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Status of Mangrove Forests in Trinidad and Tobago, West Indies

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Abstract- **Much of the mangrove forests in the Caribbean have been impacted by human activities, and now they are projected to be negatively affected by sea-level rise especially where they are constrained on the landward side by built development, or starved of sediment. This study assessed the status and trends of mangrove forests in Trinidad and Tobago so that response to human induced changes and climate changes can be determined. Mangrove forests in Trinidad and Tobago were mapped between 2008-2010 using high resolution satellite imagery (2000-2007), geographic information systems (GIS) technology and extensive ground-truthing surveys. Their sizes were determined. In Trinidad, mangrove coverage was estimated at 7,532 ha on the west coast, 1,132.8 ha on the east coast, 481.3 ha on the south coast, 0.3 ha on the north coast and 222.9 ha in Tobago. Mangrove coverage was higher than anticipated, perhaps because of inaccuracies in historical data and in some cases because of re-growth following past disturbances. While some mangrove forests are negatively impacted by land-use changes and erosion, there are instances where forests have overgrown freshwater marshes, or are expanded onto mudflats.**

Keywords: **Mangrove forest, baseline maps, land-use change, coastal erosion, climate change**

Introduction

Coastal areas worldwide are vulnerable to an unprecedented combination of climate change associated disturbances (e.g., storm surges, flooding, drought), and other local change drivers (e.g., land use change, pollution, overexploitation of resources) (Gilman et al. 2006; IPCC 2007). The Caribbean has experienced on average a mean relative sea-level rise of 1 mm year-1 during the 20th century, although there is extensive local variation. Sea-level is projected to rise between 0.18 – 0.59 m by 2099 (IPCC 2007).

Global climate change is expected to exacerbate loss and degradation of mangrove forests and loss or decline of their species, as well as harm to human populations dependent on their services (Millennium Ecosystem Assessment, 2005). Small island states like Trinidad and Tobago, have limited capacity to adapt to relative sea level rise, including accommodating landward migration of mangroves and other coastal ecosystems. This is a result of their small land mass, high population densities and growth rates, poorly developed infrastructure, and susceptibility to damage from natural disasters (Nurse et al. 2001).

Bacon (1994) suggests that responses of coastal wetlands to sea level rise in the Caribbean would be variable since there is a wide range of wetland types and geomorphic settings in the region. Mangrove forests in the insular Caribbean are of four main functional types based on edaphic and hydrologic conditions (Lugo and Snedaker 1974): - riverine, fringe, basin and scrub. Bacon (1994) stressed the importance of site-specific analysis and recommended that more attention be paid to site physiography, hydrology and ecology in predicting responses to sea level rise by tropical coastal wetlands. More importantly, if sedimentation rate keeps pace with rising sea level, mangrove forest could remain largely unaffected (Snedaker 1993; Ellison 1996).

Accurate predictions of changes to mangrove area and health, including those originating from climate change effects, enable advanced planning to minimize and offset anticipated losses and reduce threats to coastal development and human safety for specific sections of coastline (Gilman et al. 2006). Establishing mangrove baselines and monitoring gradual changes will enable the separation of site based influence from global climate change, and will provide a better understanding of mangrove responses to sea level rise and global climate changes. The study assesses the status and trend of mangrove forests in Trinidad and Tobago, and establishes a baseline so that response to human induced changes and climate changes can be determined.

Materials And Methods

Site Description

Trinidad and Tobago is situated in the southernmost end of the Caribbean island chain between 10° 02' -10° 50'N latitude and 60° 55'- 61° 56'W longitude (Figure 1). It is located on the continental shelf of South America, and immediately adjacent to the outflow of the Orinoco River. The country is less exposed to tropical storms and hurricanes than most of the Caribbean nations because of its southerly location, and has a tropical climate with two distinct seasons; dry -January-April and wet - June-November (Henry 1990). Its marine ecosystems are influenced by discharge from South American Rivers, mainly the Orinoco River, while its terrestrial biota is largely South American. The land areas of Trinidad and Tobago are 4823 km^2, and 300 km^2 respectively.

In 2010, the population of Trinidad and Tobago was estimated at 1,317,714 persons (http://cso.gov.tt). Approximately 90 % of the population lives along the west coast and the foothill of the Northern Range. Most of the population of Tobago is concentrated in the southwest part of the island. Some 80% of industrial activities of strategic national importance are located within coastal areas (Central Statistical Office (CSO) 2007).

In Trinidad and Tobago, mangrove forests are typically riverine/ estuarine, fringe or basin systems, and are associated with other plant communities such as tidal marshes and swamp forest. Seven mangrove species has been reported in Trinidad and four in Tobago. *Rhizophora*

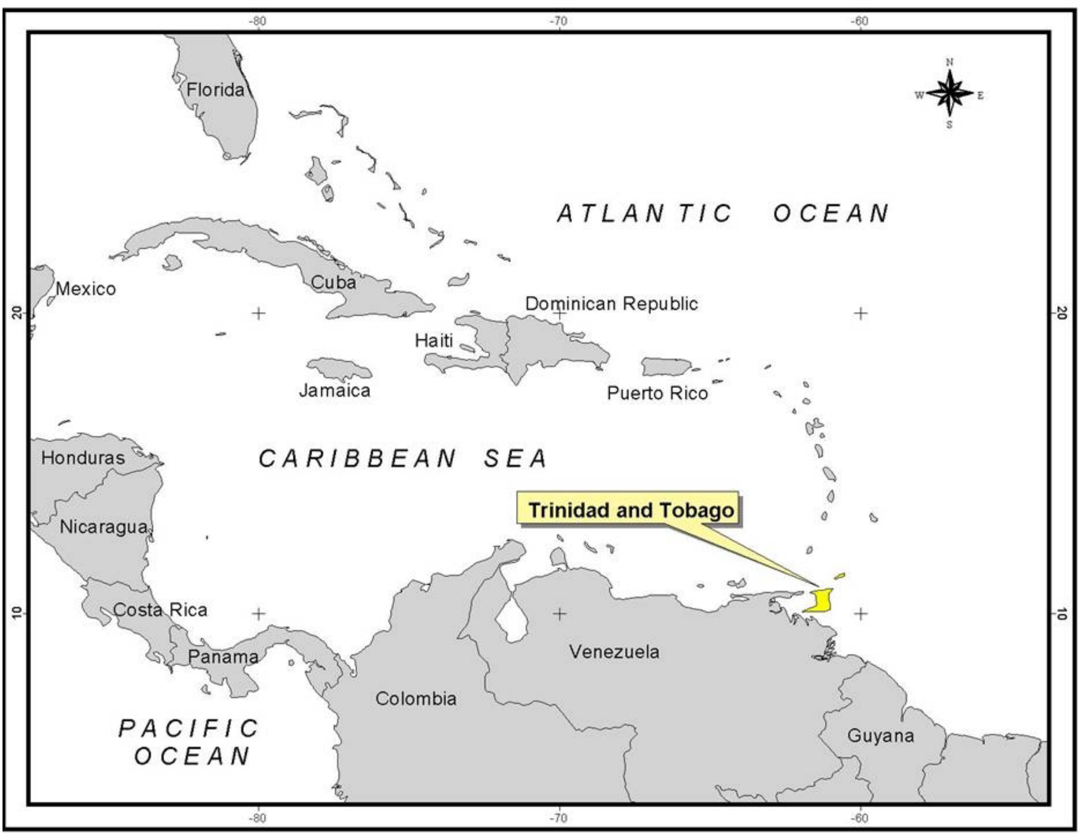


Fig 1 Map showing location of Trinidad and Tobago

mangle (L.), *Avicennia germinans* (L.) Stearn, *Laguncularia racemosa* (L.) *Gaernt and Conocarpus erectus* (L.) are found on both islands, while Rhizophora racemosa (G.F.W. Meyer), Rhizophora harrisonii (Leechman) and Avicennia schauriana (Stapf & Leechman) have a limited distribution in Trinidad.

Methods

In order to separate site-based influences from impacts due to global climate change, particularly sea-level rise, mangrove baselines were established as of 2007. The mangrove areas were delineated using IKONOS satellite imagery. This imagery had a spatial resolution of one metre (panchromatic) and four metres (multispectral). Spatial reference for the dataset was the WGS 84 UTM Zone 20 N coordinate system. The dataset consisted of thirty eight (31 for Trinidad) and (7 for Tobago) individual satellite scenes captured over the period 2000-2007. These scenes were mosaicked together using ER Mapper 7.1 image processing software to produce complete coverage for both islands.

Field surveys were conducted to verify the boundaries of the mangrove forests. Surveys were conducted in Tobago in September 2008 and between November 2008 and March 2010 in Trinidad. During field surveys information was collected on mangrove forest type using Bacon's (1993) classification, flora and fauna, hydrology and adjacent land uses and impacts.

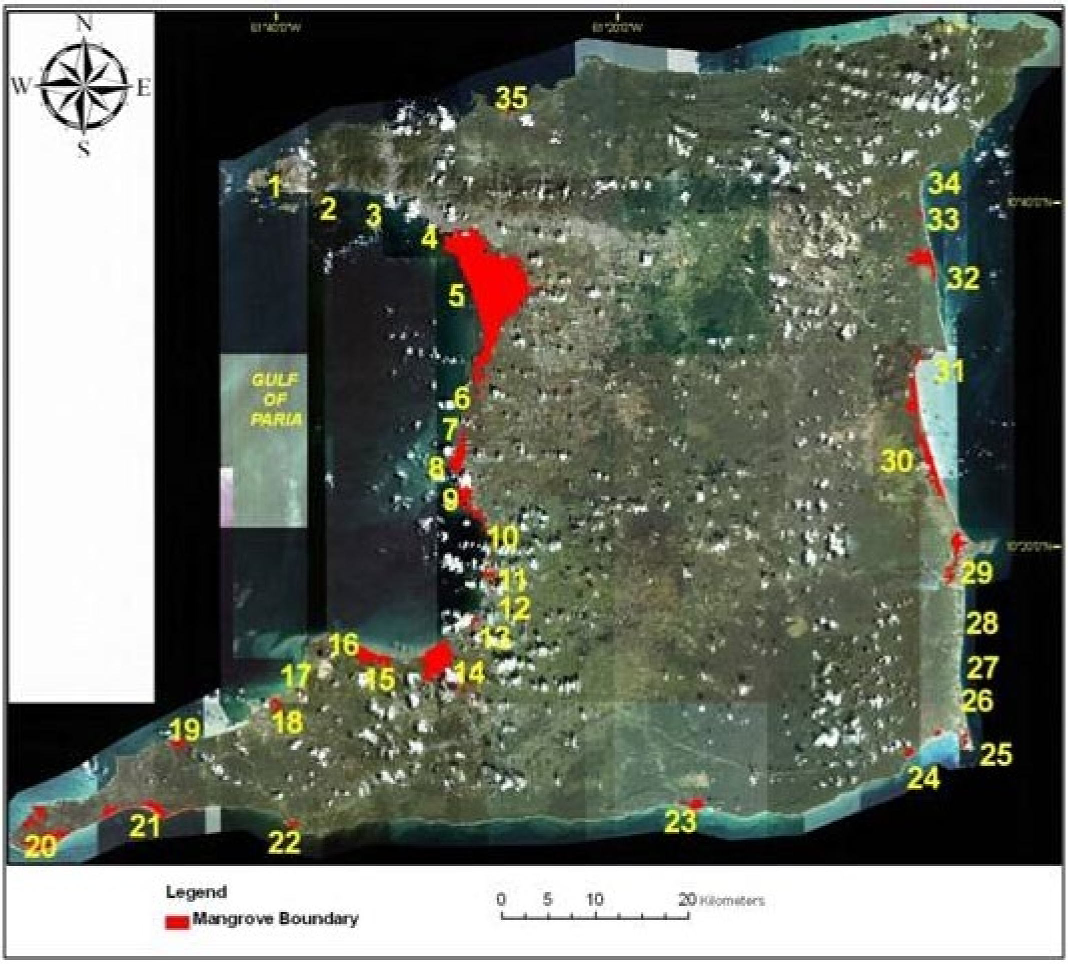
GIS software (ArcGIS 9.0) was used in conjunction with field verification data and ancillary data such as topographic and hydrographic maps to delineate mangrove areas from the IKONOS imagery. The GPS field points collected were imported into ArcGIS and overlaid onto the satellite imagery to assist in determining the margins of the mangrove vegetation. Delineation was then carried out based on visual interpretation to produce maps showing the spatial distribution and extent of the mangrove areas. In certain areas, mangroves validated by the field visits could not be delineated on the satellite imagery due to the occurrence of cloud cover. For Chacachacare and Mucurapo, Google Earth imagery was utilized to map the boundaries of the mangroves. The Spatial Analyst extension of ArcGIS 9.0 was then used to calculate the area of each of the mangrove regions mapped.

It should be noted here that the IKONOS satellite imagery utilized for this study was missing the near infrared band. This essentially reduced the effectiveness of computer aided classification techniques. Trials of supervised and unsupervised classification on the red green and blue channels yielded results that were less accurate than the manual delineation should be less accurate than the manual delineation.

Results And Discussion

In Trinidad, mangrove coverage was estimated at 7,532 ha on the west coast, 1,132.8 ha on the east coast, 481.3 ha on the south coast and 0.3 ha on the north coast (Figure 2; Table 1). In Tobago, mangrove coverage was estimated at 222.9 ha encompassing 11 systems, most of which are located on the Windward Coast (Figure 3; Table 1). Although Bacon (1993) and Alleng (1997) provided sizes for some mangrove forests, the imagery and mapping technology used in this study were not available to them. Maps were not provided so that differences in sizes could be validated. It is therefore assumed that the estimates for mangrove coverage in this study are the most accurate and up-to-date. Although comparisons between past and present mangrove coverage give some indication of change, they are not exact.

The majority of mangrove forests are found on the sheltered west coast of Trinidad; which is the coastline that is occupied by more than 70% of the population and has experienced the most intense development activities within the past five decades (CSO 2007). Seventy percent of the mangroves on this coast are found in the Caroni Swamp, 10% in the Godineau Swamp and the remaining 20% amongst smaller systems. While mangroves were cleared for housing, industries, agriculture, roads and ports, there has been some regeneration or new growth, but at the expense of other wetland communities in most instances (Table 2).



1. Scotland Bay
2. Hart's Cut
3. Cuesa River
4. Sea Lots
5. Caroni
6. Waterloo
7. Orange Valley
8. Couva River
9. North Claxton Bay
10. South Claxton Bay
11. Guaracara River
12. Marabella River
13. Cipero River
14. Godineau
15. Rousillac
16. La Brea
17. Vessigny
18. Guapo
19. Irois Bay
20. Icacos
21. Los Blanquizales
22. Frank's Bay
23. Moruga Bay
24. Guayaguayare Bay
25. Pt Galeota
26. Southern Mayaro
27. Central Mayaro
28. North Mayaro
29. Ortoire
30. Nariva
31. Manzanilla Bay
32. Fishing Pond
33. Matura Bay
34. Rincon Bay
35. Maracas Bay

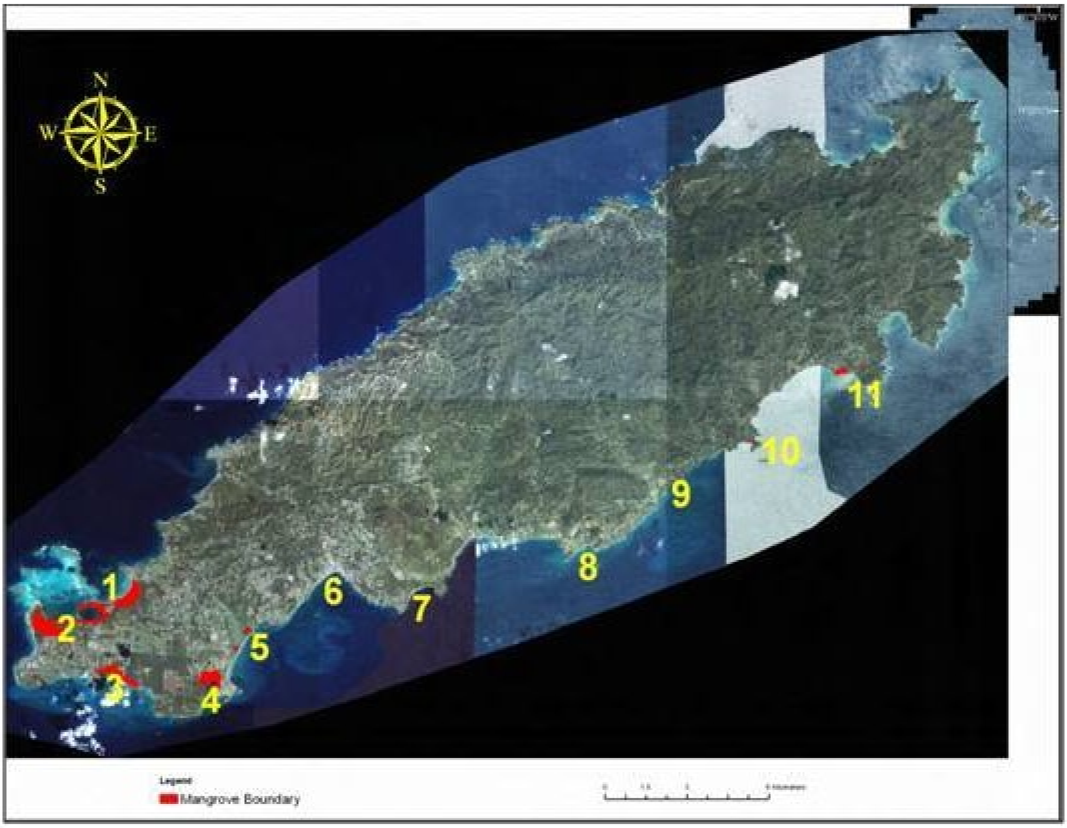
FIG 2 Map of mangrove forests in Trinidad

TABLE 1 List and size of mangrove forests in Trinidad and Tobago in 2007

Area	Dominant plant community	Size (Hectares)
WEST COAST		
Hart's Cut	Basin mangrove	0.7
Cuesa River	Estuarine mangrove	2.2
Mucurapo Swamp	Estuarine/fringed mangrove	9.5
Sea Lots	Estuarine mangrove	1.8
Caroni Swamp	Estuarine mangrove/tidal marsh	5,263
La Cuesa River, Waterloo	Estuarine mangrove	13.9
Orange Valley	Estuarine mangrove	1.5
Couva River	Estuarine mangrove	298.1
Lisas Bay	Fringed mangrove	151.1
North Claxton Bay	Fringed mangrove	88
South Claxton Bay	Estuarine/ fringed mangrove	8.7
Guaracara River	Estuarine mangrove	45.1
Marabella River	Estuarine mangrove	2.3
Cipero River	Estuarine mangrove	15.4
Godineau Swamp	Tidal marsh, estuarine mangrove	765.4
Rousillac Swamp	Fringed mangrove /freshwater	338.7

Area	Dominant plant community	Size (Hectares)
Fullerton	Estuarine mangrove	2.4
Los Gallos	Estuarine mangrove	76.1
Icacos Bay	Freshwater marsh/ Fringed and basin mangrove	326.2
SOUTH COAST		
Los Blanquizales	Basin/ fringed mangrove /freshwater marsh	250.8
Erin Bay	Estuarine mangrove	33.4
Moruga River	Estuarine mangrove	113.6
Lizard River, Guayaguayare	Estuarine mangrove	20.6
Mouville, Pt. Galeota	Basin / fringed mangrove	23.2
Rustville, Guayaguayare	Estuarine mangrove	39.3
St Hiliare, Guayaguayare	Estuarine mangrove	0.4
EAST COAST		
Matura River	Estuarine mangrove	21.1
Rincon Bay	Fringed mangrove	0.63
Le Branche River	Estuarine mangrove	28.8
North Manzanilla	Estuarine mangrove	0.7

Area	Dominant plant community	Size (Hectares)
NORTH COAST		
Scotland Bay	Fringed mangrove forest	0.3
TOBAGO		
LEEWARD COAST		
Bon Accord Lagoon	Fringed mangrove	90.8
Buccoo Bay	Basin mangrove/ Freshwater marsh	41.5
WINDWARD COAST		
Kilgwyn Swamp	Basin mangrove	33.9
Friendship Swamp	Basin mangrove	11.7
Petit Trou Lagoon	Fringed mangrove	34.2
Little Rockly Bay	Estuarine mangrove	4.3
Minster's Bay, Bacolet	Basin mangrove	2.5
Fort Gransby	Estuarine mangrove	0.8
Goldborough	Basin mangrove/ freshwater marsh	1.7



1. Buccoo Bay
2. Bon Accord Lagoon
3. Kilgwyn Friendship
4. Petit Trou
5. Little Rockly Bay
6. Scarborough
7. Minster's Bay
8. Fort Gransby
9. Goldsborough Richmond
10. Belle Garden
11. Louis Dor

FIG 3 Map of mangrove forest in Tobago

Caroni Swamp, for instance, is predominantly a mangrove dominated system with some areas of freshwater marsh and brackish marsh (Bacon 1970). The hydrology of this wetland was altered in the 1920's to accommodate rice cultivation, and later on for flood mitigation (Phelp 1997; Bacon et al. 1997). The mangrove forest in Caroni Swamp is expanding into freshwater marsh, open water and former agricultural areas. Maps showing land cover changes in different epoch are provided in Juman and Ramsewak 2013. Between 1942 and 2007, mangrove coverage increased by 1,105 ha while marshland decreased by 523 ha and agriculture decreased by 393.5 (Juman and Ramsewak 2013). The reason for the expansion is salt water intrusion.

Salinities reported in Caroni's freshwater marsh gradually increased over the years. It ranged from 2.4-5.1 ‰ between 1966 and 1967 (Bacon 1970), 10-34‰ between 1977and 1978 (Deonarine 1980), 23-38.5 ‰ between 1995 and 1997 (Bacon et al 1997) and 1-45‰ from Feb-

TABLE 2 Impacts on mangrove forests in Trinidad and Tobago

Mangrove system	Impacts
Trinidad- West Coast	
Hart's Cut	Solid waste disposal, reclamation, hydrological alteration
Cuesa River	Frequent clearing of mangroves, pollution
Mucurapo Swamp	Reclamation for built development
Sea Lots	Reclamation for unplanned housing, pollution
Caroni Swamp	Hydrological alteration, reclamation for build development, roads and for agriculture, salt water intrusion
La Cuesa River, Waterloo	Encroachment by built development
Orange Valley	Solid waste disposal
Couva River	Encroachment by industry, hydrological alteration, pollution
Lisas Bay	Reclamation for port, pollution
North Claxton Bay	Reclamation for unplanned housing and industry
South Claxton Bay	Reclamation, solid waste disposal
Guaracara River	Pollution, encroachment by unplanned housing
Marabella River	Encroachment by unplanned housing, pollution
Cipero River	Pollution, encroachment for housing
Godineau Swamp	Pollution, hydrological alteration, reclamation, oil exploration
Rousillac Swamp	Coastal erosion, encroachment for housing
La Brea	Reclamation for unplanned housing
Vessigny Bay	Siltation of river
Guapo River	Reclamation for road, car-park and beach facility, passage of pipeline
Irois Bay	Coastal erosion, oil pollution, solid waste disposal
Fullerton	Solid waste disposal

Mangrove system	Impacts
Los Gallos	Road construction, encroachment by housing, pollution
Icacos Bay	Coastal erosion, salt water intrusion, reclamation
Trinidad – South Coast	
Los Blanquizales	Coastal erosion
Erin Bay	Unplanned housing, pollution
Moruga River	Unplanned housing, pollution
Mouville, Pt. Galeota	Reclamation for industry and road construction
Rustville, Guayaguayare	Housing, road construction
St Hiliare, Guayaguayare	Bridge construction, disease/ infestation of mangroves
Trinidad – East Coast	
Rincon Bay	No impact noted
Matura River	Coastal erosion, quarrying activity upstream
Le Branche River	Reclamation, solid waste disposal, coastal erosion
North Manzanilla	Coastal erosion
North Oropuche/ Fishing Pond	Reclamation, hydrological alteration, salt water intrusion
Nariva Swamp	Reclamation for housing and farming, hydrological alteration, salt water intrusion, pollution, forest fires
Ortoire River	Solid waste disposal, reclamation, pollution
Mayaro Bay	Reclamation for housing, resorts
Trinidad- North Coast	
Scotland Bay	Oil pollution
Tobago- Leeward Coast	
Bon Accord Lagoon	Reclamation for built development, hydrological alteration pollution
Buccoo Bay	Reclamation for built development, pollution
Tobago – Windward Coast	
Kilgwyn Swamp	Reclamation for airport, solid waste disposal, pollution

Mangrove system	Impacts
Friendship Swamp	Reclamation, hydrological alteration, wind damage
Petit Trou Lagoon	Reclamation for resort, pollution
Little Rockly Bay	Erosion
Minster's Bay, Bacolet	Solid waste disposal
Fort Gransby	No impact noted
Goldborough	Coastal erosion
Belle Garden	Solid waste disposal
Louis D'or	Reclamation for housing, grazing

ruary 2004 to July 2005 with lowest salinities being reported after heavy rainfall (Nathai-Gyan 2006). Saltwater intrusion is due to a number of factors; reduced freshwater outflow in the rivers due to damming and extraction, channelization and broken embankments. Sea-level rise may exacerbate this intrusion.

Unlike Caroni Swamp, Godineau Swamp is a 3,171 ha estuarine wetland dominated by tidal marshes, but like Caroni Swamp it has undergone major hydrological alterations (Juman and Sookbir 2006). Embankments were constructed, canals were dug and sluice gates were installed to accommodate oil exploration and agriculture (Landell 1991). Mangroves currently occupy about 25% of this wetland. Between 1962 and 1969, approximately 190 ha of mangroves were cleared for rice cultivation, but since then the mangrove coverage has increased from 719 ha in 1969 to 743 ha in 2003 (Juman and Sookbir 2006) to 765.4 ha in 2007. Mangroves are extending inland along river courses and into marshland as salt water intrudes further inland. Agricultural lands were abandoned because of salt water intrusion (Juman and Sookbir 2006).

Mangroves are spreading into freshwater marsh and open pond areas in Icacos Swamp and the reason may be climate induced as opposed to human alteration. Icacos Swamp, located on the southwest peninsula of Trinidad, was predominantly freshwater marsh and open water with some fringing and basin mangroves along Columbus Bay (Ramcharan et al 1982). The Bay is eroding at an estimated rate of about 1 m per year (Institute of Marine Affairs (IMA) unpublished). As the mangroves along the coast succumb to erosion, salt water is intruding further inland and mangroves are now colonizing marshland and open water areas. Bacon (1993) reported this mangrove forest to be 237 ha while the 2007 estimate was 326.2 ha; an increase of 89 ha.

Similarly in Los Blanquizales, which is on the south coast east of Icacos, the mangrove forest continues to experience erosion. The extent of the loss of mangrove or wetland area could not be estimated as there was insufficient historical spatial data. Although Alleng (1997) reported this wetland to be 1,085 ha and the current estimate is 909.4 ha, a difference of 175.6 ha; the loss could not be attributed to the mangrove forest or to the general wetland area. It should be noted that direct human impact on this wetland is minimal since most of it remains inaccessible.

In the Mucurapo Swamp, just north of the city of Port of Spain, the mangrove forest increased from 0.5 ha in 1942 to 9.5 ha in 2009 (O'Connor 2009). This mangrove system only expanded after there was land reclamation between 1942 and 1969 and although mangroves were cleared for a highway, a stadium, and more recently a shopping centre, there has been natural regeneration. Hydrological conditions along this area of coast are conducive to mangrove colonization.

Mangrove forests in the central Gulf of Paria, south of Caroni Swamp to Claxton Bay, are expanding seaward onto extensive mudflats as there is a notable increase in sedimentation. This is affecting fishers and other boating activities, as landing sites have to be relocated or dredged. This area encompasses the Point Lisas Industrial Estate where 500 ha of mangrove forest in Couva/ Carli Bay and Lisas Bay were cleared in the late 1970's for the estate construction (Ramcharan et al. 1982). Bacon (1993) reported the mangrove forest in Couva/ Carli Bay as 171 ha, and Lisas Bay as 26 ha. The 2007 estimates were 298.1 ha in Couva / Carli Bay and 137.6 ha in Lisas Bay an increase of 127.1 ha and 111.6 ha respectively. While the landward margin of these forests is being encroached upon by built development, the mangroves are expanding seawards.

Further south on the west coast, from Guaracara to La Brea, mangrove forests are being encroached upon by housing developments, many of which are unplanned and have inadequate infrastructure. No buffer zone is left for landward migration of mangroves (Table 2).

On the east coast of Trinidad, the largest mangrove forests are found in Nariva Swamp (580.7 ha), North Oropuche/ Fishing Pond (268.8 ha) and Ortoire River (215.7 ha). There are no historical data for the smaller systems at Rincon Bay, Matura Bay and North Manzanilla Bay. The mangrove forest at the mouth of the L'Ebranche River has decreased by 18.2 ha as mangroves were cleared for a hotel and illegal housing development. Along the Ortoire River the mangrove forest is 115.7 ha larger than reported by Bacon (1993). In North Oropuche/ Fishing Pond it is 99 ha larger and in Nariva Swamp it is almost 300 ha larger than reported by Bacon (1993). In Nariva Swamp and North Oropuche/ Fishing Pond mangroves have been expanding into freshwater areas and salt water intrusion is believed to be the cause of this landward migration; with reasons similar to Caroni Swamp.

Unlike systems on the west coast, the wetlands on the East Coast (Atlantic Ocean) are subjected to higher wave energy. These wetlands are not open to the ocean but occur behind sand barriers. Most of the wetlands on this coast area are experiencing problems with coastal erosion except for North Oropuche/Fishing Pond. Bacon (1993) reported coastal erosion in North Oropuche/ Fishing Pond but this was not evident during the 2009 field survey as high sand berms were observed along the coast. The coastlines in north Manzanilla and the Cocos Bay were severely eroded. Rip-rap was installed in Cocos Bay to arrest the erosion as seawater would breach the road and enter Nariva Swamp.

On the south coast of Trinidad relatively large mangrove forests are found near the Moruga River and at Los Blanquizales. Smaller systems are found within Guayaguayare Bay and Erin Bay. The Moruga mangrove forest is much larger than the 24 ha reported by Bacon (1993). The difference in size is most likely a mapping error as mangroves in Moruga were cleared for unplanned housing. The system in Erin Bay has also been impacted by unplanned housing while the mangrove forest in Point Galeota has been fragmented by road, industrial and port development. Point Galeota mangrove forest decreased from 30.5 ha in 2001 (IMA, 2004) to 23.2 ha in 2007.

There are no extensive mangrove forests on the North Coast. The Scotland Bay system is relatively undisturbed as there are no built developments in that area and it is only accessible by boat. In Maracas Bay, there is a stand of white mangroves at the mouth of the Maracas River. Alleng (1997) recorded red mangroves in this area but they were not present in 2009.

In Tobago, the largest mangrove communities are found at the southwest end of the island which is the most populated and developed part of the island (CSO 2007; IMA 1996). Southwest Tobago has experienced rapid growth and development in the tourism and related service sectors. Mangroves were cleared in the 1990's for the extension of the Crown Point Airport and for hotel development. In 2007, mangroves were cleared in the Bon Accord Lagoon for proposed resort development and in 2008 for housing.

However, there is indication that the Bon Accord mangrove forest is migrating landward as salt water appears to be intruding further inland. Juman (2004) using 1994 aerial photographs estimated the size of the mangrove forest inclusive of ponds to be 88.8 ha. Based on the 2007 estimates, the mangrove forest has increased by 2 ha even though there was removal. Even in areas recently cleared, there were signs of new growth as many white mangrove seedlings were re-established. Whether salt water intrusion is due to channel construction or sea-level rise is unknown and needs to be determined. There is a serious concern in this area with regards to 'coastal squeeze'. Built development occurs on the landward edge of the forest leaving very little space for landward migration of mangroves.

There is little historical data for the smaller wetlands on the Atlantic coast of Tobago such as Louis D'or, Goldsborough, Belle Garden, and Rockly Bay. On this coast where most mangrove systems are found, there are concerns that coastal erosion on the seaward side and encroachment by built development on the landward edge, there is little space for landward migration by mangroves.

Conclusion

Mangrove forests in Trinidad and Tobago have exhibit some resilience as systems have regenerated and there has been an increased in mangrove coverage in larger wetlands such as Caroni, Godineau, Icacos, North Oropuche and Nariva Swamp. These increases however have been at the expense of freshwater wetland communities. The causes for vegetation change may be site-specific or climate related but this can only be determined by undertaking vulnerability assessments, and long-term monitoring of parameters such as relative sea-level, salinity and sedimentation rates.

Mangrove vegetation however continues to be threatened by human activities as present and proposed developments are concentrated on the coast (Table 2). Degraded systems that receive land-based sources of pollution are more susceptible to climate change impacts (UNEP 2007) especially where there is little space for landward migration of mangroves as sea-level rises.

The results of the site specific vulnerability assessments should be incorporated into coastal land-use policies to provide adequate lead-time to minimize social disruption and economic costs, and reduce losses of valued coastal habitats. This may include instituting setbacks from mangroves for new development for appropriate sections of coastline and building resilience to climate change effects by reducing and eliminating other stresses that degrade mangroves. The policy adopted to manage site-based shoreline response to rising sea level should be made as part of a broader integrated coastal zone management plan, which includes an assessment of the cumulative effects of coastal activities.

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