would be valuable to explore other possibilities, such as the work of Stronza and Gordillo (2008), who proposed an ethnographic approach where local people actively collaborate in the definition of benefits and the selection of success indicators.

Any rural enterprise can be assessed under the GRE framework, and the indicators can be adapted to local conditions. We are aware and open to the need to test GRE indicators on different types of rural enterprises that participate in other resource extraction industries, including forestry, agriculture and fisheries. Even though GRE was designed for enterprises in developing countries, the concept can be generalised and applied to ventures in developed countries. However, the criteria should always be adjusted to the local context. For example, indicators such as 'law' and 'land tenure' are likely to be more regulated and ordered in developed countries.

9. Conclusion

The GRE method outlines clear sustainability indicators to evaluate with solid supporting arguments and helps to define priorities for future enterprise actions. Even though rural inhabitants often have different values and opportunities from their city counterparts, the current market-based culture requires rural communities to assimilate to a business oriented scheme of development. The GRE method promotes a learning process while adhering to clear conservation and social welfare objectives. This method invites the internal evaluators of rural enterprises to get involved in their own assessment as a means of empowerment, promoting individual reflection on the enterprise's sustainability and encouraging all members to take an active part in discussions and problem solving.

The self-assessment of rural enterprises has been little explored. Evaluation tasks are often delegated to technicians or external organisations. It is evident that researchers and organisations must establish open communication channels with rural people who have distinct perceptions and understandings of natural resource management and local enterprise. Taking into consideration the local participants' opinions, knowledge and decision-making processes are important in promoting adequate natural resource use and for the future of biodiversity.

This method can be used as a systematic evaluation in rural enterprises looking to achieve sustainability. Local groups can implement this methodology on their own, adapting it to their specific needs and possibilities. Governments, NGOs and other agencies can support GREs with financial and technical assistance, especially in order to develop conservation objectives and business management skills among local entrepreneurs. It is essential to invest in human capacities that allow a GRE to be autonomously sustainable in both the mid- and long term future (Gómez *et al*. 2010).

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El uso de los árboles en Jamapa, tradiciones en un territorio deforestado

Use of trees in Jamapa, traditions in a deforested area

Adi Lazos-Ruíz[1], Patricia Moreno-Casasola[2*], Sergio Guevara S.[2], Claudia Gallardo[2] y Eduardo Galante[1]

1 Centro Iberoamericano de la Biodiversidad (CIBIO). Universidad de Alicante. San Vicente del Raspeig, Alicante, España. adi_lazos@hotmail.com, galante@ua.es

2 Instituto de Ecología, A.C. Red de Ecología Funcional. sergio.guevara@inecol.mx, claudia.gallardo@inecol.mx

* Autor para correspondencia. patricia.moreno@inecol.mx

Resumen

Los árboles han jugado un papel fundamental en el desarrollo de las civilizaciones, tanto como recursos de aprovisionamiento como por otros servicios ecosistémicos. Sin embargo hay una fuerte perturbación de los bosques tropicales que ha disminuido la cantidad y diversidad de los árboles. Una de las causas principales de esta situación es el cambio de uso del suelo, sobre todo para actividades ganaderas, que en el estado de Veracruz, México, ocupan alrededor de 3.7 millones de hectáreas (50.6% de su territorio). El objetivo de este trabajo fue investigar el conocimiento que los ganaderos tienen sobre las especies arbóreas, sus usos, su importancia cultural y los cambios que han sucedido a lo largo del tiempo. Se mencionaron 68 especies de árboles y se hizo una clasificación de 22 tipos de usos. Se calculó el índice de importancia cultural de cada especie y se describieron los cambios más importantes en el estilo de vida de las comunidades de estudio. Se encontró que hay un conocimiento amplio sobre los árboles pero se está perdiendo rápidamente. Los árboles se usan no solo para obtener beneficios en la ganadería sino para satisfacer otras necesidades de la vida cotidiana. La cantidad y la diversidad de especies arbóreas refleja el estilo de vida de las comunidades junto con sus influencias y cambios en el tiempo. Las decisiones de los ganaderos configuran el paisaje y por lo tanto se recomienda aumentar la cantidad de árboles en los potreros, su conservación y su uso para mantener los servicios ecosistémicos que proveen.

Palabras clave: acciones de conservación, conocimiento local, ganadería, importancia cultural, tipos de uso.

Abstract

Trees have played an important role in the development of civilizations, both for provisioning of resources and for other environmental services. However, there is a strong decrease in the quantity and diversity of tropical forests trees due to land use changes. One of the main causes of this situation is the livestock activity, which in the state of Veracruz, Mexico, occupies a surface of about 3.7 million hectares (representing 50.6% of its territory). The objective of this study was to research into cattle ranchers' knowledge of arboreal species, their uses, their cultural importance and the changes that have taken place over time. Sixty eight species of trees were mentioned and their uses were classified in 22 types of uses. The cultural importance index was calculated for each species and the most important changes in the communities' lifestyle were described. The results showed that ranchers have a wide knowledge about trees but it is rapidly disappearing. Trees are used not only to get benefits for the livestock activity but also to satisfy other needs of daily life. The quantity and diversity of arboreal species reflect the lifestyle, influences and changes over time within the communities. The decisions of ranchers configure the landscape, and therefore the recommendation is to increase the amount of trees, their conservation and uses to maintain the environmental services they provide.

Keywords: conservation actions, local knowledge, livestock, cultural importance, types of use.

Introducción

Los árboles han tenido un enorme valor en el desarrollo de las civilizaciones desde tiempos preagrícolas (Casas, 2001), por sus usos con fines tanto utilitarios –madera leña, alimento y derivados medicinales– como rituales y cosmogónicos (Bellefontaine *et al.*, 2002; López-Austin, 1997; Toledo *et al.*, 1995). También se les confiere una gran importancia por los servicios ecosistémicos que brindan, como refugio para vida silvestre, sombra, conectividad del paisaje, regulación del clima, control de erosión, mantenimiento de biodiversidad y formación y fertilidad del suelo, entre otros (Guevara *et al.*, 2005; Millenium Ecosystem Assessment, 2005; Moreno-Casasola y Paradowska, 2009). A pesar de su importancia, se está dando una disminución global del número de árboles de gran talla debido a causas antropogénicas (Lindenmayer *et al.*, 2012). México es uno de los diez países con mayor cobertura de bosques primarios del mundo y es el séptimo con mayor deforestación (FAO, 2010), con una pérdida anual neta de 367 224 hectáreas (Céspedes y Moreno, 2010). Esta perturbación se refleja en que más de la mitad de las superficies de bosque tropical perennifolio, subcaducifolio y caducifolio están constituidos por vegetación secundaria -i.e. la vegetación que sucede cuando se pierde el bosque original (Conafor, 2012). Los humedales arbóreos y herbáceos también han sido alterados, habiéndose perdido o degradado una superficie de 62% (Landgrave y Moreno-Casasola, 2012). Los manglares están protegidos por la legislación ambiental mexicana, pero otros tipos de vegetación como las selvas inundables, no han sido considerados ni estudiados adecuadamente y apenas quedan bordes alrededor de los manglares (Infante *et al.*, 2014; Landgrave y Moreno-Casasola, 2012).

Las principales causas de la deforestación son el cambio de uso de suelo (Toledo, 1990), sobre todo para actividad ganadera - lo cual ha traído la proliferación de grandes extensiones de pastos introducidos para ganado bovino (Guevara y Moreno-Casasola, 2008) - y acciones promovidas por políticas públicas y programas gubernamentales en diferentes épocas del país (Bravo *et al.*, 2010; Niembro, 2001) como el Programa Nacional de Desmontes en la década de 1970 (Moreno, 2011).

Veracruz, estado en la costa del Golfo de México, destina alrededor de 3.7 millones de hectáreas - 50.6% de su territorio - a la ganadería (Sedarpa, 2012); es decir, los potreros son los paisajes predominantes (Guevara *et al.*, 2005). La ganadería veracruzana se caracteriza por ser extensiva, con ganado de doble propósito (leche y carne), en unidades de pequeña escala, con un bajo nivel productivo y tecnológico y con una alta dependencia del pastizal cuya calidad y disponibilidad están marcadas por las temporadas de secas y lluvias (Travieso-Bello y Moreno-Casasola, 2011; Vilaboa y Díaz, 2009).

Árboles en la ganadería

La estructura y composición arbórea de los potreros están determinadas en gran parte por las decisiones de uso y prácticas de manejo ganaderas, por ejemplo cuántos y cuáles árboles dejar en pie, cuáles sembrar o eliminar. La selección de las especies se relaciona con los beneficios que aportan para satisfacer las necesidades del ganadero (Esquivel *et al.*, 2003; Gómez-Pompa, 1987; Gómez *et al.*, 2013), por ejemplo para postería, cercas vivas, forraje y sombra. Los postes (troncos de aprox. 1.80 m de altura) son usados para sostener el alambre que delimita el espacio accesible al ganado, una hectárea necesita alrededor de 130 postes que deben ser reemplazados periódicamente. Las cercas vivas son árboles dispuestos en hilera que marcan un lindero o forman parte de las cercas con alambre; para esta finalidad usualmente se eligen especies que se propagan por estaca porque ahorran tiempo de crecimiento y evitan que sean comidas o pisadas por el ganado (Avendaño y Acosta, 2000). El forraje obtenido de hojas, tallos tiernos, flores o frutos de los árboles diversifica los recursos nutricionales para el ganado mejorando su rendimiento (Villa *et al.*, 2009). En cuanto a la sombra de los árboles, Betancourt *et al.* (2003) encontraron que modifica el comportamiento de los animales en los potreros y favorece la producción de leche. Los árboles en pie dentro de los potreros no solo son proveedores de estos beneficios sino que funcionan como puntos de conectividad en el paisaje, facilitan la preservación y dispersión de semillas y son núcleos potenciales de regeneración de las selvas (Guevara *et al.*, 2005). De esta manera, las decisiones de los ganaderos con respecto a los árboles de sus terrenos inciden en la disponibilidad y mantenimiento de los servicios ecosistémicos.

Conocimiento tradicional de los árboles

Los principales trabajos sobre usos tradicionales de los árboles se han realizado con grupos indígenas (Toledo *et al.*, 1995), incluyendo los mayas (Rico *et al.,* 1991), los mixtecos (Casas *et al.*, 1994) y los lacandones (Levy *et al.*, 2002). Sin embargo existe poca información sobre el uso de los árboles por poblaciones mestizas - 90% de la población rural en México (Inegi, 2010) –, y muchos menos trabajos sobre el conocimiento de los ganaderos en zonas tropicales (Muñoz, 2006). Además, actualmente hay una grave pérdida del conocimiento sobre usos tradicionales de los árboles (Reyes, 2009; González *et al.*, 2012b). Las nuevas generaciones están cada vez menos interesadas en el campo y en general tienen poco sentido de apropiación de los recursos (Marín, 2013).

Objetivos

Los objetivos de este trabajo fueron investigar cuáles especies arbóreas conocen los ganaderos, los usos que les dan, su importancia cultural y los cambios que han ocurrido en la zona a lo largo del tiempo. Se espera que los resultados de este trabajo sirvan como base para rescatar y rediseñar mejores prácticas de manejo en las zonas ganaderas, que promuevan una mayor conservación y uso de los árboles para preservar sus servicios ecosistémicos.

Materiales y métodos

Sitio de estudio

El estudio se llevó a cabo en las localidades rurales de La Matamba, El Piñonal y El Yagual en el municipio de Jamapa, Veracruz, México (Fig. 1). No obstante, se considera como una sola área de estudio debido a la cercanía entre comunidades y porque todas están ubicadas en los alrededores de los últimos restos de vegetación de humedales (selva inundable) y bosque tropical caducifolio de la zona. Este lugar ha sido habitado desde tiempos prehispá-

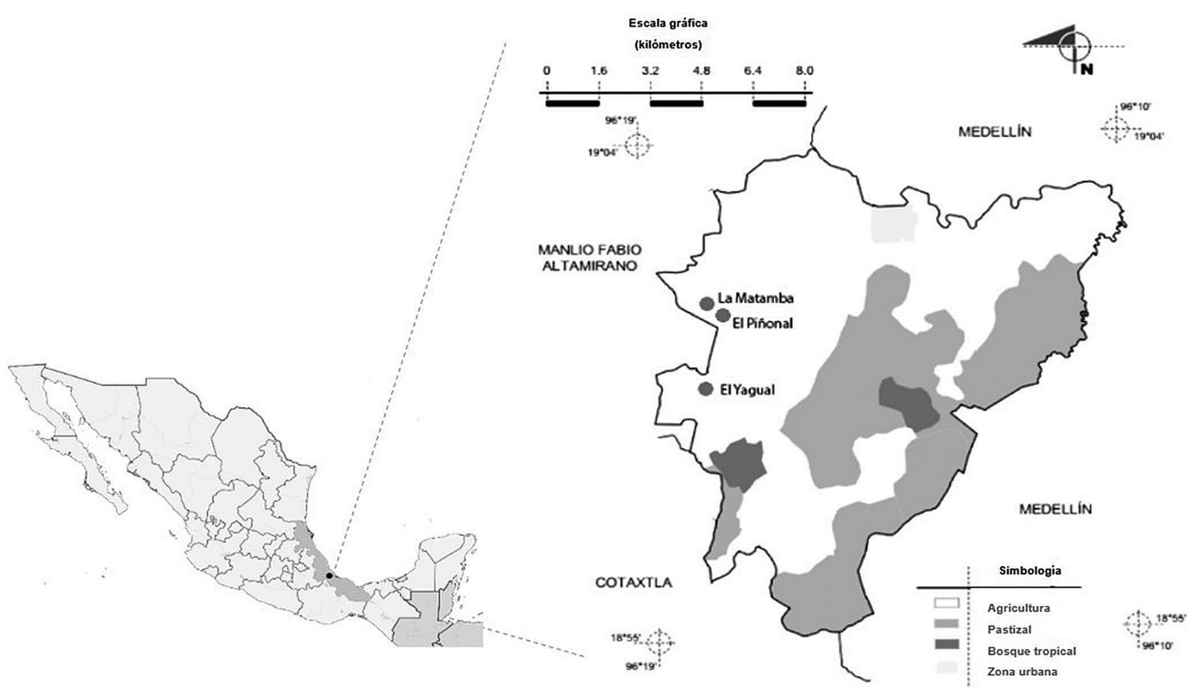

Figura 1. Ubicación, uso de suelo y vegetación del municipio de Jamapa, Veracruz, México, así como localización de las comunidades de El Piñonal, La Matamba y el Yagual (Inegi, 2009).

nicos (Moreno-Casasola e Infante, 2009) aunque actualmente es una población mestiza; el uso tradicional de recursos prevalece hasta la actualidad pero corre el riesgo de desaparecer (González *et al.*, 2012a y 2012b). El territorio del municipio está dedicado en 1% a zona urbana, 4% es bosque tropical (mayormente perturbado) y 95% a actividades agrícolas (i.e. cultivo de maíz y mango) y ganaderas; aunque solo 19% de la población económicamente activa se dedica a estas actividades (Sefiplan, 2013). El clima es cálido subhúmedo con lluvias en verano, con precipitación entre 1100 mm y 1300 mm anuales, temperatura media entre 24 °C y 26 °C y altitud entre 10 m y 40 m snm (Sefiplan, 2013).

Selección de informantes y entrevistas

Se buscaron informantes dueños de terrenos ganaderos por el método de "bola de nieve", donde una persona sugiere a otra por su conocimiento y experiencia sobre el tema (Davis *et al.*, 2010). El tamaño de la muestra se determinó por punto de redundancia y saturación de la información (Letts *et al.*, 2007). Se llevaron a cabo entrevistas semiestructuradas (Anexo 1), habiéndose clasificado todas las respuestas (Tarrés, 2004). La información se complementó con talleres y visitas a los predios, que permitieron corroborar los resultados y enriquecer la discusión del trabajo como parte del enfoque de investigación participante (Tarrés, 2004).

Colectas botánicas

Se colectó una muestra de cada especie de árbol que los informantes mencionaron, se identificó y se depositó en el Herbario del Instituto de Ecología, A.C. (XAL). Los tipos de vegetación a los que pertenece cada especie fueron consultados en la bibliografía y en el herbario XAL, posteriormente se homologaron de acuerdo con la propuesta de Rzedowski (2006). Los nombres científicos y familias botánicas se verificaron en la base de datos Tropicos (http://www.tropicos.org/), que sigue el Grupo para la Filogenia de las Angiospermas (APG *Angiosperm Phylogeny Group*).

Índice de Importancia Cultural

Se calculó el Índice de Importancia Cultural (IIC) de cada especie z (IIC_z) de Turner (1988) con las modificaciones propuestas por Ávila *et al.* (2011) y simplificado como sigue:

$$ICC_z = \frac{iu_z + fm_z + vut_z}{3} \quad (1)$$

En donde la intensidad de uso de la especie z (iu_z) se calcula con la ecuación (2), la frecuencia de mención de la especie z (fmz) con la ecuación (3), el valor de la especie z para el uso α ($vu_{z\alpha}$) con la ecuación (4) y el valor total de uso para la especie z (vut_z) con la ecuación (5).

$$iu_z = \frac{\text{Núm. de usos de la sp. z}}{\text{Núm. total de usos para todas las spp.}} \quad (2)$$

$$fm_z = \frac{\text{Núm. de menciones de la sp. z para todos los usos}}{\text{Núm. total de menciones para todas las spp. para todos los usos}} \quad (3)$$

$$vu_{z\alpha} = \frac{\text{Núm. total de menciones de la sp. z para el uso } \alpha}{\text{Núm. total de menciones para todas las spp. para el uso } \alpha} \quad (4)$$

$$vut_z = \Sigma_{\alpha=1}^{n} vu_{z\alpha} \quad (5)$$

Este índice cuantifica objetivamente la importancia de cada especie asignada por el grupo de informantes, considerando su intensidad, frecuencia y valor de uso asociados a su reconocimiento, reputación y marcaje léxico (i.e. qué tanto la gente se acuerda del nombre de la especie) a través de las menciones y los usos.

Resultados

Se entrevistaron 19 personas dueñas de terrenos ganaderos: cinco mujeres y 14 hombres, de los cuales 10,5% tenían menos de 40 años, 58% entre 41 y 60 años y 31,5% entre 61 y 80 años. Todos se dedican a la agricultura y/o ganadería y algunos además realizan otros trabajos. Los entrevistados han tenido sus terrenos en la zona durante toda su vida, con excepción de una persona que adquirió el terreno hace menos de 10 años. Once por ciento informó que su terreno se desmontó hace menos de 10 años, 37% entre hace 20 y 40 años, 16% entre 50 y 80 años, 16% hace 100 años, 21% no supo responder. Todos los informantes mencionaron que su terreno se inunda en alguna época del año.

Se mencionaron 97 especies de plantas, de las cuales se excluyeron 21 por ser herbáceas y ocho por no poder identificarse al carecer de flores y frutos. Las 68 especies restantes (70% del total) –incluyendo palmas- fueron identificadas con sus usos, las partes del árbol que se utilizan, el tipo de vegetación donde se encuentran y su valor cultural (Tabla 1).

Las familias mejor representadas fueron Fabaceae (13 especies), Moraceae (8 especies) y Malvaceae (5 especies). La tabla 2 muestra las 20 especies mencionadas por más informantes, las especies con mayor número de usos, las especies de las que se utiliza un mayor número de partes y las especies con valor cultural más alto. *Gliricidia sepium* y *Maclura tinctoria* aparecen entre los primeros cinco lugares de todas las categorías.

Tabla 1. Especies de árboles mencionadas y sus usos.

Familia/Nombre científico	*Nombre común*	*No. de menciones*	*Usos*	*IIC*	*Partes utilizadas*	*Tipo de vegetación*	*Referencias*
ANACARDIACEAE							
Mangifera indica L.	mango	6	A, E, F, J, L, M, N	0.31	tronco, ramas, fruto	bq, btc, btp, cult, pz	4, 12
Spondias mombin L.	jobo	2	F, I, L	0.07	todo, fruto	btc, btp, va, vs	4, 10
Spondias purpurea L.	ciruelo, ciruelo rojo	3	F, I	0.05	fruto	bq, btc, btp, cult, va	4
ANNONACEAE							
Annona muricata L.	guanábano	2	F	0.03	fruto	btc, btp, bts, cult	4
Annona purpurea Moc. & Sessé ex Dunal	ilama, ilana	3	F	0.03	fruto	bq, btc, btp, vs	4, 6
Annona reticulata L.	anono	2	A, F, J, M	0.13	ramas, hojas, fruto	bq, btc, btp, bts, cult, va, vs	4, 12
APOCYNACEAE							
Tabernaemontana alba Mill.	lecherillo	2	B, H, N	0.08	tronco, ramas	btc, bts, vs	2
ARECAEAE							
Acrocomia aculeata (Jacq.) Lodd. ex Mart.	palma de coyol redondo	1	F	0.02	semilla	btc, bts, du, pl, pz	3, 13
Attalea butyracea (Mutis ex L. f.) Wess.Boer	palma de coyol real	10	C, D, F, I, J	0.42	tronco, hojas, fruto, semilla	btc, btp, bts, pl, va	3, 10, 13
Roystonea dunlapiana P.H. Allen	palma de yagua	5	C, H	0.07	tronco	pl, va	11, 13
Sabal mexicana Mart.	palma de apachite	7	C, D	0.19	tronco, hojas	bq, du, btp, bts, va	4, 7, 10, 11, 13
BIGNONIACEAE							
Parmentiera aculeata (Kunth) Seem.	cuajilote	1	G	0.06	fruto	bq, btc, btp, bts, pz, va, vs	3, 4

Usos: A-leña; B-utensilios; C-construcción de casas; D–techos de casas; E-muebles; F-comestible; G-medicinal; H-postes o estantes; I-cerca viva; J-forraje para ganado; K-ornamental; L-sombra; M-vida silvestre; N-madera; O-conservación; P-artesanías; Q-ritual; R-cortina rompevientos; S-otros; T-tinta.
Tipo de vegetación: bq-bosque mesófilo/de encinos/de coníferas; btc – bosque tropical caducifolio; btp – bosque tropical perennifolio; bts – bosque tropical subcaducifolio; cult-cultivada; du-dunas; pl-palmar; pz-pastizal; va – vegetación acuática (incluye selva inundable/ripario/manglares/esteros); vs-vegetación secundaria.
Referencias para el tipo de vegetación: 1-Avendaño, 1998, 2-Castillo y Medina, 2005, 3-Castillo y Travieso, 2006, 4-Herbario XAL, 5-Ibarra *et al.*, 2012, 6-Lascurain *et al.*, 2010, 7-Moreno-Casasola e Infante, 2009, 8-Nash y Moreno, 1981, 9-Niembro *et al.*, 2010, 10-Pennington y Sarukhán, 2005, 11-Quero, 1994, 12-UNAM, 2009, 13-González *et al.* 2012a.

Tabla 1. Especies de árboles mencionadas y sus usos. (Continuación...)

Familia/Nombre científico	*Nombre común*	*No. de menciones*	*Usos*	*IIC*	*Partes utilizadas*	*Tipo de vegetación*	*Referencias*
Roseodendron donnell-smithii (Rose) Miranda	primavera	1	I	0.02	todo	btc, bts	10
Tabebuia rosea (Bertol.) DC.	roble	9	A, B, C, E, H, I, L, N	0.46	todo, tronco, ramas	btc, btp, bts, du, pz, va, vs	3, 4
BORAGINACEAE							
Cordia cf. diversifolia Pav. ex DC.	tepozán	1	G	0.03	hojas	btc, bts	3
Cordia collococca L.	nopo	3	C, I	0.06	tronco	bq, btp, bts, va	8
Cordia dodecandra DC.	cópite	7	B, C, F, I, J, M, N	0.28	todo, tronco, ramas, hojas, fruto	btc, cult, vs	4, 10
Ehretia tinifolia L.	frutillo, rayado	4	A, L, M, O, S	0.53	todo	bq, btc, btp, bts, vs	4, 8, 9
BURSERACEAE							
Bursera simaruba (L.) Sarg.	mulato, palo mulato	10	G, I, L, M	0.18	tronco, ramas, hojas, corteza	bq, btc, btp, bts, du, pz, va, vs	3, 4, 10
CASUARINACEAE							
Casuarina equisetifolia L.	pino	1	R	0.18	todo	bq, btc, btp, cult, du, va, vs	4
COMBRETACEAE							
Terminalia catappa L.	almendro	1	F, L	0.04	todo, semilla	cult	-
EBENACEAE							
Diospyros nigra (J.F. Gmel.) Perr.	zapote negro, zapote prieto	6	F	0.04	fruto	bq, btc, btp, bts, cult, va	6, 10
FABACEAE							
Acacia cochliacantha Humb. & Bonpl. ex Willd.	huizache	6	A, C, H, I, J	0.25	tronco, ramas, fruto	bq, btc, bts, dun, pz, va, vs	4
Caesalpinia cacalaco Bonpl.	tihuil	7	A, H, I, N	0.12	todo, tronco, ramas	btc	9
Cassia fistula L.	lluvia de oro	1	K, L	0.37	todo	btc, bts, cult, vs.	4
Diphysa robinioides Benth.	amarillo, quebrache	7	B, H, I, L, N, T	0.35	todo, tronco, ramas, corazón	btc, btp, bts, du, va, vs	4, 10
Enterolobium cyclocarpum (Jacq.) Griseb.	nacaxtle, nacastle, nacaste	4	A, E, F, L, N	0.14	tronco, ramas, fruto	bq, btc, btp, bts, du, pz, va, vs	3, 4, 10
Gliricidia sepium (Jacq.) Kunth ex Walp.	cocuite	12	A, B, C, F, H, I, J, L, N, S	0.79	todo, tronco, ramas, flor, hojas, brotes	bq, btc, btp, bts, du, pz, va, vs	4, 10
Haematoxylum campechianum L.	tinto	2	B, C, H, I, T	0.24	tronco, ramas, corazón	btc, btp, pz, va, vs	4
Inga sp.	chalahuite	1	G	0.03	corteza	-	-
Leucaena leucocephala (Lam.) de Wit	guaje	2	F, G	0.05	corteza, fruto	bq, btc, btp, bts, du, va	4
Lonchocarpus sp.	marinero	5	A, C, L	0.12	todo, ramas	-	-

Tabla 1. Especies de árboles mencionadas y sus usos. (Continuación...)

Familia/Nombre científico	Nombre común	No. de menciones	Usos	IIC	Partes utilizadas	Tipo de vegetación	Referencias
Piscidia piscipula (L.) Sarg.	abí	1	C, N	0.06	tronco	bq, btc, btp, bts, vs	4, 10
Pterocarpus officinalis Jacq.	sangregado	4	G	0.07	corteza	btp, bts	4
Tamarindus indica L.	tamarindo	2	F, L	0.06	todo, fruto	bq, btc, btp, du, cult, va, vs	4
LAMIACEAE							
Gmelina arborea Roxb. ex Sm.	melina	3	N	0.03	tronco	btp, bts, cult, vs	4
LAURACEAE							
Persea americana Mill.	aguacate	1	F	0.02	fruto	bq, btc, btp, cult, vs	4, 10
MALPIGHIACEAE							
Byrsonima crassifolia (L.) Kunth	nanche	2	F	0.04	fruto	bq, btc, btp, cult, du, va, vs	4
MALVACEAE							
Ceiba aesculifolia (Kunth) Britten & Baker f.	pochota	1	B	0.03	semilla	btc, btp, pz	4
Ceiba pentandra (L.) Gaertn.	ceiba	6	B, J, L, M	0.18	todo, semilla, flores	btc, btp, bts, du, pz, va, vs	1, 4, 10
Guazuma ulmifolia Lam.	guázamo, guázimo, taparrabo	6	A, B, G, H, I, J	0.24	todo, tronco, ramas, hojas, corteza, fruto	bq, btc, btp, bts, cult, du, pz, va, vs	4, 10
Luehea candida (DC.) Mart.	algodoncillo	1	A, B, C, N	0.00	tronco, ramas	bq, btc, btp, va, vs	4, 9
Pachira aquatica Aubl.	apompo	14	B, G, H, I, L, N, O	0.57	todo, tronco, ramas, fruto	btc, btp, du, pz, va	1, 4, 6, 10
MELIACEAE							
Azadirachta indica A. Juss.	neem, nim, nin	1	S	0.36	hojas	cult	-
Cedrela odorata L.	cedro	10	E, I, N, P, Q	0.82	todo, tronco, ramas	bq, btc, btp, bts, cult, pz, va, vs	3, 4
Swietenia macrophylla King	caoba	1	N	0.02	tronco	btc, btp, bts, pz, va, vs	4, 9
MORACEAE							
Castilla elastica Sessé	hule	1	B, I	0.06	todo, látex	bq, btc, btp, bts, va, vs	4, 10
Ficus aurea Nutt.	higuera blanca, negra, colorada	9	A, B, J, L, M, N	0.29	todo, tronco, ramas, fruto, raíz, aserrín	bq, btc, btp, bts, du, va, vs	4, 5
Ficus cotinifolia Kunth	higuera prieta	2	L, M, Q	0.25	todo, fruto	bq, btc, btp, bts, du, pl, va	3, 4, 5

Usos: A-leña; B-utensilios; C-construcción de casas; D–techos de casas; E-muebles; F-comestible; G-medicinal; H-postes o estantes; I-cerca viva; J-forraje para ganado; K-ornamental; L-sombra; M-vida silvestre; N-madera; O-conservación; P-artesanías; Q-ritual; R-cortina rompevientos; S-otros; T-tinta.
Tipo de vegetación: bq-bosque mesófilo/de encinos/de coníferas; btc – bosque tropical caducifolio; btp – bosque tropical perennifolio; bts – bosque tropical subcaducifolio; cult-cultivada; du-dunas; pl-palmar; pz-pastizal; va – vegetación acuática (incluye selva inundable/ripario/manglares/esteros); vs-vegetación secundaria.
Referencias para el tipo de vegetación: 1-Avendaño, 1998, 2-Castillo y Medina, 2005, 3-Castillo y Travieso, 2006, 4-Herbario XAL, 5-Ibarra *et al.*, 2012, 6-Lascurain *et al.*, 2010, 7-Moreno-Casasola e Infante, 2009, 8-Nash y Moreno, 1981, 9-Niembro *et al.*, 2010, 10-Pennington y Sarukhán, 2005, 11-Quero, 1994, 12-UNAM, 2009, 13-González *et al.* 2012a.

Tabla 1. Especies de árboles mencionadas y sus usos. (Continuación...)

Familia/Nombre científico	*Nombre común*	*No. de menciones*	*Usos*	*IIC*	*Partes utilizadas*	*Tipo de vegetación*	*Referencias*
Ficus crocata (Miq.) Miq.	higuera negra, higuera de tendón	7	A, L, M	0.13	todo, tronco, ramas, raíz	bq, btc, btp, bts, du, pz, va, vs	4, 5
Ficus obtusifolia Kunth	hule	2	B	0.03	látex	bq, btc, btp, bts, du, pl, va, vs	2
Ficus sp.	higuera	3	O	0.10	todo		
Ficus yoponensis Desv.	higuera blanca	1	J, R	0.21	todo, fruto	bq, btp, bts, pz, va, vs	4. 5
Maclura tinctoria (L.) D. Don ex Steud.	moral, mora	10	A, B, C, F, H, I, J, L, M, T	0.47	todo, tronco, ramas, fruto, corazón	bq, btc, btp, bts, du, pz, va, vs	3, 4, 10
MUNTINGIACEAE							
Muntingia calabura L.	capulín, nigüilla	1	F	0.02	fruto	bq, btc, btp, bts, cult, du, pz, va, vs	4
MYRTACEAE							
Psidium guajava L.	guayaba	2	F, G	0.05	hojas, fruto	bq, btc, btp, bts, cult, du, pz, va, vs	3, 4, 6, 10
POLYGONACEAE							
Coccoloba barbadensis Jacq.	uvero	1	I	0.02	todo	bq, btc, btp, bts, du, pl, pz, va, vs	3, 4, 10
PRIMULACEAE							
Ardisia sp.	capulín	1	F	0.02	fruto	-	-
RUBIACEAE							
Genipa americana L.	yual	3	F	0.03	fruto	bq, btc, btp, bts, cult, pz, va, vs	3, 4
Randia sp.	crucetillo	2	G, M	0.08	fruto	-	-
RUTACEAE							
Citrus limon (L.) Osbeck	limón	1	F	0.02	fruto	cult	-
Citrus sinensis (L.) Osbeck	naranjo	2	F	0.03	fruto, hojas	cult	-
SALICACEAE							
Pleuranthodendron lindenii (Turcz.) Sleumer	catarrito	1	A	0.03	tronco, ramas	bq, btc, btp, bts, va, vs	3, 4, 10
Salix humboldtiana Willd.	sauce	7	B, E, H, L, N, O	0.26	todo, tronco, ramas, hojas	bq, btc, btp, bts, pz, va, vs	4, 7, 10
Zuelania guidonia (Sw.) Britton & Millsp.	palo volador, volador	2	C, H	0.08	tronco	bq, btc, btp, pz, va, vs	4
SAPINDACEAE							
Melicoccus oliviformis Kunth	guaya	1	F	0.02	fruto	btc, btp	6
SAPOTACEAE							
Manilkara zapota (L.) P. Royen	zapote chico, chico-zapote	2	F, L, M	0.09	fruto, látex	btc, btp, bts, cult, du, pz, va, vs	4, 9

Tabla 1. Especies de árboles mencionadas y sus usos. (Final).

Familia/Nombre científico	*Nombre común*	*No. de menciones*	*Usos*	*IIC*	*Partes utilizadas*	*Tipo de vegetación*	*Referencias*
URTICACEAE							
Cecropia obtusifolia Bertol.	chancarro, guarumo	3	G	0.06	hojas	bq, btc, btp, va, vs	4, 10

Usos: A-leña; B-utensilios; C-construcción de casas; D–techos de casas; E-muebles; F-comestible; G-medicinal; H-postes o estantes; I-cerca viva; J-forraje para ganado; K-ornamental; L-sombra; M-vida silvestre; N-madera; O-conservación; P-artesanías; Q-ritual; R-cortina rompevientos; S-otros; T-tinta.
Tipo de vegetación: bq-bosque mesófilo/de encinos/de coníferas; btc – bosque tropical caducifolio; btp – bosque tropical perennifolio; bts – bosque tropical subcaducifolio; cult-cultivada; du-dunas; pl-palmar; pz-pastizal; va – vegetación acuática (incluye selva inundable/ripario/manglares/esteros); vs-vegetación secundaria.
Referencias para el tipo de vegetación: 1-Avendaño, 1998, 2-Castillo y Medina, 2005, 3-Castillo y Travieso, 2006, 4-Herbario XAL, 5-Ibarra *et al.*, 2012, 6-Lascurain *et al.*, 2010, 7-Moreno-Casasola e Infante, 2009, 8-Nash y Moreno, 1981, 9-Niembro *et al.*, 2010, 10-Pennington y Sarukhán, 2005, 11-Quero, 1994, 12-UNAM, 2009, 13-González *et al.* 2012a.

Las especies pueden pertenecer a más de un tipo de vegetación. Sesenta y tres porciento de todas las especies ocurren en el bosque tropical subcaducifolio, 54% en el bosque tropical caducifolio y 40% en el bosque tropical perennifolio; 62% en zonas inundables; 60% como vegetación secundaria y 32% son cultivadas. Las especies que ocurren en más tipos de vegetación son *Bursera simaruba, Coccoloba barbadensis, Enterolobium cyclocarpum, Guazuma ulmifolia, Maclura tinctoria, Manilkara zapota, Muntingia calabura* y *Psidium guajava*. Muchas de estas especies también son comunes en vegetación secundaria o acahuales.

Se identificaron 22 usos distintos de los árboles, que fueron clasificados en tres grupos: uso maderable, uso extractivo y uso no extractivo. Los usos maderables requieren el tronco entero, lo que provoca que se elimine completamente el árbol; los usos extractivos usan alguna parte del árbol permitiendo que se regenere y los usos no extractivos son los beneficios que se obtienen del árbol completo y vivo, lo que le permite seguir su desarrollo natural. La tabla 3 muestra los tipos de uso y el número de especies registradas para cada uno. Los usos con una mayor diversidad de especies son el comestible (26 especies), sombra (20 especies), cerca viva (19 especies) y madera (16 especies); mientras que para los usos como artesanías, insecticida y ornamental se mencionó solo una especie para cada uno. Del total de usos, los maderables representan 18%, los extractivos 46% y los no extractivos 36%.

Usos maderables

Las especies con más usos de la categoría maderable y más mencionadas fueron *Tabebuia rosea*, *Cedrela odorata*, *Diphysa robinioides* y *Mangifera indica*. La tabla 4 muestra los usos y las características de algunas especies maderables. Para la construcción de muebles se requieren maderas finas y fuertes como las de *Cedrela odorata* y *Tabebuia rosea*. Los árboles con fustes largos y derechos como *Zuelania guidonia* casi han desaparecido por completo. La producción de tinturas está en esta clasificación puesto que se utiliza el duramen de los árboles, es decir requiere troncos maduros, por ejemplo de *Diphysa robinioides, Haematoxylum campechianum* y *Maclura tinctoria*. Aunque en las comunidades no les dan este uso, los informantes lo refirieron.

Usos extractivos

Las especies más conocidas por el mayor número de usos extractivos y que fueron más mencionadas son *Gliricidia sepium*, *Maclura tinctoria*, *Guazuma ulmifolia* y *Pachira aquatica*. Para elaboración de artesanías se refirieron únicamente a las semillas de *Cedrela odorata*; sin embargo se observó que un grupo de artesanas de La Matamba elaboraba productos con semillas de *Cocos nucifera* y *Acrocomia aculeata*. Para el uso comestible se aprovechan los frutos (mesocarpo) de todas las especies citadas excepto de *Gliricidia sepium*, de la que se come la flor, y de las palmas *Acrocomia aculeata* y *Attalea butyracea*, de las que se come el endospermo de la semilla. Para el uso como

Tabla 2. Las veinte especies arbóreas con más menciones, usos, partes utilizadas e importancia cultural.

Lugar	*Especies con más menciones*	*No. de menciones*	*Especies con más usos*	*No. de usos*	*Especies con más partes utilizadas*	*No. de partes*	*Especies con IIC más alto*	*IIC*
1°	*Pachira aquatica*	14	*Gliricidia sepium*	11	*Gliricidia sepium*	6	*Cedrela odorata*	0.82
2°	*Gliricidia sepium*	12	*Maclura tinctoria*	10	*Ficus aurea*	6	*Gliricidia sepium*	0.79
3°	*Maclura tinctoria*	10	*Tabebuia rosea*	8	*Guazuma ulmifolia*	6	*Pachira aquatica*	0.57
4°	*Cedrela odorata*	10	*Pachira aquatica*	7	*Maclura tinctoria*	5	*Ehretia tinifolia*	0.53
5°	*Attalea butyracea*	10	*Cordia dodecandra*	7	*Cordia dodecandra*	5	*Maclura tinctoria*	0.47
6°	*Bursera simaruba*	10	*Mangifera indica*	7	*Pachira aquatica*	4	*Tabebuia rosea*	0.46
7°	*Tabebuia rosea*	9	*Ficus aurea*	6	*Diphysa robinioides*	4	*Attalea butyracea*	0.42
8°	*Ficus aurea*	9	*Diphysa robinioides*	6	*Salix humboldtiana*	4	*Cassia fistula*	0.37
9°	*Cordia dodecandra*	7	*Salix humboldtiana*	6	*Attalea butyracea*	4	*Azadirachta indica*	0.36
10°	*Diphysa robinioides*	7	*Guazuma ulmifolia*	6	*Bursera simaruba*	4	*Diphysa robinioides*	0.35
11°	*Salix humboldtiana*	7	*Cedrela odorata*	5	*Ficus crocata*	4	*Mangifera indica*	0.31
12°	*Caesalpinia cacalaco*	7	*Attalea butyracea*	5	*Tabebuia rosea*	3	*Ficus aurea*	0.29
13°	*Ficus crocata*	7	*Acacia cochliacantha*	5	*Mangifera indica*	3	*Cordia dodecandra*	0.28
14°	*Sabal mexicana*	7	*Ceiba pentandra*	5	*Cedrela odorata*	3	*Salix humboldtiana*	0.26
15°	*Mangifera indica*	6	*Enterolobium cyclocarpum*	5	*Acacia cochliacantha*	3	*Acacia cochliacantha*	0.25
16°	*Guazuma ulmifolia*	6	*Haematoxylum campechianum*	5	*Ceiba pentandra*	3	*Ficus cotinifolia*	0.25
17°	*Acacia cochliacantha*	6	*Bursera simaruba*	4	*Enterolobium cyclo-carpum*	3	*Haematoxylum campechianum*	0.24
18°	*Ceiba pentandra*	6	*Caesalpinia cacalaco*	4	*Haematoxylum campechianum*	3	*Guazuma ulmifolia*	0.24
19°	*Diospyros nigra*	6	*Ehretia tinifolia*	4	*Caesalpinia cacalaco*	3	*Ficus yoponensis*	0.21
20°	*Roystonea dunlapiana*	5	*Annona reticulata*	4	*Annona reticulata*	3	*Sabal mexicana*	0.19

Tabla 3. Tipos de usos de los árboles y número de especies por cada uno.

Maderables	*Extractivos*	*No extractivos*
construcción de casas (13)	artesanías (1)	cerca viva (19)
madera (16)	comestible (26)	conservación de agua (4)
muebles (5)	forraje (12)	cortina rompevientos (2)
tinturas (3)	insecticida (1)	ornamental (1)
	leña (14)	refugio de vida silvestre (12)
	maduración de mangos (1)	ritual (2)
	medicinal (11)	sombra (20)
	postes (13)	tutor (1)
	techos (2)	
	utensilios (15)	

Tabla 4. Especies usadas para madera y construcción de casas, su uso y/o características.

Especie	*Uso y/o características de la madera*
Acacia cochliacantha	horquetas para enramadas*
Attalea butyracea	vigas y alfardas*
Enterolobium cyclocarpum	resistente a la intemperie, tiene una sustancia que irrita los ojos al trabajarla
Diphysa robinioides	madera muy dura
Sabal mexicana	vigas y alfardas*
Salix humboldtiana	madera suave para albañilería porque es fácil de clavar
Tabebuia rosea	varengas*
Tabernaemontana alba	madera suave
Zuelania guidonia	fustes derechos y largos, ideal para vigas*

* en la construcción de casas: las vigas son los troncos que soportan la mayor carga de la casa, las alfardas se colocan en los techos para sostener las hojas de palma, las varengas se usan para hacer corrales de madera, las horquetas son las ramas que tienen forma de Y, las las enramadas son las construcciones ligeras y temporales que se ponen para dar sombra.

Tabla 5. Características de la leña de algunas especies usadas en la zona de estudio.

Especie	*Características de la leña*
Acacia cochliacantha	muy buena para hacer pan
Ficus aurea	buena para horno de ladrillos
Gliricidia sepium	no echa humo
Guazuma ulmifolia	puede arder en verde
Maclura tinctoria	echa chispas y truena
Mangifera indica	mala para cocinar pues no deja brasa, buena para horno de ladrillos

Tabla 6. Especies de árboles medicinales, los padecimientos que tratan y las partes que se utilizan.

Especie	*Padecimiento (parte utilizada)*
Bursera simaruba	sarampión, rubeola (hojas)
Cecropia obtusifolia	diabetes, dolor de huesos, reumatismo (hojas)
Cordia cf. diversifolia	dolor de rodillas (hojas)
Guazuma ulmifolia	roña (corteza)
Pachira aquatica	diabetes (fruto)
Parmentiera aculeata	problemas de riñón (fruto)
Psidium guajava	diarrea (hojas)
Pterocarpus officinalis	diabetes, anemia (corteza)
Randia sp.	picaduras de víbora (fruto)

forraje para diferentes tipos de ganado, se aprovechan los frutos de *Acacia cochliacantha*, *Annona reticulata, Attalea butyracea, Cordia dodecandra, Ficus aurea, Ficus yoponensis, Guazuma ulmifolia, Maclura tinctoria, Mangifera indica, Parmentiera aculeata*; las hojas de *Gliricidia sepium* y *Guazuma ulmifolia*; y las flores de *Ceiba pentandra*. El uso como leña, principalmente para cocinar, se señaló como casi obvio, especialmente de aquellos árboles que no proveen otros beneficios; no obstante subrayaron las características de algunos de ellos (Tabla 5). Otro uso se da con las hojas de *Gliricidia sepium* cuando se mezclan con la fruta de mango (*Mangifera indica*) para acelerar su maduración. Para el uso medicinal las especies más señaladas fueron *Pachira aquatica*, *Pterocarpus officinalis* y *Cecropia obtusifolia*. La tabla 6 muestra las especies para las que se indicó la parte utilizada y el padecimiento para el cual se aplica.

Para postes se utilizan 13 especies, de las que sobresalen *Maclura tinctoria* por su durabilidad y *Gliricidia sepium* y *Diphysa robinioides* por ser buenas madrinas -postes más fuertes situados en las esquinas y donde se tensa el alambre. Para conservar la frescura de las casas tradicionales –escasas hoy día– suelen fabricar techos de hojas de palmas de *Attalea butyracea* (también registrada en la literatura como *A. liebmannii)* y de *Sabal mexicana*. Los utensilios más comunes son cabos para azadones o hachas. La tabla 7 muestra otros utensilios derivados de los árboles y las partes de las que se obtienen. La pólvora no se utiliza propiamente en la comunidad pero los informantes conocen ese uso porque les han comprado árboles para su extracción.

Tabla 7. Ejemplos de utensilios que se obtienen de diferentes partes de los árboles y los materiales que los han ido sustituyendo.

Especie	Utensilios (parte utilizada)	Sustituto actual
Castilla elastica, Ficus obtusifolia	pelotas (látex)	juguetes de plástico
Ceiba aesculifolia, Ceiba pentandra	relleno de almohadas (vilano de las semillas)	relleno sintético de almohadas
Cordia dodecandra	fibra para lavar loza (hojas)	fibra de plástico
Ficus aurea	bateas (raíz), columpios (raíz)	lavadoras, cuerdas de diversos materiales
Ficus obtusifolia	mangas de hule (látex)	mangas de plástico
Gliricidia sepium	horquetas para detener trojas –manojos- de ajonjolí (ramas bifurcadas y jóvenes)	-
Guazuma ulmifolia	palos de escoba, cortineros (ramas derechas y jóvenes)	madera de pino de bajo costo
Manilkara zapota	chicle natural (látex)	chicle artificial
Pachira aquatica	yugos de yunta (raíz, tronco)	ya casi no se usa yunta, más tractor
Salix humboldtiana	escobas (ramas con hojas)	escobas de plástico

Usos no extractivos

A los árboles también se les reconocen propiedades que permiten aprovecharlos y beneficiarse de ellos por su sola presencia. Las especies con más usos de este tipo y más mencionadas fueron *Ehretia tinifolia*, *Pachira aquatica*, *Bursera simaruba*, *Maclura tinctoria* y *Ficus cotinifolia*. Como cercas vivas se refirieron principalmente *Gliricidia sepium*, *Bursera simaruba* y *Cordia dodecandra*. Para la conservación del agua emplean *Ehretia tinifolia*, *Ficus* spp., *Pachira aquatica* y *Salix humboldtiana*. Como cortina rompevientos usan *Casuarina equisetifolia* y *Ficus yoponensis*. Como ornamental está *Cassia fistula* –especie exótica- por sus vistosas flores amarillas. Como refugio de vida silvestre se nombraron especies que proveen frutos carnosos y numerosos como *Annona reticulata, Ficus* spp., *Maclura tinctoria* y *Manilkara zapota*; árboles con oquedades en su estructura como *Ehretia tinifolia* y *Ficus* spp., y de troncos muy altos como *Ceiba pentandra*. Para uso ritual *Ficus cotinifolia* sirvió para rezar bajo su copa para pedir por lluvias cuando hubo un tiempo prolongado de sequía y *Cedrela odorata* es considerado como árbol sagrado porque se dice que detrás de este árbol se escondió la virgen con el niño Jesús. Como especies para sombra más utilizadas están *Pachira aquatica*, *Ficus aurea*, *Gliricidia sepium*, *Mangifera indica* y *Tabebuia rosea*. Finalmente, el uso como tutor -el tronco sirve para dar sombra y crear las condiciones ambientales para soportar otras plantas de interés- señalaron a *Ehretia tinifolia* como tutor de *Hylocereus undatus* (pitaya – fruta comestible).

Partes que se utilizan

Gliricidia sepium, Ficus aurea y *Guazuma ulmifolia* son las especies de las que se usan más partes (Tabla 2). Se utiliza todo el tronco de 41% de las especies, lo que representa principalmente usos maderables; el fruto de 46%, la mayoría para uso comestible o medicinal; las ramas de 32%, usualmente para leña y postes; y las hojas de 19%. En menor número de especies se usan las flores, semillas, corteza, brotes, raíz y látex.

Cambios en la comunidad a lo largo del tiempo

Los informantes hablaron de la vida en las comunidades en las décadas de 1950 y 1960 aproximadamente. Los caminos eran de tierra y tardaban ocho horas en burro para llegar al Puerto de Veracruz (ciudad más cercana); hoy día tardan 30 minutos en auto. No tenían acceso a médicos ni medicamentos, vivían en casas de madera con techos de palma y estufas de leña, sobrevivían con lo que sembraban o colectaban en el bosque, cuya extensión era mucho mayor que la actual. El clima era más fresco, había más agua, las familias tenían muchos más miembros, no había acceso a escuelas. En los últimos 50 a 60 años el estilo de vida se ha transformado: hay mejores comunicaciones (i.e. carretera, teléfonos celulares, transporte público), hay acceso a clínicas y escuelas, las familias son más pequeñas, se ocupa menos tiempo en la preparación de comidas, hay entrada constante de otros productos envasados y procesados, hay electricidad, ha habido migración al extranjero o a las ciudades y la vegetación se ha reducido mucho. Estos cambios también trajeron nuevos materiales u objetos que sustituyeron parcial o totalmente a los que tradicionalmente se obtenían de los árboles (Tabla 7).

Discusión

Los resultados de las encuestas y la búsqueda de informantes a través de la bola de nieve, muestran un fuerte sesgo de género entre los informantes; hay menos mujeres dueñas de terrenos que hombres, denotando que la ganadería es un gremio mayoritariamente masculino. No obstante 26% de mujeres informantes en este estudio sobrepasa 6% encontrado por Vilaboa y Díaz (2009), si bien estos autores manejaron una muestra diez veces mayor que la de este estudio. El número de especies registradas en este trabajo (68) es menor a lo encontrado sobre todo en zonas con población indígena (Casas *et al*., 1994; Levy *et al*., 2002; Rico *et al*., 1991) o en trabajos extensos de etnobotánica (Toledo *et al*., 1995), pero similar a lo encontrado por Muñoz (2006), que estudió el conocimiento de árboles que tenían los ganaderos en Costa Rica.

Usos

Se mencionaron muchos más usos que los meramente relacionados con la ganadería (postería, cerca viva, forraje y sombra), mostrando que los beneficios que se obtienen de los árboles no solo son para esta actividad económica sino que abarcan otras necesidades de la vida cotidiana. La categoría de usos maderables representa 18% de los tipos de utilización; no obstante, al utilizar todo el árbol se ponen en detrimento los usos extractivos y no extractivos. Por ejemplo, hay especies de plantas comestibles y medicinales como bejucos y herbáceas que crecen sobre los árboles y que se pierden como consecuencia de la tala. El uso para tinta no es muy habitual en la zona, pero cabe mencionar el caso de Brasil donde la especie *Caesalpinia echinata* fue llevada casi a la extinción para la extracción de tinta en tiempos de la colonización (Bolzani y Barreiro, 2006). Por ello, en especial para los usos maderables, es indispensable la planificación y la resiembra para evitar la desaparición de las especies que conlleva pérdidas irreparables del acervo genético, así como para lograr un manejo más sustentable.

En cuanto a los usos extractivos, el uso comestible fue el más recurrente (*ca*. 38% de las especies). Sin embargo ha cambiado el consumo de frutos silvestres y se ha ido reemplazando por otras frutas cultivadas o que llegan desde otros lugares. Por esta razón posiblemente los árboles ya no son una fuente tan importante de alimento aunque antiguamente sí lo fueron. Por ejemplo, el fruto del coyol (*Attalea butyracea*) era consumido para hacer tortillas y atoles pero este conocimiento y costumbre ya solo queda en las personas mayores (González *et al*., 2012a). Las especies de árboles que actualmente se consumen son usualmente frutales que no pertenecen al bosque nativo como el mango, el aguacate y el tamarindo; o bien, ya solo se consumen algunas variedades que tampoco son nativas del lugar, como el caso de las guayabas que vienen de fuera. En un vivero local de un grupo de mujeres de la comunidad, las plantas más buscadas por la propia comunidad son estos frutales. Por lo tanto, el uso comestible no sería tan preponderante si solo se consideran las especies nativas; los árboles frutales probablemente no requieren medidas de conservación pero los árboles de bosque nativo sí las pueden necesitar. En este sentido, Lascurain *et al.* (2010) proponen recuperar el consumo de frutos nativos como estrategia para aumentar la seguridad alimentaria rural y ayudar a conservar las especies locales. El uso medicinal de los árboles sigue siendo importante en la zona (Escamilla, 2013) y representa 16% de las especies de este estudio. Las tres especies más usadas son para tratamiento de la diabetes (Tabla 6), una enfermedad relativamente reciente en las zonas rurales y que se ha incrementado por el consumo de comida de baja calidad nutricional (Jiménez, 2007), revelando un cambio radical en los hábitos de la población en detrimento de su salud. Para la construcción de techos, las especies usadas se limitan a dos tipos de palmas, coincidiendo con González *et al.* (2012a). El uso de una tercera palma de humedales, *Roystonea dunlapiana,* es más limitado porque es más escasa, crece lentamente, ha sido muy afectada por la disminución de humedales y está protegida legalmente (González *et al.*, 2012a). Asimismo, las palmas se han sustituido por materiales como lámina o cemento, aunque los precios sean mayores y guarden más calor dentro de las casas (González *et al.*, 2012a). El uso para leña en la zona es muy común; en México y otras zonas rurales a nivel mundial la leña aporta 80% de la energía usada en el campo (Abbot *et al.*, 1997, Masera *et al.*, 2006). La identificación de las características de la leña por los informantes de este estudio es similar a los resultados de Abbot *et al.* (1997) en el centro sur de África, quienes también aprecian propiedades como la duración de la brasa.

Dentro de los usos no extractivos de los árboles sorprende que no se haya mencionado la producción de miel. No hubo menciones de que se haya realizado esta actividad en la zona a pesar de que varias especies –e.g. *Bursera simaruba*, *Persea americana*- tienen ese potencial (Montoy, 2010). El uso para sombra, en especial de *Mangifera indica* y *Ficus* spp. coinciden con las sombras consideradas como "buenas" encontradas por Muñoz (2006) en Costa Rica. Ese mismo autor recalca que cuando una sombra es demasiado densa tampoco gusta tanto a los ganaderos pues impide el crecimiento del pasto. Este es uno de los factores limitantes para la adopción de sistemas silvopastoriles, que combinan la producción de ganado con el aprovechamiento sistemático de los árboles (Mahecha, 2003).

Otros usos no extractivos que resultaron de esta investigación tienen que ver con los servicios ecosistémicos (*sensu* Millenium Ecosystem Assessment, 2005): de aprovisionamiento como la conservación del agua; de regulación como el control de la erosión por la protección del viento con las cercas vivas; de soporte de la biodiversidad como el hábitat de fauna silvestre; y culturales como el uso ritual de algunas especies. Esta valorización no material por parte de los informantes puede favorecer la conservación de los árboles (Svorc y Oliveira, 2012).

Importancia cultural

El índice de importancia cultural (IIC) mostró las especies más significativas para este grupo de informantes al momento de la entrevista, es decir, si se preguntara a otros informantes con otros intereses, las especies serían distintas. Asimismo, preguntar a los mismos informantes hace 50 años hubiera dado otro resultado. Esta metodología permitió registrar los árboles más apreciados por los ganaderos de hoy en día, no obstante se encontró que las especies con valor más alto no necesariamente corresponden a las más usadas en la actividad ganadera. Al calcular el IIC, las especies que son únicas para un uso en particular ganan un puntaje muy alto, el valor total de uso (vut_z) se dispara frente a los otros dos parámetros (intensidad de uso y frecuencia de mención) del indicador. Por ejemplo en el caso de *Ehretia tinifolia* –es el único usado como tutor y de los pocos mencionados para la conservación del agua- y en principio se encuentra en los primeros cinco lugares de importancia cultural, pero si no se considera el vut_z, pasa hasta el lugar 16 de la lista. Cuando una especie es la única para un uso, el índice considera que tiene una importancia cultural más alta porque no tiene sustitutos. Es interesante el caso de *Cedrela odorata* que tiene el IIC más alto de todas las especies; aunque no sobresale ni en el número de usos ni en el número de partes que se utilizan (Tabla 2); el resultado del índice logra reflejar que es uno de los árboles favoritos en la comunidad como fue indicado por los informantes.

Vegetación

Los resultados muestran la importancia de las especies de vegetación secundaria, que es similar al estudio de Chazdon y Coe (1999), quienes hallaron que 70% de las especies leñosas muestreadas en su estudio eran de este tipo de vegetación. Ello indica que aunque haya un fuerte problema de perturbación del bosque primario, la vegetación secundaria provee también múltiples beneficios y es de interés para los usuarios locales. La vegetación de humedales, principalmente de selva inundable, es importante en la zona. El trabajo de Infante *et al.* (2014) demuestra la importancia de conservar este tipo de ecosistemas para beneficio de la sociedad local, lo que hace urgente tomar acciones que conserven los humedales funcionales para seguir suministrando servicios ecosistémicos, como aprovisionamiento de agua, contención de inundaciones, entre otros.

Algunas especies exóticas como *Azadirachta indica, Cocos nucifera, Gmelina arborea* y *Casuarina equisetifolia* fueron introducidas en la zona. Algunas de ellas han sido promovidas para aumentar la productividad o dar alternativas económicas a los productores, sin embargo ha faltado mayor atención a posibles consecuencias de la introducción de estas especies como plagas sin enemigos naturales, especies invasoras y desequilibrio en los procesos ecológicos (Vázquez y Batis, 1996). Cabe decir que en la región no se mencionó ningún problema en este sentido. Por otra parte, aunque *Mangifera indica* es una especie exótica, lleva más de 60 años en la región (Escamilla, 2013) y ya es uno de los árboles con mayor número de usos. En contraste, *Azadirachta indica* se introdujo hace pocos años y aunque tiene muchos usos en India, su lugar de origen (Biswas *et al.*, 1995), en la zona solamente se utiliza como insecticida. Esto sugiere que el conocimiento local se va enriqueciendo con la experiencia empírica sobre el uso de los recursos arbóreos, incluso en poblaciones no indígenas.

Cambios a lo largo del tiempo

La información sobre el estilo de vida en las décadas de 1950 y 1960 coincide con las fechas en que el uso de los árboles era más intensivo y se había desmontado 32% de los terrenos de este estudio. Esto podría mostrar que había una mayor cantidad de bosque y se hacía un uso más diverso de los árboles, lo cual presupone un amplio conocimiento sobre los mismos. No obstante, algunos autores han demostrado que la pérdida de árboles no necesariamente motiva a los locales a sembrar más (Kishor y Mitchell, 2004), especialmente si hay sustitutos para su uso (Gordon *et al.*, 2003), como en el caso de este estudio. Moreno-Casasola y Paradowska (2009) encontraron que en los bosques tropicales caducifolios de las dunas, hay especies que la gente reconoce y aprecia, pero no están dispuestos a sembrar aunque ya no haya, debido a que se propagan solos (aunque después no se cuiden las condiciones para favorecer su desarrollo) o no hay seguridad de quién utilizará esos individuos en el futuro.

El mecanismo de búsqueda de informantes por bola de nieve muestra que en la propia zona no se reconoce que la gente más joven (menor de 40 años) se dedique a la actividad ganadera o tenga muchos conocimientos sobre el uso de los árboles. En los resultados se nota que aunque los productores actuales poseen conocimientos sobre el uso de los árboles, ya no lo están utilizando porque ya no lo necesitan (como el caso de *Attalea butyracea*) o porque ya son muy escasos (como el caso de *Zuelania guidonia*). Ante esto, parece probable una pérdida del conocimiento tradicional, pues difícilmente pasará a la siguiente generación (Reyes, 2009; Marín, 2013).

Conclusiones

Los ganaderos entrevistados poseen un amplio conocimiento sobre las especies arbóreas y sus usos. El presente trabajo es una contribución importante para la documentación de este acervo de conocimiento etnobotánico ante su probable pérdida en el futuro próximo. El tipo, el uso, la cantidad y la salud de los árboles son un reflejo del modo de vida de los habitantes de la zona, incluyendo sus necesidades, preferencias e influencias. Si bien el estilo de vida actual tiene beneficios para la población, como mayor comodidad o mayor acceso a información, también tienen repercusiones como nuevas enfermedades, hábitos de alimentación menos saludables y desapropiación de los recursos naturales. La sustitución de materiales naturales por la utilización de plásticos por ejemplo, ha disminuido la presión hacia los árboles pero por otro lado ha aumentado la cantidad de residuos no biodegradables, entre otros efectos secundarios.

La pérdida de la vegetación arbórea y de sus servicios ecosistémicos es un problema complejo que exige la renovación de la actividad ganadera con acciones en favor de la sustentabilidad. El trabajo de incrementar el arbolado en potreros es una vía importante para mantener la conectividad, ayudar a la conservación de la biodiversidad y el germoplasma y mantener tradiciones. Esto se vuelve primordial al considerar la gran extensión de tierra dedicada a la ganadería en Veracruz, así como por el bienestar de las localidades rurales usuarias de estos recursos. La configuración del paisaje depende en gran medida de las decisiones individuales de cada propietario de terrenos, haciendo urgente el trabajo con este gremio para favorecer la conservación de sus recursos. En este sentido, ya existen incentivos de la Sagarpa (Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) que impulsan el mantenimiento de arbolado en los potreros, aunque pocos ganaderos hacen uso de estas posibilidades. Por otro lado se requiere trabajo de educación ambiental e incentivos para la siembra y sobre todo para el cuidado de los árboles sembrados, no solo en plantaciones sino bajo las condiciones actuales de actividad agropecuaria. Algunas acciones son promover un mayor uso de los árboles nativos en los potreros, tanto en sistemas silvopastoriles como en cercas vivas; impulsar plantaciones para producción de leña; resembrar especies nativas para recuperación del acervo genético; valorizar los recursos comestibles silvestres; mantener las zonas riparias forestadas y mantener y manejar los árboles aislados dentro de los potreros. Para evitar la pérdida del conocimiento de usos tradicionales es fundamental involucrar a las generaciones más jóvenes, que próximamente estarán encargadas del manejo de su territorio y los recursos naturales. Asimismo, se puede enriquecer este trabajo en el futuro estudiando más a fondo la abundancia, composición y estado sucesional de las especies de árboles presentes en la actualidad, así como investigar de forma cuantitativa los cambios en la necesidad de uso de materiales derivados de los árboles. En suma, la conservación de los árboles, su conocimiento y los servicios ecosistémicos que proveen requiere una población rural más activa y formada, que conozca sus recursos y tenga más bases de conocimiento para tomar decisiones y para ayudar a moldear las políticas que regulan su territorio (Lazos-Ruíz *et al*., 2013).

Reconocimientos

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Anexo 1. Entrevista semiestructurada utilizada en el municipio de Jamapa.

I. Datos del entrevistado
- Nombre
- Edad
- Comunidad
- Ocupación
- ¿Su terreno se inunda?

II. Árboles
- ¿Qué árboles conoce y utiliza?
- ¿Para qué?
- ¿Qué partes del árbol usa?

III. Cambios en el tiempo
- ¿Hace cuánto tiempo fue desmontado su terreno?
- ¿Cómo era la vida antes?
- ¿Cómo ha cambiado esta comunidad desde que usted se acuerda?
- ¿Los árboles tenían otros usos?

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.

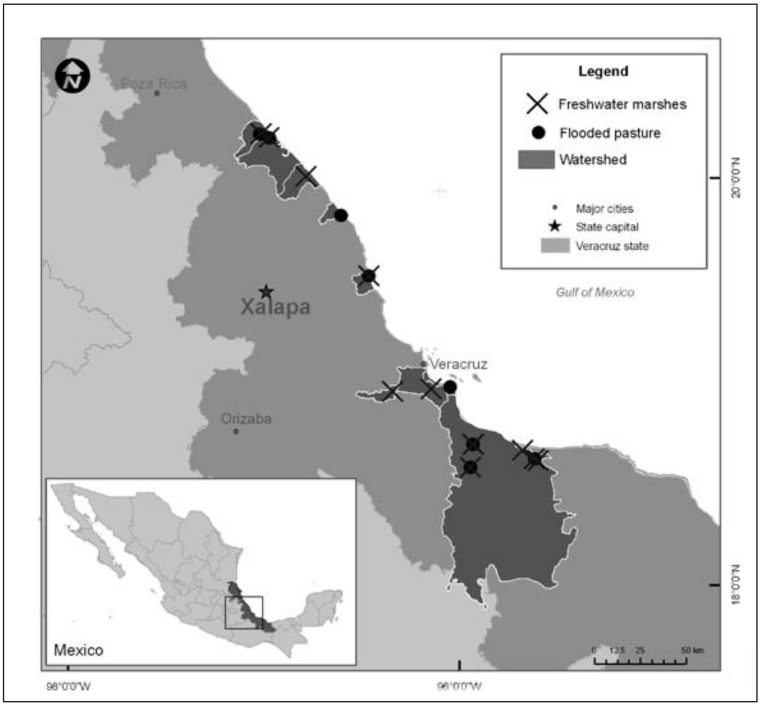

FIGURE 1

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.

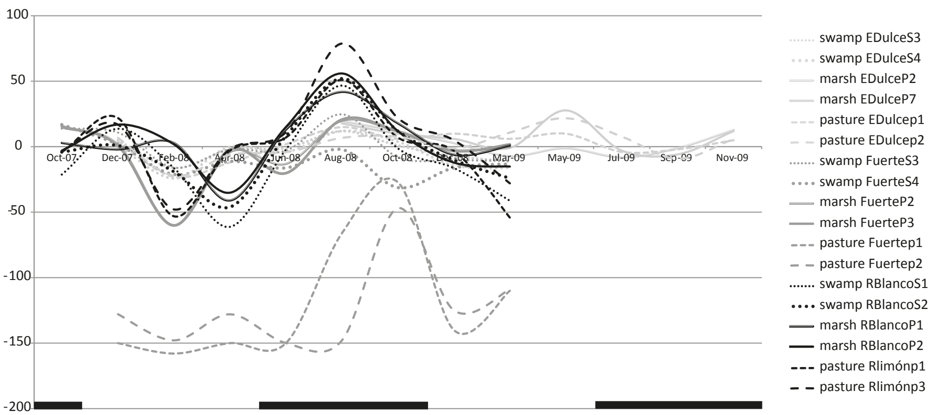

FIGURE 2

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).

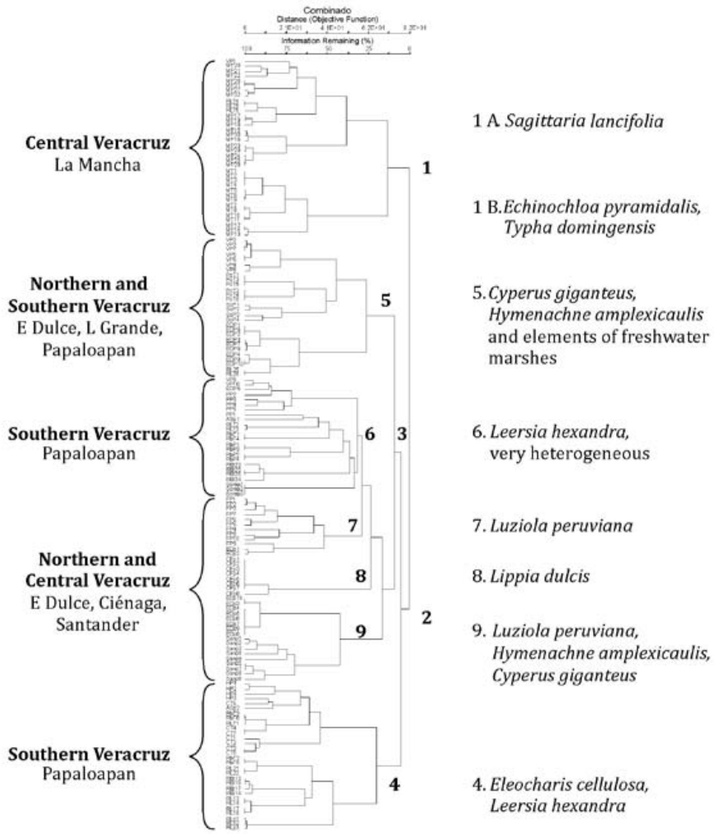

FIGURE 3

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.

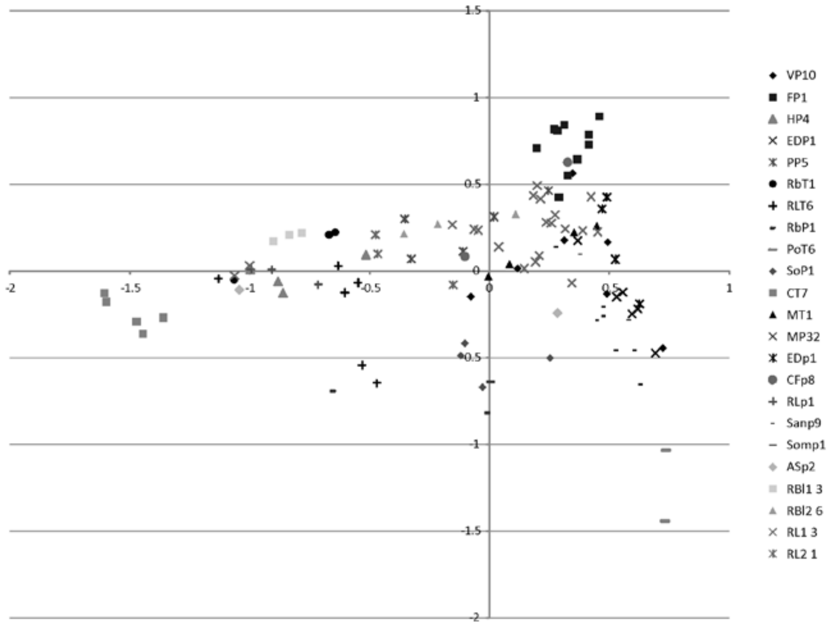

FIGURE 4

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.

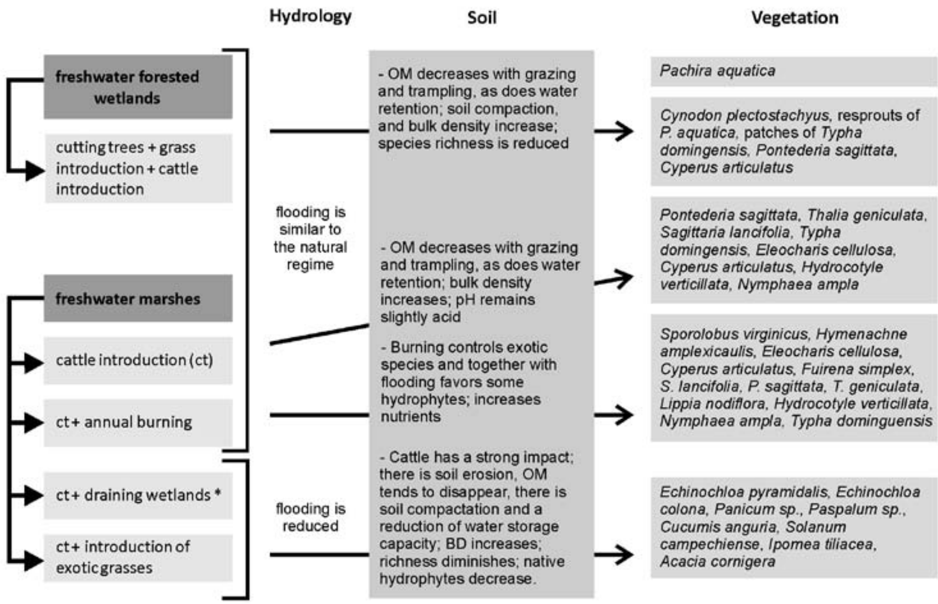

FIGURE 5

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).

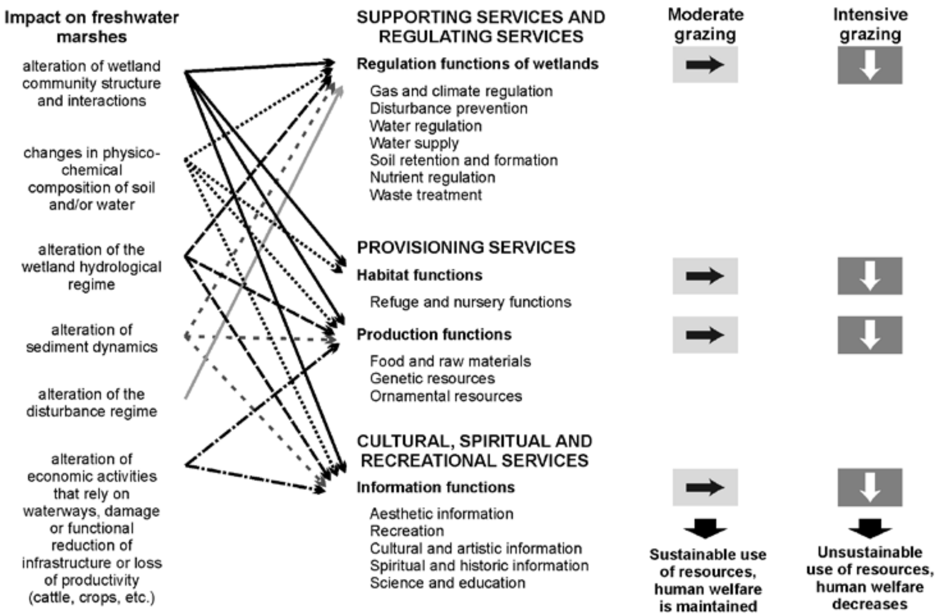

FIGURE 6

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.


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Scenarios of vulnerability in coastal municipalities of tropical Mexico: An analysis of wetland land use

César Vázquez-González [a], José Luis Fermán-Almada [b], Patricia Moreno-Casasola [a], Ileana Espejel [b,*]

[a] Red de Ecología Funcional, Instituto de Ecología A.C., Xalapa 91070, México
[b] Universidad Autónoma de Baja California (UABC), Ensenada 22860, México

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ABSTRACT

Coastal wetlands in the Alvarado Lagoon System (ALS) have been drained by sugar cane agriculture and cattle ranching. The ALS is located in the Papaloapan river basin, which is the second most important in Mexico, as determined by its area (46 000 km^2) and water surface flow. The purpose of this article is to assess the coastal wetlands' vulnerability under three scenarios, current, actual trend and strategic, by building an index at the municipality scale using a Pressure-State-Response (PSR) model. The index includes indicators of land use and vegetation cover. According to the index, each municipality in the ALS has a critical current scenario, and the actual trend scenario increases the vulnerability in all municipalities because of current land use strategies. Only in the strategic scenario does the vulnerability index fall beneath the critical point. The strategic scenario entails reducing the current land use for both sugar cane crops (by 25%) and cattle ranching (by 50%). This study provides an integrated vulnerability evaluation for stakeholders and decision-makers in local and regional arenas. We conclude that changes to the economic policies in the various sectors are necessary to encourage sustainable land use and promote other activities such as coastal wetlands conservation and restoration.

1. Introduction

Coastal wetlands are recognized as highly productive ecosystems because of the ecosystem services they provided to human society (Barbier et al., 1997; Daily et al., 1997; Mitsch and Gosselink, 2000; Moreno-Casasola, 2005a). Economic valuations show the socioeconomic and ecological importance of wetlands. The Millennium Ecosystem Assessment, (2005) encouraged countries to undertake an integrated assessment and conduct an economic valuation of the ecosystem services provided by coastal wetlands and to analyze the negative impacts of their degradation. Mexico's wetlands are not exempt from the global trend in wetland degradation, and 62% have deteriorated (Landgrave and Moreno-Casasola, 2012). Sanjurjo (2005) and Sanjurjo et al. (2005) analyzed the contribution of mangroves to their local economies as a function of the profit derived from fisheries. They determined that mangrove cover, because of its habitat function, was directly related to fisheries.

Seingier et al. (2011b) developed an integrated coastal index and used it to estimate the capacity for sustainability in each coastal municipality in Mexico. Sustainability was defined as the combination of three aspects (the state of the environment, the quality of life of the human population, and pressure applied by human activities). Landgrave and Moreno-Casasola (2012) discussed the vulnerability of the Mexican coast to climate change effects and loss of coastal wetland cover, and Mendoza-González et al. (2012) assigned economic values (derived from other countries) to the loss in ecosystem services that would result from wetland loss. However, in tropical regions, including Mexico, there are no published data assessing the vulnerability of municipalities as a function of wetland land use and conservation.

For our study, we chose the ALS, a wetland complex located in the Papaloapan river basin of the Gulf of Mexico, which is the second most important wetland complex in Mexico because of its size (46 000 km^2) and surface water flow (45 × 10^9 m^3) (CSVA, 2006) and is an example of both wetland depletion and conservation in Mexico (Fig. 1a). According to a study by Campos et al. (2011), in wetlands further north in the same state, the water-holding capacity of soil ranges from 687 to 880 L m^2 in herbaceous wetlands (marshes) and from 556 to 834 L m^2 in swamps (forested wetlands). However, this capacity decreases with wetland trampling, drainage and vegetation cover change. The transformation of wetlands in the area has mainly been caused by sugar

* Corresponding author. Tel.: +52 646 1745925x126.
E-mail addresses: iespejel@gmail.com, ileana.espejel@uabc.edu.mx (I. Espejel).

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cane plantations and cattle ranching (14.5% and 65.5%, respectively, of the wetland area in relation to the total ALS area). In the same area north of Veracruz along the Gulf of Mexico, Robledo-Ruiz (2012) found that the soil of wetlands that were converted to inundated pastures dominated by *Sporobolus indicus, Oxalis corniculata* and *Axonopus* sp. retains 414 L m^2. These metrics open the discussion on the vulnerability of coastal wetlands and the possibility of their transformation by external agents such as those mentioned by Dong et al. (2011); Fraser et al. (2011) and Füssel (2007) in their conceptual framework of vulnerability; further, they expose some of the negative effects that anthropogenic activities can have on natural attributes.

One of the primary sources of water pollution in tropical areas is herbicides such as atrazine that are applied to sugar cane crops (Cejudo-Espinosa et al., 2008). Several sugar cane mills (five in the ALS area) are located in the watershed of the Papaloapan river. They use 343×10^6 m^3 of surface water and discharge 287×10^6 m^3 of untreated water into the wetlands (CSVA, 2006). This situation converts them into a negative externality as explained by Gómez-Baggethun and de Groot (2007). Fishermen from the Papaloapan watershed argue that herbicides and water discharged from the sugar mills affect the water quality and the lagoon's productivity (personal communication, Antonio Zamudio). Furthermore, loss of herbaceous wetlands and mangroves to cattle ranching has been shown to be one of the main problems in coastal management planning (Guevara and Moreno-Casasola, 2008). This situation is closely tied to the economic policy that has been implemented for subsiding sugar cane crops through a federal farming program (PROCAMPO by its Spanish acronym) by the Agriculture Ministry (SAGARPA by its Spanish acronym) (SAGARPA, 2010). Before this, in the 1960s and 1970s, federal subsidies encouraged cattle ranching and contributed to the deforestation of enormous swathes of land (Fernández-Ortiz et al., 1993).

Several authors have noted that both landowners and decision makers have followed inadequate strategies for coastal management in ALS (Juárez-Eusebio, 2005; Moreno-Casasola et al., 2002). Currently, local coastal management planning requires specific studies that focus on problems in a holistic manner through monitoring environmental stressors such as site land use, water pollution, etc. (Moreno-Casasola, 2005b). It also requires evaluations of the state of the ecosystem at both local and finer scales. The objective of this work is to propose a coastal vulnerability index (CVI) that defines vulnerability as being threatened by changes in land use pressure or some component of vegetation cover. Such an index would allow us to expose anthropocentric pressure as a main stressor of the state of wetlands and mangroves. Accordingly, we integrate the proposed CVI into a conceptual framework for the Pressure-State-Response (PSR) model highlighted by the OECD (2001) for use at a municipal scale. Municipalities were used as terrestrial units on which to apply the CVI because they are the smallest political unit at which land use is defined in Mexico (Seingier et al., 2011a, 2011b).

The CVI was modeled under three scenarios: current (CS), actual trend (ATS) and strategic (SS). Thus, the CVI measures both the state of natural attributes of coastal wetlands to sustain impacts from anthropogenic activities and the environmental or eco-centric vulnerability due to the loss of ecosystem services.

2. Material and methods

2.1. Study area

In Mexico, wetlands are widely distributed along the coast (Olmsted, 1993). The ALS is located in the state of Veracruz on the Gulf of Mexico. This natural complex is politically divided into ten municipalities, but only nine municipalities were included in the analysis due to the availability of information (Fig. 1a). The importance of the region can be defined by the natural, social and economic spheres.

i) Natural sphere. The ALS wetland complex encompasses 373 021 ha, including an estuarine lagoon system formed by coastal lagoons such as Buen País and Camaronera. Others with lower salinity values are Tlalixcoyan and Las Pintas, and the main rivers are the Papaloapan, Acula, Blanco and Limón (Contreras-Espinosa et al., 1996; Portilla-Ochoa, 2003). Moreno-Casasola and Infante-Mata (2010) name ALS as one of the most important hydrological resources for the state of Veracruz and for Mexico due to its multiple types of wetlands, its resources and the environmental services it provides.
ii) Social sphere. According to CONAPO (2010) and SEFIPLAN (2010), the population of the ALS is 183 187 inhabitants. Historically it has important cultural values that are part of today's coastal culture. Its heritage is represented by the Candelaria Virgin and its festivities in Tlacotalpan (Córdoba-Olivares, 1998) and also by its historical relevance since pre-Hispanic time (Vargas-Montero, 1998), through the Colonial period and during the Porfiriato era at the beginning of the XX century (Vergara-Ruíz, 1998). Tlacotalpan is a site on the UNESCO World Heritage list. There are also archeological resources in the municipalities of Tlalixcoyan and Acula (Maldonado-Vitae, 1998), villages that made use of wetlands long before the Spanish arrived to America.
iii) Economic sphere. Cattle ranching has been established in the area since the arrival of the Spanish conquerors. Ranching grew significantly during colonial times (Guevara and Moreno-Casasola, 2008) and in contemporary Mexico. During the 1950s, Cebu cattle were substituted for the longhorns brought by the Spanish. The former required more land and better pastures, and the government encouraged deforestation to increase cattle ranching. This resulted in the proliferation of great areas of land under both private and communal land tenure and the use of wetlands for cattle ranching (Skerritt, 1993). Currently, ranching occupies most of the land in the ALS (65.5%) (see Flooded grasslands in Fig. 1a). According to (SIAP, 2010), the total income from sugar cane crops (the most important economic activity in the ALS) was 106×10^6 USD in 2010, and cattle ranching generated 34×10^6 USD in 2010. The income generated by fishing activities was the lowest, at 28×10^6 USD, though the ALS has the highest density of fishermen cooperatives in State of Veracruz (Moreno-Casasola and Infante-Mata, 2010).

According to the most recent census in Mexico, Alvarado is the most populated municipality in the ALS, and Acula is the least populated. Another important feature is the percentage of the population employed by each economic sector. All municipalities are focused on activities in the primary sectors of sugar cane cultivation, cattle ranching, fishing and perennial agriculture. Lerdo de Tejada and Carlos A. Carrillo are the municipalities with the highest population dedicated to the secondary sector (Table 1) due to the sugar cane industry (CONAGUA, 2007).

Although the municipalities have a marginalization index lower than 50 percent (Table 1), which can be interpreted as a low to medium degree of marginalization of the population, there are many people living on only two minimum salaries or less (4.42 USD per day is the current minimum salary in DF (SHCP-SAT, 2013) and 1 USD = 13$).

2.2. Conceptual framework

The Pressure sub-index is composed of indicators describing the land use of coastal wetlands, such as the cover of sugar cane crops, cattle ranching, urban growth and perennial agriculture. The State sub-index integrates indicators of mangrove, forested and herbaceous coastal wetland cover, while the Response sub-index is considered as equivalent to the Coastal vulnerability index and is the sum of the Pressure sub-index and the State sub-index.

The indicators shown in Table 2 were integrated into the CVI through a conceptual scheme (Fig. 2) that was modified from the PSR model proposed by OECD (2001). In Fig. 2, the eco-centric optimum (EO) is an unrealistic situation in which people do not have any negative effects on natural resources, that is, a state without anthropogenic disturbance. Sustainable use (SU) describes anthropogenic use that is compatible within ecological processes and does not impact the coastal wetlands, e.g., reducing atrazine use on sugar cane crops due to its negative effects (Cejudo-Espinosa et al., 2008). Strategic use (EU) is defined as a value between 0 and 0.5 for any indicator, that is, vulnerability caused by land use is acceptable within a certain range. Critical use (CU) for any indicator is between 0.5 and 1; it represents an unsustainable behavior and a

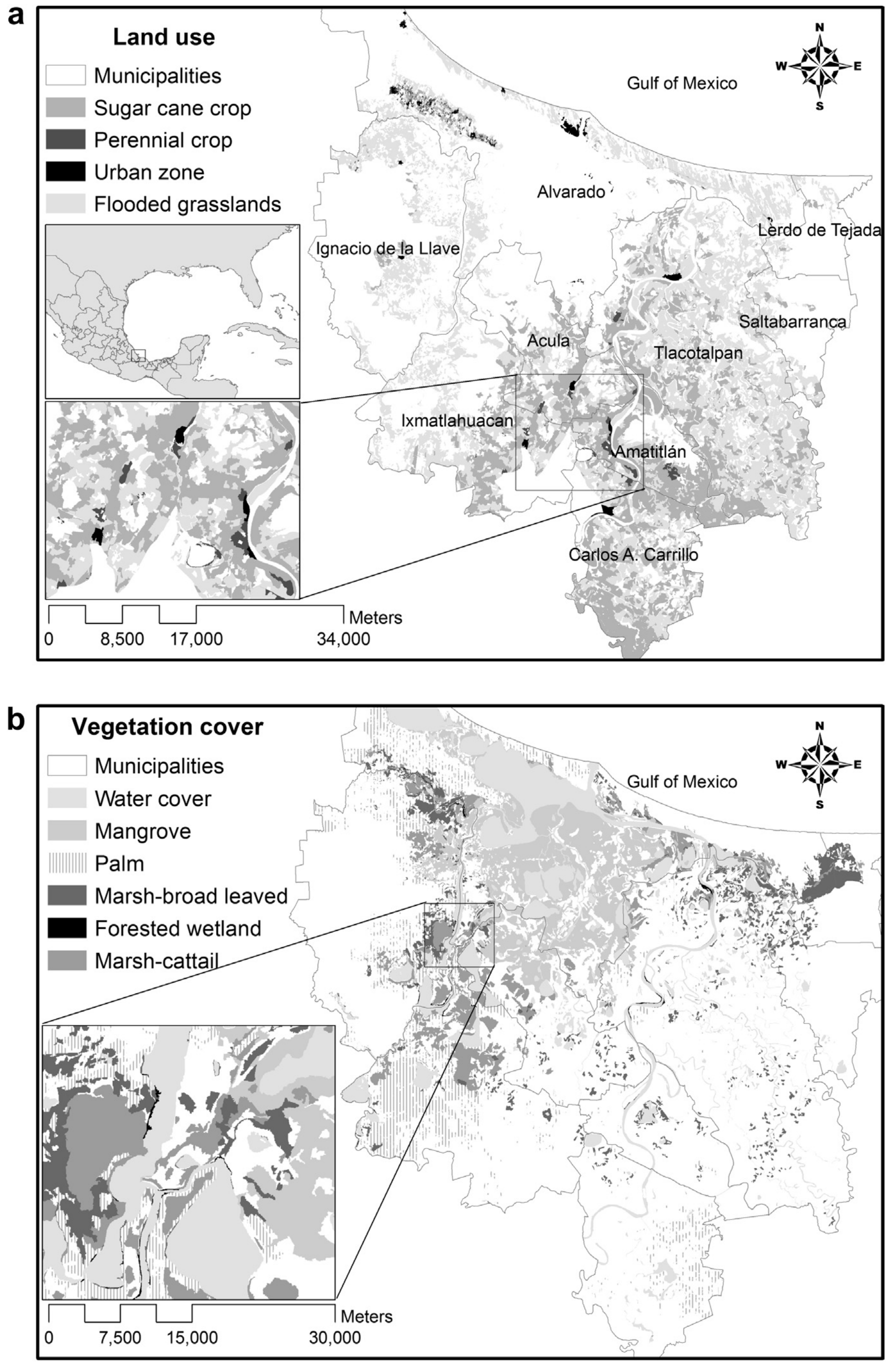

Fig. 1. Study Area. Vegetation cover and land use in the Alvarado Lagoon System (ALS) municipalities. The land use and vegetation maps were taken from the Coastal Wetlands Inventory of the Papaloapan River Basin (taken from Research project CONAGUA-CONACYT-48247 (2009). (a) Land use in the Alvarado Lagoon System and macro-localization, (b) Vegetation cover in the Alvarado Lagoon System. Projected coordinate system: Lambert Conformal Conic. Datum: ITRF 1992.

Table 1
Socioeconomic description, land use and vegetation cover in municipalities of the Alvarado Lagoon System (ALS). The highest values for each metric are shown in bold.

Municipalities	Popu-lation[a]	Economi-cally active population. (employed)[b]	Percentage of population employed by each economic sector[c]			Populati-on with two minimum salaries[d]	Marginalization index[e]	Land use and vegetation cover per municipality (%)[f]				Loss of wetland cover (%)[g]
			1st.	2nd.	3rd.			Cattle ranching	Sugar cane	Mangro-ves	Fresh-water wetland	
Acula	5 129	1 603	48.5	15.3	33.9	59.9	30.3	41.8	22.3	15.1	13.0	92.3
Alvarado	**51 955**	**20 140**	34.2	18.3	47.5	52.3	20.8	**65.0**	1.5	**19.2**	13.1	**98.8**
Amatitlán	7 487	2 460	43.5	17.1	38.1	53.0	29.7	57.3	32.5	0.0	2.9	92.7
Ignacio de la Llave	17 121	5 435	41.0	18.0	40.8	**70.2**	**35.2**	60.3	1.2	3.9	14.6	80.0
Ixmatlahuacan	5 727	2 050	**61.5**	8.5	29.8	63.3	31.4	43.1	14.1	0.0	**19.3**	76.4
Lerdo de Tejada	20 141	6 866	9.9	26.0	**62.4**	44.0	14.5	36.0	32.7	0.0	13.7	82.3
Saltabarranca	5 908	1 859	39.5	17.3	42.6	60.5	28.5	55.9	22.5	0.0	1.5	79.9
Tlacotalpan	13 284	5 250	28.4	18.9	50.9	54.2	24.9	64.3	20.3	1.3	8.6	94.5
Carlos A. Carrillo	22 907	7 604	17.7	**36.1**	45.4	43.7	18.2	8.8	**41.1**	0.0	1.6	51.4

[a] Population and marginalization indices were taken from CONAPO (2010).
[b] Economically active population (employed) and
[c] percentage of population employed by each economic sector were obtained from SEFIPLAN (2010).
[d] Minimum wage refers to the official minimum salary per day, which varies among regions. For the study area it was 9.96 USD per day for the year 2013.
[e] The marginalization index is used in Mexico by the government and other institutions to measure the quality of life and the poverty level among the population. Values closer to 100 indicate a higher degree of marginalization and lower quality of life.
[f] Land use and vegetation cover per municipality were obtained from the research project CONAGUA-CONACYT no. 48 247, SIAP (2010).
[g] The percentage of wetland's loss cover (%) was estimated from Landgrave and Moreno-Casasola (2012) by dividing wetland's loss cover by the potential wetland area.

critical land use that reduces the ecosystem services and puts wetlands in a critical situation. According to the conceptual relationship shown in Fig. 2, when the pressure is higher (closer to 1), the sub-index will be closer to 1 because this reflects the impact of land use (per activity) on the natural cover of wetlands (see indicator scale values in Fig. 2).

2.3. Method

According to OECD (2001), we selected indicators (Fig. 2 and Table 2) based on the availability and reliability of data, which were drawn from current statistical information that was directly related to the observed problems, the micro-region's situation, and an integrated approach to qualitative and quantitative terms.

Table 2
Describing indicators of the Coastal vulnerability index (CVI) built for the municipalities of the Alvarado Lagoon System (ALS).

Indicator	Sub-index name	Equation for assessment
Land use cover occupied by perennial crops (LUPC)	Pressure sub-index (PSI)	$(LUPC_{ij})/MLE_i$
Land use cover occupied by cattle ranching (LUCR)		$(USG_{ij})/MLE_i$
Land use cover occupied by sugar cane crops (LUSC)		$(LUSC_{ij}/MLE_i)$
Land use cover occupied by urban zone (LUUZ)		$(LUUZ_{ij}/MLE_i)$
Surface water cover (SWC)	State sub-index (SSI)	(SWC_{2010}/MLE_{2010})
Mangrove cover (MVC)		(MC_{2010}/MLE_{2010})
Palm cover (PAC)		(PAC_{2010}/MLE_{2010})
Marsh (broad leaved) cover (POC)		(POC_{2010}/MLE_{2010})
Marsh (cattail) cover (TC)		(TC_{2010}/MLE_{2010})
Forested wetland cover (FWC)		(FWC_{2010}/MLE_{2010})

MLE means municipal land extension, i prefix is the municipality evaluated, and j is the time period of the data. Forested wetlands are dominated by *Pachira aquatica* and *Annona glabra*. Palm groves are dominated by *Sabal mexicana, Quercus oleoides, Coccoloba barbadensis, Achatocarpus nigricans, Daphnopsis americana, and Casearia corymbosa*, among others. Marsh (cattail) is a freshwater marsh dominated by *Typha domingensis*. Marsh (broad leaved) is dominated by *Pontederia sagittata, Thalia geniculata, Sagittaria lancifolia, Leersia ligularis, Eleocharis cellulosa, Cyperus articulatus, Typha domingensis, Phragmites australis, Zizaniopsis miliacea, Cyperus giganteus, and Hymenachne amplexicaulis*.

2.4. Normalization of indicators and indexes

To add the estimated values for the indicators (Table 2), they were normalized according to the method applied by Posthumus et al. (2010). This standardization allowed us to compare the performance of indicators and indices with one another under different scenarios. As a result, the normalized value for the maximum indicator and index can score $xij = 1$, while the minimum indicator and index can score $xij = -1$. However, our normalized indicator values differ from Posthumus et al. (2010) because we took the maximum score as an undesirable situation; negative or minimum scores reflect a desirable value for each indicator, sub index and index.

2.4.1. Pressure sub-index (PSI)

According to Fig. 2, PSI integrates the different types of land use: LUPC, LUSC, LUCR and LUUZ. First, each indicator was normalized. Second, land use per economic activity was added, and third, the sum was normalized again to obtain the PSI (Eq. (1)). This study estimates a PSI value for each scenario "i" (current, actual trend and strategic) in each municipality "j". Indicators were evaluated using the same methodology.

$$PSI_{ij} = \sum(LUPC_{ij},\ LUSC_{ij},\ LUCR_{ij},\ LUUZ_{ij}) \quad (1)$$

Indicators, sub-indices and indices of the current scenario were estimated from a technical report by CONAGUA-CONACYT-48247 (2009), whereas the actual trend and strategic scenarios were calculated with information from SIAP (2010). This allowed us to estimate the increase of land use per economic activity over the period 2006–2010. The tendency between 2006 and 2010 was used to obtain the land use cover in 2018. Because of the time period covered by the database, it was not statistically possible to make inferences farther into the future.

2.4.2. State sub-index (SSI)

The SSI was built using six indicators that measure different types of forested and herbaceous wetlands with respect to vegetation cover: SWC, MC, PAC, POC, TC and FWC (Table 2 and Fig. 2). As explained in Eqs. (1) and (2), they show the indicators' sum and estimates for each scenario (current, actual trend and strategic).

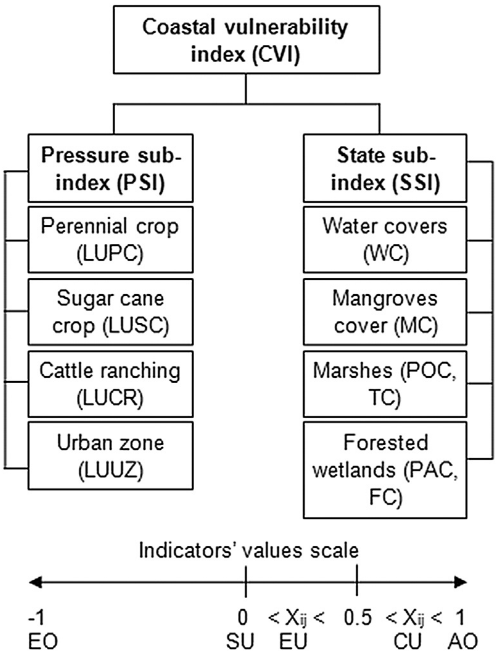

Fig. 2. Components of the Coastal vulnerability index (CVI), PSI sub-index (based on land use cover) and SSI sub-index (based on the cover of the different type of wetlands) and current indicators (EO: Eco-centric optimum; SU: Sustainable use; EU: Strategic use; CU: Critical use; AO: anthropocentric optimal). The indicator value scale helps to compare the indices. See the text for further explanation.

Furthermore, SSI incorporates indicators that correspond to marsh vegetation (POC-Marsh (broad leaved) and TC-Marsh (cattail)). The same was done for PSI. In SSI, "i" refers to the scenario, and "j" represents the municipality under evaluation.

$$SSI_{ij} = \sum (SWC_{ij},\ MC_{ij},\ PAC_{ij},\ POC_{ij},\ TVC_{ij},\ FWC_{ij}) \qquad (2)$$

The values of the indicators were taken from a CONAGUA-CONACYT-48247 (2009) technical report and the geographic information system analysis that accompanied it. First, the equations in Table 2 were applied to obtain the indicators, and second. They were normalized before adding them as in Eq. (2). Finally, the sum was normalized again to estimate the SSI per scenario (i) and municipality (j).

2.4.3. *Coastal vulnerability index (CVI)*

CVI evaluates the vulnerability for each scenario and municipality in the ALS. It is the sum of the pressure sub-index (PSI) and the state sub-index (SSI) (Eq. (3)). This means that the CVI jointly monitors the level of pressure exercised by economic activities (sugar cane and cattle ranching) and the state of the area based on the extent of the wetlands cover. Furthermore, it shows the relationship between economic activity (in terms of increased land use or pressure) and the cover of natural wetlands (either types of vegetation or state), as described in the conceptual framework.

$$CVI_{ij} = \sum (PSI_{ij},\ SSI_{ij}) \qquad (3)$$

3. Results

3.1. *Pressure sub-index (PSI) assessment*

All municipalities have a PSI-CS at the critical use level (CU). If the trends from 2006 to 2010 are maintained from 2010 to 2018, each municipality will have a PSI-ATS near the anthropocentric optimal (AO), except for Lerdo de Tejada and Amatitlán. However, under the strategic scenario (PSI-SS), pressure diminishes through a 50% reduction of the land used for cattle ranching and 25% reduction for sugar cane crops. The land used for perennial crops can be increased to 100%, replacing current sugar cane crops. Such a strategy would diminish the pressure from critical use (CU) to strategic use (SU) (Fig. 3).

3.2. *State sub-index (SSI) assessment*

All municipalities have a State sub-index under the current scenario (SSI-CS) at the critical use level (higher than 0.5) (Fig. 4). If land use continues according to the current trend (2006–2010), the State sub-index for the actual trend scenario (SSI-ATS) for all municipalities will be above 0.5. On the other hand, the strategic scenario shows SSI-SS values below 0.5 for each area except Carlos A. Carrillo. This scenario could result from altered strategies such as conservation and restoration of the wetland vegetation cover. Logically, this result implies a reduction in the land use and a change in the current policies.

3.3. *Coastal vulnerability index (CVI) assessment*

Under the current scenario (CVI-CS), all municipalities have a Coastal vulnerability index at the critical use level (CU), that is, higher than 0.5 (Fig. 5). Additionally, they present a CVI-ATS higher than 0.8, which means all municipalities will be closer to 1 (the anthropogenic optimum), except Amatitlán, which is the only area with a decreasing CVI. Even its value will still be above 0.5. If the trends are changed, the CVI-SS calculated all of the municipalities

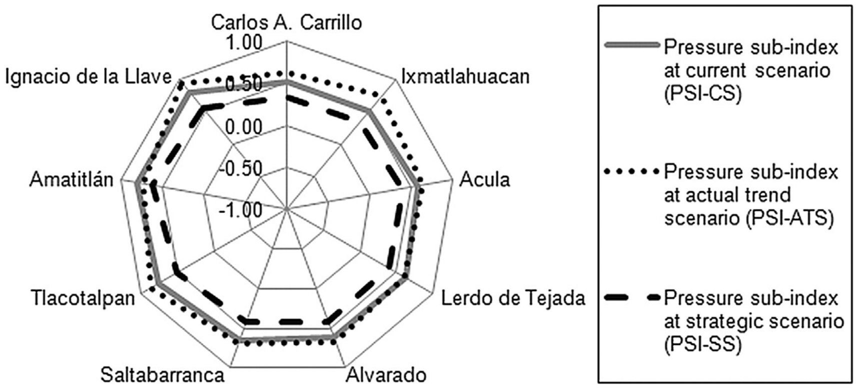

Fig. 3. Scenarios of the Pressure sub-index (PSI) for each municipality in the Alvarado Lagoon System (ALS).

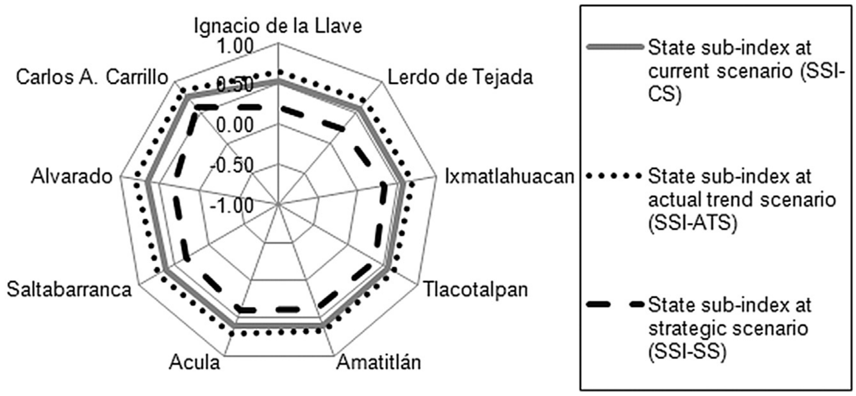

Fig. 4. Scenarios of State sub-index (SSI) for each municipality of the Alvarado Lagoon System (ALS). Negative values might be obtained when the quality state shows a decrease in the level of impact because land use pressure has diminished.

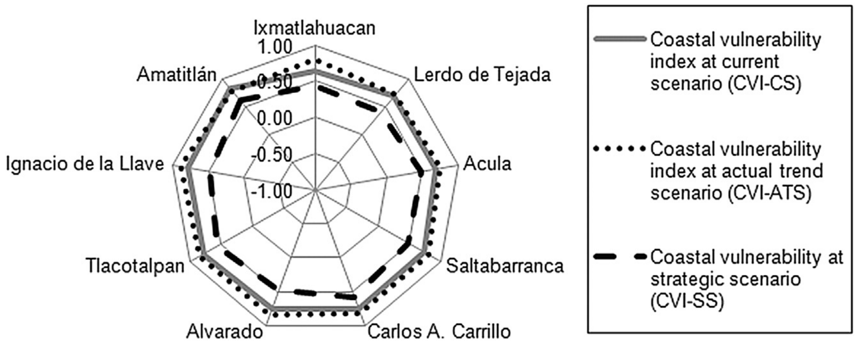

Fig. 5. Scenarios of Coastal vulnerability index (CVI) for each municipality in the Alvarado Lagoon System (ALS).

as under the strategic use level except Tlacotalpan, Carlos A. Carrillo and Amatitlán.

4. Discussion

The conceptual framework proposed by Kaly et al. (1999) was used to evaluate other ecosystems; however, in this case it was used to construct our conceptual framework in order to evaluate coastal wetlands vulnerability. Indicators were selected according to the PSR model from OECD (2001) and follow its general criteria. The results of this study demonstrate that the vulnerability indices under the current scenario (CVI-CS) and the strategic scenario (CVI-SS) were high (Fig. 6a and b). Although the index did not include indicators for fishing productivity in areas covered by water or mangrove productivity associated with the fisheries, it is reasonable to assume that if there were more water, wetland, and mangrove cover and if the water was less polluted, then the fishing productivity would be higher, as shown by Aburto-Oropeza et al. (2008) and Sanjurjo et al. (2005) for other regions in Mexico.

As we hypothesized, municipalities with the greatest relative change in land use between 2006 and 2010, both for sugar cane crop and cattle ranching, are more vulnerable under the actual trend scenario (see Alvarado, Ignacio de la Llave and Tlacotalpan). In the past, the first two municipalities did not have sugar cane crops (year 2005, according to SIAP (2010)). Additionally, according to Table 2, the economically active population (PEA by its Spanish acronym) depends entirely on fisheries in Alvarado, Tlacotalpan and Acula, as shown in Table 1, and this activity relies on coastal wetland cover.

Acula and Lerdo de Tejada will maintain the vulnerability index value because of their land use performance between 2006 and 2010; however, Lerdo de Tejada depends less on fishing than on sugar cane (Table 1). As a consequence, the productivity of the lagoons will diminish, and there will be negative effects on the income from many fisheries. As highlighted by Landgrave and Moreno-Casasola (2012), the coastal situation due to the loss of wetland cover (89% in the state of Veracruz) has numerous repercussions such as compacting the soil, reducing plant diversity, and decreasing soil capacity for water storage (Travieso-Bello et al., 2005). These adverse effects are the result of unsustainable management practices and the lack of coastal management strategies. Such is the case for mangroves in the municipalities of Alvarado and Acula, where there has been loss of mangrove cover, conversion to *Spartina spartinae* marshes and trampling in the remaining mangroves due to cattle ranching (Fig. 1). Most of the freshwater marshes and forested wetlands have been used for cattle ranching or were drained and transformed into sugar cane and pineapple crops (Table 1). The coastal vulnerability index (CVI) for each municipality shows this situation. A more integrated approach that allows the comparison of stressors on wetland use is to examine the disaggregated metrics in Fig. 2. It is possible to analyze the differences among municipalities according to land use features and the levels of pressure in the agriculture, cattle ranching and urban zones.

An alternative situation would reduce the vulnerability for each municipality, as shown in Fig. 7. This scenario results from the strategies presented above, such as reducing by 50% the land used for sugar cane crops that are built by draining and constructing borders on all watercourses to prevent flooding, and reducing the ranching lands that degrade coastal wetlands by 25%. This scenario also entails encouraging the conservation of mangroves and freshwater coastal wetlands (forested wetlands and marshes),

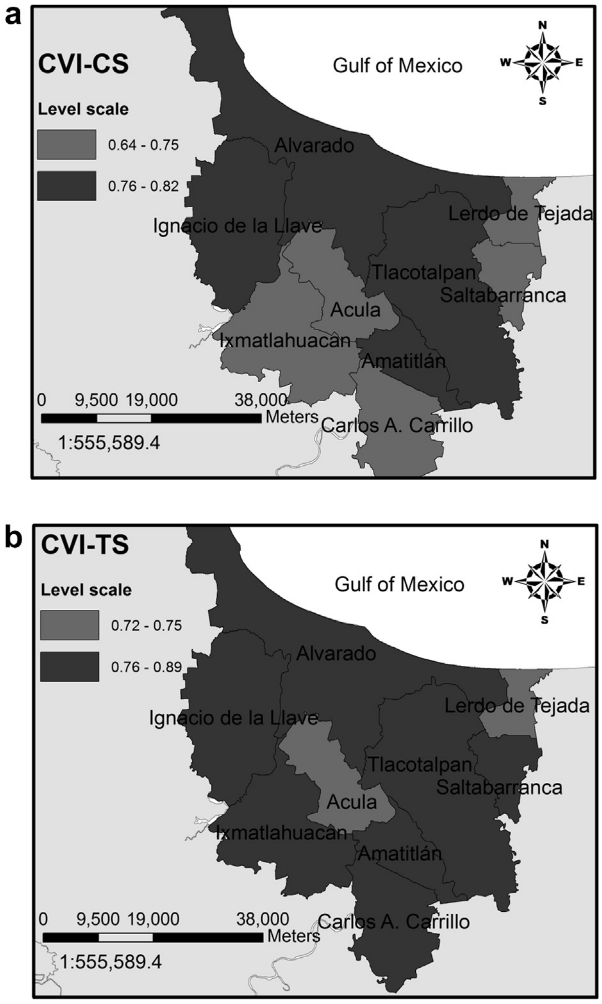

Fig. 6. Spatial representations of (a) the Coastal vulnerability index under the current scenario (CVI-CS) and (b) the Coastal vulnerability index under the actual trend scenario in 2010–2018 (CVI-ATS). The changes in values indicate an increase in municipal vulnerability.

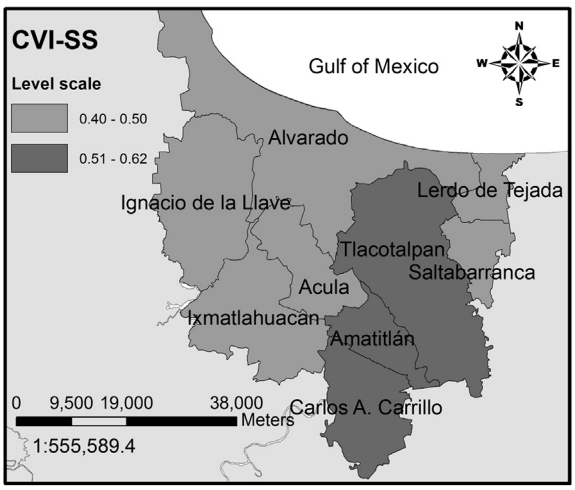

Fig. 7. Spatial representation of the Coastal vulnerability index under the strategic scenario (CVI-SS).

developing alternative economic activities, recovering fishery production, decreasing subsidies for sugar cane cultivation and encouraging mangrove and freshwater wetland restoration, which has proved to be successful in other sites (López-Rosas et al., 2013).

Even under the strategic scenario (CVI-SS), three municipalities still present a municipal vulnerability index at a critical use level. Tlacotalpan, Amatitlán and Carlos A. Carrillo municipalities will need to implement drastic strategies in relation to their pressure sub-index (Fig. 7). It is worth noting that Tlacotalpan has important cultural and touristic values (it is a UNESCO World Heritage site), but it has been suffering from severe flooding that has led to great economic loss. These floods are partly a consequence of wetland degradation and poor territorial planning.

Seingier et al. (2011a) and Seingier et al. (2011b) determined that less sustainable coastal municipalities in Mexico are located in the state of Veracruz, specifically in Alvarado, Lerdo de Tejada and Acula, which are part of the ALS. On a difference scale, this study shows that all of the municipalities have a critical use level of the vulnerability index under current and actual trend scenarios. Because sustainability includes natural, social and economic goals, it is possible to suppose that such impacts result in decreased sustainability. On one hand, a higher vulnerability implies lower natural quality and less sustainability. On the other hand, Barrera-Roldán and Saldívar (2002) found greater sustainability where land use and economic activities have put more pressure on land use (through ports, industrial and urbanized municipalities). They estimated municipal vulnerability indices for another coastal zone in Veracruz (Coatzacoalcos, Minatitlán and others) using a differently weighted index. We do not agree with their results. For example, the Port of Veracruz has suffered severe floods in urban areas, causing loss of property, diseases, psychological damage and other problems (Tejeda-Martínez, 2005), reducing welfare for a high proportion of the population (23 500 affected persons in Boca del Río). This is also shown by the urban zone growth from 2000 to 2010, an area which corresponds to new settlements on zones with a high risk of flooding and which correspond to herbaceous wetlands according to the Geography Information System elaborated by INEGI (2010) (the National Institute of Geography and Statistics) and included in the INEGI hydrological emulator (http://antares.inegi.org.mx/analisis/red_hidro/SIATL/#). This occurs despite the economic revenue obtained through port activity and commerce. This income does not benefit people affected by flooding. In contrast, this study assigned the same weight to each indicator and index and thus obtained different results. Taking into account agriculture and sugar cane crops, the index indicated that municipalities with higher land surface used for sugar cane show no significant differences in the quality of life, despite the economic benefits. This difference in opinion can be examined using the social marginalization index and the life quality data that appear in CONAPO (the National Population Council), as shown in Table 1.

The assessment obtained with the vulnerability index in this study notes the relationship that exists between the historical description of land use and vegetation cover change and the problems related to the wetlands quality state (Juárez-Eusebio, 2005; Portilla-Ochoa et al., 1998), and it also shows the different situation under three scenarios. Furthermore, it gives the possibility to monitor damages produced by unsustainable land use. It is a tool for decision-makers in relation to natural resources management. This index becomes an important tool for regions with valuable wetlands because it is the first one to integrate the effects of land use and wetlands vegetation cover under one value, by using the Alvarado Lagoon System as a study site.

Additionally, to ensure the conservation of wetlands and their sustainable use, different strategies and policies should be promoted. One of them is payment of ecosystem services. Under this scheme, municipalities can add other ecosystem services such as carbon storage and sequestration, soil water storage and filtering, fishing productivity and develop complementary economic activities such as ecotourism and aquaculture of native species such as clams, shrimp and fin fish. As already mentioned, Campos et al. (2011) found that the soil water-holding capacity of organic wetland soils is seven times their weight in water. This service is valuable in regions with intense tropical storms and hurricanes that cause flooding, loss of lives and economic livelihoods. They also estimated the average carbon stored per unit area, resulting in 520 t C ha^{-1} in swamps (forested freshwater wetlands), in comparison with 310 t C ha^{-1} in marshes. With this type of data, municipalities could form a portfolio for compiling different ecosystem services provided by wetlands and support their conservation within economic goals through the inclusion of mechanisms such as REDD + projects (White and Minang, 2011).

5. Final considerations

The structure of the proposed index and its indicators means that the results of this study can be used as a baseline because its components are easy to monitor. Additionally, it alerts the authorities and government institutions to the problems in the study area. It can also help them visualize scenarios to design strategies and achieve solutions. For example, it indicates which municipalities could reduce the land devoted to cattle ranching by intensifying land use and making it more productive and which areas could reduce sugar cane cover by modernizing the industry to increase efficiency and use its true economic value free of current subsidies, ensuring conservation of ecosystem services provided by wetlands.

The indices presented in this study are some alternatives for land use planning that cannot be postponed in the Papaloapan river basin and, particularly, in the ALS. For example, municipalities expanding their land use to increase sugar cane crops have negative externalities such as atrazine use on their land (Cejudo-Espinosa et al., 2008), nitrogen accumulation in the soil and its subsequent infiltration to underground water (Colegio de Postgraduados, 2003; de Figueiredo et al., 2010). Increased water pollution and overfishing make fisheries less sustainable each day. Hence, Alvarado and Ignacio de la Llave should reduce or end this trend in land use. The same is true of Carlos A. Carrillo, Tlacotalpan, Lerdo de Tejada and Ixmatlahuacan. Cooperation among all municipalities is necessary to implement this strategy because some municipalities (Acula, Tlacotalpan, Carlos A. Carrillo, Lerdo de Tejada, Saltabarranca and Ixmatlahuacan) affect not only themselves but also others such as Alvarado because of their geographic position. In the area, water flows (with all its pollutants) toward Alvarado and the sea.

The PSR model is adaptive, that is, it can be adjusted and reevaluated according to the time period. As an example, by including water quality data from CSVA (2006), the Coastal vulnerability index might take into account indicators of water pollution and evaluate the impacts of industrial discharge on water quality. Additionally, it could be used to show the future impacts of housing developments. This is important because authorities should not repeat mistakes as has been done in Veracruz and Boca del Río municipalities, where there is high social vulnerability to floods because of housing development in inappropriate, frequently flooded areas. This was demonstrated in 2005 and 2010 when hurricanes Stan and Karl (respectively) hit the coastal plain of Veracruz State, especially in the area of Veracruz and Boca del Río (Tejeda-Martínez, 2005).

Although the Alvarado Lagoon System relies economically on the sugar cane crop and cattle ranching, there are alternatives to stop or reduce the conversion of land to sugar cane crop, such as payments for ecosystem services to landowners, as explained in (UNCSD and UNCTAD, 2011). This would be a strong economic incentive to landowners, both farmers and ranchers. Thus, conservation and restoration might realize both ecological and economic goals under different time schedules. Additionally, strategies to adapt to and mitigate climate change recommend taking into account fragility and vulnerability due to sea level rise. The ALS is a fluvial deltaic plain of uniform elevation, and its urban populations such as Alvarado, Acula and others are extremely vulnerable to this phenomenon. The Ministry of the Environment (SEMARNAT by its Spanish acronym) considers it to be one of the more vulnerable sites in the Gulf of Mexico. Hence, better practices based on land planning through an integrated view of coastal management, with the cooperation of all economic sectors related to wetlands use, should be implemented and monitored as an adaptation strategy to climate change.

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Trade-offs in fishery yield between wetland conservation and land conversion on the Gulf of Mexico

César Vázquez-González [a], Patricia Moreno-Casasola [a, *], Abraham Juárez [a, †], Nadia Rivera-Guzmán [a], Roberto Monroy [a], Ileana Espejel [b]

[a] Red de Ecología Funcional, Instituto de Ecología A.C., Carretera antigua a Coatepec 351 Col. El Haya, Xalapa, Veracruz, Mexico
[b] Facultad de Ciencias, Universidad Autónoma de Baja California, Carretera Tijuana-Ensenada, Baja California, Mexico

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1. Introduction

Wetlands are recognized as highly productive ecosystems because of the goods and ecosystem services that they provide (Mitsch and Gosselink, 2007). Mangroves are among the most productive coastal wetlands (Ewel et al., 1998), and one of their most important ecosystem functions is as a habitat for the juveniles of both crustacean and fish species consumed by humans and traded in local and international markets (Costanza et al., 1989; Millennium-Ecosystem-Assessment, 2005). Freshwater wetlands are among the most productive ecosystems in the world and, similarly, are of great importance due to their additional ecosystem functions (Drew et al., 2005; Zedler and Kercher, 2005), including their natural litter fall productivity (Infante-Mata et al., 2012; Moreno-Casasola et al., 2012), their role as a habitat for species caught by fishermen (Ewel, 2010; Hamerlynck et al., 2011; Knowler et al., 2003) and their nutrient contribution to water bodies (Fisher and Acreman, 2004; Posthumus et al., 2010).

Based on the market value of fishing in Louisiana, the economic value of coastal wetlands was estimated at $317 to $846 USD/acre/1983 (Costanza et al., 1989). On the Gulf of Thailand, the economic importance of mangroves based on their providing habitats that increase fishing productivity was estimated at $83.69 to $110.23 USD/ha/1993 (United States dollar, USD) (Barbier, 2000). In Pakistan, the economic value of mangrove shoreline was calculated at $1,287 USD/ha/2005, highlighting the economic relationship between *in situ* mangroves and *ex situ* local communities (Pervaiz and Lftikhar, 2005). In Latin America and the Caribbean more than 15 million biomass tons were caught in 2010, and over 80% of this was associated with estuarine environments such as mangroves and brackish lagoons (Salas et al., 2011). This is supported by a study carried out by Aburto-Oropeza et al. (2008), in which they estimated the value of mangroves at $37,500 USD/ha/year based on their value to commercial fishing in the Gulf of California. Another estimate for mangroves was $895 USD/ha/year because they offer habitat and refuge from predators (Sanjurjo et al., 2005) based on information from the fishermen's organization, their mode of fishing, and the percentage of mangrove cover.

Few studies have focused on valuing the economic importance of freshwater wetlands from the perspective of the ecosystem services provided by these habitats. Knowler et al. (2003) obtained values of C$1,322 to C$7,010 (Canadian Dollars) per kilometer by correlating freshwater wetland cover and salmon fishing productivity, and concluded that managers must take into account the trade-offs between ecosystem services and land use alternatives in order to optimize the benefits that can be obtained from wetland conservation. This is an example of the economic valuation of ecosystem services as a practical measure to help decision-makers, rather than just an exercise that can create a blindspot, a problem characteristic of various economic valuation studies (Laurans et al., 2013). The economic contribution of the freshwater wetlands of the floodplains and lakes of Tanzania to local fisheries was between $0.2 and $0.8 USD/fishery/hour, depending on management regime and water flow (Hamerlynck et al., 2011). Also, Ewel (2010) mentioned that the value of fishery products obtained from forested wetlands on the island of Kosrae, Federated States of

* Corresponding author.
E-mail address: patriciamorenoc@gmail.com (P. Moreno-Casasola).
† Deceased author.

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Micronesia, was $666,000 USD per year, illustrating not only the importance of mangroves, but also of freshwater forested wetlands.

Despite the importance of wetlands, these ecosystems are still being transformed for anthropogenic activities (Siikamäki et al., 2012). It is estimated that worldwide 3.6 million hectares of mangrove, equivalent to 20% of the total, were lost between 1980 and 2005 (FAO, 2007). Mexico has lost or degraded 62.1% of its wetlands (Landgrave and Moreno-Casasola, 2012) and even though the law protects mangroves and logging is prohibited, López-Portillo and Ezcurra (2002) estimated the annual rate of mangrove loss at 5%. For example, the state of Veracruz, located on the coastal plain of the Gulf of Mexico, has lost 58% of its brackish and freshwater wetlands (Landgrave and Moreno-Casasola, 2012). One of the natural systems in this region most threatened by agricultural activities is the Alvarado Lagoon System (ALS), located in the lower basin of the Papaloapan River. In the ALS 14.5% of its freshwater wetland and mangrove area has been transformed into sugarcane crops (mainly by draining freshwater wetlands) and 65.5% into livestock pastures (Vázquez-González et al., 2014). This conversion has reduced the habitat of harvested species (clams) and of those used in fisheries (crustaceans and fish) (Juárez-Eusebio, 2005; Moreno-Casasola et al., 2012). The reduction in the surface area of freshwater forested wetlands and broad-leaved and cattail marshes has also resulted in a decrease in the quantity of nutrients and organic matter relative to that of neighboring rivers and lagoons (Drew et al., 2005; Ewel, 2010). Thus, fishing activity in the ALS is in danger due to the loss of wetland habitat and corresponding decline in the productivity of water bodies because of pollution and overfishing.

The objective of this study was to estimate the economic value of mangroves and freshwater wetlands based on the commercial value of fishing in the ALS and to determine whether there is any statistical correlation between economic output and the different types of wetland cover. We compared the monetary value of fishermen's cooperatives with the monetary value of raising livestock and growing sugarcane, the two main productive activities replacing wetlands. At the national and international levels, this analysis will enable decision makers to choose the most profitable option in direct and indirect economic terms based on the activities upon which local communities depend. It also provides a basis for regional planning and development to select the best economic alternative, as proposed by Aburto-Oropeza et al. (2008) and Knowler et al. (2003) for Mexico and Canada, respectively. This approach provides a model for the economic valuation of fisheries, linking them to the wetland gradient of coastal areas, including a variety of wetland vegetation, thus helping to manage and conserve wetlands.

2. Methods and materials

2.1. Description of the study area

In Mexico, there are more coastal wetlands than inland wetlands (Olmsted, 1993). Coastal wetlands are located on coastal plains and are formed by estuaries with mangroves bordering lagoons, seagrass, forested wetlands, broad-leaved and cattail marshes. These establish along salinity and flood gradients (Mitsch and Gosselink, 2007; Moreno-Casasola et al., 2009; Odum, 1961). However, in many regions of Mexico, such as the Alvarado Lagoon System (ALS), wetlands have been transformed into flooded grasslands for grazing cattle or drained for crops (Guevara and Moreno-Casasola, 2008; Vázquez-González et al., 2014).

The ALS is located on the central coastal plain of the state of Veracruz on the western Gulf of Mexico. With an area of 373,021 ha, the ALS covers 8.15% of the Papaloapan River Basin and 22.85% of the lower basin (Vázquez-González et al., 2014). The region is the largest lagoon-wetland complex in the state of Veracruz and sustains many fisheries (Moreno-Casasola and Infante-Mata, 2010) (Fig. 1). The ALS is an estuarine lagoon with the seagrass *Ruppia maritima*, surrounded by mangrove, and also has several oligohaline water bodies surrounded by freshwater wetlands (Contreras-Espinosa and Warner, 2004; Rivera-Guzmán et al., 2014). The latter authors describe salinity changes, especially in the main water body of Alvarado, from freshwater values during the rainy season to brackish during the dry season.

The study region has thirteen municipalities, rather than the nine cited by Vázquez-González et al. (2014) based on the administrative region known as the ALS. We decided to include four more municipalities (Cosamaloapan, Chacaltiaguis, Tierra Blanca, and Tlalixcoyan) that overlap the Papaloapan Basin. During field work (interviews with fishermen in 2007, field vegetation analysis and mapping in 2009, and analysis of database was in 2013), we realized these four municipalities engage in fishing activities in nearby lagoons, though not all of them have fishing cooperatives. Hereafter, references to the ALS encompass the 14 municipalities mentioned (Fig. 1).

In the ALS, crop cultivation and raising livestock are the main types of land use, with sugarcane crops representing 22.52% (50,318 ha) and livestock pastures 33.49% (73,747 ha) of the area (Fig. 2).

2.2. Brief socioeconomic description of the ALS

In each of the 14 municipalities, more than 25% of the population works in the primary sector (agricultural and fishing activities). Ixmatlahuacan has the highest proportion of people employed in the primary sector at 61.5%, and Carlos A. Carrillo, where the San Cristobal sugarcane mill is located, has the highest proportion of its inhabitants working in the secondary sector (36.1%) (CONAGUA-CONACYT-48247, 2009). In the municipality of Tierra Blanca, livestock and sugarcane activities employ 28% of the population working in the primary sector; activities that had a production value of $12.5 and $5.6 million USD, respectively, in 2012 (Table 1). Fishing is also a common way to make a living for local populations, and in the study area more than 10,000 fishermen belong to 84 fishing cooperatives for a total of 2,500 families that are directly dependent upon fishing activities; an additional 1,500 people are not organized into cooperatives (CONAGUA-CONACYT-48247, 2009). This highlights the importance of the primary sector in the regional economy. However, there are trade-offs when considering the allocation of land for agricultural purposes versus the conservation of the freshwater wetlands and mangroves that maintain fishing productivity levels (Vázquez-González et al., 2014).

2.3. Characterization and productivity of riverine fishing

From the regional study by CONAGUA-CONACYT-48247 (2009), we obtained the number of fishing cooperatives in the ALS (Fig. 4) and the area their work covers within the wetlands. We surveyed 39 of the 84 cooperatives listed in this study (46% of the total) (CONAPESCA, 2006). We gave our questionnaire to six members of each cooperative, for a total of 234 questionnaires. Members were asked about the number of people in the cooperative, the name of the lagoon or water body where they operated, the biomass of crustaceans and fish extracted, fishing methods used, and seasons of capture. In this paper, we will only present the information obtained for the six most representative species based on their yearly levels of marketing and consumption: snook (*Centropomus undecimalis*), chucumite (*Centropomus parallelus*), tilapia (*Orechromis mossambicus*), shrimp (*Macrobrachium acanthurus*), and crab (*Callinectes rathbunae* and *Callinectes sapidus*).

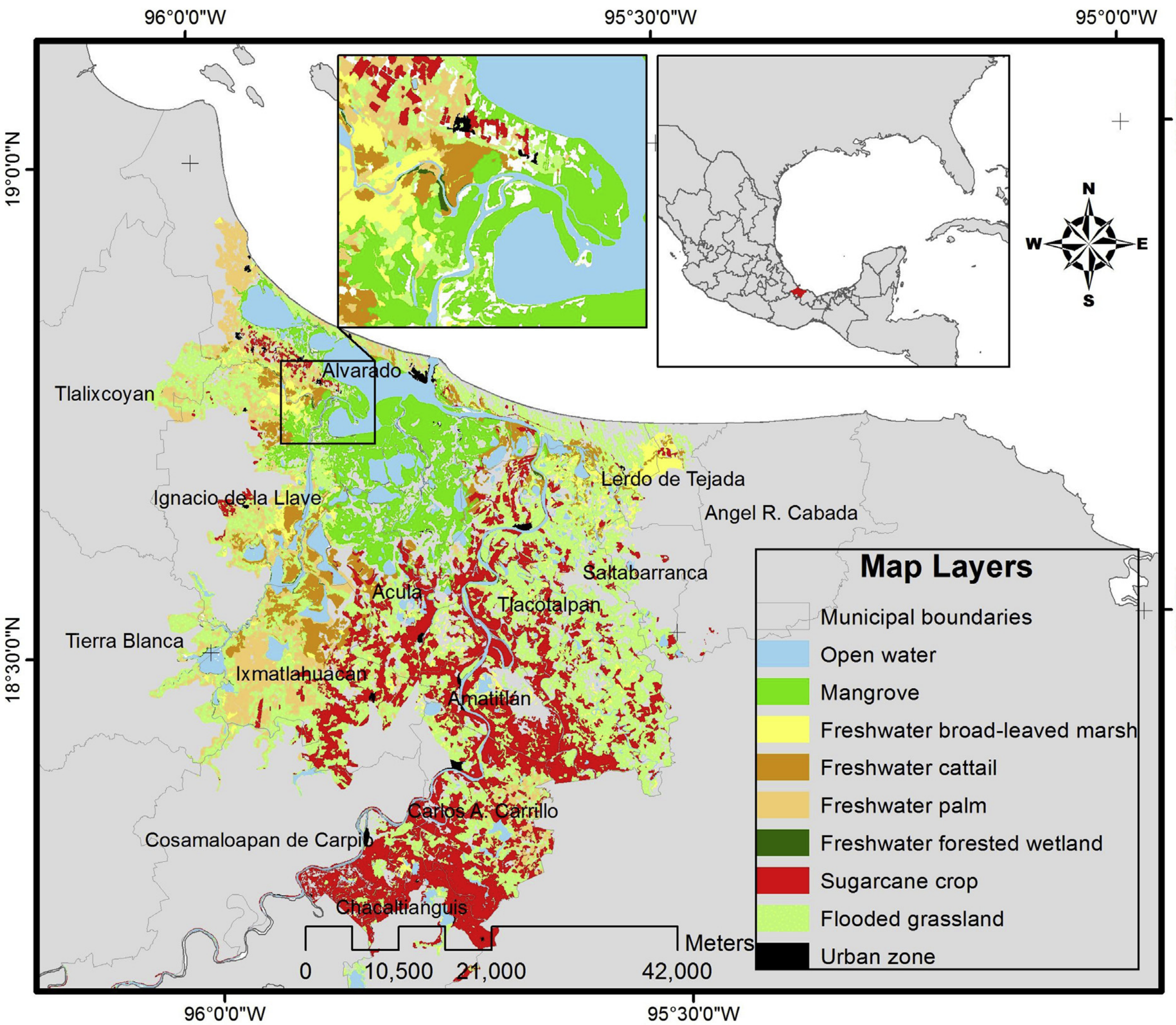

Fig. 1. Study area. Vegetation cover and land use in the Alvarado Lagoon System (ALS). The land use and vegetation maps are from the Coastal Wetlands Inventory of the Papaloapan River Basin (CONAGUA-CONACYT-48247 Research project (2009)). Projected Coordinate System: North America Lambert Conformal Conic, Datum: ITRF 1992. Mangroves are dominated by *Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemosa*. Forested wetlands are dominated by *Pachira aquatica* and *Annona glabra*. Freshwater palm wetlands (hereafter, palm wetlands) are dominated by *Sabal mexicana*, *Quercus oleoides*, *Coccoloba barbadensis*, *Achatocarpus nigricans*, *Daphnopsis americana*, and *Casearia corymbosa*, among other species in a grass matrix. Freshwater broad-leaved marsh is dominated by *Pontederia sagittata*, *Thalia geniculata*, *Sagittaria lancifolia*, *Leersia ligularis*, *Eleocharis cellulosa*, *Cyperus articulatus*, *Typha domingensis*, *Phragmites australis*, *Zizaniopsis miliacea*, *Cyperus giganteus* and *Hymenachne amplexicaulis*. Freshwater cattail marsh is dominated by *Typha domingensis*. Flooded grasslands are areas were there used to be freshwater wetlands (forested and herbaceous) that have been transformed into flooded pastures (see Moreno-Casasola et al. (2012)).

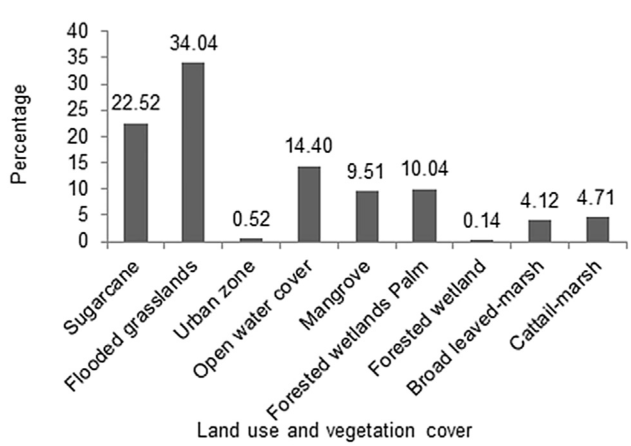

Fig. 2. Land use and vegetation cover in the Alvarado Lagoon System (ALS). Prepared with the Geographic Information System from CONAGUA-CONACYT-48247 (2009).

2.4. Commercial value of fishing activity

The study was done in two phases: the first consisted of fieldwork (interviews with fishermen in 2007, field vegetation analysis and mapping in 2009) and for the second part, in 2013 we estimated the commercial value of the six species and did the statistical analysis. We analyzed the results obtained on the fisheries' commercial values (obtained from the 2007 interviews) and following Mankiw (2002), the revenue value was calculated. We estimated the commercial value of fishing production (CVF) per cooperative (i), per species (j), where Qc is the quantity of commercialized biomass that results from subtracting the quantity consumed by the fishermen and their families (Qco) per cooperative (i) and per species (j) from the captured biomass (Qca). Qc was multiplied by the average price (AP) per species (j) (Eq. (1)). We decided to subtract the quantity consumed (Qco) because we were only interested in the quantity commercialized and its net commercial value.

Table 1
Socioeconomic description of the fourteen municipalities located in the Alvarado Lagoon System included in this analysis. The highest values are in bold.

Abbreviation	Municipality	Population	Population employed by each economic sector (%)			Total production value (millions in USD)		Number of fishing cooperatives
			1st	2nd	3rd	Livestock	Sugarcane	
M1	Acula	8,223	48.5	15.3	33.9	0.8	4.6	5
M2	Alvarado	51,955	34.2	18.3	47.5	11.0	0.6	**59**
M3	Amatitlán	7,487	43.5	17.1	38.1	1.0	10.4	1
M4	Angel R. Cabada	33,528	39.7	15.0	44.7	4.0	26.1	1
M5	Carlos A. Carrillo	22,907	17.7	**36.1**	45.4	1.4	11.8	
M6	Chacaltianguis	11,638	57.1	12.9	29.7	1.0	13.2	1
M7	Cosamaloapan	57,366	22.4	17.3	59.7	1.8	44.6	
M8	Ignacio de la Llave	17,121	41	18.0	40.8	11.1	0.4	3
M9	Ixmatlahuacan	5,727	**61.5**	8.5	29.8	2.6	8.7	6
M10	Lerdo de Tejada	20,141	9.9	26.0	**62.4**	0.7	8.5	1
M11	Saltabarranca	5,908	39.5	17.3	42.6	1.3	5.9	3
M12	Tierra Blanca	**94,087**	25.8	19.6	54.1	**12.5**	**50.0**	1
M13	Tlacotalpan	13,284	28.4	18.9	50.9	6.8	8.4	3
M14	Tlalixcoyan	37,037	40.3	15.2	43.2	12.2	5.6	1

Data are from SEFIPLAN (2013) handbooks of municipality information. The location of the fishing cooperatives was obtained using the Geographic Information System from the CONAGUA-CONACYT-48247 project (2009).

Eq. (1). Commercial value of fishing production (CVF) for each cooperative (i) and species (j)

$$CVF_{ij} = \left[Qc_{ij} = \left(Qca_{ij} - Qco_{ij}\right)\right] * AP_j \quad (1)$$

2.5. Testing the correlation between the commercial value of fishing and vegetation cover

This analysis was based on the methodology used by Aburto-Oropeza et al. (2008) to analyze the correlation between wetland vegetation cover and the productivity of fisheries. A 10-m-wide buffer zone was delimited around the lagoons (Fig. 3), encompassing the area with plants in different types of wetlands, including mangrove and the various types of freshwater wetlands in Fig. 1. This area was considered representative of the habitat and area necessary for the reproduction of each species.

Due to the diversity of wetland vegetation (Fig. 1), a multiple linear regression was run according to Anderson et al. (2008) to estimate the correlation between fishing productivity and vegetation cover type (mangroves, freshwater wetlands such as forested wetlands, palm wetlands, broad-leaved marshes, and cattail marshes), and open water (the lagoons, rivers, and lakes) as the environment being fished. Other types of land use, such as growing sugarcane and flooding grasslands for cattle (Fig. 1 and Fig. 2) were also included to determine the type of correlation (direct or inverse) that exists between the fishing productivity of coastal lagoons and the use of the land that surrounds them. This way, we determined the difference in productivity between lagoons and water bodies surrounded by wetland vegetation, and those

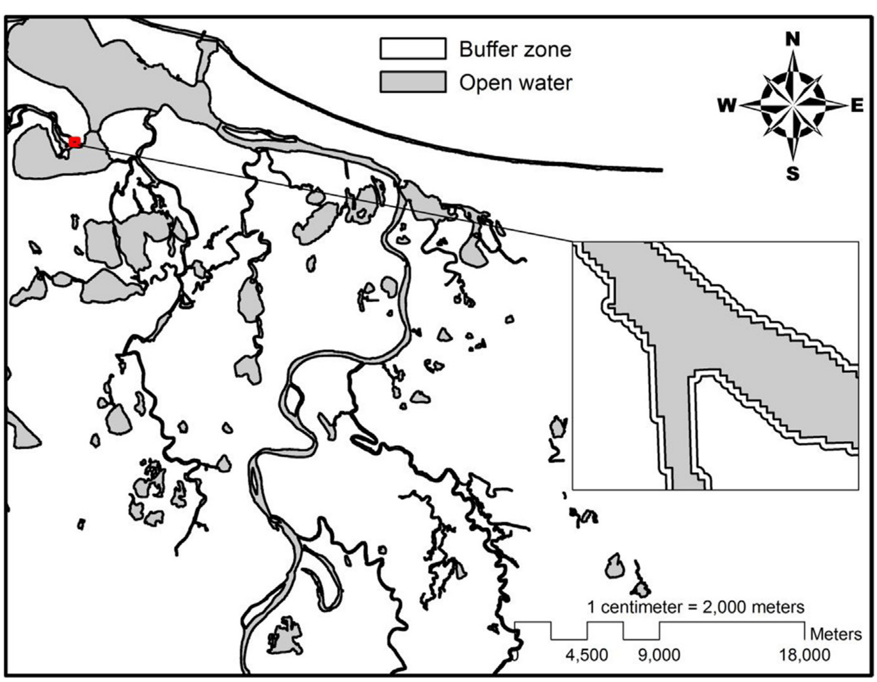

Fig. 3. Buffer zone (10 m wide) around open water (lakes, lagoons, and rivers). Wetland types bordering the bodies of water are as in Fig. 1. Cattle ranching in wetlands and drained land used for growing sugarcane were included as well.

surrounded by former wetlands transformed into livestock pastures and sugarcane crops.

We also ran a statistical analysis of the significance coefficient, calculating the standard error and p level for each coefficient, the R square and p level, and the F statistic and its p level for the multiple regression. The analysis was run in SPSS statistical software.

2.6. Comparison of our results and those of other studies

In order to be able to compare our results, which are based on the prices of 2007, with those of other studies done in other years, we updated the monetary values using Eq. (2) from Mankiw (2001), where $Value_0$ is the value today, CPI_{2007} is the consumer price index in 2007 and CPI_0 is the consumer price index in the year of the value that is used for updating and for comparison. The consumer price index was taken from INEGI (2013), the National Institute of Statistics and Geography that is in charge of calculating consumer prices.

Eq. (2). Updating monetary values

$$Updated\ value = \frac{Value_0 * CPI_{2007}}{CPI_0} \tag{2}$$

3. Results

3.1. Location of fishing cooperatives and their density per water body

The majority of the fishing cooperatives surveyed was located in the estuary and at the mouth of the Alvarado Lagoon, near the town of Alvarado (Fig. 4); the next most common locations were Ixmatlahuacan and Acula. In the other municipalities, only a few cooperatives —one to three— were surveyed in each.

The density of cooperatives on each lagoon or river of the ALS varied, with more fishermen using brackish water bodies. Fishermen reported fishing on 88 lakes and 10 rivers, in addition to the coastline environment. The Alvarado Lagoon and Acula River had the highest number of fishing cooperatives (between 33 and 45) and the highest extraction levels in terms of biomass. The Camaronera, Tlalixcoyan, and Las Pintas lagoons had between 15 and 32 cooperatives each (Fig. 5).

3.2. Capture and commercial value of fishing

The most biomass captured per year was 3,290 tons of tilapia, followed by 1,761 tons of chucumite, and the lowest was 271 tons of shrimp. The capture of the other harvested species, snook and crab, was 694.3 and 1,420.6 tons, respectively. Total consumption (84 cooperatives) was 424.7 tons: chucumite (149.7 tons), tilapia (113 tons), and shrimp (25.9 tons) and the other three species (136 tons).

Estimated commercial value varied for each species depending on the quantity commercialized and the average price per kilogram (Table 2). The total annual commercial value of fishing activities was estimated at 23.6 million USD for 2007 for the six commercial species used in this analysis. Although the fishermen stated that 81 other species are also fished, and this was confirmed by the annual databases of CONAPESCA (2006), these species were not included in this study because the information available for them was not consistent enough to include in the statistical analyses. The total commercial value of tilapia was 7.8 million, chucumite 6.9 million, snook 4.4 million, crab 2.8 million, and shrimp 1.6 million. Quantities reported in Table 2 are underestimates because they are only based on the cooperatives whose members we interviewed, *i.e.* 46% of the total. The values for the entire ALS could potentially be twice the values we report.

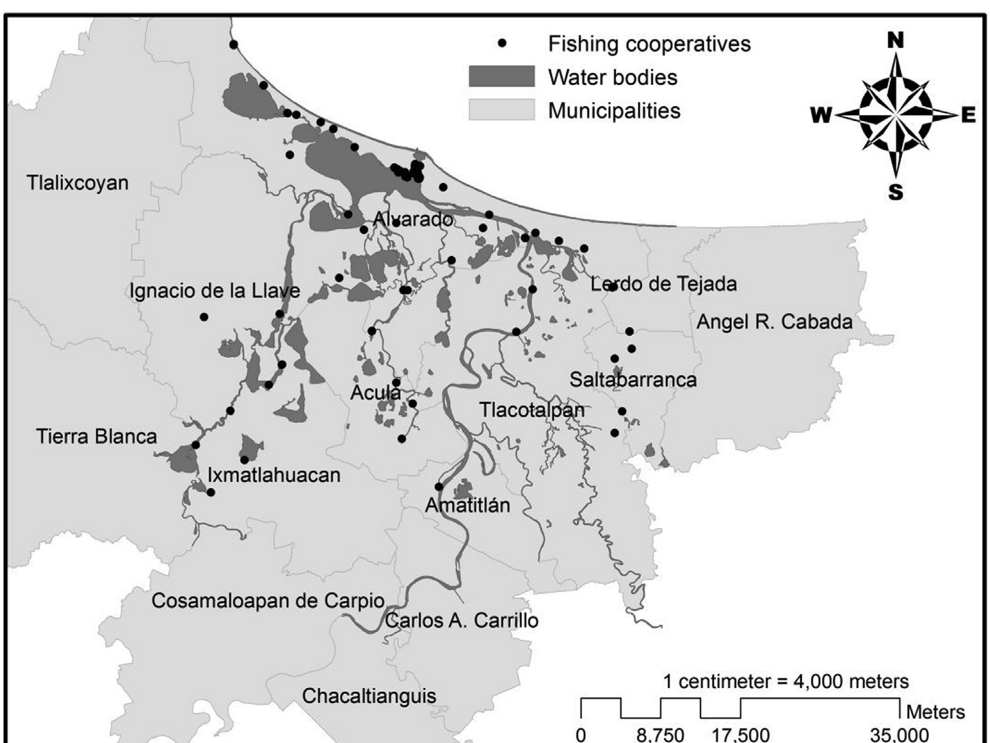

Fig. 4. Location of fishing cooperatives in the Alvarado Lagoon System (ALS) (CONAGUA-CONACYT-48247, 2009).

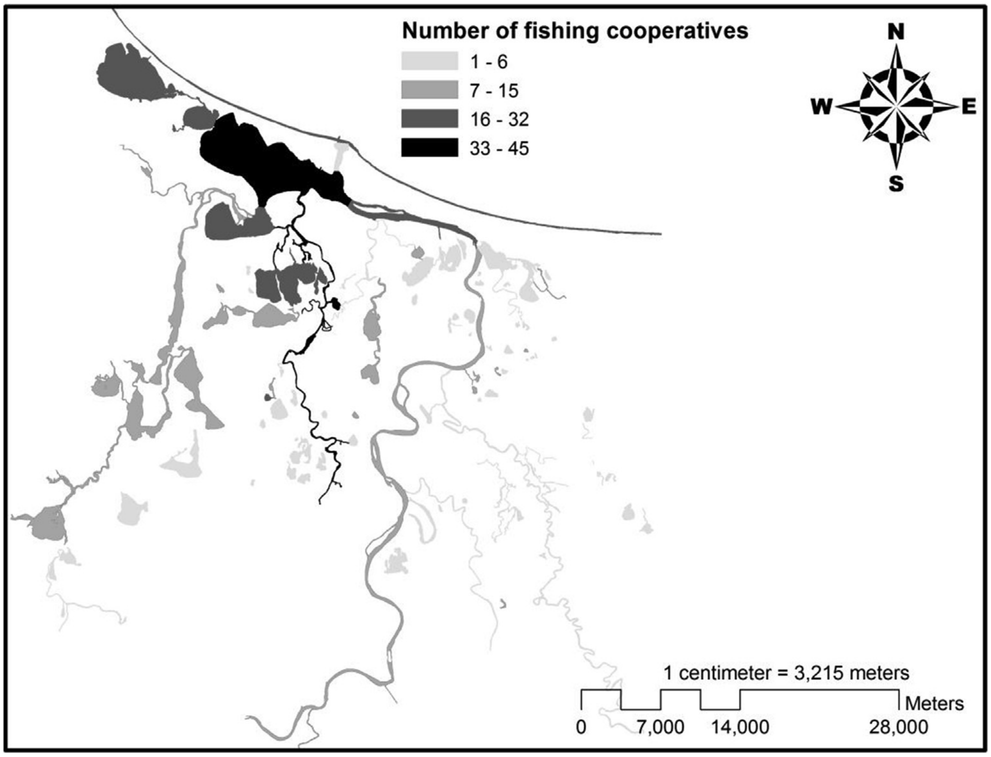

Fig. 5. Density of fishing cooperatives per water body in the Alvarado Lagoon System (ALS).

Table 2
Estimates of captured biomass, consumption by the fishermen and their families, commercialized quantity, average price per kilogram of sold product, and fishing commercial value in 2007 or the six main species reported by the 39 cooperatives surveyed.

Species	Captured biomass (ton)	Consumption (ton)	Commercialized quantity (ton)	Average price per kilogram (kg)	Fishing commercial value (millions of USD)
Chucumite	1,761.3	149.7	1,611.6	4.3	6.9
Snook	694.3	59.8	634.4	6.9	4.4
Tilapia	3,290.0	113.0	3,177.0	2.5	7.8
Shrimp	270.9	25.9	244.9	6.7	1.6
Crab (two species)	1,420.6	76.2	1,344.4	2.8	2.8
Total	**7,437.1**	**424.7**	**7,012.5**		**23.6**

The price and the commercial value are in American dollars (USD) (10.9 pesos for 1 dollar), based on the exchange rate in 2007 published by BANXICO (2013).

3.3. Correlations among vegetation coverage, fishing productivity, and wetland value

Table 3 shows the coefficients of the linear regression for each independent variable (vegetation type) as predictors of biomass productivity within the 99 lagoons, rivers, and coastline of the study area. Using a 10-m-wide buffer zone from the edge of the water bodies out toward the vegetation cover, sugarcane was negatively correlated with biomass productivity (coefficient: −0.0561), as were the flooded grasslands (coefficient: −0.0565). Mangroves had the highest correlation (0.6735), followed by the broad leaved-marsh (0.0372), palm wetland (0.0336), cattail marsh (0.0251), and forested wetland (at 0.0423). Thus, the vegetation cover of mainly mangroves and freshwater wetlands is associated with an increase in fishing productivity, and productivity decreases when wetlands are transformed into sugarcane crops (including drained areas) or used for cattle ranching. Therefore, as the intensity of wetland transformation increased fishing productivity decreased.

The range of commercial values for coastal wetlands was $825 (palm wetland) to $18,849 USD/ha/2007 (mangrove) (Table 3). For every hectare of coastal wetland that is lost, there was a decrease in value due to the direct relationship between vegetation cover, habitat quality, and fishing productivity as indicated by the regression coefficients. For every hectare converted to sugarcane, $5,882 USD/ha/2007 is lost due to the inverse relationship with fishing productivity in the ALS, and when wetlands are converted to flooded pastures for livestock, the economic loss is $1,133 USD/ha/2007 (Table 3).

All of the coefficients estimated in the analysis were significant (Table 3), except for the palm wetland, for which the standard error was over 5% and its p level greater than 0.05. The F statistic for the multiple regression was 11.24 with a p level less than 0.03, indicating that the multiple regression result is significant in general terms.

By multiplying the value per hectare of existing wetlands in the ALS by vegetation cover, as based upon the fishing commercial value for each type of coastal wetland, including the negative values (sugarcane and flooded grassland pastures) (Table 3), we found that the 2007 ecosystem value of wetlands owing to fisheries productivity was $495.54 million USD per year (Table 4).

Table 3
Linear regression between the commercial value of fishing and type of wetland vegetation cover or land use.

Independent variable	Regression coefficient	Commercial value per ha (USD/2007)	Standard error (±5%, USD)	*p* level
Type of wetland				
Mangrove	0.6735	18,849	29	0.00
Broad-leaved marsh	0.0372	5,394	228	0.04
Forested wetland	0.0423	5,066	218	0.04
Cattail marsh	0.0251	2,401	116	0.04
Palm wetland	0.0336	825	51	0.06
Land use				
Sugarcane crop	−0.0561	−5,882	166	0.04
Flooded grassland	−0.0565	−1,133	33	0.04

Value of $R^2 = 0.7$, $p < 0.004$, Intercept = 161,085.52 USD.
F statistic (7,91) = 11.24, $p < 0.03$.

Table 4
Total commercial value per type of vegetation cover and land use in the Alvarado Lagoon System obtained by multiplying the commercial value per hectare (Table 3) by the total vegetation cover for 2007.

Land use and vegetation cover	Total cover (thousands of hectares)	Economic value derived from fishing productivity (millions of USD)
Type of wetland		
Mangrove	21.25	400.50
Broad-leaved marsh	9.21	49.68
Forested wetland	0.31	1.60
Cattail-marsh	10.52	25.27
Palm wetland	22.42	18.49
Total produced by wetlands		**495.54**
Land use		
Sugarcane	50.32	−295.99
Flooded grasslands	76.05	−86.20
Total wetlands value minus land use value		**113.35**

4. Discussion

The commercial value of fishing associated with mangroves, freshwater forested wetlands, palm wetlands, and freshwater broad-leaved marshes are among the highest reported values (Table 5); greater than those obtained by Costanza et al. (1989) and De la Lanza Espino et al. (2013). We estimate the commercial value of mangroves at $18,849 USD/ha/2007 based on fishing productivity. However, there are some exceptions, since Aburto-Oropeza et al. (2008) reported values of $37,500 USD/ha/year for mangroves. The highest estimate in the literature was for the lagoon environment (forest and thickets) at $62,209.7 USD/ha, reported by De la Lanza Espino et al. (2013). It is worth noting that those authors obtained economic values for freshwater wetlands ranging from $825 to $5,394 USD/ha/2007, the latter very close to the values reported by Knowler et al. (2003) for salmon fisheries ($5,838 USD/ha/2007). Our results show that the fishing value of one hectare of mangrove is slightly higher than that of 4 ha of freshwater wetlands (Table 3).

We compared several studies on the economic valuation of fishing activities under a variety of scenarios, *i.e.* in different types of environment, different types of fishing (riverine, commercial, recreational), and for different years (Table 5). Not all studies are comparable since, for example, the values used by De la Lanza Espino et al. (2013) were decided by experts during workshops. Also, the value reported by Aburto-Oropeza et al. (2008) for mangroves is much higher than that found in our study, mainly because the value of fisheries in the area of Baja California included species with a high commercial price (lobster, scallops). In the Alvarado region, the species with the highest commercial value are red snapper and shrimp, among others, which are now extracted in low quantities or have almost disappeared due to overfishing and pollution (Juárez-Eusebio, 2005). Although the fishing cooperatives of the ALS are formally constituted, they are less organized than those of Baja California and rarely sell the product directly to the consumer or have any control over pricing. Therefore, despite the high overall commercial value of fishing, the income of fishermen is lower in the ALS than that of fishermen in regions like Baja California.

Given the commercial value of fisheries, the results of this analysis highlight the real value of the ecosystem services that wetlands offer with respect to the habitat they provide. It differs from the gross values estimated by Camacho-Valdez et al. (2013), who used the benefit transfer method to calculate the values for mangrove and from those of De la Lanza Espino et al. (2013) who extrapolated values from other study areas, standardizing them without taking into account the difference between gross values and values reported by the benefits generated in local areas.

The present study not only provides estimates of the economic value of mangroves and freshwater wetlands in terms of their cover and the relationship between cover type and fisheries productivity, but also demonstrates the inverse relationship between economic value and livestock and sugarcane cropping: the commercial value of fisheries decreased for each hectare transformed into sugarcane plantations or livestock pastures (Table 3 and 4). Knowler et al. (2003) showed the importance of habitat quality and economic value, and our comprehensive analysis confirms the importance of ecosystem services offered by coastal floodplains and lagoon systems. We also show the value of protecting the ecosystem services provided by natural habitats and the importance of preventing land use changes in freshwater wetlands.

This analysis focused on the entire Alvarado Lagoon System, which is composed of estuarine and freshwater wetlands. Calculations of fishing values should be system-focused and include the entire floodplain, where gradients develop and affect different processes, such as nutrient exchange, which vary among mangrove, freshwater herbaceous vegetation, and forested wetlands. There are no data on nutrient contribution by wetland type, but

Table 5
Comparison of the economic value of fisheries. Values estimated by different authors for different types of coastal wetlands and/or environments. Original values were adjusted to 2007 rates for comparison.

Study	Study area	Environment and/or wetland vegetation	Type of fishery activity	Original values (USD/ha)	Updated value (2007) (USD/ha)
This study	Papaloapan River Basin, Gulf of Mexico, Mexico	Mangrove	Riverine-commercial	18,849	18,849
		Broad-leaved marsh	Riverine-commercial	5,394	5,394
		Forested wetland	Riverine-commercial	5,066	5,066
		Cattail marsh	Riverine-commercial	2,401	2,401
		Palm wetland	Riverine-commercial	825	825
Costanza et al. (1989)	Louisiana, USA	Coastal wetlands	Commercial	846	1,274
Rönnbäck (1999)	Worldwide	Mangrove	Seafood production	16,750	25,124
Woodward and Wui (2001)	Worldwide	Wetlands	Recreational fishing	1,342	9,902
			Commercial fishing	5,618	41,455
Knowler et al. (2003)	British Columbia, Canada	Freshwater wetland	Riverine-commercial	7,010[a]	5,838
Aburto-Oropeza et al. (2008)	Gulf of California, Mexico	Mangrove	Commercial	37,500	37,500
Huu Tuan et al. (2009)	Tam Giang–Cau Hai, Vietnam	Lagoon-wetland	Aquaculture	518	468
			Capture fishes	350	316
de Groot et al. (2012)	Worldwide	Coastal wetlands[b]	Nursery services for fishing species	17,138	13,807
Camacho-Valdez et al. (2013)	Sinaloa, Mexico	Coastal lagoon	Commercial	27	32
			Recreational	77	90
		Saltmarsh unconsolidated	Commercial	459	538
		bottom	Recreational	922	1081
		Saltmarsh forested mangrove	Commercial	3,386	3,971
		Riverine	Commercial	39	46
De la Lanza Espino et al. (2013)	Mexico	Coastal plain	Commercial	713	836
		Coastal plain	Recreational	10,915	12,802
		River	Commercial	3,748	4,396
		River	Recreational	1,109	1,301
		Lagoon system	Commercial	957	1,122
		Lagoon system	Recreational	957	1,122
		Lagoon system-(shrub/forested)	Commercial	53,039	62,210
Tuya et al. (2014)	Grand Canary Island	Sea grass (large fish)	Commercial	132[c]	99
		Sea grass (small fish)	Commercial	1,194[c]	897

The economic values in this study were estimated using data from 2007 (original values), as were the prices from Aburto-Oropeza et al. (2008). The values estimated by Costanza et al. (1989) are based on 1983 prices, and those of De la Lanza Espino et al. (2013) were estimated based on 2003 prices.
[a] Original value in Canadian Dollars.
[b] According to the authors, these include tidal marshes, mangroves, and salt water wetlands.
[c] Original value in Euros.

productivity data measured as leaf fall indicates that forested freshwater wetlands are as productive as mangroves (Infante-Mata et al., 2012), though this particular type of wetland covers a very small area in the ALS (Fig. 2). The commercial value for the five species used in this study amounted to $23.6 million USD per year (Table 2). However, the value obtained for the different types of wetlands varied greatly. The mangrove and estuary system are the most productive in terms of fishing (Fig. 5 and Table 3). This is socially recognized by the local population as most of the co-operatives (33–45 groups) fish in this area, with fewer cooperatives working in the wetlands located further inland (Fig. 5). Also, the species that fisheries extract is variable in areas with a more limited variety of fish where salinity does not change throughout the year.

Potentially, if the area that has been transformed to sugarcane to date were restored, the productivity of the lagoons and rivers would increase in proportion to the biomass captured. Maintaining current prices, the fishing commercial value would increase according to the values shown in Table 5. In contrast, while the commercial value of sugarcane production reached $4,338 USD/ha/2011 (SIAP, 2011), this does not reflect the decrease in fishery value that can be attributed to sugarcane farming and its inverse relationship with the productivity of fisheries: $2,228.95 USD/ha/2007 less per year (Table 3). Water pollution produced by sugarcane mills is another important external factor that is not taken into account. Local fishermen said that when the mill is active and dumps water used during refining, many dead fish are found floating in the river and lagoons. The Mexican government continues to offer a variety of incentives for planting sugarcane, including the guarantee of its base price (http://www.infocana.gob.mx/campo_fabrica.html), medical insurance to land owners, subsidies for producers in highly marginalized locations (SAGARPA, 2013a, c), and financial support for acquiring equipment and infrastructure, among others (see the Ministry of Agriculture, Livestock, Rural Development, Fishing, and Food, SAGARPA's webpage at http://www.sagarpa.gob.mx/ProgramasSAGARPA). However, our results indicate that the government is investing in an unprofitable activity (sugarcane) in coastal areas in cost-benefit terms, especially since growing sugarcane also creates conditions that negatively affect the habitats that are beneficial to fishing, an activity with a higher economic value.

Livestock has a potentially lower impact on fishing activity in ALS. Economic losses from flooded grasslands or pastures used for cattle were less than those from growing sugarcane as they continue to provide nutrients in the form of organic matter. When livestock is present in low numbers (1 or 2 head per hectare) and the land is not drained, pastures can maintain wetland characteristics and functions, making it a more sustainable activity than growing sugarcane (Rodríguez-Medina and Moreno-Casasola, 2013). Livestock provides an important source of income to a large number of people in the ALS and other regions such as the lowlands in Brazil (Junk and Nunes da Cunha, 2012; Moreno-Casasola et al., 2012). Cattle ranching is also supported by the government in the form of an incentive payment for each cow (SAGARPA, 2013b), but this is much lower in value than sugarcane subsidies.

The loss of coastal wetlands in the Alvarado Lagoon System causes a decrease in ecosystem functions and the loss of others, leading to a reduction in economic income because of reduced fishing productivity. Based on projections by CONAGUA-CONACYT-48247 (2009), by 2018 and 2032 the rate of mangrove deforestation in the Alvarado Lagoon System will be 11% and 28%, respectively. This would cause a corresponding decrease in the commercial economic value of fishing of $39.86 million USD (2018) and $101.1 million USD (2032) (Table 4); values that do not take into consideration that this loss also reduces carbon sequestration (Adame et al., 2013; Marín-Muñiz et al., 2011), water storage in the soil and the capacity for flood mitigation (Campos et al., 2011), water purification (Russi et al., 2013), or the provision of raw material for cooking and local housing construction (González-Marín et al., 2012a, 2012b), among the other goods and environmental services provided by wetlands. Were we to include the value of each of these services per hectare of coastal wetland, the economic value of the wetland system would increase considerably.

In addition, Rivera-Guzmán et al. (2014) found that water bodies along the Veracruz coast, including the ALS (Fig. 1), have similar conditions to those recorded in the 1980s, despite increases in population and water pollution. They believe that this is most likely due to the maintenance of wetland cover, which helps keep the water pure. This finding is supported by the results of Cejudo-Espinosa et al. (2008), who estimated the ability of plant species in tropical freshwater herbaceous wetlands (Fig. 1) to retain harmful substances like atrazine, used in the cultivation of sugarcane. Thus, numerous studies show the capacity of wetlands to remove pollution from the water (Fisher and Acreman, 2004).

5. Final considerations

Our results suggest that careful analysis is required in order to define and promote economic and environmental policies that encourage fishing activities, and take into consideration the people who make their living from livestock and sugarcane. The value of fisheries in Alvarado is relatively high and could increase if the most valuable species (in commercial terms) were to be recovered through the conservation and restoration of coastal wetlands and sustainable aquaculture. In addition, stronger organization among fishermen could positively affect outcomes, since technical training and an improved organizational structure would have a positive effect on the functioning of cooperatives and economic return. Likewise, it would be beneficial to encourage an economic enterprise (fishing) that demonstrates a greater economic return than the conversion of wetland for other land uses.

The development of investment strategies based on our findings would provide social and economic benefits to the population of the region. These strategies must take into account all the links in the fishery chain of value, from production (by local fishermen), distribution (by local fisheries), and consumption, to supermarkets and the other establishments that commercialize and use fishing products in local cuisines.

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