Dichotomy of mangrove management: A review of research and policy in the Mesoamerican reef region.

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Abstract

Mangroves are declining globally at faster rates than tropical forests and coral reefs, with primary threats including, aquaculture, agriculture and climate change. Mangroves provide ecosystem services to coastal communities of Mexico, Belize, Guatemala and Honduras, which comprise the Mesoamerican Reef (MAR) ecoregion. Over the past two decades mangroves within the MAR have declined. Current estimates of mangrove cover in the region suggest that mangroves cover 239,176 ha of the MAR, equivalent to 1.7% of the world's mangroves. Concerted efforts to manage, conserve and protect mangrove forest are apparent in all four countries. Comprehensive laws that prohibit the cutting and clearing of mangroves have been implemented in Mexico, Guatemala and Honduras. Belize has a permitting system to regulate mangrove alterations. In addition, a total of seven international and regional agreements have been ratified. Across the ecoregion, forty-three protected areas have been designated that contain mangroves, providing protection to 111,396 ha of mangroves (47% of the total). However, our findings suggest a lack of transparency in the governance framework, a disconnect between management and research, and geopolitical differences have all played a role

in reducing management efficacy. A key finding of our study reveals a distinct division in the perceived major threats to mangroves between Ramsar site managers and researchers. Ramsar site managers identify anthropogenic disturbances as key threats, while in contrast, the bulk of research focuses on natural disturbances. To promote the inclusion of evidence-based research within mangrove management plans, greater efforts to connect these important stakeholders are required.

Keywords: Mangroves, Management, Conservation, Research foci, Mesoamerica, Threats.

Introduction

Mangroves are a diverse group of halophytic plant species, which form highly productive forests in the area between mean sea level and the highest spring tide mark along tropical and sub-tropical coastlines and estuaries (Tomlinson, 1994). Once perceived as mosquito infested wastelands, mangroves have now been recognized as highly productive and ecologically important ecosystems. Providing ecosystem services to marine and terrestrial environments, and human societies (Gilman *et al.*, 2008; Nagelkerken *et al.*, 2008), which are valued at US$9,900–35,900 $ha^{-1}yr^{-1}$ (Costanza *et al.*, 1997; Sathirithai and Barbier, 2001; Barbier, Hacker, Kennedy, Kock, Stier, 2011). Some of the most important mangrove ecosystem services include: coastline protection (in particular storm, hurricane and tsunami protection); waste water treatment; production of extractable materials; and provision of cultural sites (Rönnbäck, Crona and Ingwall, 2007; Warren-Rhodes *et al.*, 2011). Despite the known value of these forests, mangroves are highly threatened. Deforestation estimates suggest mangrove cover has declined by 30-86% since the mid 1990's (Duke *et al.*, 2007), and mangroves

continue to decline globally at unprecedented rates (FAO, 2007). Globally the main threats to mangrove forests include: coastal development; logging for timber and fuel; aquaculture; salt extraction; and agriculture (Valiela, Bowen and York, 2001; Alongi, 2002; Rönnbäck, Crona and Ingwall, 2007). The additional threats of climate change, e.g. sea-level rise, are also of concern (Schaeffer-Novelli *et al.*, 2016; Short *et al.*, 2016). Understanding if or how mangroves can adapt to such changes is of particular relevance to already threatened ecosystems, e.g. in the Caribbean (Godoy and De Lacerda, 2015; Sasmito *et al.*, 2016).

The majority (over 70%) of mangroves are located within developing countries (Giri *et al.*, 2011), where limited resources and capacity can inhibit effective management. At the international level, a number of treaties and conventions afford some protection to mangroves (Macintosh and Ashton, 2002), for example: the Ramsar Convention (1974); the Cartagena Convention (1983); and the International Tropical Timber Agreement (2011). However, few of these treaties provide any effective legal protection and none of them address the conservation, preservation, or management of a particular mangrove species (Polidoro *et al.*, 2010). National legislation pertaining to mangrove management in the 1960's was primarily focused on mangrove exploitation (Carter, Schmidt and Hirons, 2015). However, over the past five decades management has progressed and has led to the integration of mangroves into coastal zone management plans (Carter, Schmidt and Hirons, 2015).

Common tools for the preservation and management of mangrove and other marine ecosystems include: marine protected areas (MPA's); nature reserves; wilderness areas; national monuments and national parks. Since 1974, increasing protection has

been provided through Ramsar site designation. To date, 281 Ramsar sites (12.5% of all Ramsar sites) are intertidal forested wetlands, which includes mangrove forests (www.ramsar.org). Although increased recognition of mangroves in management plans is encouraging, the majority of plans associated with MPA's and Ramsar sites are based on generalized characteristics and threats, with limited reference to prior scientific research. In fact, there appears to be no effective mechanism for creating links between management activities for, and scientific research on, mangroves, thus research is rarely incorporated into management plans. Similar observations have been made in the management of coral reef ecosystems, where a mere 14% of information cited in management plans for the reefs of Australia, Kenya and Belize was primary research (Cvitanovic *et al.*, 2014). In this case, research was deemed to be inaccessible to managers due to, long publication times, subscription only access to research and poor articulation of management implications of the research (Cvitanovic *et al.*, 2014). Yet, for effective management to take place, evidence based decision-making is critical (Christensen *et al.*, 1996; Ruckelshaus *et al.*, 2008).

In this article we use the Mesoamerican reef (MAR) ecoregion as a case study, to examine the current status of mangroves, the legislation implemented to protect, manage and conserve mangroves, and review peer-reviewed scientific outputs from the region. The aim of this paper is to understand the current management paradigms within the MAR and identify threats to mangroves within the region. We compare the foci of management strategies and research programs in order to determine where overlap occurs and where there are gaps in the knowledge base.

Methods

93 *Study area*

94 We have chosen to focus on the Mesoamerican Reef (MAR) ecoregion because the
95 majority of mangrove research is concentrated in South-East Asia, where larger and
96 more diverse stands of mangroves are located (Saenger, 2002). Much less is known
97 about these ecosystems in Latin America and the Caribbean (but see, Ellison and
98 Farnsworth, 1997; Núñez-Farfán *et al.*, 2002; Ellison, 2004). The MAR ecoregion
99 extends over 1000 km from the Yucatan peninsula, Mexico (21.56°N; 087.09°W) to the
100 east coast of Honduras (14.97°N; 083.16°W), encompassing the Caribbean coastlines,
101 open-ocean, networks of cays, and offshore banks of Mexico, Belize, Guatemala and
102 Honduras (Kramer and Kramer, 2002) (Figure 1). It is home to the largest barrier reef in
103 the western hemisphere and supports the livelihoods of approximately two million
104 people (Kramer and Kramer, 2002), of particular importance are the fishing (Box and
105 Canty, 2010) and tourism industries (Doiron and Weissenberger, 2014). Considerable
106 attention has been given to coral reefs in the region, however seagrass and mangrove
107 ecosystems have often been overlooked. In this review we consider the entire
108 Honduran north shore as part of the MAR ecoregion, due to potentially high levels of
109 connectivity between the Honduran east coast and the MAR (Butler *et al.*, 2011;
110 Truelove *et al.*, 2015; Chollett *et al.*, 2017). The boundaries of the ecoregion were
111 originally defined by the presence of several physiogeographic boundaries, these
112 include the Gulf of Mexico, strong oceanic currents between the Yucatan penninsular,
113 Mexico and south west Cuba, the shallow waters of the Nicaraguan rise, Honduras, in
114 addition to a number of terrestrial environmental variables, e.g. rainfall. The ecoregion
115 was officially declared in 1997 as part of the Tulum agreement, where all four countires

116 came together recognizing the importance of the region and the need to jointly manage
117 a shared marine resource (Kramer and Kramer, 2002).

118 *Mangrove cover estimations*

119 First, we estimated mangrove forest cover for each country across the region. The three
120 true mangrove species: *Rhizophora mangle; Avicennia germinans* and *Laguncularia*
121 *racemosa* are considered as part of the mangrove forest system in all four countries.
122 However, the mangrove associate *Conocarpus erectus* (Buttonwood mangrove) is only
123 defined as part of the mangrove forest in Guatemala and Honduras. Regardless of a
124 country's definition of the mangrove complex, mangrove cover estimates herein include
125 all four species. Country specific estimates of mangrove cover were taken from the
126 most recent estimates available (Mexico (Rodríguez-Zúñiga *et al.*, 2013), imagery from
127 2010; Belize (Cherrington *et al.*, 2010), imagery from 2010; Guatemala (MARN, 2013),
128 imagery from 2010; and Honduras (Carrasco and Caviedes, 2014), imagery from 2008-
129 2010).

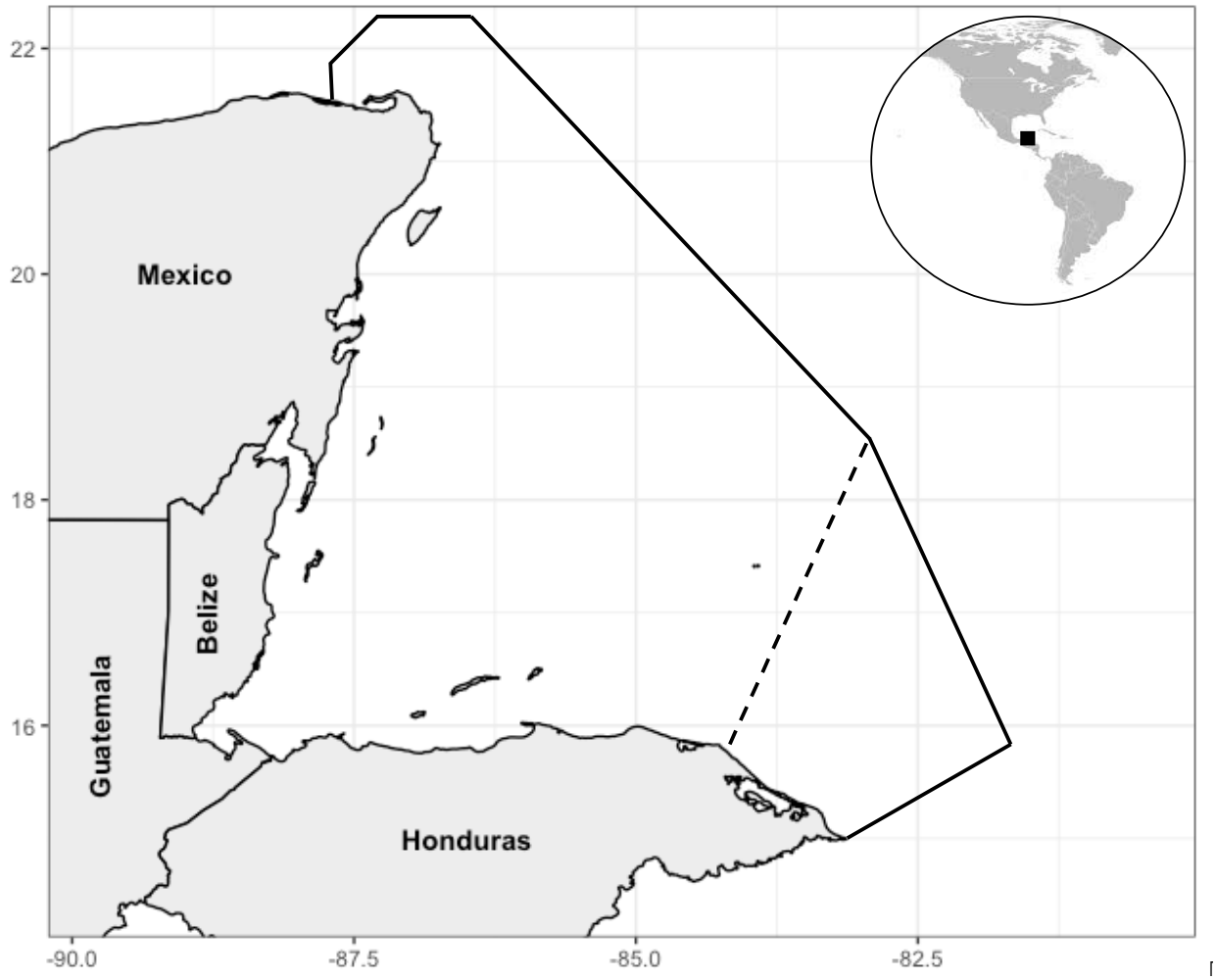

Figure 1. Map of the Mesoamerican Reef Eco-region. Solid line highlights the area included within the study, the official boundary of the MAR (dotted line) does not include the eastern north shore of Honduras.

Mangrove management plans

To ascertain the level of management and protection directly focused on mangroves in each country, we first reviewed national environmental legislation, using Google searches and accessing management plans. We subsequently identified which international and regional conventions and agreements relating to mangroves each country has signed or ratified. Within the Caribbean, protected areas that contain mangroves include Ramsar sites and Marine Protected Areas (MPAs). Ramsar sites

that contain mangroves were identified through the American Ramsar Secretariat (Pers. Comms.) and the Ramsar website (www.ramsar.org). The Healthy Reefs for Healthy People Initiative (HRI; www.healthyreefs.org) provides the names of all of the MPAs within the MAR, which have marine territory, and provides the associated management plan. If a managent plan was not available on the HRI website a wider web search was conducted, if after the search we did not identify a management plan we assumed that one did not exist or is not publicly available. Web searches (in English and Spanish), were used to identify management plans for each of the named protected areas. Management plans for protected areas, where available, were downloaded and searched using the keywords mangroves (mangr*) in English, and manglar (mangl*) in Spanish to find explicit references to the management of mangroves. It must be noted that the most recent management plans were used in this review and that management plans within the region are generally designed for a five-year period. In many cases the management period had expired, but we assume that current management strategies are based on the most recent plans.

Scientific literature review

To determine the focus of scientific research on mangroves in the MAR, peer-reviewed scientific publications were searched for using the Boolean search methodology. Multiple combinations of the following keywords (and their equivalents in Spanish) were used in the search: 'Mangrove'; '*Rhizophora*'; '*Avicennia*'; '*Laguncularia*'; '*Conocarpus*'; 'Mesoamerica'; 'MBRS'; 'MAR'; 'Caribbean'; 'Mexico'; 'Belize'; 'Guatemala'; and 'Honduras'. Only articles published from 1997 to date were used, as this date coincides with the declaration of the MAR as an ecoregion by all four countries, and therefore to

the direct management of the ecoregion. Books or book sections were not used, as we could not be sure of the peer-review process, and reviews were not included. Methodologies of articles were examined to ensure that research occurred in at least one of the four MAR countries and within the boundaries of the MAR ecoregion, as we delimited it. A total of 81 peer-reviewed publications (see supplementary materials for a full list of publications) were identified and the research undertaken in each country was tallied. Where research occurred in multiple countries in a single paper, each country received a tally.

Identification of threats

A fine scale analysis of articles that were identified to focus on threats to managroves was conducted to categorize the type of threat. Eight different threats were identified, a total of 29 times, and each threat was categorized as either natural or anthropogenic disturbances. *Natural disturbances* were: hurricanes; sea-level change; light gaps; seismic activity; tsunamis; and subsidence. *Anthropogenic disturbances* were: commercial development and deforestation. Threats identified were tallied and a proportion of each threat category was calculated based on the total number of threats identified.

A list of threats to Ramsar sites was obtained from the American Ramsar Secretariat. The threats were identified by future managers of Ramsar sites from a list of 51 options supplied by Ramsar (see supplementary materials for the full list of threats and their definitions) during the Ramsar site application process. The list of threats provided was pre-defined, and as a result not all threats reported may be relevant to the protected area, e.g. in Guatemala ‘agriculture and aquaculture’ was a reported threat. However,

187 aquaculture is currently not present in the Guatemalan Caribbean, in contrast
188 agriculture is present and is considered a threat to mangroves.

189 Thirty-seven different threats were identified by Ramsar managers, across the four
190 countries, a total of 236 times, with a maximum of twenty-two at a single site. We
191 categorized threats as either natural disturbances or anthropogenic disturbances.
192 *Natural disturbances* were: storms and flooding; fire and fire suppression; problematic
193 native species; invasive and other problematic species and genes; climate change and
194 severe weather; and invasive non-native/alien species. *Anthropogenic disturbances*
195 were: biological resource use; human settlements (non-agricultural); tourism and
196 recreation areas; housing and urban areas; fishing and harvesting aquatic resources;
197 natural system modifications; agriculture and aquaculture; pollution; logging and wood
198 harvesting; human intrusions and disturbances; hunting and collecting terrestrial
199 animals; vegetation clearance/land conversion; recreational and tourism activities;
200 gathering terrestrial plants; transportation and service corridors; water regulation;
201 household sewage; livestock farming and ranching; urban waste water; agriculture and
202 forestry effluents; drainage; dams and water management/use; energy production and
203 mining; unspecified development; wood and pulp plantations; mining and quarrying;
204 industrial and military effluents; water abstraction; garbage and solid waste; shipping
205 lanes; and air-borne pollutants. Individual threats that were reported were tallied as
206 either natural or anthropogenic disturbances, a proportion of each threat category was
207 calculated from the combined number of threats identified.

208 **Results**

209 *Mangrove cover*

Mangrove cover in the MAR is estimated at 239,176 ha, cover has declined across the region since the 1990's, where mangroves covered approximately 350,000 ha (Figure 2), a loss of over 110,000 ha in a twenty-year period. Proportional cover of mangroves in the MAR region varies considerably between and within the four countries. The majority of mangrove cover within the MAR is located along the Yucatan Peninsula, Campeche and Quintana Roo regions of Mexico (53.5%; 128,049 ha; Figure 2), however Mexico has significantly greater mangrove cover in the Gulf of Mexico and on the Pacific coastlines. Belize is the only country to have its entire coastline in the MAR, and approximately one third of mangrove cover of the MAR is found in Belize (31.2%; 74,684 ha; Figure 2). Only a small fraction of the total mangrove cover of the region is located in Guatemala (0.5%; 1,170 ha; Figure 2), the majority of Guatemalan mangroves are located on the Pacific coast. Despite the size of its coastline, mangrove cover in Honduras is a small proportion of the MAR total (14.7%; 35,273 ha; Figure 2). Mangrove cover in Honduras is almost equally divided between the Caribbean and Pacific coasts.

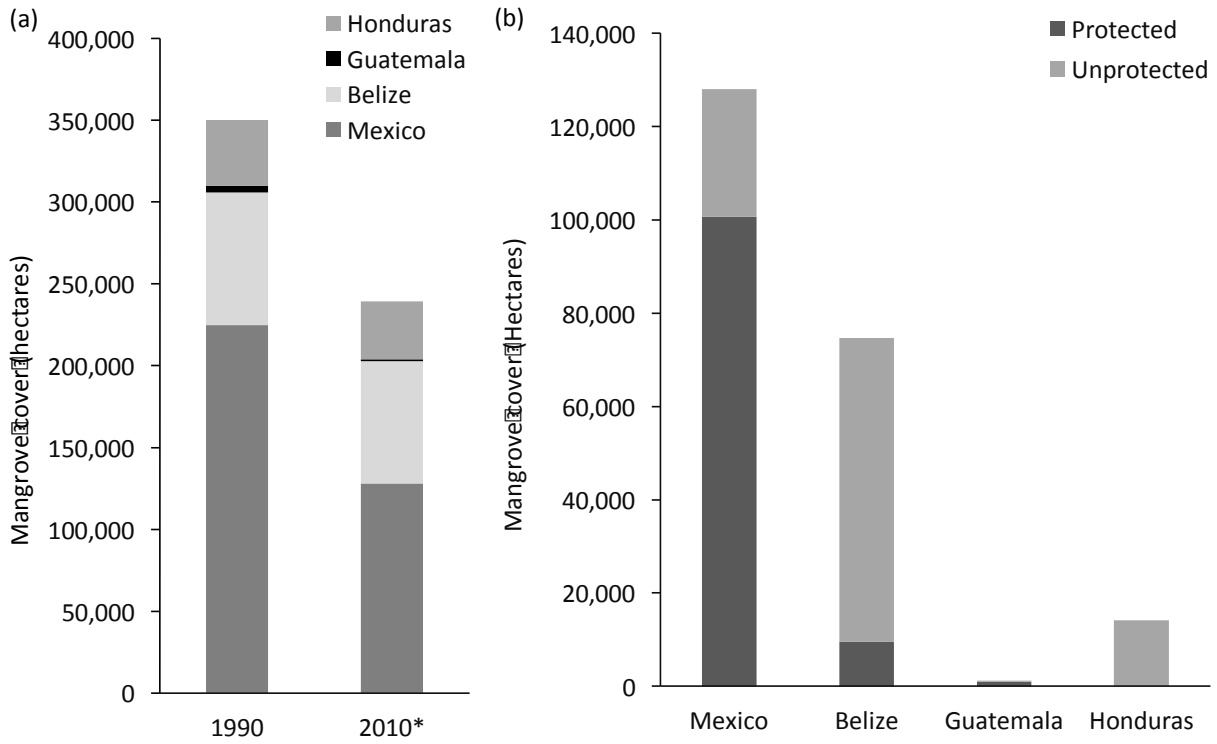

Figure 2 Mangrove cover within the MAR region**.** (a) Historical (Kramer and Kramer, 2002) and recent estimations of mangrove cover. (b) Total mangrove cover in each of the four MAR countries, with hectares of protected and unprotected mangrove highlighted. (Mexico (Rodríguez-Zúñiga *et al.*, 2013); Belize (Cherrington *et al.*, 2010); Guatemala (MARN, 2013); Honduras (Carrasco and Caviedes, 2014). *Some data from Honduras is from 2008.

Legislation and management

Comprehensive legislation exists within the region to protect mangroves. In Mexico, Guatemala and Honduras, mangroves are property of the state and stringent laws exist which prohibit the removal and cutting of mangroves and prevent changes in land use (Table 1). In contrast, the majority of Belizean mangroves are privately owned and only 30% are state owned. However, national legislation in Belize is applicable to all mangroves regardless of ownership. Within Belize, the cutting and clearance of mangroves is controlled by a permitting system, however the dredging and landfill of mangroves is only permitted under exceptional circumstances.

240 At the international level, the four countries of the MAR have ratified a total of seven
241 international conventions and agreements to promote the management and sustainable
242 use of marine and wetland resources (Table 1). The most important of these for
243 mangroves is the Ramsar (wetlands) convention. Geopolitical differences influence
244 regional cooperation, e.g. Mexico, a North American country, is excluded from Central
245 American agreements, and Belize with a British rather than Spanish colonial heritage
246 exhibits preferences with Caribbean Community agreements. All four countries are
247 parties of the two main international conventions that are relevant to environmental
248 protection: the Cartagena convention and Ramsar convention (Table 1). Honduras is
249 the only country not to have ratified the Cartagena convention, but is a signatory to the
250 convention. Additionally, all four countries ratified the Tulum declaration and the
251 subsequent Mesoamerican barrier reef system project (www.mbrs.doe.gov.bz).

252 We identified a total of 43 protected areas in the MAR which have mangroves within
253 their borders (Table 2), and estimate that just under half (46.6%; 111,396 ha) of the
254 mangroves in the MAR are within the boundaries of a protected area. Over two thirds
255 (31) of the protected areas have management plans (Table 2), although implementation
256 of these plans may vary. The majority of management plans had no specific
257 management strategies for mangroves, other than a reference to the national
258 legislation, in the few instances where strategies were stated they were related to
259 mangrove restoration, e.g. Shipstern Conservation and Management Area, Belize.

260 In Mexico, mangroves are the responsibility of the Department of Ecology and
261 Environment, and the Institute for Flora, Fauna and Culture within the Secretariat of the
262 Environment and Natural Resources. In addition, the National Commission for Natural

263 Protected Areas (CONANP) assumes responsibility for mangroves when they are
264 located within a protected area. CONANP may co-manage protected areas with a local
265 non-governmental organization (NGO). We identified 13 protected areas that contain
266 mangroves in Mexico, these areas provide protection to approximately 80% (100,764
267 ha) of Mexican mangroves forests in the MAR (Table 2; Figure 2).

268 In Belize, the Forestry Department within the Ministry of Agriculture and Fisheries is
269 responsible for managing Belizean mangroves. The Coastal Zone Management
270 Authority and Institute and Fisheries Department may also assume a management role.
271 NGO's co-manage a number of protected areas in Belize and therefore assume a direct
272 role in the management of mangroves. Private protected areas are increasingly popular,
273 and these areas are coordinated by the Belize Association of Private Protected Areas.
274 We were not able to identify any private protected areas that provided protection to
275 mangroves. Only a small proportion (12.9%) of the total mangrove cover of Belize is
276 located within the 15 protected areas (Table 2; Figure 2).

Table 1. Legislation, Agreements and Protection of Mangroves in the Mesoamerican Reef Region.

Mangrove Legislation		**Mexico**	**Belize**	**Guatemala**	**Honduras**
Legislation		General Wildlife Act 2000, Article 60.	Forestry Act 1989, Article 52. Forests Act Chapter 213, revised in 2003	Forestry Act 1996, Article 35.	Fisheries Act 1959, Article 52.
		It is prohibited to remove, transplant, prune or conduct any work or activity that may affect the integrality of the hydrological flow of mangroves.	Dredging and landfill is strictly prohibited unless there is significant benefit to the general population. Three types of permits can be issued for the alteration of mangroves, depending on the area of mangrove to be altered. Permits can be denied.	Change of land use of mangrove ecosystems is prohibited. By-law Resolution No. 01.25.98, Article 15 allows family consumption to a maximum of $5m^3.yr^{-1}$	The removal and cutting of mangroves is prohibited.
State ownership of mangroves		100%	30%	100%	100%
Government Agencies					
Government hierarchy for the management of mangroves	*Ministry*	Secretariat of the Environment and Natural Resources	Ministry of Agriculture and Fisheries	Ministry of the Environment and Natural Resources	Secretariat of Energy, Natural Resources, Natural Environment and Mines
	Department	Department of Ecology and Environment; Institute for Flora, Fauna and Culture	Department of Forestry	National Forest Institute	Fisheries department
	External departments		Coastal Zone Management Authority and Institute; Department of Fisheries	National Council for Protected Areas	Institute for Conservation and Forest Development, Protected Areas and Wildlife
	Other Agencies	National Commission for Protected Natural Areas		National Council for Protected Areas	Local Municipal Environment Units
	Non-government organizations	e.g. Comunidad y Biodiversidad Asociacion Civil; Amigos de Sian Ka'an	e.g. Belize Association of Private Protected Areas; Toledo Institute for Development Environment	e.g. Fundación para el Ecodesarrollo y la Conservación	e.g. Bay Island Conservation Association; Roatan Marine Park
International and Regional Agreements					
Cartagena Convention (*Signatory only)		1985	1999	1989	1983*
Wetlands Convention (Ramsar[2])		1986	1998	1990	1993
Tulum Agreement		1995	1995	1995	1995
Mesoamerican Barrier Reef System Project		1997	1997	1997	1997
Central American Policy for the Conservation and Rational Use of Wetlands		N/A	2002	2002	2002
Ramsar Regional Initiative for the Integral Management and Wise use of Mangroves and Coral Reefs		2009	-	2009	2009
Ramsar Caribbean Wetlands Initiative		-	2009	-	-

Table 2. Protected areas of the Mesoamerican Reef ecoregion with mangroves within their borders.

		MPA /NP	Ramsar site	Management plan	Reference
Mexico (n=13)					
Área de Protección de Fauna y Flora Yum Balam		X	X	Y	(CONANP, 2013)
Parque Nacional Isla Contoy		X	X	Y	(SEMARNAT & CONANP, 2015b)
Manglares de Nichupte			X	Y	(SEMARNAT & CONANP, 2014)
Parque Nacional Arrecifes de Puerto Morelos		X	X	Y	(SEMARNAP, 2000a)
Manglares y humedales del norte de la isla Cozumel			X	Y	(SEMARNAT, 2014)
Parque Marino Nacional Arrecifes de Cozumel		X	X	Y	(SEMARNAP, 1998a)
Playa Tortuguera X'Cacel-X'Cacelito			X	-	
Reserva de la Biósfera de Sian Ka´an		X	X	Y	(SEMARNAT & CONANP, 2015a)
Reserva de la Biósfera Banco Chinchorro		X	X	Y	(SEMARNAP, 2000b)
Parque Nacional Arrecifes de Xcalak		X	X	Y	(CONANP, 2004)
Parque Marino Nacional Punta Occidental Isla Mujeres, Punta Cancun y Punta Nizuc		X		Y	(SEMARNAP, 1998b)
Área Marina y Costera Protegida Actam Chuleb		X		-	
Zona Sujeta de Conservación Ecologica Santuario Manati Bahia Chetumal		X		-	
	Total:	*10*	*10*	*10*	
Belize (n=14)					
Bacalar Chico National Park and Marine Reserve		X		Y	(BFD, 2004)
Laughing Bird Caye National Park		X		Y	(BFoD, 2010)
Payne's Creek National Park		X		-	
Sarstoon-Temash National Park		X	X	Y	
Shipstern Conservation & Management Area		X		Y	(PACT, 2016)
Corozal Bay Wildlife Sanctuary		X		-	
Swallow Caye Wildlife Sanctuary		X		-	
Half Moon Caye Natural Monument		X		Y	(BAS, 2007)
Caye Caulker Marine Reserve		X		Y	(BCZMIA & BFD, 2004)
Gladden Spit and Silk Cayes Marine Reserve		X		Y	(BFD, 2010a)
Glover's Reef Marine Reserve		X		Y	(BFD, 2007)
Hol Chan Marine Reserve		X		Y	(BFD, 2002)
Port Honduras Marine Reserve		X		Y	(BFD, 2012a)
Sapodilla Cayes Marine Reserve		X		Y	(BFD, 2010b)
South Water Caye Marine Reserve		X		Y	(BFD, 2009)
Turneffe Atoll Marine Reserve		X		Y	(BFD, 2012b)
	Total:	*15*	*1*	*12*	
Guatemala (n=2)					
Reserva de usos multiples rio Sartsun		X	X	Y	(CONAP, 2009)
Punta de Manabique		X	X	Y	(CONAP, 2011)
	Total:	*2*	*2*	*2*	
Honduras (n=13)					
Parque Nacional Sistema de Humidales de Cuyamel – Omoa		X	X	-	
Parque Nacional Jeannette Kawas		X	X	Y	(ICF, 2012a)
Refugia de Vida Silvestre Punto Izopo		X	X	Y	(ICF, 2012b)
Sistema Humedales Laguna de Zambuco			X	-	
Refugio de Vida Silvestre Cuero y Salado (Barras de Cuero y Salado)		X	X	Y	(ICF, 2011)
Parque Nacional de las islas de la Bahia		X		Y	(IHT y ICF, 2015)
Zona de Proteccion Especial Marina Turtle Harbour – Rock Harboury el Sistema de Humedales de la Isla de Utila		X	X	Y	(IHT y ICF, 2012)
Zona de Protección Especial Marina Sandy Bay West End		X		-	
Parque Nacional Port Royal		X		-	
Monumento Natural Marino Archipielago Cayos Cochinos		X		Y	(CMCC, 2009)
Refugio de Vida Silvestre Laguna de Guaimoreto		X		-	
Reserva de la Biósfera del Rio Platano		X		Y	(ICF, 2013)
Laguna de Bacalar			X	-	
	Total:	*11*	*7*	*7*	
Grand totals	**43**	**38**	**18**	**31**	

277 Mangroves in Guatemala are the responsibility of the National Forest Institute within the
278 Ministry of the Environment and Natural Resources. The National Council for Protected
279 Areas (CONAP) has a role in mangrove management when mangroves are located in
280 protected areas (Table 1). Protected areas are co-managed by CONAP and local
281 NGO's and these organizations assume the day to day responsibilities of the protected
282 areas. The majority of mangroves within Guatemala (88.2%) are located within the two
283 protected areas (Table 2; Figure 2).

284 The responsibility of mangroves in Honduras resides with the Department of Fisheries
285 under the Secretariat of Energy, Natural Resources, Natural Environment and Mines,
286 and local municipal environmental units have a role in mangrove management within
287 their jurisdiction. Within protected areas, mangroves receive additional management
288 from the Conservation and Forest Development, Protection and Wildlife Institute and
289 local NGO's. The NGO's assume the day-to-day responsibilities of the protected areas.
290 A total of 13 protected areas have been declared that have mangroves within their
291 boundaries, however limited mangrove cover data is available, which precludes an
292 accurate estimation of mangrove coverage within Honduran protected areas (Table 2).

293 *Threats to mangroves*

294 A total of 81 peer-reviewed articles focusing on mangroves were identified within the
295 MAR region. The majority of the research was conducted in Belize (68.2%), the
296 remaining studies were conducted in Mexico (22.0%) and Honduras (9.8%). No peer-
297 reviewed primary mangrove research identified from Guatemala. Of the 81 peer-
298 reviewed articles identified, 15 of these address threats to mangroves (Ellison and
299 Farnsworth, 1997; Feller *et al.*, 1999; Cahoon *et al.*, 2003; Piou *et al.*, 2006; Mckee,

300 Cahoon and Feller, 2007; McKee, Rooth and Feller, 2007; Taylor *et al.*, 2007;
301 Vaneslow, Kolb and Fickert, 2007; Granek and Ruttenberg, 2007; Carrillo-Bastos,
302 Elizalde-Rendón, Erika Marcela Torrescano Valle and Flores Ortiz, 2008; Islebe *et al.*,
303 2009; Macintyre *et al.*, 2009; Mckee and Vervaeke, 2009; Hirales-Cota *et al.*, 2010;
304 McCloskey and Liu, 2013),, a total of 8 different threats were classified. A total of 37
305 different threats, were identified from the 20 Ramsar sites, the majority of which were
306 anthropogenic (90.7%), e.g. 'logging', 'aquaculture and coastal development' (Figure 3).
307 The majority of peer-reviewed mangrove research from the MAR region has focused on
308 natural disturbances (71.4%) of mangrove systems (Figure 3). These trends are not just
309 a regional trend, but hold for each of the individual countries, where researchers and
310 managers foci are on natural and anthropogenic disturbances, respectively (Figure 3).
311 Primary research interests include hurricanes and sea-level change, and Ramsar
312 managers across the region are concerned with deforestation, agriculture, and
313 development.

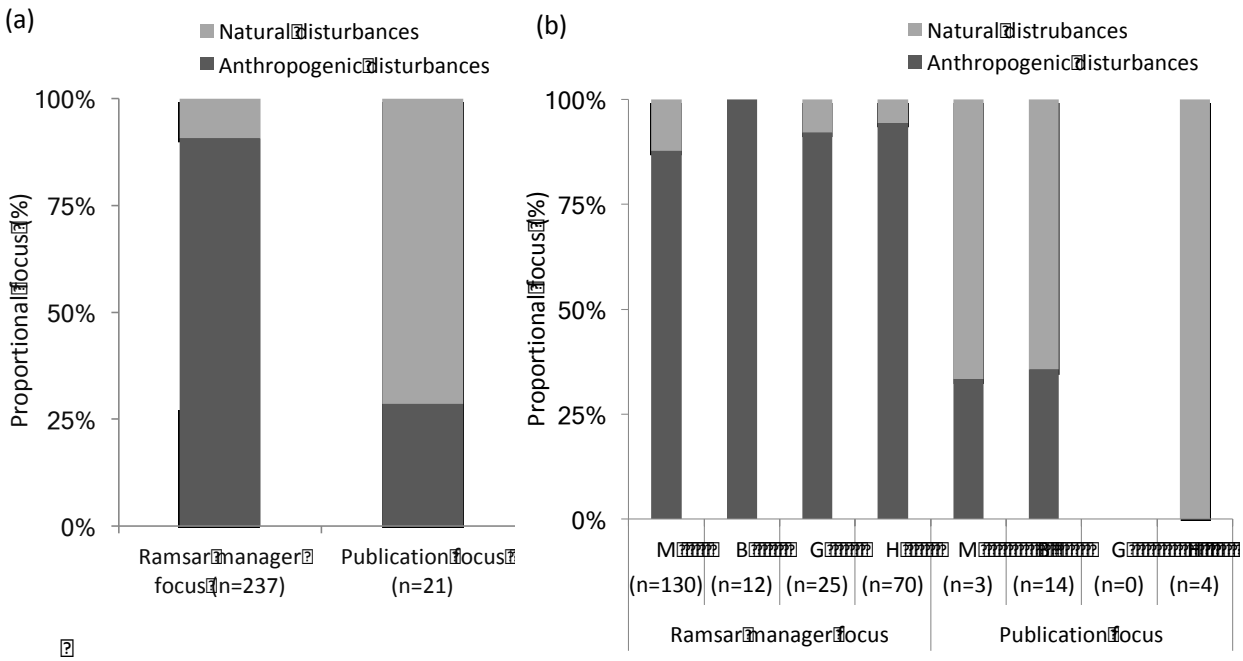

Figure 3. Threats to mangroves of the MAR as identified by Ramsar managers and within peer-reviewed publications (a) throughout the MAR; and (b) individual countries: M – Mexico; B – Belize; G – Guatemala; and H - Honduras.

Discussion

Despite the stringent national legislation and international agreements which provide protection to mangrove forests, and the additional protection provided by the 43 protected areas (which contain mangroves), mangrove cover in the MAR declined by over 110,000 ha from 1990-2010, with an esimtated current cover of 239,176 ha, equivalent to 1.7% of the world's mangroves (Giri *et al.*, 2011). The greatest losses were observed in Mexico and Honduras. The decline in mangrove cover suggests a problem with enforcement. We suggest a lack of resources for enforcement, transparency within the governance framework, and lack of political will as potential reasons for the failure in the enforcement of mangrove legislation. The number of organizations responsible for the management and protection of mangroves in each country varies and causes confusion, with the exact role of each party unclear. Each

country has a specific government department responsible for mangrove protection, with additional oversight from external agencies and non-government organizations (NGO's) when mangroves are located in protected areas. It must be noted that such discrepancies are not unique to mangrove systems or to this region (Rife *et al.*, 2013). Limited national budgets of the four countries reduce governmental institutional capacity, which has resulted in civil society in the form of NGO's filling the void in the management of protected areas. NGO's assume an important role as co-managers of protected areas, fulfilling the day-to-day management duties. However, a lack of authoritative power and a lack of human capacity to physically patrol often large and remote areas, inhibits the ability of NGO's to enforce environmental legislation (Cudney-Bueno *et al.*, 2009; Rife *et al.*, 2013). In essence many of the protected areas in each of the four countries could be considered "paper parks", as they provide no greater protection or management to mangroves than national legislation (Rife *et al.*, 2013). It is important not to be too critical of these institutions, however, all of which are operating on limited resources. The focus should be on how to support and build capacity of these organizations to allow them to improve mangroves and natural resource management efficacy.

Geopolitical interests of the different countries have reduced collaborative efforts of mangrove protection. Despite the four countries sharing an ecoregion, significant geopolitical divisions exist. This is exemplified by Belize ratifying a separate Ramsar initiative to the other three countries. The paradox is that despite having the same or very similar objectives, the four countries are not working together to achieve these goals. A lack of collaboration and harmonization in how management strategies are

353 developed and implemented can reduce mangrove protection, especially in forests that
354 straddle international borders (McCallum, Vasilijević and Cuthill, 2015). Belize is the
355 only country where all of mangroves are within the boundaries of the MAR. In contrast
356 Mexico and Guatemala have significantly greater mangrove cover on other coastlines,
357 and a little more than half of the mangrove cover of Honduras is concentrated within the
358 Gulf of Fonseca, on the Pacific coast. Threats to mangroves may vary significantly on
359 the different coasts, and therefore influence how national mangrove legislation is
360 developed, and how governments prioritize limited management resources. Regardless,
361 greater collaborative efforts, such as the Mesoamerican Barrier Reef System Project,
362 need to be established to promote the protection of marine resources, and facilitate
363 transboundary initiatives that recognize that ecological populations do not align with
364 geopolitical boundaries. There is a high probability that mangrove forests within the
365 region are connected as recent studies have shown high levels of ecological
366 connectivity in the MAR region for lobster, fish and corals (Butler *et al.*, 2011; Truelove
367 *et al.*, 2015; Chollett *et al.*, 2017).

368 Evidence based decision-making has been well documented as an important
369 component of resource management (Christensen *et al.*, 1996; Ruckelshaus *et al.*,
370 2008). However, in the papers we reviewed there appears to be no discernible link
371 between researcher recommendations and resource manager decision-making or
372 actions. Concluding statements within articles may make some reference to
373 conservation or management, but usually included no advice on how to apply research
374 findings directly to management. Additionally, our study identified a disconnection
375 between Ramsar site managers and the scientific community. Managers were primarily

376 focused on localized anthropogenic threats (e.g. Macintyre *et al.*, (2009)), while
377 researchers focused on natural disturbances, such as hurricane events (Vaneslow, Kolb
378 and Fickert, 2007) and the impact of sea-level change (Mckee, Cahoon and Feller,
379 2007). Both anthropogenic and natural threats have either had, or have, the potential to
380 negatively affect mangrove cover, but the different foci of researchers and managers is
381 likely to hinder progress in mitigating threats from either source.

382 It is crucial that researchers and managers increase their communication and work
383 together to understand the full complexity of the threats to mangrove forests. Combining
384 these different priorities could bring important benefits. For example, the identification of
385 areas of mangrove forests resilient to climate change can focus management efforts
386 and create local priority conservation zones where anthropogenic disturbances should
387 be minimized. Both groups are focusing on important issues, however the assumed lack
388 of dialogue between stakeholders precludes the integration of science into mangrove
389 management plans. Cvitanovic et al. (2014) have reported similar disconnects in the
390 management of coral dominant marine protected areas. They proposed knowledge
391 brokers, boundary organizations, knowledge co-production and management-orientated
392 summaries in research articles as potential solutions to provide managers access to
393 scientific outputs. The HRI program has put some of these in place within the MAR
394 primarily focused on coral reefs, but these could be adapted to facilitate greater
395 communications between managers to promote science lead mangrove management.
396 In addition, discussion forums exist, such as the mangrove list
397 (majordomo@essun1.murdoch.edu.au). Listserves provide a forum where individuals

398 can pose questions to experts in an array of different fields and can provide useful
399 dialogue between praticioners and researchers.

400 These potential solutions provide important links between peer-reviewed conservation
401 science and conservation managers, but the dichotomy of researcher and manager foci
402 must also be addressed. Combining current research interests of natural disturbances
403 with local management concerns of anthropogenic stresses, in particular the
404 understanding of local drivers of deforestation, is critical. However, if institutional
405 capacity is lacking, then the implementation of management strategies will always be
406 problematic. Building capacity within and among government departments and NGO's
407 to ensure the effective enforcement of legislation and promote links with the scientific
408 community to facilitate science-based decision-making is vital for the management of
409 mangroves in the MAR, and elsewhere. It is important that managers have access to
410 and make use of current research, especially when developing management plans
411 (Adeel and Pomeroy, 2002; Iftekhar and Islam, 2004; Schmitt and Duke, 2015). There is
412 also an onus on researchers to increase the availability of their research to
413 management authorities, not just government agencies, potentially through regional
414 online archives or data repositories. Additionally, researchers should engage managers
415 prior to conducting their research to foster a dialogue that can promote mangrove
416 management and conservation efforts. Promoting public awareness to garner political
417 will is also important, and a greater understanding of the ecosystem services provided
418 by mangroves to local communities and their inclusion in management has the potential
419 to increase the protection and conservation of mangroves (Shunula, 2002; Sudtongkong
420 and Webb, 2008; Datta, Chattopadhyay and Guha, 2012).

421 We propose the following recommendations to promote management of mangroves
422 within the region:

423 (1) Coordinated and detailed mapping projects in Belize and Honduras to provide more
424 recent estimates of mangrove cover that can be used to set baselines from which
425 management actions can be monitored and assessed;

426 (2) The implementation of a systematic, harmonized, mangrove monitoring protocol
427 throughout the region that will facilitate comparisons of mangrove forest status;

428 (3) A program of work to increase understanding of the connectivity of mangrove
429 populations throughout and beyond the MAR ecoregion, which can then be used to
430 identify areas where greater collaborations are needed;

431 (4) The creation of a repository of scientific literature of the region to which researchers
432 can submit their research, making it available for practitioners in the region and
433 providing another step towards an increased dialogue between managers and the
434 scientific community.

435 Our proposals require coordination and management of resources and information
436 across the MAR. The HRI program already brings together stakeholders from across
437 the region, but at present is heavily coral reef focused. Mangrove coverage was an key
438 indicator within the original HRI guide (McField and Kramer, 2007), and therefore could
439 become part of the biennially produced report card, which provides stakeholders an
440 update on the status of marine resources. Our suggestion is that the network of
441 contacts and collaborations within this program could be used to facilitate more

coordinated monitoring and assessment of mangroves and seagrass ecosystems in the region.

Conclusion

The stringent national legislation and international agreements which should provide protection to mangrove forests within the MAR are ineffective. A number of local anthropogenic stressors threaten mangrove forests, and despite comprehensive legislation, mangrove cover has declined in all four countries. Capacity building of government and non-government institutions is required, as a lack of capacity has reduced environmental regulation enforcement. Local anthropogenic stressors are of greatest concern to managers of protected areas, whilst scientific research is focused on natural disturbances, primarily climate change. These different focuses can be advantageous if they can be linked effectively. For example, the identification of climate change resilient mangrove forests can channel mangrove management efforts to maximize effectiveness of limited resources. Greater understanding of drivers of local anthropogenic threats to mangroves is required to provide managers with the necessary tools to reduce these threats and promote mangrove forests and the ecosystem services they provide. To promote successful management, we suggest the reinforcement of institutional capacity, enhance links between government departments and civil society and increase science-based decision-making within protected areas management plans.

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