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Impact of Shrimp Farming on Mangrove Forest and Other Coastal Wetlands: The Case of Mexico

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1. Introduction

Since the middle of the twentieth century, the shrimp farming industry has shown steady growth along the tropical and subtropical coasts of the world. The world's cultivated shrimp production in 1950 was 1325 tons, amounting just 0.3% of the total production for these crustaceans, which were mainly extracted from coastal and estuarine environments. Thirty years later, by 1982, the global shrimp production surpassed one million tons. By 2009, shrimp production grew to nearly 3.5 million tons valued at approximately 14.6 billion dollars, amounting to 34% of the world's shrimp production, including marine and estuarine catches (Fig. 1) (FAO, 2011).

This escalation has seen intense debate regarding the economic, social and, particularly, environmental impacts produced by this activity. There is special concern for wetland losses, increased organic loading in coastal waters, the introduction of exotic species and the dispersal of harmful diseases (Boyd and Clay, 1998; Primavera, 2006).

The most controversial impact of shrimp farming is related to habitat loss. One of the main concerns is the deforestation of mangrove, a coastal vegetation type recognized as a highly productive shelter habitat for many commercial aquatic species. It has been estimated that between 1.0 and 1.5 million hectares of the world's coasts are covered by some type of shrimp farming (extensive, semi-intensive or intensive systems), and between 20 and 40% of this area is blamed as a cause of mangrove loss (Primavera, 2006). Thailand is considered to be an extreme example of this problem, as mangrove cover in this country was halved from 1960 to 1996. Approximately 200,000 ha of mangroves were deforested, with a third of the area being transformed into shrimp farming ponds (Aksornkoae & Tokrisna, 2004).

Although shrimp farming impacts have been widely documented and discussed, there is little evidence on the real mangrove deforestation rates at regional or national scales due to this activity. Thus, some of the global estimates on mangrove deforestation for shrimp pond construction are imprecise projections based on very local studies or generalizations of extreme cases such as Thailand.
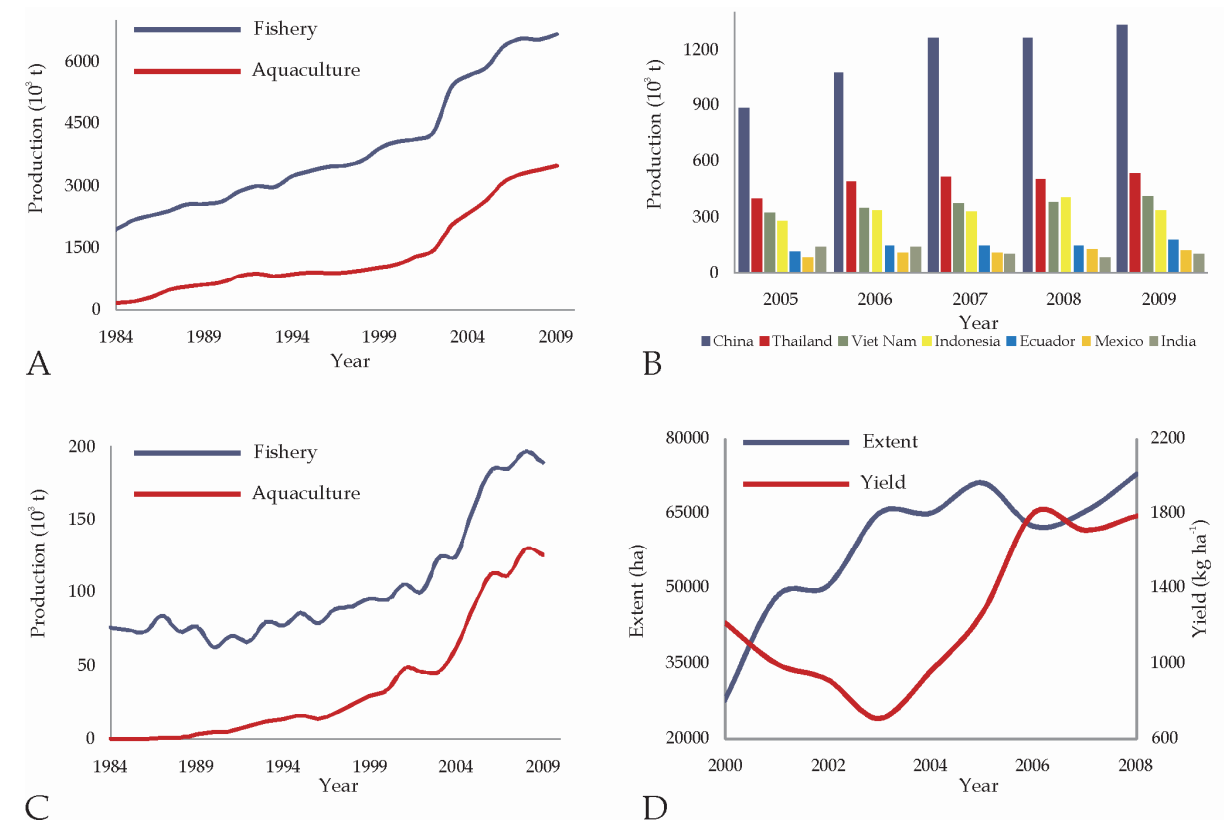
Fig. 1. Shrimp farming indicators: A) World shrimp production (1984-2009). B) Main producing countries (2005-2009). C) Mexican shrimp farming production (1984-2009). D) Extent and annual yield in Mexico (2000-2008).

The objective of the present study was analyze the land use changes caused by shrimp farming in the coastal landscape of Mexico, one of the main producers worldwide, using remote sensing (RS) and geographic information system (GIS) tools within a landscape change framework to contribute to a better understanding of the impacts of shrimp farming on coastal wetlands. The results were then compared with others obtained at different latitudes to gain a more precise knowledge of the responsibility of shrimp farming on mangrove deforestation and other environmental impacts.

1.1 Shrimp farming in Mexico

Shrimp farming has its origin in the late nineteenth century, but it was not until the 1960s and early 1970s that it became a commercial activity (Kungvankij et al., 1986). Mexico followed a similar trend, starting shrimp production in the early 1970s with the operation of an experimental farm to the northwest. However, legal issues related to land tenure complicated this development, particularly for private investments, until the middle 1980s, when laws changed, allowing the expansion of commercial farms, mainly in the same region.

Thereafter, like the rest of the world, shrimp farming in Mexico displayed rapid evolution, growing from 35 t of shrimp production in 1985 to 125,778 t in 2009 (Fig. 1). Profits also increased, from $ 175,000 to 405 million dollars, respectively. The net income by farms in northwest Mexico (semi-intensive systems) has been estimated between US$1.2 and US$2.9

per kg, with feed and seed prices as the major constraints for investors (Ponce-Palafox et al., 2011). However, farmed shrimp production has grown from 0.05% to 40% of the total national production for this crustacean (FAO, 2011), and Mexico is currently positioned among the ten largest producers of farmed shrimp in the world (Fig. 1) (Conapesca, 2009; 2010).

At the country level, shrimp aquaculture is practiced in almost all 17 coastal states. Even in inland locations, there are some initiatives to cultivate the same species used in marine aquaculture but adapted to freshwater environments. Although shrimp aquaculture is widespread nationally, the Gulf of California region is the most highly concentrated region of activity, with the states of Sonora, Sinaloa and Nayarit representing more than 95% of the total shrimp pond extent and production in Mexico. By contrast, Jalisco, Michoacán, Oaxaca, Chiapas and Tabasco together amount to less than 1% (Fig. 2) because physiographic or economic factors have inhibited the development of this activity.

Some species of the genera *Litopenaeus* and *Farfantepenaeus* have been used for commercial purposes, but the white shrimp *L. vannamei* is currently the most common species in culture. This species is grown in one (8-9 months) or two cycles (3-4 months each) a year, obtaining a final weight between 10 to 25 g in the first case and 7 to 11 g in the second. Even when the use of wild postlarvae (PL) is allowed in Mexico, with permission granted for extraction, this activity is sustained by PL production controlled in 33 laboratories that produce in average of approximately 76 million PL per year. The last reliable record of aquaculture in Mexico (CONAPESCA, 2010) states a total output of approximately 72 900 ha as of 2008 (Figure 1). In almost all cases, the shrimp farms use semi-intensive production systems, which, aside from the certified larvae, require substantial amounts of fertilizers to increase natural productivity and complementary feed to maintain stocking densities from 6 to 30 postlarvae per area (PL/m^2).

With this system, and considering the figures on total shrimp pond area and production, the average yield from 2000 to 2008 was 1260 kg ha^{-1} (Fig. 1), although it was lower from 2000 to 2003, when sanitary problems associated with viral diseases occurred, increasing later to approximately 1750 kg ha^{-1}, a level that has been maintained since 2006 (CONAPESCA, 2009; 2010). In agreement with Ponce-Palafox et al. (2011), the top three producer states in Mexico obtained average yields of 800 (Nayarit), 900 (Sinaloa) and 3200 (Sonora) kg ha^{-1} per crop.

2. Methods: Land use changes associated with shrimp farming in Mexico

To analyze the land use changes caused by shrimp farming in Mexico and to estimate rates of coastal wetland loss induced by this activity, we performed a change detection analysis in three steps following a procedure similar to that proposed by Berlanga-Robles et al. (2011). Because shrimp farming in Mexico is concentrated around the northern states, particularly the east coast of the Gulf of California, to make this study representative, four states that account for 97% of this activity in extent and production were chosen for the analysis: Nayarit, Sinaloa and Sonora in the Gulf of California and Tamaulipas in the Gulf of Mexico (Figure 2).

2.1 Shrimp farm location and inventory

First, the shrimp farms of the four states selected were geographically located with a database provided by the National Commission for Fisheries and Aquaculture (CONAPESCA).
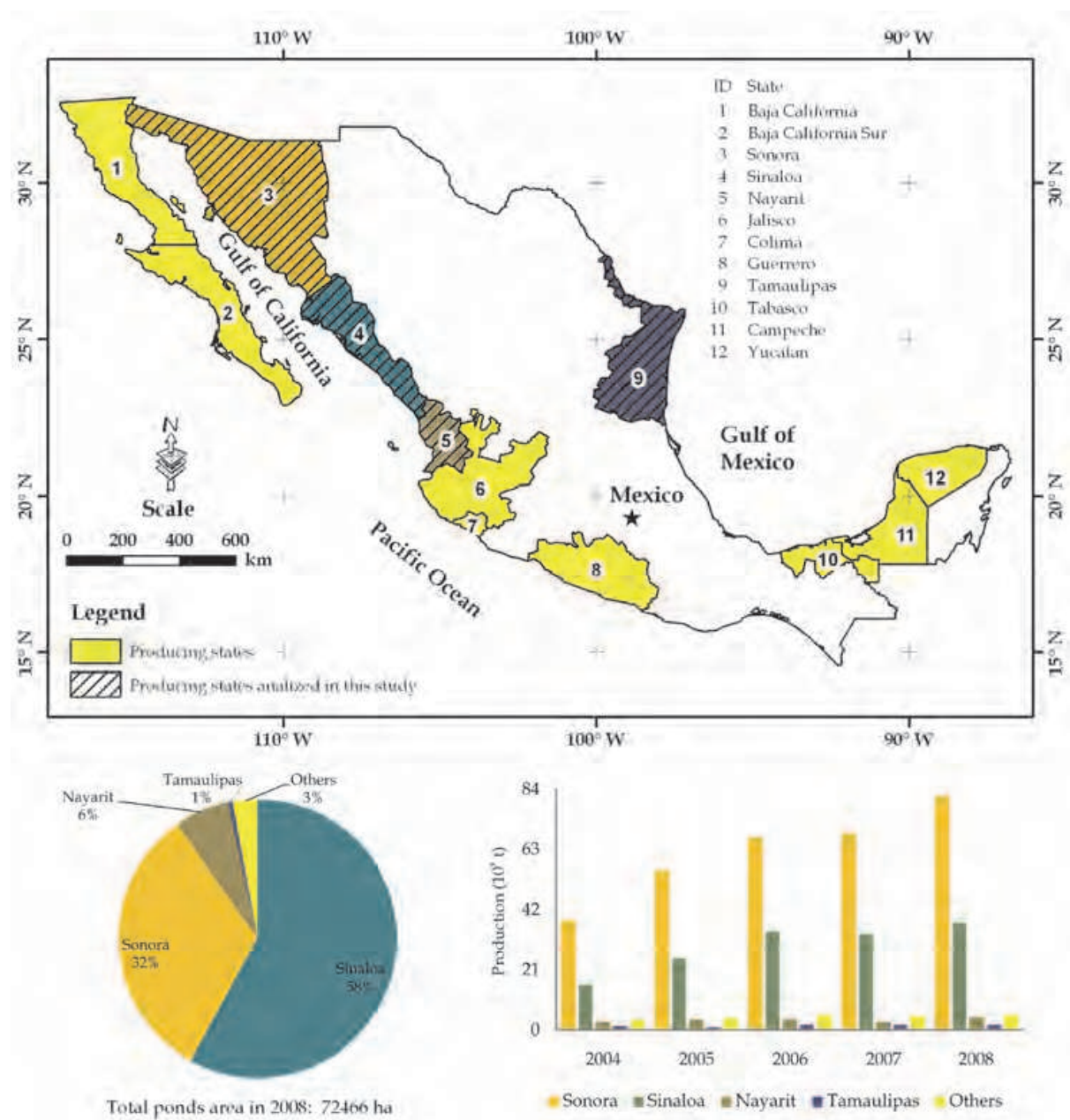
Fig. 2. Shrimp farming in Mexico. The bar graph shows the proportion of pond area by state and the bar graph shows production by state from 2004 to 2008.

This database was updated and corrected by visual interpretation of the Quickbird and GeoEye imagery available on Google Earth (2002 to 2011) as well as false-color composites from Landsat TM (2010 and 2011) and SPOT panchromatic (2010) imagery with a 30 and 2.5 m pixel size (Figure 3).

When the polygons in the four states were completed, a 500 m buffer zone was created around them using geographic information system (GIS) tools. The farms' area and their buffer zones were then used to mask the Landsat TM images used in the next step so that the area outside of them formed a background without spectral information.

Step 1: Shrimp farms inventory

shrimp farm polygons extraction

On-scrren digitization on shrimp farms polygons. The red polygons were imported from CONAPESCA-Mexico dataset. In blue, polygons corrected and updated from GeoEye and QuickBird imagery (2010-2011) in Googe Earth.

Step 2: Classification of Landsat TM images (1986-1990)

Band 1: 0.45-0.52 μm (blue-green)   Band 2: 0.52-0.60 μm (green)   Band 3: 0.63-0.69 μm (red)

Band 4: 0.76-0.90 μm (near infrared)   Band 5: 1.55-1.75 μm (mid infrared)   Band 7: 2.08-2.35 μm (mid infrared)

unsupervised classification

Spectral bands of sensor Thematic Mapper (TM) carried on satellites Landsat 4 and 5 used in this study. Coast of Sinaloa (path/row: 32/43).

Unsupervised classification output using K-means algorithm. Aquatic surfaces (blue), mangrove (green), saltmarsh (grey) and terrestrial covers (brown).

Step 3: Land use change detection

Cross tabulation

		t2			
	Class	1	2	K	Total rows $n_{i.}$
t1	1	n_{11}	n_{12}	n_{1k}	$n_{1.}$
	2	n_{21}	n_{22}	n_{2k}	$n_{2.}$
	k	n_{k1}	n_{k2}	n_{kk}	$n_{k.}$
	Total Columns $n_{.}$	$n_{.1}$	$n_{.2}$	$n_{.k}$	N

Post-classification change detection method: Overlapping of two maps produces a change detection matriz. Inner cells values represent land use changes from t_1 to t_2.
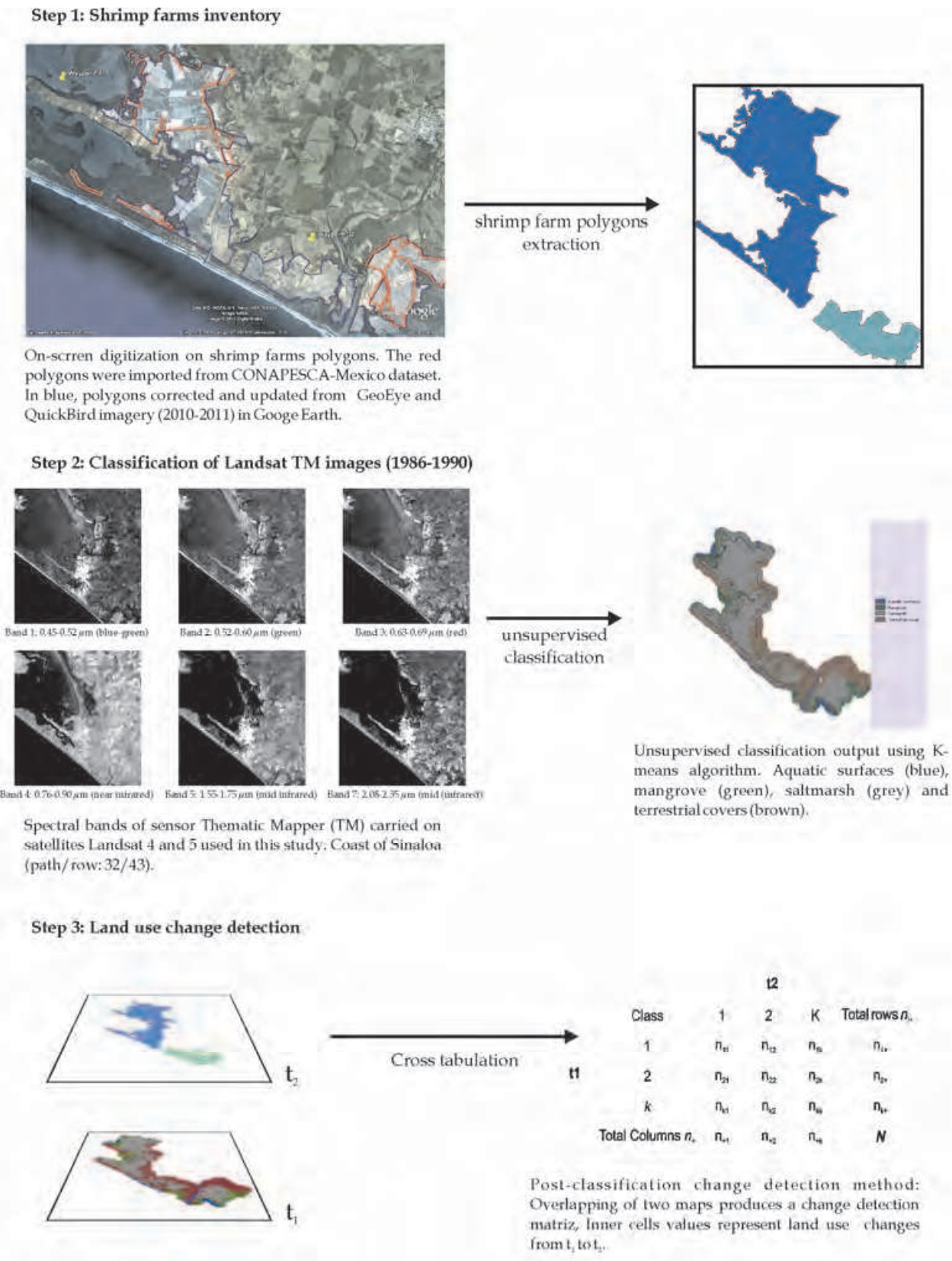
Fig. 3. Technical process to detect and assess landscape changes produced by shrimp ponds construction based on satellite imagery analysis and ancillary data.

2.2 Landscape characterization

In the second step, performed by analysts different than those whose updated and prepared the shrimp farm polygons, the coastal landscape of four selected states before the advent of shrimp farming were characterized by means of thematic maps generated by the classification of Landsat TM images from 1986 to 1999, downloaded from the USGS Global Visualization Viewer portal (http://glovis.usgs.gov/). The imagery covering the shrimp farming area in the states of the Gulf of California comprises 14 Landsat TM images among paths 30 to 37 and rows 39 to 45. The area of Tamaulipas was covered with three images recorded in path 26 among rows 41 and 43. All the spectral bands except thermal infrared were used.

The images underwent unsupervised classification using a K-means clustering technique (Richards & Jia, 1999). A 16 spectral cluster map was produced first, which was subsequently associated with natural covers represented by three coastal wetland types (aquatic surfaces, saltmarsh and mangroves), while other natural vegetation (dry forest, thorn scrub forest) and vegetation of anthropic origin (agriculture, settlements, lineal infrastructure) were integrated into a fourth category: terrestrial covers (Fig. 3). Landsat TM images recorded earlier than 1986 were not available, so in some cases the maps also include a fifth land cover category corresponding to the shrimp farms present since that time.

2.3 Change detection analysis

In the third step, the changes produced by shrimp farming in the Mexican coastal landscapes were assessed by overlaying the buffered shrimp farm polygons (t2) on the 1986-1999 thematic maps (t1) following a post-classificatory analysis scheme (Mas, 1999, Berlanga-Robles et al. 2010; Berlanga-Robles & Ruiz-Luna, 2011), which outputs a matrix for change detection, identifying trends and the extent of variations on every cover presumably produced by shrimp farming (Fig. 3). Considering just the Gulf of California region, a similar analysis was performed only on mangroves, using a dataset produced with 1973 Landsat MSS images (60 m pixel size) developed in earlier studies (Ruiz-Luna et al., 2010).

3. Results

Based on the photo-interpretation process with Google Earth and ancillary data, a total of 273 polygons were identified, representing isolated farms or systems with more than one farm amounting to a total of approximately 80,000 ha. All structures identified as shrimp farms were included, even if the system was empty or out of operation. Sinaloa state has the largest area allocated for this industry, amounting to 51% of the estimated area, followed by Sonora, Nayarit and Tamaulipas, with 41, 6 and 1%, respectively (Table 1).

Regarding the transformations due to aquaculture, the main subsidiaries were those that integrate anthropic and vegetation cover other than that identifiable as wetland, namely, terrestrial coverage, with 46%, and saltmarsh, with 45%. Approximately 3% of the ponds were built on the shallow coastal lagoons and estuaries (water surface), and mangrove was the least modified cover (1%). The change in mangrove cover is estimated to be more than 1150 ha, mainly in Sinaloa (≈ 700 ha) and Nayarit (≈ 400), the states with the largest mangrove cover in the Mexican Pacific, which account for approximately 70,000 ha each (Ruiz-Luna et al., 2010). These states are also first in the execution of shrimp aquaculture

Subsidiary cover	State				
	Nayarit	Sinaloa	Sonora	Tamaulipas	TOTAL
Aquatic surfaces	103 (2)	1918 (5)	268 (1)	24 (1)	2313 (3)
Mangrove	392 (8)	689 (2)	85 (<1)	0	1166 (1)
Saltmarsh	1726 (35)	23225 (56)	10779 (33)	48 (6)	35778 (45)
Terrestrial covers	2507 (50)	12215 (30)	21133 (64)	929 (93)	36784 (46)
Shrimp farming*	238 (2)	3090 (2)	642 (2)	0	3970 (5)
Total shrimp farm extent (ha)	4966	41137	32907	1001	80011

Table 1. Land use changes produced by shrimp farming in four states of Mexico. Area in hectares and corresponding proportion (%) in parenthesis. *Some farms were built before 1986, the initial time for this study (t1), consequently, figures in this row represent no change after this date.

projects. It is important to highlight that shrimp aquaculture started prior to 1986, the date of the first Landsat image included in this analysis, which explains why 5% of the shrimp aquaculture use was unchaged in land use . It means that approximately 4000 ha of shrimp ponds had been constructed by 1986 on undetermined covers.

As most of the changes happened in the Gulf of California region, it is important to have look at Tamaulipas, the only representative of shrimp aquaculture in the Gulf of Mexico. No mangrove deforestation was associated with shrimp ponds, and the main subsidiary cover was terrestrial cover, amounting to 93% of the total area used for shrimp pond installation.

Based on the 1973 estimates for mangrove distribution proposed by Ruiz-Luna et al. (2010) for the Gulf of California region, the change detection analysis output some differences with the previous analysis, showing a slight reduction of the assessed mangrove loss for Nayarit and Sonora (Table 2). The mangrove change at Nayarit was 77 ha less, as evaluated with the 1973 map with respect to the 1986 map. The changes in Sonora were similar in both studies; even so, the reduction is 14 ha more with the 1986 map than that estimated with the 1973 map. The differences in both cases are approximately 15-20%. By contrast, the mangrove loss estimated for Sinaloa increased by approximately 40% when the 1973 map was analyzed, agreeing with a technical report published by Ruiz-Luna et al. (2005). Even so, the technical differences in both Landsat devices (MSS and TM) make an underestimation of the 1973 mangrove area possible due the low resolution of the Landsat MSS imagery (60 m) used to produce these maps, as noted by Ruiz-Luna et al. (2010). Thus, the differences among Nayarit and Sonora could be reduced, but in the case of Sinaloa, it could increase.

		Land covers (1973)		
	State	Mangrove	Others covers	Total
Shrimp farms (2010)	Nayarit	315 (6)	4651 (94)	4966
	Sinaloa	956 (2)	40181 (98)	41376
	Sonora	71 (<1)	32836 (>99)	32907

Table 2. Change detection matrix for land cover change from mangrove (1973) to shrimp farms (2010). Area in hectares and relative proportion (%) in parenthesis.

Mexican laws protect mangrove forests (Federal Wildlife Law 2000, NOM-022-SEMARNAT-2003, NOM-059-SEMARNAT-2010). These laws declare all mangrove species endangered, and they forbid changes on this cover while prohibiting adjacent economic activities (with some exemptions). Therefore, we defined a 100-m buffer zone around the shrimp farm polygons to assess the impact on mangroves within this fringe restricted by law. Using this criterion, the impacted area is almost twice the preceding figure, and Sinaloa was again the most unsafe area. The results of this analysis are shown in Table 3.

State	Shrimp farm polygons	% of farms adjacent	Mangrove in 100 m zone
Nayarit	43	81.4	426
Sinaloa	163	68.7	1635
Sonora	45	26.7	113
Tamaulipas	22	4.5	2
Total	273	58.6	2176

Table 3. Shrimp farms adjacent to mangrove forests in some Mexican states and mangrove extent (ha) inside the 100 m fringe banned by law for any economic activity. Estimations are based on a 100 m buffer created around the shrimp farm polygons and overlaid on mangrove thematic maps.

Even when a farm's design excluded the polygon from the mangrove cover, the shrimp farms were sometimes constructed in the vicinity of mangroves, thus transgressing some environmental regulations. From our results, close to 60% of the total analyzed shrimp farms were in proximity with mangroves, almost doubling the lost area estimated here for this vegetation if the 100 m fringe is considered. Sinaloa and Nayarit, both with the largest mangrove coverage, were the states with the highest interaction between polygons and the forbidden perimeter, affecting more than 80% of the farms in the case of Nayarit.

4. Mexican shrimp farming in the international context

Comparing the observed conditions of Mexican shrimp farming with other producing countries worldwide highlights the fact that most of the declarations about mangrove deforestation by shrimp farming are not properly documented. Documents with data and descriptions of the technical process to assess mangrove deforestation are limited and, in some cases, only generalize observed trends. From the available information, it was possible to analyze some cases from Asia and America, including six cases in Mexico (Table 4).

At first sight, the situation of the Mexican states can be roughly compared with that from other countries. In some regions of India, Bangladesh and Vietnam, though not necessarily at the country level, shrimp ponds are practically the only cause of deforestation, with rates between 85 and 100%, even when those ponds generally represent a small to medium fraction (17.6 to 53%) of the activity (Table 4).

Shrimp farming growth in Latin America also had negative effects on mangrove cover, particularly in Ecuador and Honduras (Gulf of Fonseca), with a decline in total mangrove cover of approximately 27% and 22% between 1969-1995 and 1973-1992, respectively (DeWalt et al., 1996; Tobey et al., 1998). These references agree with the present analysis,

Country/Region (period)	Mangrove area (ha)		A	B	C		
	t[1]	t[2]	Loss	Ponds	Conv	%1	%2
Chakaria Sunderban, Bangladesh (1952-1988)[1]	7500	978	6522	6522	6522	100	100
Thailand (1961-1996)[2]	367900	167582	200318	80000	66998	84	33
Tien Hai, Viet Nam (1986-1992)[3]	1250	390	860	1490	790	53	92
Philippines (1997)[a 4]	295000[17]	250000[17]	45000	6940	3470	50	8
Ecuador (1969-1999)[5]	362700	149557	213143	10000	48649	49	23
Machala-Pto. Bolivar, Ecuador (1966-1982)[6]	4693	3294	1399	2331	931	40	67
Giao Thuy, Viet Nam (1986-1992)[3]	750	320	430	938	364	39	85
Golfo de Fonseca, Honduras (1973-1992)[7]	30697	23937	6760	11515	4307	37	64
Indonesia (1997) [a 4]	4200000[17]	3150000[17]	1050000	20000	5320	27	1
Thailand (1997) [a 4]	280000[17]	244100[17]	35900	47755	9933	21	28
Godovari delta, India (1977-2005)[8]	19480	18610	870	4650	820	18	94
Taiwan (1997)[a 4]	--	--	--	1407	173	12.3	--
San Blas, Mexico (1973-2001)[9]	7644	7353	521	1900	230	12	44
CaiNuoc district, Viet Nam (1968-2003)[10]	19507	47614	14746	59684	5643	10	38
Mazatlan, Mexico (1973-1997)[11]	910	710	200	170	10	6	5
India (1989-1999)[12]	467000[17]	448200[17]	18800	130000	6500	5	35
Marismas Nacionales, Mexico (1973-2000)[13]	89182	75042	14140	3208	102	3	1
Sinaloa, Mexico (1992-2003)[14]	75364	84912	--[b]	46882	790	2	--
Ceuta Lagoon, Mexico (1984-1999)[15]	7558	7217	341	3192	23	1	7
North of Sinaloa (1986-2005)[16]	21983	21873	110	9949	26	<1	24

t1 and t2, initial and final mangrove area in every period study. A Loss, differences in mangrove cover (ha) in the study period. B Ponds, area (ha) occupied by shrimp ponds. C Conv., conversion from mangrove to shrimp ponds (area in ha). %1, proportion of ponds built on mangrove = (C/B)100. %2, proportion of mangrove loss caused by shrimp farming = (C/A)100. [a] Only considering intensive shrimp farms. [b] Authors found a positive change in Sinaloa's mangrove cover. Sources: [1]Hossain (2001); [2]Aksornkoae and Tokrisna (2004); [3]Bélard et al. (2006); [4]Kongkeo (1997); [5]Bravo (2003); [6]Terchunian et al. (1986); [7]Dewalt et al. (1996); [8] Sudhaka-Reddy & Roy (2008); [9]Berlanga-Robles & Ruiz-Luna (2006); [10]Binh et al. (2005); [11]Ruiz-Luna & Berlanga-Robles (2003); [12]Hein (2002); [13]Berlanga-Robles & Ruiz-Luna (2007); [14]De la Fuente & Carrera (2005); [15]Alonso-Pérez (2003); [16]Berlanga-Robles et al. (2005); [17]FAO (2007).

Table 4. Changes in mangrove cover related to shrimp farming in Asia and America.

which reveals that Ecuador's mangrove loss and conversion was close to 90% of approximately 54000 ha at the nation level and 67% at the regional level (Machala-Puerto Bolivar), where mangrove loss was estimated at approximately 1400 ha. Honduras in the early 1970s accounted for more than 11500 ha of shrimp ponds in the Gulf of Fonseca, approximately 65% of which were constructed on mangrove sites.

In Mexico, the highest conversion ratio from mangrove to shrimp ponds has been recorded for San Blas, at Nayarit state, and northern Sinaloa, with 44.1% and 23.6%, respectively, amounting to a total of approximately 260 converted hectares. In relative terms, these numbers represent 12.1% and 0.3% of the total pond area constructed by region, respectively, at approximately 12 000 ha in total. Other studies in Mexico on mangrove conversion attributable to shrimp farming show output ratios less than 7% of lost mangrove cover. It is also remarkable that two independent works conducted in Sinaloa state found an increase in the mangrove cover, and, with some differences, they even found that the mangrove area occupied by shrimp farm developments represents between 1.7 and 2.2% of a pond surface estimated above 40 000 ha (De la Fuente & Carrera, 2005; Ruiz-Luna et al., 2005).

5. Discussion

Intense debate about the environmental impacts caused by shrimp farming has been engaged in Mexico since the beginning of this activity, particularly by environmentalists, regarding the denunciation of the environmental risks associated with shrimp farming development. Considering the international background of this issue and bearing in mind the importance of the environmental services offered by mangroves and the possible impact caused by land cover changes, the general opinion is that Mexico could confront environmental risks similar to Indonesia, Philippines, Thailand and Ecuador, where extensive deforestation of mangrove forests is associated with the construction of shrimp ponds.

This perception has been maintained and consistently declared even though there are few studies documenting changes in mangrove at a national extent or the possible causes of mangrove deforestation when it is proved. It is common that some differences in mangrove cover estimations obtained by the extrapolation of local values or using different inputs and evaluation techniques would be misinterpreted as deforestation (Ruiz-Luna et al. 2008).

Thus, the studies conducted by Hernández-Cornejo & Ruiz-Luna (2000), Alonso-Pérez et al. (2003), De la Fuente & Carrera (2005), Ruiz-Luna et al. (2005), Berlanga-Robles & Ruiz-Luna (2007), and Berlanga-Robles et al. (2011), among others, have attempted to verify the extent and intensity of the impact of shrimp farming in Mexico.

Most of the above papers mainly describe the conditions observed in Sinaloa and Nayarit, in northwest Mexico. This paper is the first attempt to document changes at a nationwide level based on our own and other authors findings obtained with remote sensing techniques, analyzing very high spatial resolution satellite imagery (Landsat, Spot, QickBird, GeoEye) and updating the existing information up to 2010. The main restriction imposed to these studies is the lack of reference data to validate the accuracy of the earlier dates' estimates. Even so, the similitude among the results from independent analyses give confidence to the general trends followed by shrimp farm growth and its impact on mangrove forests in Mexico, making a comparison possible with analogous developments elsewhere.

We must emphasize that, even with the largest mangrove extent and the best developed area being located in the Yucatan Peninsula (Campeche, Yucatan, Quintana Roo and Chiapas states), which accounts for approximately 60% of the mangrove forests in Mexico (Acosta et al., 2009), the shrimp farming in this area represents less than 1% of the total extent and production of Mexico (CONAPESCA, 2010). For this reason, neither of the abovementioned states were included in the analysis. The four states analyzed here currently amount to 97% of the area dedicated to shrimp farming (CONAPESCA, 2010), which is enough to document the impact of this activity on mangrove cover.

The present findings indicate that Mexico has approximately 82 500 ha dedicated to shrimp production, though not all of this area is necessarily in operation. From these areas, between 1.5% and 1.7% could be constructed on mangrove cover, removing approximately 1300 ha, which is equivalent to less than 1.0% of the 770 000 ha of mangrove reported by the Mexican National Commission for the Knowledge and Use of Biodiversity (Acosta et al., 2009). These results greatly contrast with other tropical and subtropical countries, where shrimp farming has been responsible for of most of the mangrove deforestation (Bangladesh, Ecuador) or an important part of it (Honduras, India, Thailand). However, although shrimp farming could not be considered a risk to Mexican mangrove cover, it has been established on other important coastal wetlands rarely mentioned in literature (estuaries, lagoon, saltmarsh).

The worldwide estimation of mangrove deforestation caused by shrimp farming is difficult because not all producing countries have reliable data at the national level. The analysis of the literature shows that in many instances, nationwide or global estimates are based on local or regional case studies or are extrapolated from foreign conditions, such as those from Thailand and Ecuador, or even Indonesia, where mangrove loss has been severe though mostly independent of shrimp farming activity.

In agreement with FAO (2007), the global mangrove cover declined from approximately 19 million ha in 1980 to almost 16 million ha in 2000, while the shrimp pond area was 1.25 million ha in 1998 (Rönnbäck, 2002). Considering the extreme case of all the shrimp ponds constructed on mangroves areas, this activity could be responsible for 41% of mangrove loss. As observed here, in approximately 70% of the cases, the shrimp farming accounted for less than 50% of deforestation, and within this 70%, the half has contributed with less than 30% of mangrove decline. Considering both scenarios, shrimp farming could be directly responsible for 20.8 to 12.5% of the mangrove loss between 1980 and 2000.

The Mexican case could be a result of a postponed development of the industry, with a delay of approximately 10 to 15 years in respect to other countries due to legal constraints. After this late beginning, the industry grew rapidly even while acknowledging environmental problems and is now among the ten top producers, second to Latin America, which is after Ecuador. Consequently, shrimp farming has been responsible for mangrove deforestation but not at the same level observed in the former shrimp producers. Regrettably, the risk has been transferred to other coastal wetlands, as 46% of the ponds have been built on saltmarshes. This land cover is more suitable for shrimp pond construction farms because of soil characteristics and topography. In addition, these wetlands are cheap in economic terms, as they are considered unproductive, and they are barely protected by Mexican laws. Studies on saltmarsh loss show that 12% of this cover in Nayarit and Sinaloa was lost because of 25 000 ha of ponds (Berlanga-Robles et al., 2011). Even more, the impact of shrimp farming on the coastal landscapes goes beyond the direct

loss of wetlands because the ponds themselves and mostly the linear infrastructure necessary for the operation of farms, such as canals and roads, have a strong impact on the connectivity of coastal landscapes, fragmenting saltmarsh habitat, modifying the water flows and sediment supplies in the intertidal zone, and threatening the overall stability of coastal wetlands (Berlanga-Robles et al., 2011).

In conclusion, the shrimp aquaculture in Mexico is not the main cause of mangrove deforestation, as has happened with other countries. Even so, the industry is far from sustainable because almost half of the pond area has resulted in the direct removal of other natural wetlands. Also, the entire associated infrastructure interrupts local and regional ecological process by fragmentation of the intertidal zone (Berlanga-Robles et al., 2011). Finally, even when those farms do not have contact with the mangrove cover, a significant proportion of them were built near mangrove patches, particularly in Sinaloa and Nayarit, infringing upon legal rules and threatening the 100 m fringe established by Mexican law. To move toward real sustainability, some areas must be restored in agreement with laws. Future developments must require an ecologic and economic reevaluation of coastal wetlands prior to operation to avoid new impacts and to provide the systems with the essential connectivity among wetlands and other wetlands, maintaining the water and sediment flows in the intertidal zone.

6. Acknowledgment

7. References

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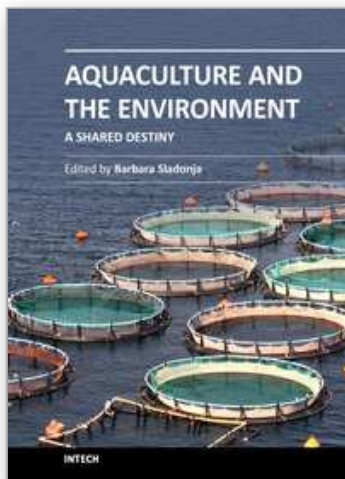
Aquaculture and the Environment - A Shared Destiny

Edited by Dr. Barbara Sladonja

Aquaculture is the art, science and business of cultivating aquatic animals and plants in fresh or marine waters. It is the extension of fishing, resulted from the fact that harvests of wild sources of fish and other aquatic species cannot keep up with the increased demand of a growing human population. Expansion of aquaculture can result with less care for the environment. The first pre-requisite to sustainable aquaculture is clean wate, but bad management of aquatic species production can alter or even destroy existing wild habitat, increase local pollution levels or negatively impact local species. Aquatic managers are aware of this and together with scientists are looking for modern and more effective solutions to many issues regarding fish farming. This book presents recent research results on the interaction between aquaculture and environment, and includes several case studies all over the world with the aim of improving and performing sustainable aquaculture.

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