J Coast Conserv (2012) 16:399–403
DOI 10.1007/s11852-012-0210-7

# The productivity of mangroves in northwestern Mexico: a meta-analysis of current data

**Xavier López-Medellín · Exequiel Ezcurra**

Received: 3 August 2011 / Revised: 4 February 2012 / Accepted: 16 April 2012 / Published online: 27 April 2012


**Abstract** Mangroves constitute highly productive ecosystems that export organic material to surrounding areas. They reach their northernmost distribution on the American Pacific coast in arid northwestern Mexico where they grow under sub-optimal conditions. Nevertheless, they maintain high litterfall rates with important ecological and economical implications. These mangroves are threatened by the region's accelerated development and population growth. In order to explore and describe large-scale patterns in the production of organic material and to assess their importance in the productivity of coastal ecosystems, we performed a meta-analysis of studies that measured mangrove litterfall in northwestern Mexico. We found that litterfall is strongly associated with latitude, and that evaporation was negatively correlated with it. Additionally, we found high correlation between the presence of *Rhizophora mangle* and productivity, while the presence of *Laguncularia racemosa*, showed a less pronounced trend. Despite the harsh conditions, mangroves produce high amounts of organic matter, which is perhaps the most important service of mangroves in these coasts. Their capacity to produce organic matter contrasts with that of their surrounding ecosystems. Substantial reductions in their surface will have consequences for the exchange of energy at the land-sea transition, which will be detrimental for biological communities and human populations.

**Keywords** Baja California Sur · Sonora · Mangrove litter production · Northernmost mangrove distribution

X. López-Medellín (✉)
Centro de Investigaciones en Ecosistemas,
Universidad Nacional Autónoma de México,
Mexico City, Mexico
e-mail: xlmedellin@oikos.unam.mx

E. Ezcurra
Department of Botany and Plant Sciences,
University of California, Riverside,
Oakland, CA, USA

## Introduction

Mangroves are among the most productive ecosystems in the tropical and subtropical continental margins worldwide (Day et al. 1996; Jennerjahn and Ittekkot 2002). Their high productivity yields large amounts of organic matter in the form of leaves, branches, flowers and fruits that are incorporated by tides and currents into the surrounding environments (Flores-Verdugo et al. 1992; Twilley and Day 1999). This litterfall constitutes precious sources of nutrients that sustain marine and terrestrial trophic chains, and its importance can be especially high in lagoons and estuaries in coastal drylands and other harsh environments (Holguín et al. 2001).

On the American Pacific coasts, mangroves reach their northernmost distribution in the arid shores of the Sonoran Desert and neighboring tropical thornscrubs, with a surface of 105,000 hectares in the states of Sinaloa, Sonora and the Baja California peninsula (CONABIO 2008). Due to the aridity of the region, the lack of permanent rivers, and the hyper-salinity of many estuaries, mangroves grow under sub-optimal conditions, evidenced by smaller heights and less developed structure and extension (Flores-Verdugo et al. 1992; Whitmore et al. 2005). However, some mangroves in this region maintain high litterfall rates, similar to those of humid tropical zones, with important ecological and economic implications (Flores-Verdugo et al. 1992; Félix-Pico et al. 2006; Aburto-Oropeza et al. 2008).

Despite the great importance of the ecosystem services mangroves provide in coastal and marine ecosystems (Aburto-Oropeza et al. 2008), their environmental conditions are threatened by the accelerated development of the region, which harbors some of Mexico's highest population growth rates (INEGI 2000). Rapid and unplanned coastal growth is causing considerable degradation of natural environments, threatening the provision of mangrove ecosystem services (Berlanga-Robles et al. 2011). The reduction or disappearance of mangroves can drastically alter the biochemical cycling of nutrients and disrupt coastal trophic chains, affecting the livelihood of coastal populations (Aburto-Oropeza et al. 2008, López-Medellín et al. 2011).

In order to explore and describe large-scale patterns in the production of organic material from mangrove forests and to assess their importance in the productivity of coastal ecosystems, we performed a meta-analysis of existing scientific studies and reports that measured mangrove litterfall around the Gulf of California and the Mexican Pacific northwest. Our main objective was to put a set of local studies on mangrove litter production into a larger geographical context within the region, and to evaluate the relationship of these productivity values with large-scale geographic, climatic, and oceanographic variables.

## Methods

We included litterfall measures obtained from five published articles (Flores-Verdugo et al. 1987, 1990, 1992; Arreola-Lizárraga et al. 2004; Félix-Pico et al. 2006), two unpublished theses (Sandoval-Castro 2005; Chávez-Rosales 2006), a technical report (Espinoza et al. 1981), plus an unpublished dataset provided by Alf Meling-López, University of Sonora, compiled from different studies his research group has done. These studies report annual mangrove litterfall measured by placing litter-baskets below the canopy to collect fallen organic material on different estuarine localities in Sinaloa, Sonora and Baja California Sur between 1981 and 2004, totaling 20 sites (Table 1, Fig. 1).

A database was constructed with the litterfall values from these studies, and six biotic and abiotic variables, which have been reported to influence the productivity of mangroves, were added as predictors of litterfall: (1) species

**Table 1** Data matrix with studies selected and sampled localities included in our analysis. Includes litter productivity values (gr $m^2$ $yr^{-1}$) and abiotic and abiotic variables that were selected for this study. Average precipitation mm $yr^{-1}$; Temperature in Celsius; Evaporation mm $yr^{-1}$; and Salinity ppm

| Locality | State | Prod. | Rm | Lr | Ag | Precip. | Max. T° | Min. T° | Avg. T° | Evap. | Salinity | Latitude | Longitude | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agua Brava | SIN | 1,015 | 1 | 1 | 1 | 853.5 | 32.7 | 18.5 | 25.6 | 1736 | 35 | 22.668 | 105.710 | Flores-Verdugo et al. 1990 |
| El Colorado | SIN | 806 | 1 | 0 | 1 | 421.8 | 30.4 | 20.5 | 25.4 | 1833.8 | 42.5 | 25.654 | 109.286 | Sandoval-Castro 2005 |
| Estero de Urías | SIN | 1,010 | 1 | 0 | 0 | 846 | 32 | 14 | 24.1 | 2146 | 34 | 23.207 | 106.395 | Flores-Verdugo et al. 1992 |
| Agua Grande | SIN | 1,263 | 1 | 1 | 1 | 853.5 | 32.7 | 18.5 | 25.6 | 1736 | 32.5 | 22.110 | 105.510 | Flores-Verdugo et al. 1990 |
| El Verde | SIN | 1,100 | 0 | 1 | 0 | 541.1 | 29.4 | 18 | 23.7 | 1333.3 | 34.5 | 23.442 | 106.562 | Flores-Verdugo et al. 1987 |
| Enfermería | BCS | 1,634 | 1 | 0 | 0 | 182.6 | 30.7 | 16.4 | 23.3 | 1996.5 | 42.5 | 24.235 | 110.306 | Espinoza et al. 1981 |
| Bahía Magdalena | BCS | 1,094 | 1 | 1 | 1 | 111.7 | 29.5 | 14.1 | 19.3 | 2000 | 36.5 | 25.254 | 112.123 | Chávez-Rosales 2006 |
| Balandra | BCS | 948 | 1 | 0 | 0 | 182.6 | 30.7 | 16.4 | 23.3 | 1996.5 | 39 | 24.322 | 110.324 | Espinoza et al. 1981 |
| El Conchalito | BCS | 852 | 0 | 1 | 0 | 182.6 | 30.7 | 16.4 | 23.3 | 1996.5 | 39 | 24.143 | 110.351 | Félix-Pico et al. 2006 |
| El Conchalito | BCS | 657 | 1 | 0 | 0 | 182.6 | 30.7 | 16.4 | 23.3 | 1996.5 | 39 | 24.143 | 110.351 | Félix-Pico et al. 2006 |
| El Conchalito | BCS | 424 | 0 | 0 | 1 | 182.6 | 30.7 | 16.4 | 23.3 | 1996.5 | 39 | 24.143 | 110.351 | Félix-Pico et al. 2006 |
| Agiabampo | SON | 740 | 0 | 0 | 1 | 400 | 32.6 | 18 | 25.3 | 2650 | 40.5 | 26.352 | 109.159 | Meling-López et al. Unpublished data |
| Yavaros | SON | 666 | 0 | 0 | 1 | 300 | 43 | 17 | 30 | 1750 | 21 | 26.708 | 109.544 | Meling-López et al. Unpublished data |
| Tobari | SON | 585 | 0 | 0 | 1 | 259.2 | 31.2 | 15.5 | 23.3 | 2124.3 | 35 | 27.100 | 109.970 | Meling-López et al. Unpublished data |
| Lobos | SON | 467.3 | 0 | 0 | 1 | 297.7 | 24.7 | 18 | 22 | 2591.5 | 26.5 | 27.353 | 110.454 | Meling-López et al. Unpublished data |
| El Sargento | SON | 396 | 0 | 0 | 1 | 137.5 | 33 | 11 | 21 | 2000 | 40 | 29.340 | 112.276 | Meling-López et al. Unpublished data |
| La Cruz | SON | 226 | 0 | 0 | 1 | 139.6 | 27 | 13.8 | 20.4 | 2159.5 | 37.5 | 28.807 | 111.920 | Meling-López et al. Unpublished data |
| La Cruz | SON | 185 | 0 | 0 | 1 | 139.6 | 27 | 13.8 | 20.4 | 2159.5 | 37.5 | 28.807 | 111.920 | Meling-López et al. Unpublished data |
| Las Guásimas | SON | 197 | 0 | 0 | 1 | 253.4 | 31 | 17 | 24 | 2712 | 38 | 27.781 | 110.580 | Arreola-Lizárraga et al. 2004 |
| Las Guásimas | SON | 204 | 0 | 0 | 1 | 253.4 | 31 | 17 | 24 | 2721 | 38 | 27.781 | 110.580 | Meling-López et al. Unpublished data |

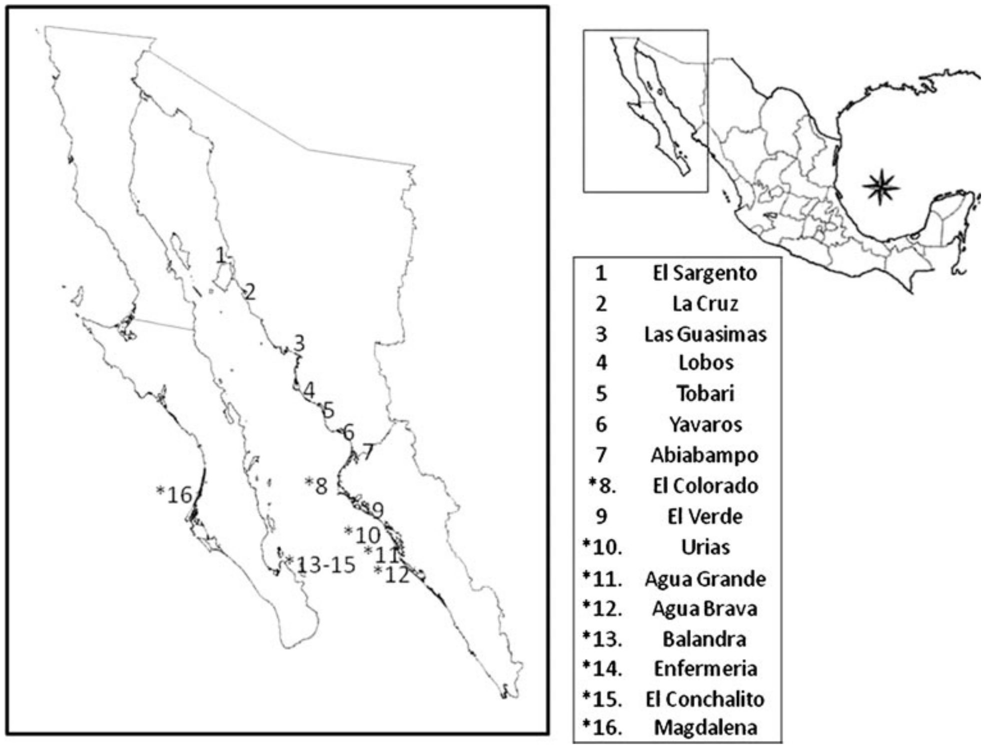


**Fig. 1** Localities with litter productivity studies in northwestern Mexico. * = Estuaries with *Rhizophora mangle*

composition of mangroves, (2) average precipitation, (3) average temperature, (4) average evaporation, (5) overlying water salinity, and (6) latitude (Flores-Verdugo et al. 1992; Twilley and Day 1999). The abiotic information was obtained from the Mexican Meteorological System website (http://smn.cna.gob.mx/, February 2010; Table 1).

We used multiple linear regression analysis to explore and model the relationships between these variables and evaluate their quantitative effect on the overall litter production of mangroves in northwestern Mexico by fitting a linear equation to observed data.

## Results

The results of the regression analysis showed that latitude was the environmental variable that best predicted overall litterfall at a regional scale ($r^2$=0.62, $P$=0.0004; Fig. 2). Evaporation also showed significant, and negative, relationship with litterfall ($r^2$=0.31, $P$=0.01). We found no other significant relationship between litter production and the other environmental variables (Table 2).

The species composition of the forest was also highly associated to litterfall. Forests with *Rhizophora mangle* and *Laguncularia racemosa* had mean litterfall values of 1053 and 1065 $gm^{-2}$ $yr^{-1}$, respectively (SE=105 and 67), while *Avicennia germinans* forests had significantly lower values, with 590 $gm^{-2}$ $yr^{-1}$ (SE=95). This trend, however, is strongly confounded by latitude, as *Rhizophora* and *Laguncularia* forests in the dataset dominate at low latitudes (22–24°) and forests measured at higher latitudes (25–28 °) were composed mostly by *Avicennia*. Indeed, if comparison between species is done after including latitude in the regression, the predictive power of species composition disappears.

## Discussion

Mangrove litter production in northwestern Mexico is strongly associated with latitude. However, latitude *per se* is not an environmental factor capable of having direct

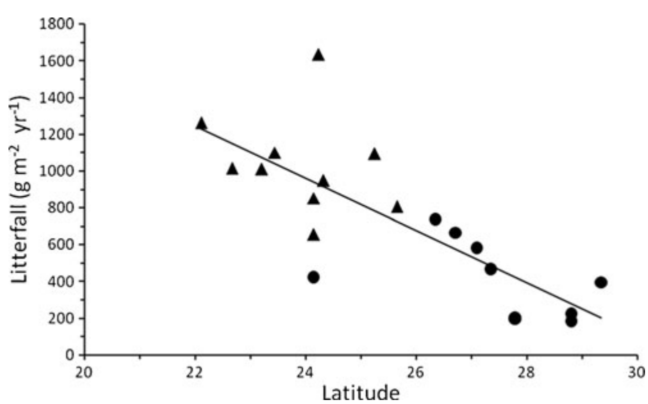


**Fig. 2** The relationship between latitude and productivity in mangroves of northwestern Mexico. ▲ = Mangroves with *Rhizophora mangle* ● = Mangroves with *Avicennia germinans* and/or *Laguncularia racemosa* ($r^2$=0.62, $P$=0.00004)

**Table 2** Linear regression results of the abiotic and biotic variables used to litter production. The best predictor was latitude, which had an inverse slope with litterfall. The second best predictor was the simple presence of the red mangrove *Rhizophora mangle*, which increased litterfall to around 550 $gm^{-2}$ $yr^{-1}$ (SE±135)

| | *Rm* | *Lr* | *Ag* | Prec | Tmx | Tmn | Tmd | Evap | Salinity | Latitude |
|---|---|---|---|---|---|---|---|---|---|---|
| $r^2$ | 0.48 | 0.26 | 0.27 | 0.19 | 0.03 | 0.08 | 0.05 | 0.31 | 0.00 | 0.62 |
| *P* | 0.0006 | 0.022 | 0.018 | 0.05 | 0.46 | 0.22 | 0.34 | 0.011 | 0.84 | 0.00004 |

influence on mangrove growth, but rather a summary variable that condenses a set of factors that vary regionally from south to north, including species composition, seasonal patterns in day length and temperature, evaporation, precipitation, estuary salinity, and winter–summer oscillations. In agreement with this, we found that annual evaporation, which increases from the tropics towards the Sonoran Desert coasts, was negatively correlated with litter production. Saenger and Snedaker (1993) found that, globally, mangrove productivity varies locally but that at a broader scale the general trend is that it declines as latitude increases. They also found a strong correlation between tree height and latitude, suggesting that the latter influences the elevation of vegetation through insolation, temperature and, perhaps, water availability, which is reflected in the amount of organic matter produced.

We found a high correlation between the presence of *Rhizophora mangle* species and productivity ($r^2$=0.48, $P$= 0.0006). *Laguncularia racemosa*, showed a similar, albeit less pronounced, trend ($r^2$=0.26, $P$=0.02). However, the sites where *Rhizophora* and *Laguncularia* litterfall had been measured are concentrated in the southern Gulf region, below 25 °, so the latitudinal gradient cannot be statistically distinguished from the purely floristic effect. One location in our dataset, however, was obtained by Félix-Pico et al. (2006) for three neighboring sites at *El Conchalito,* an estuary of 18.5 ha; one was dominated by *Rhizophora*, a second by *Laguncularia*, and the third by *Avicennia*. Because these sites are nearby in the same estuary, latitudinal effects can be discarded. Litter productivity in this estuary was 656.5 $gm^{-2}$ $yr^{-1}$ for *Rhizophora mangle*, 851.9 g $m^{-2}$ $yr^{-1}$ for *Laguncularia racemosa*, and 423.9 $gm^{-2}$ $yr^{-1}$ for *Avicennia germinans*, suggesting that indeed there is an inherent difference in litter production between *Avicennia* and the other two species. Twilley and Day (1999) also mentioned that patterns of litter production can be affected by species composition in a particular ecosystem because some mangrove species have intrinsically higher growth rates than others. The lowest reported values in our dataset (185–197 $gm^{-2}$ $yr^{-1}$) fall below the minimum worldwide estimations for mangrove litterfall (Saenger and Snedaker 1993), and come from forests dominated by *A. germinans* in the northernmost limit of mangrove distribution between 28 and 30°N. Arreola-Lizárraga et al. (2004) attribute this low litter production to the combined effects of minimal tidal flooding and the scarce availability of fresh water in coastal desert localities where evaporation is greater than rainfall.

In contrast, a study conducted with *Rhizophora mangle* in Baja California Sur reported litterfall values (1634 g $m^{-2}$ $yr^{-1}$) that are among the highest for mangrove ecosystems worldwide (Espinoza et al. 1981). This study was performed in an estuary impacted by a highway construction which disrupted the water flow between the estuary and the bay, and since litterfall in mangroves results from the shedding of leaves and reproductive structures, it might be temporarily caused by senescence or stress. Espinoza and collaborators mention that such large litterfall might result from the poor environmental conditions in the estuary at the time of their study, reflected in the shedding of plant parts due to stress. However, other mangroves in the dataset, at latitudes 22–23°N with *R. mangle* under good environmental conditions also presented high litterfall (1100–1263 g $m^{-2}$ $yr^{-1}$), that are comparable to those reported for estuaries closer to the equator, with more suitable conditions for the development of mangrove forests (Flores-Verdugo et al. 1992; Saenger and Snedaker 1993).

In conclusion, despite the harsh conditions of the arid and semi-arid coasts of northwestern Mexico, mangroves are able to produce high amounts of organic matter. Alongi et al. (2005) suggest that in environments with nutrient scarcity, mangroves exhibit rapid leaf turnover rates and high litterfall. In a study on the Bay of La Paz in Baja California Sur, Holguín et al. (2001) described an effective nutrient-recycling system formed by fungi, bacteria, protozoa and algae associated with the roots of mangroves, which help retain important nutrients and produce organic matter despite the rapid leaf turnover.

High litter production is perhaps the most important service of mangroves in the coastal areas of Mexico's arid northwest. This litter represents a major source of organic material and nutrients that flow into adjacent communities and nurtures coastal food chains, contributing with energy sources for bacteria and filter-feeders (Jennerjahn and Ittekkot 2002). The capacity of mangroves to produce high amounts of organic matter contrasts with that of their surrounding ecosystems: North of latitude 25 °, along the coasts of the Sonoran Desert, mean mangrove litter production was 407 $gm^{-2}$ $yr^{-1}$, while that of the surrounding desert is less than 100 $gm^{-2}$ $yr^{-1}$

(Handley and Szarek 1981). South of latitude 25 °, along the coasts of Sinaloa and southern Baja California, mean mangrove litter production is 982 $gm^{-2}\ yr^{-1}$, while that of the nearby thornscrubs is less than 400 $gm^{-2}\ yr^{-1}$ (Martínez-Yrizar and Sarukhan 1990).

For these reasons, any substantial reduction in their surface will almost certainly have consequences for the exchange of nutrients and energy at the land-sea transition, which will be detrimental for many biological communities and for human coastal populations (Aburto-Oropeza et al. 2008; López-Medellín et al. 2011). Mangrove litterfall is many times higher than the organic matter produced by other terrestrial ecosystems, a fact that emphasizes the critical need for the conservation of mangroves and their ecosystem services in northwestern Mexico.

**Acknowledgements** This manuscript is part of the doctoral studies of the first author, at Posgrado en Ciencias Biológicas, CIEco-UNAM, financed by CONACyT. The authors thank A. Meling for providing data on litterfall of mangroves in Sonora, and F. Flores-Verdugo who reviewed and commented an earlier version of this manuscript. Comments of N. Jacobson and one anonymous reviewer improved this manuscript.

## References

Aburto-Oropeza O, Ezcurra E, Danemann G, Valdez V, Murray J, Sala E (2008) Mangroves in the Gulf of California increase fishery yields. PNAS 105(30):10456–10459

Alongi DM, Clough BF, Robertson AI (2005) Nutrient-use efficiency in arid-zone forest of the mangroves *Rhizophora stylosa* and *Avicennia marina*. Aquat Bot 82:121–131

Arreola-Lizárraga JA, Flores-Verdugo FJ, Ortega-Rubio A (2004) Structure and litterfall of an arid mangrove stand on the Gulf of California, Mexico. Aquat Bot 79:137–143

Berlanga-Robles CA, Ruíz-Luna A, Bocco G, Vekerdy Z (2011) Spatial analysis of the impact of shrimp culture on the coastal wetlands on the Northern coast of Sinaloa, Mexico. Ocean Coast Manage 54:535–543

Chávez-Rosales S (2006) El papel de los manglares en la producción de las comunidades acuáticas de Bahía Magdalena, BCS. Dissertation. Centro Interdisciplinario de Ciencias Marinas-IPN

CONABIO (2008) Manglares de México. CONABIO. México

Day JW Jr, Coronado-Molina C, Vera-Herrera FR, Twilley R, Rivera-Monroy VH, Alvarez-Guillen H, Day R, Conner W (1996) A 7 year record of above-ground net primary production in a southeastern Mexican mangrove forest. Aquat Bot 55:39–60

Espinoza M, Sánchez P, Muñoz P (1981) Ecología de Manglares. Technical Report CIB. pp 137–179

Félix-Pico EF, Holguín-Quiñones OE, Hernández-Herrera A, Flores-Verdugo F (2006) Producción primaria de los mangles del estero El Conchalito en Bahía de La Paz (Baja California Sur, México). Cienc Mar 32(01A):53–63

Flores-Verdugo F, Day JW, Briseño-Dueñas R (1987) Structure, litter fall, decomposition, and detritus dynamics of mangroves in a Mexican coastal lagoon with an ephemeral inlet. Mar Ecol Prog Ser 35:83–90

Flores-Verdugo F, González-Farías F, Ramírez-Flores O, Amezcua-Linares F, Yañez-Arancibia A, Alvarez-Rubio M, Day JW Jr (1990) Mangrove ecology, aquatic productivity and fish communty dynamics in Teacapan-AguaBrava Lagoon Estuarine system (Mexican Pacific). Estuaries 13(2):219–230

Flores-Verdugo F, González-Farías F, Zamorano DS, Ramírez-García P (1992) Mangrove Ecosystems of the Pacific coast of Mexico: distribution, structure, litterfall and detritus dynamics. In: Seeliger U (ed) Coastal plant communities of Latin America. Academic, San Diego, pp 269–288

Handley NF, Szarek SR (1981) Productivity of desert ecosystems. Bioscience 31(10):747–753

Holguín G, Vazquez P, Bashan Y (2001) The role of sediment microorganisms in the productivity, conservation and rehabilitation of mangrove ecosystems: an overview. Biol Fert Soils 33:265–278

INEGI (2000) XII Censo general de población y vivienda 2000. INEGI. Aguascalientes, México

Jennerjahn TC, Ittekkot V (2002) Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. Naturwissenschaften 89:23–30

López-Medellín X, Castillo A, Ezcurra E (2011) Contrasting perspectives on mangroves in arid Northwestern Mexico: implications for integrated coastal management. Ocean Coast Manage 54:318–329

Martínez-Yrizar A, Sarukhan J (1990) Litterfall patterns in a tropical deciduous forest in Mexico over a five-year period. Trop Ecol 6 (4):433–444

Saenger P, Snedaker SC (1993) Pantropical trends in mangrove above-ground biomass and annual litterfall. Oecologia 96:293–299

Sandoval-Castro E (2005) Productividad del manglar de la Bahía "El Colorado", Ahome, Sinaloa y su relación con la pesquería local. Bachelor thesis. Departamento de Ciencias Biológicas, Universidad de Occidente

Twilley RR, Day JW (1999) The productivity and nutrient cycling of mangrove ecosystems. In: Yáñez-Arancibia A, Lara-Domínguez L (Eds) Ecosistemas de manglar en América Tropical, Instituto de Ecología, A.C., NOAA, U.S. Department of Commerce and UICN, pp 127–152

Whitmore RC, Brusca RC, de la Luz JL, González-Zamorano P, Mendoza-Salgado R, Amador-Silva ES, Holguín G, Galvan-Magaña F, Hastings PA, Cartron JE, Felger RS, Seminoff JA, McIvor CC (2005) The ecological importance of mangroves in Baja California Sur: Conservation implications for an endangered ecosystem. In: Cartron JE, Ceballos G, Felger RS (Eds) Biodiversity, ecosystems, and conservation in northern Mexico, New York, pp 298–362