



Review and synthesis

Mangroves and people: Lessons from a history of use and abuse in four Latin American countries

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ABSTRACT

From native pre-Columbian subsistence economies to the modern global economy, mangroves have played an important role providing goods and services to human societies for millennia. More than 90% of the world's mangroves are located in developing countries, where rates of destruction are increasing rapidly and on large scales. In order to design effective conservation strategies, it is critical to understand the natural dynamics and anthropogenic drivers of these coastal wetland habitats. We use retrospective techniques to reconstruct mangrove forest history in the Eastern Tropical Pacific. We examine available, present day estimates of mangrove area and evaluate the representation of mangroves in the protected area systems of Costa Rica, Panama, Colombia and Ecuador, evaluating existing policies regarding mangroves. Archaeozoological evidence shows that mangroves were exploited for many thousands of years by pre-Columbian societies. Post-conquest deforestation prevailed during the next 400 years. Since 1990, despite increasingly positive attitudes towards mangroves and their inclusion in protected areas and conservation policies, mangrove cover has continued to decline due to expanding human activities (agriculture, aquaculture, coastal development), even in the presence of laws prohibiting their removal. Here we provide an historical ecology baseline of mangroves in the Eastern Tropical Pacific, from which to view current trends and map future trajectories. Given the myriad negative consequences of mangrove loss recorded worldwide, and the strong ecological connectivity of the region, developing effective strategies for mangrove management at an appropriate scale will be paramount to protect coastal livelihoods and biodiversity.

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1. Introduction

Largely restricted to tropical and subtropical latitudes, mangroves are the only vascular flowering trees that can live in the confluence of land, freshwater, and ocean (Hogarth, 2007). This involves adapting to fluctuating environmental conditions such as changes in salinity, regular soil inundation, shifting sediments, and in-water low oxygen concentrations (Kathiresan and Bingham, 2001). As such, mangroves display a large set of morphological and ecophysiological adaptations to help them survive in these dynamic habitats. Among these adaptations are (1) the exclusion of salt by roots, (2) rapid canopy growth, (3) viviparous embryos, (4) tidally dispersed propagules, (5) exposed roots that breathe above ground, (6) highly vascularized wood, (7) efficient nutrient retention, and (8) salt-excreting leaves (Alongi, 2002; Duke, 2011).

Despite being considered a rare forest type because of their small global extent (less than 1% of tropical and subtropical forests worldwide), mangroves provide a wide range of ecosystem services and direct uses including coastal protection, fuel (charcoal, firewood), food (fruit, leaves, associated vertebrates and invertebrates), and construction material (Hogarth, 2007). Even though the ecological importance of mangroves has come to be widely recognized, reports of the Food and Agriculture Organization show a widespread decline of mangrove area, with losses over 20% of total global coverage (36,000 km²) between 1980 and 2005 alone (FAO, 2007a). It has been claimed that estimated rates of mangrove loss are three to five times greater than the overall loss rates calculated for other forests and coral reefs on a global scale (Valiela et al., 2001). In light of the current degradation rate of marine ecosystems, intensifying anthropogenic impacts, and climate change, protected areas emerge as an essential strategy for conservation. More than 90% of the world's mangroves are located in developing countries, where rates of destruction are rapidly increasing (Duke et al., 2007).

In order to design more effective conservation strategies, it is critical to understand long-term anthropogenic effects as well as the natural dynamics of this marine-coastal habitat in space and time. Study of forests' past dynamics represents a fundamental insight (Dahdouh-Guebas and Koedam, 2008). Pre-Columbian societies represent more than 95% of the history of mangrove/human interaction in the neotropics. Historical ecology techniques derived from social sciences, such as exploration of documentary archives and archaeological investigations, can provide valuable information and complement other direct survey methods (e.g. remote sensing) applied to understand current processes and map possible future trajectories (Dahdouh-Guebas and Koedam, 2008).

The Eastern Tropical Pacific (ETP), is a distinct marine ecoregion encompassing continental shore between southern Baja California to northern Peru including oceanic island groups such as Cocos, Malpelo, and Galápagos oceanic islands (Spalding et al., 2007). However, within this broader region, the Pacific waters of Panama, Costa Rica, Colombia and Ecuador (Fig. 1) share particular conservation significance by containing a cluster of World Heritage Sites (Edgar et al., 2011). This area, termed in this study as the ETP, is an important biogeographical region in terms of marine resource productivity and biodiversity, supporting a range of rich fisheries and exhibiting many endemic species (Fiedler and Talley, 2006). In this paper we use retrospective techniques to reconstruct mangrove forest history in ETP countries, with the aim of understanding the historical reasons behind mangrove deforestation in the region. Additionally, we review available estimates of mangrove area from recent years and evaluate the representation of mangroves in the marine protected areas of four countries, examining existing policies regarding mangrove conservation. The historical timeline of ETP mangrove forests and their current protection status that we

present improves our understanding of the relationship dynamics between mangroves and humans, and provides a regional information baseline from which governments can build improved management strategies.

2. An historical timeline of mangrove decline

2.1. Evolution of perceptions & attitudes towards mangroves

Mangroves' ability to thrive in salt water has attracted substantial scientific attention and academic curiosity, especially among botanists (Walters et al., 2008). However, since our understanding of the services provided by mangroves, as a coastal habitat has been scant and defective until recently, attitudes towards mangroves as an ecosystem have been ambivalent (Lugo and Snedaker, 1974).

As far as we know, the first descriptions of mangroves by ancient literate observers were made in the year 325 BCE by Nearchus, the Greek Admiral of Alexander the Great's fleet. In the 'Chronicles of Nearchus' he described mangroves in the Red Sea, the Persian Gulf, and the Indus Delta (Bowman, 1917). Twenty years later in 305 BCE Theophrastus, a pupil of Aristotle, also referred to mangroves in his 'Enquiry into Plants' (Schneider, 2011): "But there are plants in the sea, which they call 'bay' and 'olive' [...]. On the islands which get covered by the tide they say that great trees grow, as big as planes or the tallest poplars..." (Hort, 1916). On the American continent, the first Spanish chronicler to describe mangroves from a botanical standpoint was Gonzalo Fernández de Oviedo in his 'General and Natural History of the Indies' in 1531, placing emphasis on their usage by indigenous communities: "Mangrove is one of the best trees in these lands, and it is common in these islands (Greater Antilles) and in Tierra Firme (mostly the Isthmus of Panama). Its wood is one of the best ones around for building shelves, poles, posts for houses, fences, window frames, and doors and other small things...the bark of these mangroves is singularly good for tanning cow leather in a short time" (de Oviedo y Valdés 1535).

Literature about mangroves between the 17th and 20th centuries focused mainly on describing mangrove morphology, habitat, distribution, species diversity, taxonomy, and systematics (Bowman, 1917). From around 1900 onwards, studies that highlighted the ecological role of mangroves (mostly regarding their functions of sediment consolidation and shoreline maintenance) emerged to join earlier descriptive literature (Lugo and Snedaker, 1974). The second half of the 20th century signalled the first public initiatives for mangrove conservation following work that highlighted their economic value for Florida fisheries due to their role in food web enrichment (Lugo and Snedaker, 1974). Thus, the history of society's perceptions towards mangrove systems has evolved only recently from being considered as a barren wasteland of unhealthy soils, to being complex ecosystems upon which humans depend. The following sections explore the decline of mangrove forests in the ETP region.

2.2. Early pre-Columbian societies

As the 16th century quote from Oviedo (above) implies, mangroves played a crucial role in the way of life for many coastal societies, and are closely linked with human culture. In India, the Solomon Islands and Kenya, mangroves have been regarded as sacred spaces where special rites take place, temples are erected, and trees worshipped (Kathiresan and Bingham, 2001). In Latin America, the importance of these habitats to indigenous cultures is evident from zooarchaeological data, which supports cultural anthropological inferences about prehistoric subsistence and



Fig. 1. The Eastern Tropical Pacific region encompasses the Pacific coasts of Panama, Costa Rica, Colombia and Ecuador (red line, inset map). The distribution of mangroves in the region according to Giri et al. (2011) is shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ecology (Wake et al., 2013). Examples of regional mangrove resource exploitation by pre-Spanish peoples are numerous. When present, mangroves were intensively utilized for timber, charcoal, tannins, shell collection, and fishing (Prah, 1989; Lacerda et al., 1993). Species that frequent mangroves often represent a large biomass accessible from the land, and can be readily harvested by fairly simple techniques (e.g. by hand, and with weirs and traps) (Cooke and Jiménez, 2004). This generated a steady source of animal protein and enhanced human population growth, sedentism and ultimately societal complexity. Dating from the early Formative Period (1800 BCE–200 CE), the coastal culture of Valdivia

(Ecuador) holds evidence not only of broad-based fish and marine molluscs capture from mangrove habitats and shallow intertidal waters, but of hunting for mangrove associated birds like grebes, ibises, ducks and coots (Stahl, 2003). In central Panama, aquatic resources and particularly fresh and preserved fish contributed substantially to the diet of pre-Columbian societies (Cooke et al., 2008).

In the early indigenous communities' transition from nomadic to sedentary living, resource rich habitats such as estuarine mangrove are thought to have played a fundamental role (Prah, 1989; Lacerda et al., 1993; Raymond, 2008). The earliest and most

complete records of permanent settlements have been discovered in the small coastal valleys of south-western Ecuador (Raymond, 2008). Using carbon dating of fossilized *Cucurbita* fruit (squash and gourd), Piperno and Stothert (2003) were able to identify an early pattern of agriculture in coastal Ecuador that dates back to the Early Holocene (10–12,000 calendar years ago). Relevant early agricultural sites were located at the interface between marine coastal, fluvial and mainland habitats. Therefore, fertility and diversity of coastal low lands adjacent to mangroves might have provided a suitable place to hunter-gatherer communities in coastal Ecuador while they started cultivating edible plant varieties, on their way to establishing fairly sedentary occupations (Piperno and Stothert, 2003). Evidence of pre-Columbian use of mangrove-estuarine resources has been found throughout the ETP: Reitz and Masucci (2004) found that the main invertebrates in deposits of the Ecuadorian coastal settlements, Valdivia and Machalilla, are mangrove-associated molluscs such as the horn shell *Cerithidea pulchra* and the blood cockle *Anadara tuberculosa*. Between 700 BCE and 500 CE, the culture called “Tumaco/Tolita” situated between Buenaventura (Colombia) and Esmeraldas (Ecuador), harvested mangrove products, such as molluscs, fish, crabs, birds, and mammals (Villegas et al., 1994; Zuluaga and Romero, 2007).

Pre-Columbian societies took advantage of the biologically diverse ichthyofauna of the ETP by exploiting a wide range of species, mostly marine inshore and euryhaline freshwater fish found in mangrove channels and low salinity shallow waters using tidal traps, weirs, and perhaps hook and line (Cooke and Jiménez, 2004). The importance of fish in the diet is evident in archaeological sites of the Coclé culture from the lowlands of central Panama, where the targeted fish taxa (e.g. catfish, sleepers, snook, toadfish and croakers), point towards a fishing strategy that focused on intertidal mudflats, mangrove forests and tidal rivers (Cooke and Ranere, 1999). However, not only coastal settlements benefited from the abundant fish resources: In one of the most populated zones in pre-Columbian Panama, the littoral and adjacent wooded savannahs of Parita Bay (a mangrove fringed estuarine system), marine fish bones have been recovered in sites located 13–60 km from the coast (Cooke and Jiménez, 2004). Cooke and Ranere (1999) found that 70% of the fish consumed between 1500 and 1800 years ago in a site 13 km away from the Parita Bay coast, were of marine origin. These included many that frequent mangroves, but also others that eschew this habitat and favour clearer water currents at the seaward edge of the turbid estuarine mixing zone. According to ethnoarchaeological data, it is suggested that fish was preserved to be exchanged with inland communities by salting and sun-drying (Carvajal-Contreras et al., 2008). The facility of sun-drying salted fish for local and regional consumption, and its subsequent distribution inland, is apparent at the Vampiros rock-shelters on an ephemeral ancient strand line in Parita Bay (Carvajal-Contreras et al., 2008).

The above summary underlines the potential of archaeozoological research in Latin America to provide detailed data about how pre-Columbian societies interacted with the coastal habitats through time, in tandem with substantial diachronic geomorphological changes that affect mangrove extent, accessibility and distribution. Much information, however, remains to be uncovered in this field. This type of research is challenging given that: (1) the conservation of archaeological evidence is impaired by the instability and ephemerality of relevant coastal landforms in time and space (Clary et al., 1984; Cooke and Ranere, 1999); (2) the difficulty of accurate identification of species, especially in speciose families and genera with heterogeneous life histories, and (3) the scarcity of qualified researchers in fish biology and archaeoichthyology in most countries (Cooke and Martin, 2010).

2.3. Conquistadores and the colony

The Spanish were the first to provide written accounts and descriptions of the mangroves of the American continent during their expeditions. Some coastal pre-Columbian societies used mangrove wood, apparently preferentially. In the early stages of the colonial period, however, the Spanish intensified the exploitation of mangrove wood by utilising it heavily for construction, especially shipbuilding, because of its water resistant qualities, hardness, length, and girth (De Ulloa and Juan, 1826). Timber harvesting played an important role in construction and leatherwork, while mangrove charcoal was used in sugar production. For these reasons, mangrove wood became part of the tax or ‘tribute’ that the indigenous communities had to pay the Spanish king (Plate 1) (De Ulloa and Juan, 1826; Prah, 1989).

During the 17th century, the Spanish were eager to broaden their naval domain and promoted the construction of shipyards in strategic cities of Ecuador, Costa Rica and Panama (Guayaquil, Nicoya, Ciudad de Panama) (Jordán Reyes, 2006). These demanded large quantities of wood, such as *Tabebuia sensu lato*, mangrove, and laurel (*Cordia* spp.). The Spanish monarchy claimed that the Guayaquil shipyard was the most important of the Pacific coast of the Americas because of the quality of its ships (De Ulloa and Juan, 1826). Between the 16th and mid-18th centuries, the demand for wood for the shipyard and for the construction of churches and buildings in Lima was so high, that mangrove poles exported from the Pacific of Colombia reached six thousand poles per year (Prah, 1989). Mangrove wood from Ecuador (Esmeraldas and Guayaquil regions) was also exported to Perú to build coastal cities such as Lima, because of the lack of forests in this region (Patiño, 1990). Jorge Juan and Antonio de Ulloa mention the exploitation of mangrove wood in Ecuador in their book ‘*Secret news of America*’, published in 1747:

“In these works [building and repairing] they employ great quantities of mangroves taken from Guayaquil annually by the King... the loss of mangroves and workforce [on the repair of walls], rises to very considerable quantities” (De Ulloa and Juan, 1826).

Translation by J. Lopez-Angarita

The demand for mangrove wood was so high that the Spanish monarchy were forced to issue regulations for its exploitation, such as licences and permits required for cutting certain species, or in certain areas (Jordán Reyes, 2006). After gaining independence from the Spanish crown in the early 19th century, the young Republics were left without an understanding of the importance of managing their forestry resources, while facing political volatility and instability (van Bottenburg, 1952). Mangrove wood exploitation became a very important industry on the Pacific coast of the continent, with its main hubs in Buenaventura (Colombia) and Guayaquil (Ecuador). Uncontrolled logging activity continued for many years without any replantation of trees (Cifuentes, 2002).

Exploitation and commercialization reached industrial levels after 1948, when two businesses located in Buenaventura monopolized tannin production for the next 30 years. By the 1960s they were producing approximately 3000 tons of mangrove wood per month, mostly red mangrove, *Rhizophora mangle* (Leal, 2000). By the 1970s mangrove wood exploitation in Colombia for tannin extraction and construction, had reached its peak, and subsequently collapsed, for two reasons: (1) Prices in Colombia were undercut by the international tannin market, and (2) deforestation levels increased tannin manufacturing effort (Cifuentes, 2002). Large trunks were diverted to making power line poles and railway sleepers (Prah, 1989).

For more than 400 years, colonial and republican use of mangrove wood was governed only by profit maximisation, causing



Plate 1. “Indigenous exploitation by the Spanish conquerors”. A mural by Diego Rivera (1929–1945) showing an indigenous workforce involved in wood extraction (top right quarter). Because of its high quality, large amount of mangrove wood was utilized as building material. Mexico City – Palacio Nacional. Source: <http://tinyurl.com/qdxx3j>.

widespread deforestation. It wasn't until the 1990s that mangrove forests began to be considered as ecosystems, and managed as such (Lacerda et al., 1993). In Costa Rica, mangroves started to be impacted by coastal development in the early 1940s when the country's population underwent a rapid rise and began to convert large areas of mangrove stands to agriculture, aquaculture, and wood extraction (FAO, 2007b). By 1982, Ecuador had the world's largest area dedicated to shrimp production, and in only 30 years following the construction of the first shrimp ponds in 1969, 57% of Ecuador's mangroves had been cleared for shrimp farming (Ocampo-Thomason, 2006). This was the result of the high international demand for shrimp and the economic incentives provided by the government (Martinez-Alier, 2001).

Panama was one of the first countries in Latin America to establish a commercial shrimp farming industry (Bolanos, 2012) and after shrimp aquaculture began in 1974, production grew rapidly with 8100 ha under production in 1998 (Suman, 2002). However, despite mangrove-lined channels being often eradicated, the most impacted habitat was that of high tidal flats or salt flats (*albina* in local Spanish) publicly owned and adjacent to mangroves in the central Pacific provinces of the country (Suman, 2002). Into the 1990s mangroves were still important assets in Costa Rica and Panama for tannins and charcoal production (Lacerda et al., 1993).

Nowadays, mangrove clearance or other anthropogenic modification is related to aquaculture, agriculture and urban land uses. Timber extraction still causes degradation of remaining forests, although newer threats include solid waste disposal, pollution, rising sea level and overfishing (Hogarth, 2007). Where mangroves are close to urban areas, their conversion to a constructed environment (e.g. housing, ports, and industries) is widespread (Benfield et al., 2005). Other areas are transformed into arable and grazing land (Giri et al., 2008). However, the most important driver of

mangrove loss is aquaculture, in particular extensive shrimp aquaculture, which is often related to unsustainable practices involving the use of (1) fishmeal production from wild-caught fish, driving overfishing and associated bycatch to feed shrimp, and (2) fungicides, pesticides and antibiotics, which pollute ground water and damage soil leading to pond abandonment and prevention of recolonization by mangroves (Páez-Osuna et al., 2003, 1998).

3. Change in mangrove extent

Obtaining reliable estimates of long-term changes in the areal extent of mangroves is compromised by the lack of data and large variance of area estimates. Significant differences between each country's estimates are apparent. These discrepancies in part reflect the difficulties in arriving at accurate estimates through mapping (Heumann, 2011; Kuenzer et al., 2011). By 1999 it was suggested that certain Latin American countries had lost up to 40% of their total mangrove area (Lacerda and Schaeffer-Novelli, 1999). However, precise estimates of mangrove deforestation are still lacking for the region due to the inherent difficulties in establishing a baseline. Only since the late 1990s has satellite spatial imagery been used for systematically mapping natural resources at a global scale (the *Enhanced Thematic Mapper Plus* system of Landsat was launched in 1999) and recent advances in remote sensing technology have facilitated the availability of higher resolution estimates (Spalding et al., 2010). Even so, many present-day mangrove formations are narrow or patchy, and blend subtly with other habitats, making them hard to detect using satellite data imagery, and estimates prone to error (Manson et al., 2001).

To determine the change of mangrove coverage in the ETP we collected published estimates of total mangrove forest area for Panama, Costa Rica, Colombia and Ecuador. We compiled all

Table 1
The most recent and first available estimates of mangrove area, the percentage lost, and the mean annual rate of loss for the four countries of the Eastern Tropical Pacific.

Country	Mangrove area (ha)		Percentage loss of mangrove area (ha)	Annual rate of loss (ha y ⁻¹)	Annual percentage loss rate
	Most recent estimate (Giri et al., 2011)	Earliest estimate (year)			
Panama	154,227	486,000 (1980) ^a	68.2	10,702	2.20
Ecuador	137,698	362,727 (1969) ^b	62.0	5358	1.48
Colombia	213,857	501,300 (1960) ^{c,A}	57.33	5636	1.12
Costa Rica	39,034	64,452 (1979) ^{d,A}	39.4	794	1.23

^A The year of the earliest estimate provided corresponds with the most reliable estimate in relation to the data, hence this year of earliest estimates do not match those of Fig. 2.

^{a,d} FAO (2007b).

^b Ocampo-Thomason (2006).

^c Villalba (2005).

estimates available in the literature, from the earliest to the latest, regardless of the detection method (FAO, 2007b,c; Giri et al., 2011; Guevara-Mancera et al., 1998; Lacerda et al., 1993; Prah, 1989) (Table 1. Supplementary material). In some cases more than one annual estimate was reported (by different sources). Here we averaged the estimates and used the standard error as an indicator of precision for the different estimates. For our calculations, we used the dates of the dataset rather than the date of publication of the estimate, unless the dataset date was not specified. Including all the available figures of mangrove cover will likely increase the error margin of the estimation of trends, however, given the scarcity of historical mangrove area information we decided the possible bias was justifiable.

We estimated the change in mangrove area by country and the rate of mangrove loss by calculating the difference between the earliest and latest available estimates of mangrove area. We then divided the change in area by the number of years between the latest and earliest estimate (Table 1).

We found high variability among published estimates of mangrove area with notable oscillations in time, and a high standard error for area measurements estimated in different sources for the same year (Fig. 2). From this we assume that the irregular results were due to the different techniques being used to conduct year-by-year area measurements since the precision and accuracy of remote sensors can vary significantly depending on methods and mapping objectives (Mumby et al., 1999). As our results represent all existing estimates of the region, they should be interpreted with this in mind. Some values are likely to have underestimated

or overestimated the real coverage, however, despite the variability of the data, there is a clear trend of mangrove area decline. From the rate-of-loss data (Table 1), it seems that Panama has experienced the greatest overall loss of mangrove cover in the region, followed by Colombia and Ecuador. Costa Rica shows the highest proportion of intact mangrove forest, but also has the smallest mangrove area of the four countries.

Neighbouring Panama and Costa Rica showed the greatest difference in the magnitude of mangrove area loss. Costa Rica has a strong tourism sector and thanks to the high proportion of protected areas (World Economic Forum, 2013) and national laws in favour of ecosystem conservation, has maintained a successful ecotourism industry (Krüger, 2005). Therefore, total area of mangrove lost in Costa Rica is low compared to the other countries in the region, as legislation has proven effective in general (Jiménez, 2004). On the other hand, Panama has a growing infrastructure sector, with urban areas spreading rapidly into natural areas such as wetlands, despite protection policies in place (Kaufmann, 2012) (Box 1). The greatest proportion of mangrove destruction in Panama has occurred around Panama City where coastal wetlands have been heavily disturbed in the last two decades as the city grows and land is reclaimed from the sea (Kaufmann, 2012). Beach areas that are near small patches of mangroves, i.e. Punta Chame to San Carlos, have also suffered mangrove loss for tourism development. Many Panamanian environmental organizations, government and non-profits, are vociferous about the dangers of mangrove destruction, but political corruption too often inhibits protection and conservation action (Mate, 2005).

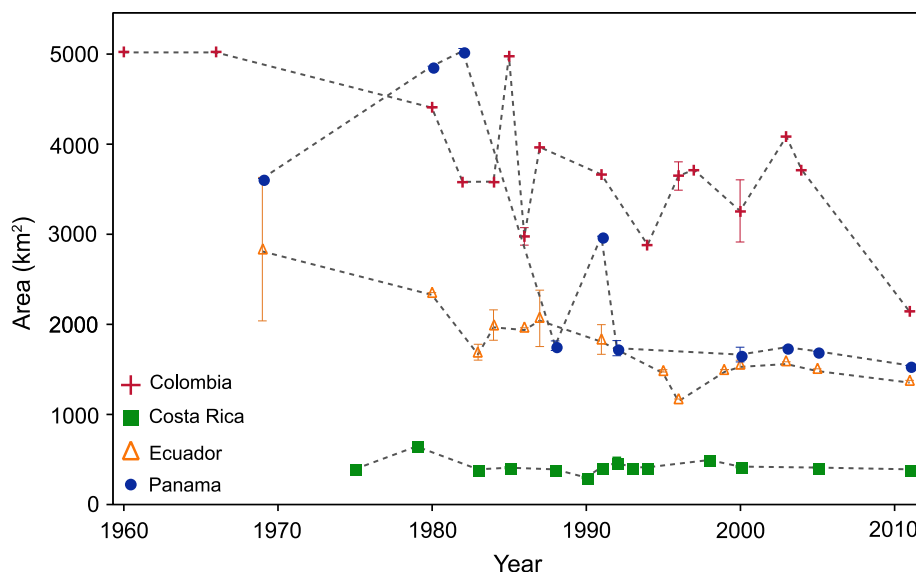


Fig. 2. Change of mangrove area from 1960 to 2010 in the Eastern Tropical Pacific. The graph was constructed using all available mangrove area estimates in the literature. Error bars are calculated using one standard error from the mean for years with more than one independent estimate.

Box 1 Panama City's disputed treasure.

The earliest mentions of Panama City are found in Spanish chronicles from the 16th century, which describe it as “sick” given its location on “a lagoon of foul smell” with rivers “filled with crocodiles”, where the Spanish conquerors used to feed on “the great quantity of clams” (de Cieza de LeAEn, 2005). Authors describe the wetlands of Panama Bay with a negative connotation common until the last decades of the 20th century (D’Croz and Kwiecinski, 1980). Thanks to awareness regarding the importance of the ecosystem services that mangroves provide to the capital, Panama Bay was designated a Ramsar wetland site in 2003 and a protected area in 2009 (CREHO, 2010).

In April 2012 the supreme Panamanian Court of Justice approved a “provisional suspension” of the resolution that created the protected area, reducing the rates for mangrove logging permits for commercial projects and illegal logging penalties.¹ Later in May 2012 the Ministry of Development approved construction of exclusive residential areas inside the protected area. Several environmental protection organizations and citizens rejected the Court’s decision and criticized it heavily, while protests were held and demands made for re-establishment of the bay’s protection status. This pressure was effective and on April 2013, the Court lifted the former suspension of the protected area, emphasizing that the suspension contradicts Panamanian laws for the protection of wetlands (*Entrada No. 123–12*). However, the constant conflict of interests competing for the bay’s land, create a continuous legal tug of war for the protected area.²

The case of Panama Bay is a clear example of how mangrove destruction can continue, despite existent international agreements and national laws protecting mangroves. Examples like this exist all over the ETP, where wetlands are bought for private use (agriculture, rice and oil palm) without public consultation or in complete defiance of their protected area status.³

Historical losses of mangrove cover will never be fully appreciated (Alongi, 2002), but even the recent reported losses of coverage in the ETP highlight the urgent need to strengthen information systems and obtain reliable figures on which to base future estimates and conservation measures. The best estimates rely on a combination of remote sensing images, aerial photos, forest surveys, and ground-truthed maps, yet for remote and inaccessible areas achieving a high accuracy is still very challenging (Manson et al., 2001).

Mangrove losses can be very costly, especially for developing countries, and are the result of our failure to link ecological processes with their societal and economic benefits. The need to protect mangroves with effective conservation measures is best advocated by the negative impacts recorded after human-caused perturbations to the habitat (Alongi, 2002). As valuation of mangrove services has proven to be a useful tool for proposing a more sustainable use of wetlands, we have been able to understand more clearly how costly are the ecological and social implications of mangrove loss (Naylor et al., 2000; Valiela et al., 2001; Walters et al., 2008), and have discovered some of the prominent economic benefits that may represent hope for the future conservation of mangroves (Aburto-Oropeza et al., 2008; Rönnbäck, 1999).

¹ http://www.ancon.org/index.php?option=com_content&view=article&id=452:rechazo-total-a-nefasta-decision-de-la-corte-contra-area-prottegida-bahia-de-panama&catid=102:notas-actuales-ancon&Itemid=225.

² <http://www.aida-americas.org/es/refdocs/1843>.

³ <http://www.aida-americas.org/es/project/el-humedal-bah%C3%AD-de-panam%C3%A1-mantiene-su-condici%C3%B3n-de-%C3%A1rea-prottegida>.

4. The state of mangrove protection in the ETP

In Latin America and the Caribbean, Guarderas et al. (2008) found that, despite the increase through time in the number and area of Protected Areas only 1.5% of the coastal and shelf waters of the region are under some type of conservation protection (percentage of exclusive economic zone protected: Costa Rica = 0.45%, Panama = 1.18%, Colombia = 9.17%, Ecuador = 12%) (Table 2. Supplementary material). Since lack of protection can be extremely costly in terms of loss of ecosystem services (Tallis and Kareiva, 2005), there is a great need to include highly valuable coastal wetland habitats such as mangroves within protected schemes. Polidoro et al. (2010) found that the highest proportion of threatened mangrove species in the world occur in Costa Rica, Colombia and Panama, with 25–40% of mangrove

Box 2 Mangrove diversity in the ETP.

There are two major floral realms widely recognized in patterns of mangrove distribution: the Indo West Pacific (IWP) and the Atlantic East Pacific (AEP). The IWP comprises 57% of the global mangrove area, is rich in species (62) and extends from East Africa eastwards to the Central Pacific; whereas the AEP that encompasses all of the Americas, West and Central Africa only hosts 12 species in 43% of the global mangrove area (Spalding et al., 2010).

The major differences in floral composition of mangroves in tropical America started to develop after the closure of the Panama isthmus 3.5 million years ago, which separated the Pacific from the Atlantic. Afterwards very particular climatic processes (dry seasonal climate) that started in the Miocene era gave shape to the actual flora which has two distinct groups of mangroves: species restricted to seasonal dry climates, and species restricted to high precipitation climates (Jimenez, 1999). In Panama and Costa Rica there are marked dry and rainy seasons in certain areas, but precipitation shows a strong spatial pattern depending on topography. In zones with high terrestrial runoff, mangrove communities can be very extensive and diverse. Examples of this are the Golfo de Nicoya and the TÁrraba-Sierpe delta in Costa Rica, and Golfo de Chiriquí and Golfo de San Miguel in Panama. The largest areas of mangroves in western South America can be found in the humid coastline of the Colombian Pacific and the north of Ecuador (Esmeraldas region), whereas dryer areas in southern Ecuador have limited mangrove cover (Spalding et al., 2010).

In the ETP, mangrove swamps are generally more abundant on the Pacific coastline as many estuaries, bays and rivers provide a suitable environment for development of extensive coverage, contrasting with the sandy, high-energy shoreline and narrow tidal amplitude of the Caribbean coast (Spalding et al., 2010). A high number of tidal flats and the significant freshwater input from upstream and precipitation allow mangrove trees of the Pacific coast to grow up to 50 m in height, while only small and stunted trees not exceeding 5 m are found in the Caribbean (FAO, 2007a).

Mangroves in Latin America and particularly in the ETP have relatively low plant diversity (Table 3), with only 11 species (Ya-éz-Arancibia and Lara DomÓnguez, 1999). However, as an ecosystem they provide great structural complexity creating highly diverse environments that provide multiple ecosystem services. In the ETP the most common genera of mangroves are *Rhizophora* and *Avicennia*. These two genera are widely distributed in the continent with the most widespread species being *R. mangle* and *A. germinans* (Lacerda et al., 1993).

Table 2
A summary of the international conventions, regional agreements, and national laws, policies and regulations related to mangrove habitats for each of the countries of the Eastern Tropical Pacific.

Policy description	Costa Rica	Panama	Colombia	Ecuador
International Level Ramsar Convention on Wetlands	Approved in 1991	Approved in 1989	Approved in 1997	Approved in 1991
Convention of Biological Diversity	Ratified in 1992	Ratified in 1992	Ratified in 1992	Ratified in 1992
Regional Level Regional agreements involving mangroves	Central American agreement for the protection of the environment (1989) Marine Corridor of the Eastern Tropical Pacific (2004) Central American policy for the Conservation and Rational Use of Wetlands (2002)	Central American agreement for the protection of the environment (1989) Marine Corridor of the Eastern Tropical Pacific (2004) Central American policy for the Conservation and Rational Use of Wetlands (2002)	Permanent Commission of the South Pacific includes an action plan for the protection of the coastal areas of the region (1979) Marine Corridor of the Eastern Tropical Pacific (2004) No regional agreement specifically on wetlands	Permanent Commission of the South Pacific includes an action plan for the protection of the coastal areas of the region (1952) Marine Corridor of the Eastern Tropical Pacific (2004) No regional agreement specifically on wetlands
National Level Definition of wetland, land tenure laws Policies and laws relating to mangroves. Exploitation and usage regulations.	1992. Wetlands are public assets with multiple uses – 1940. Wastelands Law, mangrove wood extraction needs specific government approval – 1996. Forestry Law limits the exploitation and logging of mangroves – 1998. Biodiversity Law makes all wetlands protected areas, dedicated to the conservation and protection of biodiversity, soil, and water resources. All exploitation prohibited only research and recreation permitted	1992. Wetlands are public assets – 1998. General law for the Environment. Mangroves are given conservation priority as an ecosystem with high biodiversity and productivity – 2006. The logging, use, commercialization, and modification of any mangrove are prohibited. Only allowed if authority declares the activity as sustainable – 2006. Highly valuable habitats such as mangroves have conservation priority – 2008. All wetland areas and particularly mangroves are special zones of management	Mangroves are public assets – 1982. Commercialization of mangrove wood poles prohibited – 1995. Logging of certain mangrove species restricted or prohibited – 1996. Any activity that exploits mangrove or associated resources is required to have a special licence – 1998–2002. National Environmental Policy puts all coastal ecosystems under integrated marine and coastal management – 1996. Certificates for Forestry Incentives – 2000. National Policy of the Ocean and Coastal Spaces 1993. Ministry of the Environment, National Natural Parks of Colombia 2011. National Authority of Fishery Resources	Mangroves are public assets – 1994. Construction of new shrimp farms prohibited – 2004. Exploitation and logging of mangrove prohibited, for all but ancestral communities – 2004. Forestry Law, license needed to exploit mangroves – 2007. 1 nautical mile from the coastline declared as zone reserved for species reproduction (with specific regulation and uses) – 2008. Shrimp farms obliged to restore 10–30% of the areas illegally occupied – 2008. Conservation and management of fragile and threatened ecosystems such as mangroves regulated by the state Ministry of the Environment of Ecuador 2008. National System of Protected Natural Areas
National Environmental authority with jurisdiction over mangroves	1978. Ministry of the Environment and Energy National System of Conservation Areas (SINAC)	1998. National Authority for the Environment (ANAM) 1994. National System of Protected Areas (SINAP) 2006. Panama Authority for Aquatic Resources	1993. Ministry of the Environment, National Natural Parks of Colombia 2011. National Authority of Fishery Resources	Ministry of the Environment of Ecuador 2008. National System of Protected Natural Areas
National research and conservation initiatives	– 1993. National Strategy for Wetlands – 1999. National Wetland Programme – 2001. National Policy for Wetlands	– 2004. Inventory of continental water bodies with emphasis on fishing and aquaculture – 2010. Inventory of continental and coastal wetlands of the Republic of Panama	– 1990. Mangroves of Colombia – 1990. Conservation, Management and Use of the Mangroves of Colombia – 2000. National Programme for Mangroves	– 1984. Temporal and spatial study of mangroves, shrimp ponds and salinas. This study was updated in 1987, 1991, 1995, 1999, 2004, and 2007 1985. Inventory of mangroves in Continental Ecuador
Management strategies	1998. All wetlands are protected areas Most Ramsar sites have management plans	2003. The Aquatic Resources Authority issues special permits to guarantee the sustainable exploitation of mangroves	1991. Afro-descendant and indigenous communities have authority to manage their traditionally occupied lands	2000. Agreements of sustainable use of the mangroves with ancestral users

species classified as threatened under the IUCN Red List Categories of Critically Endangered, Endangered and Vulnerable (Box 2).

Despite the high mangrove biomass found in the ETP (Hutchison et al., 2014), mangrove tree species diversity within the region is low relative to other regions (Box 2), making it particularly vulnerable to species loss, and consequently, the effects on human livelihoods and ecosystem services are expected to be greater than in other regions with higher diversity (as systems with higher regional species richness are argued to be more stable) (Worm et al., 2006). Moreover, the ETP suffers from significant gaps in protected area coverage compared to other regions such

as the Caribbean, as well as little connectivity between existing protected areas (Guarderas et al., 2008). These are factors that highlight the need to focus on designation of a protected area network in the region, rather than single reserves established in isolation (Guarderas et al., 2008).

To explore the characteristics and management strategies of the protected area system in the ETP, we consulted the literature and available information in government websites to create a list of those protected areas that include mangroves and are formally recognized by each national authority. We conducted a review of the management plans of the protected areas identified and, given the

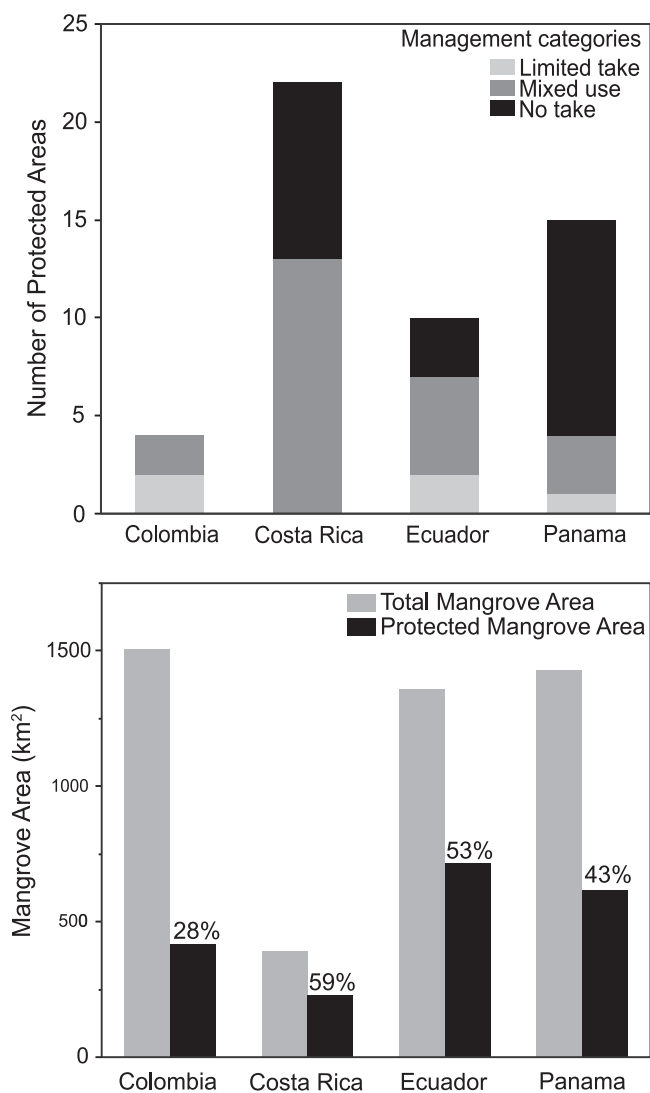


Fig. 3. The number of protected areas including mangroves in the ETP by country and management category (no take, limited take and mixed use) (Upper panel). Total mangrove area by country in the ETP, and percentage included in protected areas (Lower panel).

multiple management categories found, we classified the protected areas following Guarderas et al. (2008) into: no-take protected areas, limited-take protected areas, and mixed-use protected areas

(a no-take area within a limited take area). To determine how well mangrove habitats are represented in these protected areas, we used data from Giri et al. (2011), representing the latest spatial information of global mangrove coverage available from the World Conservation Monitoring Centre (WCMC). Giri et al. (2011) used 1000 Landsat images, ground-truthed data, and published literature to estimate the global distribution of mangroves. Mangrove area calculations were performed inside and outside protected areas using polygons in ArcGIS 10.2 (ESRI). We estimated the proportion of protected mangroves using maps of the protected areas obtained from Protected Planet (www.protectedplanet.net) the online interface of the World Database on Protected Areas, combined with national databases from government and non-governmental organisation databases.

According to our sources, there are fifty-one protected areas in the ETP that include mangroves and these cover a wide range of management categories and schemes (Table 3. Supplementary material). Twenty-two occur in Costa Rica, 15 in Panama, 10 in Ecuador and 4 in Colombia (Fig. 3). Protection schemes range from national parks to wildlife refuges and ecological reserves managed by local communities. There are marked differences in the management approaches of each of the countries. Costa Rica and Panama have a higher proportion of no-take protected areas than Ecuador and Colombia. In Costa Rica coastal wetlands are all no-take areas (RAMSAR, n.d.) (Table 2), so any protected areas that allow use of non-wetland natural resources and have mangroves within their limits are classified as mixed-use protected areas. Mangrove representativeness results show that at a regional level 47% of the total mangroves of the region are included within protected areas. Costa Rica and Panama lead the region in mangrove protection, with 58.7% and 51.9% respectively, whereas Colombia, at 23.7%, has the lowest proportion of protected mangroves in the region.

Among the key protected areas in the region, which conserve a high proportion of mangrove area are the Terraba–Sierpe Ramsar wetland in Costa Rica (Plate 2) with an extent of 30,000 ha, Sanguanga National Park in Colombia with 80,000 ha, and the Ecological Reserve Manglares Cayapas Mataje in Ecuador with 51,300 ha. As a general trend across the ETP, there is poor documentation on the governance of protected areas and many still lack management plans. Additionally, the administrative structure of protected areas were originally designed for terrestrial areas, but recently governments have increased the representation of marine areas and habitats in protected areas (Alvarado et al., 2012). Official agreements for marine conservation facilitate the implementation of participatory management schemes for protected areas (García, 2010), with the aim of generating economic alternatives for communities, such as ecotourism (TNC, 2011). Evidence of participatory management processes and schemes during the creation and administration of

Table 3

Mangrove species found in the Eastern Tropical Pacific. The IUCN column provides the species conservation status according to the IUCN Red List of Threatened Species: (VU) Vulnerable, (LC) Least Concern.

Species	Common name	IUCN	Costa Rica	Panama	Colombia	Ecuador
<i>Acrostichum aureum</i>	Helecho de playa	LC	X	X	X	X
<i>Avicennia bicolor</i>	Mangle salado, negro, o prieto	VU	X	X	X	
<i>Avicennia germinans</i>	Mangle negro o iguanero	LC	X	X	X	X
<i>Conocarpus erectus</i>	Mangle Jeli	LC	X	X	X	X
<i>Laguncularia racemosa</i>	Mangle blanco	LC	X	X	X	X
<i>Mora oleifera</i>	Mangle nato	VU		X	X	
<i>Pelliciera rhizophorae</i>	Mangle piñuelo	VU	X	X	X	X
<i>Rhizophora mangle</i>	Mangle rojo	LC	X	X	X	X
<i>Rhizophora racemosa</i>	Mangle rojo	LC	X	X	X	X
<i>Rhizophora × harrisonii</i>	Mangle rojo	–	X	X	X	X
<i>Tabebuia palustris</i>	Mangle marica	VU	X	X	X	
Total			10	11	11	8



Plate 2. Mangroves of Costa Rica showing an aerial view of a mangrove fringed river mouth in Golfoito (left panel) and the mangrove forests of Terraba-Sierpe protected area (right panel). Photo (c) López-Angarita, J.

the protected areas are limited, even though governments officially recognize their importance (Fundación Futuro Latinoamericano, 2011).

5. Environmental policy related to mangroves

We reviewed all existing environmental policies related to mangroves at international and national levels, by searching the literature, soliciting legal documents from government offices, and consulting their websites (Table 2). We found that as recently as 30 years ago, wetlands and especially mangroves were considered unproductive land by local governments. The ignorance of the value of mangroves in terms of provision of ecosystem services, or merely the attraction of short-term financial gains to be had from developing mangrove land, enhanced their destruction and clearance. Frequently governments and multinationals like the World Bank and the International Monetary Fund encouraged this attitude (FAO, 2007c; Ocampo-Thomason, 2006; Warne, 2011; Yañez-Arancibia and Lara Domínguez, 1999). This situation started to change in the 1990s as a result of increased global awareness of ecosystem services, and soon governments of the ETP joined international movements towards more environmentally oriented policies through international initiatives, such as The Ramsar Convention on Wetlands and the Convention on Biological Diversity (CBD).

Regional agreements emerged later such as the Central American Policy for the Conservation and Rational Use of Wetlands (2002), a common working agenda to strengthen the conservation and sustainable use of wetlands through regional cooperation and action. In South America, the Permanent Commission of the South Pacific created an action plan for the protection of coastal areas of the region (1981). Decades later, in 2004, the UNESCO declared the Marine Conservation Corridor of the Eastern Tropical Pacific (<http://whc.unesco.org/en/seascape/>) aiming to support the sustainable use of marine natural resources in the ETP, through the establishment of joint regional policy strategies that are supported by the community at large, international cooperation mechanisms and non-governmental sectors (www.cmarpacifico.org). The countries in the ETP have different approaches to mangrove protection

policies ranging from full protection to managing them as crucial components for human livelihoods (summarised in Table 2).

6. Prospects for the mangroves of the ETP

For a long time mangroves were considered tantamount to waste lands in Latin America because governments failed to understand their ecological significance. Nor did they understand their great importance for local subsistence economies and, ironically, lucrative export resources such as shrimp. A shift in attitudes began to appear in the 1990s in the face of increasing numbers of scientific investigations that demonstrated the utility of mangroves for human well being (Lacerda et al., 1993). Concomitantly, Latin American environmental policy underwent a transformation and approved many international agreements (e.g. CBD, Ramsar, CITES), which led to the modification of political constitutions. New environmental legislation was passed, and several conservation and research initiatives started with the assistance of international agencies and NGOs (Columba, 2013; CREHO, 2010; Ministerio de Medio Ambiente, 2002; SINAC, 2010). Currently the appearance of much new legislation and of the proliferation of protected areas, bear witness to the political will of Latin American countries to conserve their mangroves. However, coastal deforestation persists in the region despite of the emplacement of protection mechanisms such as protected areas and national environmental policies (Box 1). Other noteworthy problems persist, such as the lack of resources for implementing new policies, weak institutional platforms, and the need for qualified personnel (López Angarita et al., 2014). In addition enforcement is often not effective (Alvarado et al., 2012; García, 2010; TNC, 2011). Even though the new legislation is laudable and often effective, it is imprudent to assume that illegal activities have ceased in mangroves. They have not. There are still illegal activities threatening mangroves in all nations, highlighting the need for institutional capacity to support legislation (FAO, 2007c).

Natural resource management of interface habitats such as mangroves can be highly challenging given the multiple sectors with jurisdiction over them (e.g. fisheries, forestry, agriculture, urban development, transport), all with differing agendas and

positions on their use (Box 1). This translates into frequent conflicts of interests between sectors, often disregarding mangrove conservation, a risky situation given the strong cohesion and association of mangroves and local livelihoods. In coastal communities with strong ecological and social linkages conservation has a higher economic value than any form of destructive exploitation, such as logging or aquaculture. These linkages are bound to be stronger in highly connected regions such as the ETP, where non-destructive mangrove exploitation represents the main livelihood activity for many local communities. The ETP region needs to protect mangroves effectively, with tangible actions and accurate figures, by taking advantage of the existent regional agreements and commitments, homogenizing political barriers, and framing sustainable development objectives at a regional level.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.foreco.2016.03.020>.

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