Simulation of Impacts of Sea Level Rise on Mangrove Survival in Central and Eastern Visayas

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I. Introduction

Sea level rise (SLR) is the change in sea level due to climate change. It is affected by the expansion of oceans due to warming, and the transfer of water stored from land to water, e.g., glacier and ice sheets (Church et al. 2013). The SLR is perceived to be the most serious threat on the long-term survival of mangroves (McLeod & Salm 2006). David et al. (2015) classified 11 geographical clusters of Philippine waters based on climate hazard exposures such as SLR, extreme heating, extreme rainfall events, disturbed water budget, and increasing ocean temperature (**Fig. 1**). Among the hazards, only SLR was prevalent in all clusters.

Although mangroves can adapt to rising sea level (Gilman et al. 2007), areas that will be affected will vary depending on several bio-physical and geomorphological factors. In this study, the effects of SLR on the distribution of mangrove extent in the Central and Eastern Visayas regions were determined using spatial modeling.

II. Data and Methodology

Mangrove cover in Central and Eastern Visayas

The Central and Eastern Visayas regions are composed of the islands and provinces of Negros Oriental, Cebu, Bohol, Siquijor, Biliran, Leyte, Southern Leyte, Samar, Northern Samar, and Eastern Samar (**Fig. 2**). These regions are home to an estimated 31,500 ha of mangroves (as of 2015; Phil-LiDAR 2 CoastMap 2016). Historically, the total mangrove extent coverage is at 47,100 ha in 2000 and 41,100 ha in 2010 (**Table 1**; Long & Giri 2011; Long et al. 2014). Among these provinces, Bohol has the largest mangrove cover with 8,200 ha, followed by Northern Samar and Eastern Samar with 6,400 and 5,900 ha, respectively.

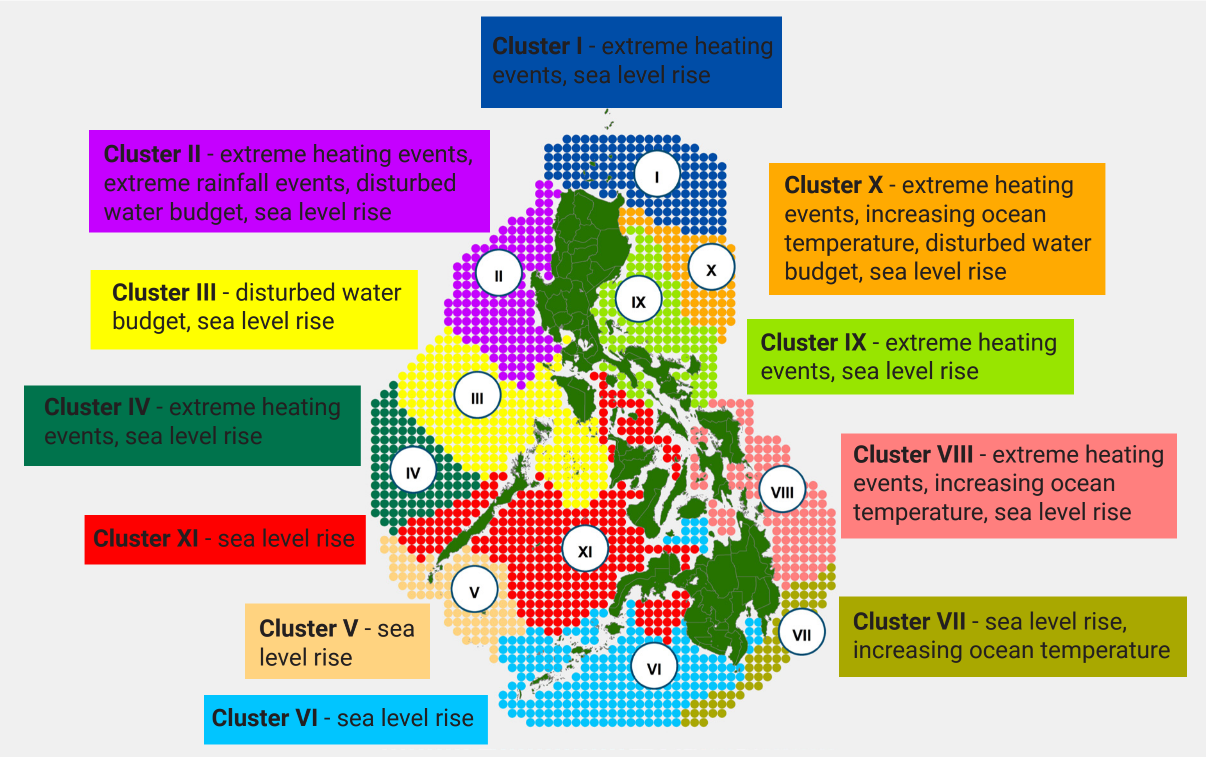

Figure 1. Climate hazard clusters of Philippine waters (David et al. 2015).

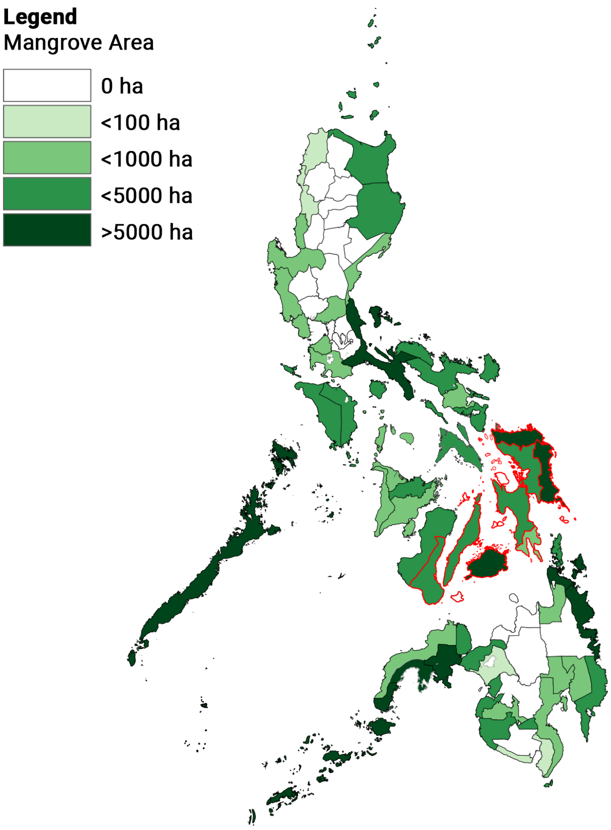

Figure 2. Mangrove extent per province, Central and Eastern Visayas outlined in red (Phil-LiDAR 2 CoastMap 2016).

Table 1. Mangrove area estimates, in ha (Phil-LiDAR 2 CoastMap 2016). There is no available data from Siquijor probably because of the low resolution of satellite images or mangroves are thinly/sporadically distributed.

Province	2000	2010	2015
Biliran	100	100	-
Bohol	10,600	8,700	8,200
Cebu	2,900	2,400	2,200
Eastern Samar	6,400	6,900	5,900
Leyte	7,000	6,600	4,000
Negros Oriental	2,300	1,700	1,700
Northern Samar	5,200	3,800	6,400
Samar	11,800	10,500	2,900
Siquijor	-	-	-
Southern Leyte	800	400	200

From 2010 to 2015, the largest decrease in mangrove cover was observed in Samar (69 %) and Leyte (36 %). This period includes the occurrence of Super Typhoon Yolanda (international name: Haiyan; 2013) affecting the area and could have been a possible cause of mangrove losses (**Fig. 3**). However, during the mangrove summit, it was evident that these mangrove area estimates were not consistent with provincial datasets and therefore need to be validated.

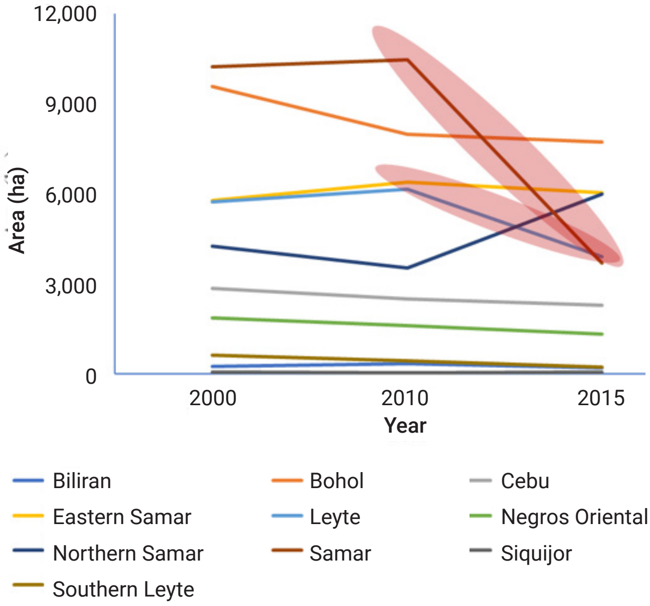

Figure 3. Historical mangrove extent coverage in Central and Eastern Visayas. Highlighted in red are decreased coverage in the provinces of Samar and Leyte (adapted and modified from Phil LiDAR 2 and Long & Giri 2011).

Sea level rise measurements

In a global scale, sea level is monitored through satellite altimetry—a height measuring technique using radar pulses. Satellites such as Topex/Poseidon, Jason-1, Jason-2, and Jason-3 have observed sea level since the 1990s. According to the Centre National d'études Spatiales (CNES 2017), the global rate of SLR is at 3.31 mm/year (**Fig. 4**). The data resolution is one degree or approximately 110 km.

On the other hand, the regional rate for North Pacific, where the Philippines is located, is at 2.89 mm/year (**Fig. 5**). These rates have high inter- and intra-site spatial variability and is expected to accelerate in the succeeding years (Nerem et al. 2017).

Similarly, in-situ measurements on surface elevation change were made through a USAID-PEER project in selected mangrove sites across the country (**Table 2**). However, due to differences in scale and resolution of satellite altimetry data, the differences in values between the two datasets are large.

Table 2. Difference in SLR between in-situ and satellite altimetry values (in mm) (USAID-PEER Project Data; unpublished).

Site	In-situ (Average)	Altimetry	Difference
Pangasinan	32.6	3.8	28.8
Masinloc	1.1	3.7	(2.7)
Subic	22.4	3.5	18.9
Palawan	(7.8)	3.8	(11.6)
Kalibo	18.1	3.5	14.6
Bantayan	(4.6)	(0.1)	(4.5)
Palompon	17.3	(0.3)	17.6
Manila Bay (LPPCHEA)	(5.0)	(4.2)	0.8
Puerto Galera	(5.1)	2.4	(7.5)
Calapan	(4.2)	(1.3)	(2.9)
Samar	(55.6)	4.1	(59.7)

Scenario simulation

The simulation determined how much mangroves will be affected or vulnerable to SLR at varying degrees, as 0.1 m, 0.2 m, 0.5 m, and 1 m rise. Spatial analysis was run using the latest mangrove coverage and SLR data. Elevation values for mangroves were assigned using the open sourced digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) with a 90 m resolution.

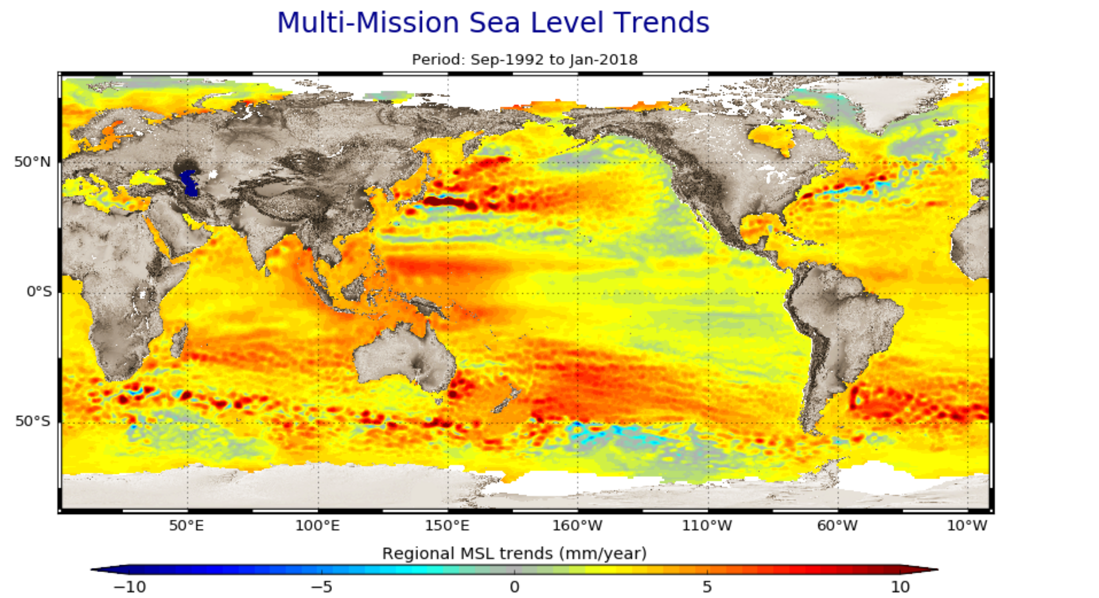

Figure 4. Global sea level rise observation (EU Copernicus Marine Service/CNES/LEGOS/CLS 2018).

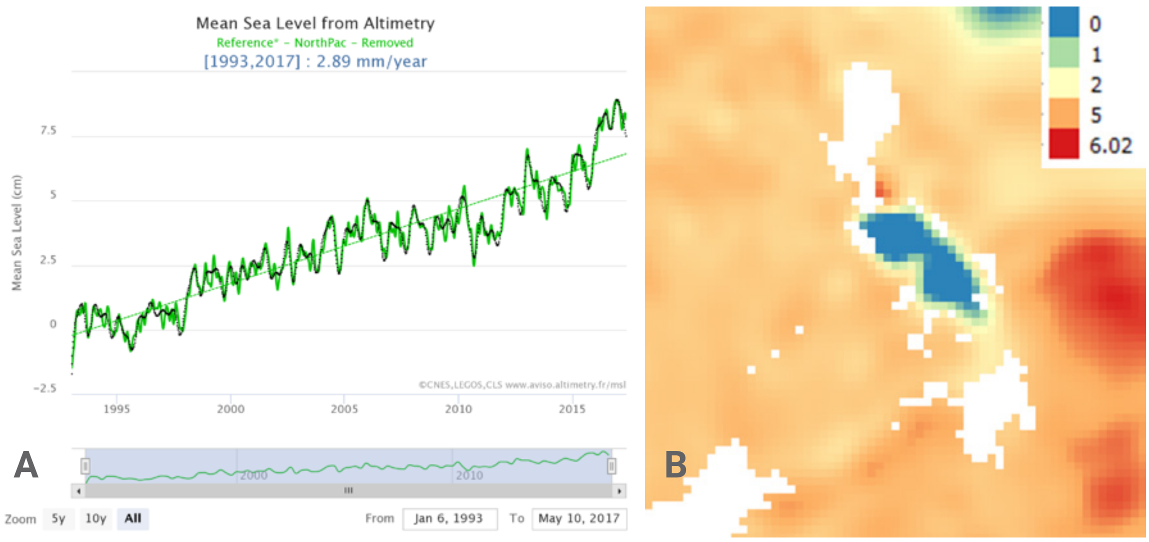

Figure 5. Historical sea level observation in North Pacific (A) and mean sea level rise in the Philippines in mm (B; CNES 2017)

To supplement the assessment of vulnerability, normalized difference vegetation index (NDVI) data from 250-m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) was added (**Fig. 6**). NDVI, as an indicator of vegetation health, indicates that lower values corresponds to higher vulnerability while higher values corresponds to lesser vulnerability.

The degree of vulnerability was assessed using a matrix that combined NDVI and elevation change values (**Table 3**).

Sample simulation using field observations was also performed using the average value in Palompon, Leyte—the only observation site within the study area

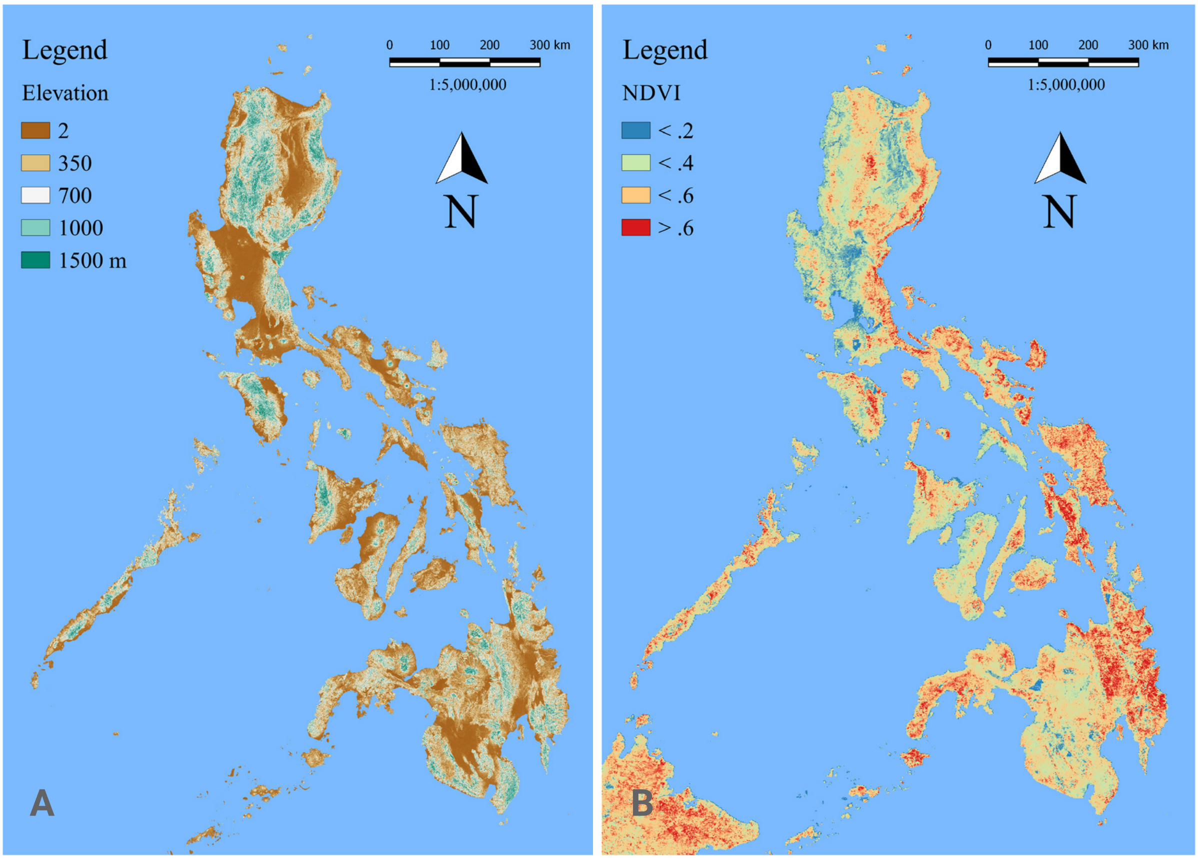

Figure 6. SRTM Digital Elevation Model (A) and MODIS Normalized Difference Vegetation Index (B).

Table 3. Vulnerability matrix.

NDVI/Elevation Change	> 1m	< 1	< 0.5	< 0.2	< 0.1
> 0.75	Less vulnerable	Less vulnerable	No Change	Moderately vulnerable	Highly vulnerable
0.5 – 0.75	No Change	No Change	No Change	Moderately vulnerable	Highly vulnerable
< 0.5	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable	Highly vulnerable
< 0.25	Highly vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable	Highly vulnerable

that has a positive measurement (i.e., sea level rise). Mean values in both Samar and Bantayan Island, Cebu were negative (i.e., sea level lowering).

III. Results and Discussion

At increasing sea level, larger mangrove areas in more provinces were affected (**Table 4**; **Fig. 7**). At 0.1-m rise, 3,980 ha of mangroves in 23 provinces (in the Philippines) will be affected and increased to 8,813 ha in 32 provinces at 1.0 m. Among the leading provinces that will be affected are Bohol and Northern Samar in Central and Eastern Visayas, respectively.

Focusing in Central and Eastern Visayas, the mangroves in Negros Oriental, Cebu, Leyte, Samar, and Southern Leyte are located in relatively higher elevation; thus, will be less vulnerable to SLR (**Table 5**).

Using the values on annual rate on SLR, the years to take each scenario to happen were also estimated (**Table 6**). The slowest rate occurred in Leyte at 0.06 mm/year, while the fastest was at Negros Oriental at 4.14 mm/year. It will take around 242 years for Negros Occidental to be submerged in 1.0 m scenario as compared to 1,520 years in Leyte. In addition, Biliran was recorded to experience lowering of sea level, i.e., receding seawater.

Table 4. Result of the simulation showing estimates of mangrove areas vulnerable to SLR.

Sea Level Rise	0.1 m	0.2 m	0.5 m	1.0 m
Affected mangroves (in ha)	3,980	4,025	5,757	8,813
Affected provinces	23	23	28	32
Top provinces and area (in ha)	Northern Samar (923)	Northern Samar (923)	Zamboanga Sibugay (1,727)	Zamboanga Sibugay (2,105)
	Sulu (778)	Sulu (778)	Northern Samar (1,129)	Northern Samar (1,836)
	Basilan (587)	Basilan (587)	Sulu (859)	Basilan (1,700)
	Zamboanga Sibugay (534)	Zamboanga Sibugay (556)	Basilan (587)	Bohol (1,115)
	Tawi-tawi (510)	Tawi-tawi (510)	Tawi-tawi (529)	Sulu (859)
	Bohol (435)	Bohol (458)	Bohol (505)	Tawi-tawi (529)
			Iloilo (127)	Iloilo (127)

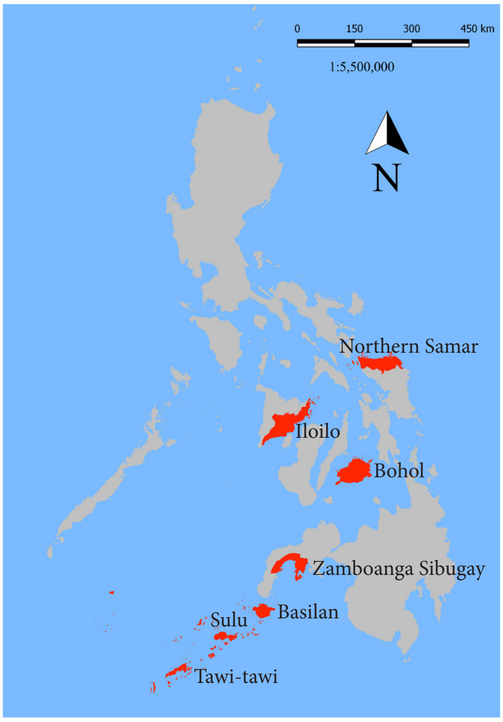

Figure 7. Location of most affected provinces.

Table 5. Result of simulation showing mangrove areas (ha) vulnerable to SLR in Central and Eastern Visayas.

Province	0.1 m	0.2 m	0.5 m	1.0 m
Negros Oriental	-	-	-	-
Cebu	-	-	24	29
Siquijor	2	2	2	2
Bohol	435	458	505	1,114
Biliran	27	27	27	27
Leyte	-	-	-	8
Southern Leyte	-	-	-	-
Northern Samar	924	924	1,133	1,836
Samar	-	-	20	60
Eastern Samar	5	5	5	5

Table 6. Result of sea level rise simulation in Central and Eastern Visayas.

Province	Annual rise (mm)	Years to reach level			
		0.1 m	0.2 m	0.5 m	1.0 m
Negros Oriental	4.14	24	48	121	242
Cebu	2.74	36	73	182	364
Siquijor	3.97	25	50	126	252
Bohol	3.22	31	62	155	310
Biliran	-0.51	(sea level getting lower)			
Leyte	0.06	152	304	760	1,520
Southern Leyte	2.17	46	92	230	460
Northern Samar	2.76	36	73	181	363
Samar	1.78	56	112	280	560
Eastern Samar	3.87	26	52	129	258

Filling up the vulnerability matrix, 40,246 ha or 24.4 % of total mangrove areas in the Philippines can be considered as highly vulnerable (**Tables 7 & 8**). Northern Samar, Bohol, and Eastern Samar were included in the top ten provinces vulnerable to SLR (**Table 9**).

In Central and Eastern Visayas, all provinces have at least 11 % of their mangrove areas considered as highly vulnerable (**Table 10**). Biliran has the largest percentage of vulnerable mangroves at 54.5 %, followed by Northern Samar and Southern Leyte at 47.7 % and 47.3 %, respectively.

Table 7. Vulnerability matrix (Filled up with areas in ha).

NDVI/Elevation Change	> 1 m	< 1 m	< 0.5 m	< 0.2 m	< 0.1 m
>0.75	25,437	154	-	22	244
0.5 – 0.75	55,667	604	1,181	23	633
< 0.5	40,271	1,263	146	-	1,839
< 0.25	34,362	1,500	404	-	1,264

Table 8. Summarized vulnerability matrix

Classification	Area (ha)	%
Highly Vulnerable	40,246	24.4
Moderately Vulnerable	41,726	25.3
No Change	57,451	34.8
Less Vulnerable	25,591	15.5
	165,014	
No Data	51,093	

Table 9. Top 10 provinces with largest area of vulnerable mangroves.

Rank	Province	Highly Vulnerable (ha)	Total Area (ha)	%
1	Palawan	6,840	43,735	15.60
2	Sulu	4,883	20,860	23.40
3	Tawi-Tawi	4,163	12,219	34.10
4	Zamboanga Sibugay	3,059	12,442	24.60
5	Northern Samar	2,857	5,994	47.70
6	Basilan	2,307	8,271	27.90
7	Zamboanga del Sur	2,266	9,054	25.00
8	Quezon	1,994	10,541	18.90
9	Bohol	1,770	7,725	22.90
10	Eastern Samar	1,428	6,043	23.60

Table 10. Percentage of highly vulnerable mangroves in Central and Eastern Visayas.

Province	Highly vulnerable (ha)	Total mangrove area (ha)	%
Biliran	111	204	54.5
Northern Samar	2,857	5,994	47.7
Southern Leyte	1,030	2,180	47.3
Negros Oriental	398	1,336	29.8
Eastern Samar	1,428	6,043	23.6
Bohol	1,770	7,725	22.9
Cebu	388	2,294	16.9
Siquijor	7	61	12.7
Leyte	474	3,905	12.2
Samar	409	3,704	11.0

Table 11. Result of sea level rise simulation in Central and Eastern Visayas using field measurement in Palompon, Leyte.

Annual rise (mm)	Years to reach level			
	0.1 m	0.2 m	0.5 m	1.0 m
17.3	6	12	29	59

Using *in situ* elevation measurement values in Palompon, Leyte (which is much higher than satellite altimetry values), it will take less time for mangrove areas to be affected by SLR (**Table 11**). If field observation was validated to be correct, then a more pro-active management intervention (through conservation and restoration programs) is needed to alleviate the effect of SLR.

Figures 8 and 9 show zoomed-in maps of selected areas in Central and Eastern Visayas. Mangrove areas near San Juanico Strait between the islands of Samar and Leyte are generally located in higher elevation; thus, less mangroves will be affected by a 1.0 m SLR. On the other hand, all mangroves in Bantayan Island, Cebu will be affected by 1.0 m SLR due to lower elevation; hence, more vulnerable to submergence.

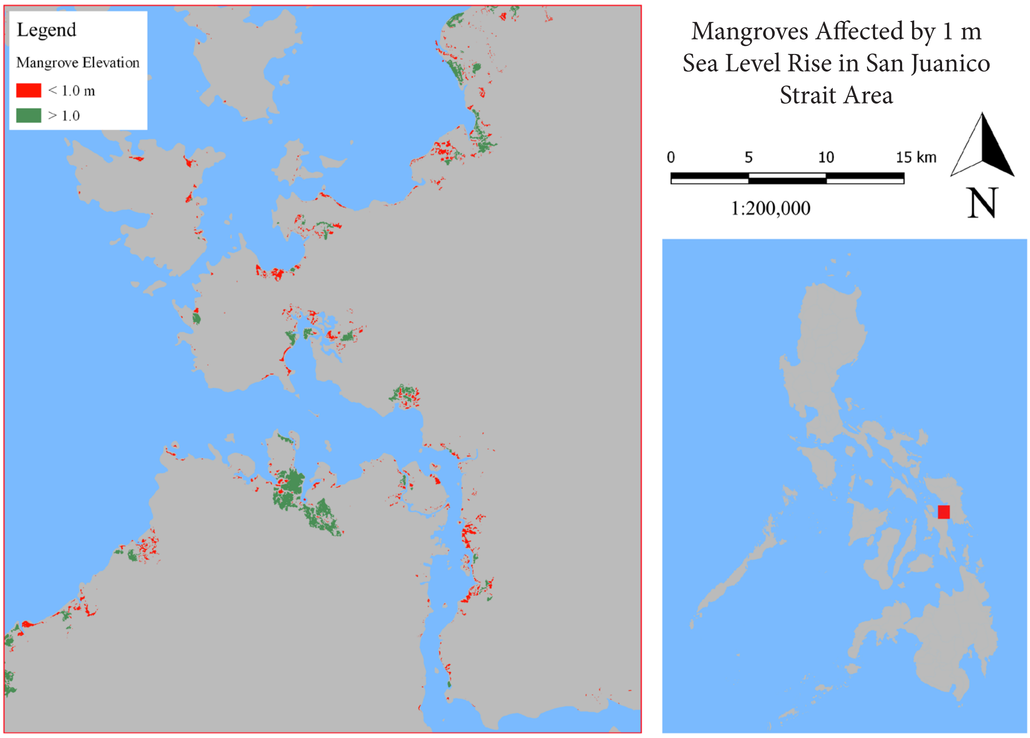

Figure 8. Affected mangrove area (highlighted in red) by 1.0 m SLR in the vicinity of San Juanico Strait between Samar and Leyte islands.

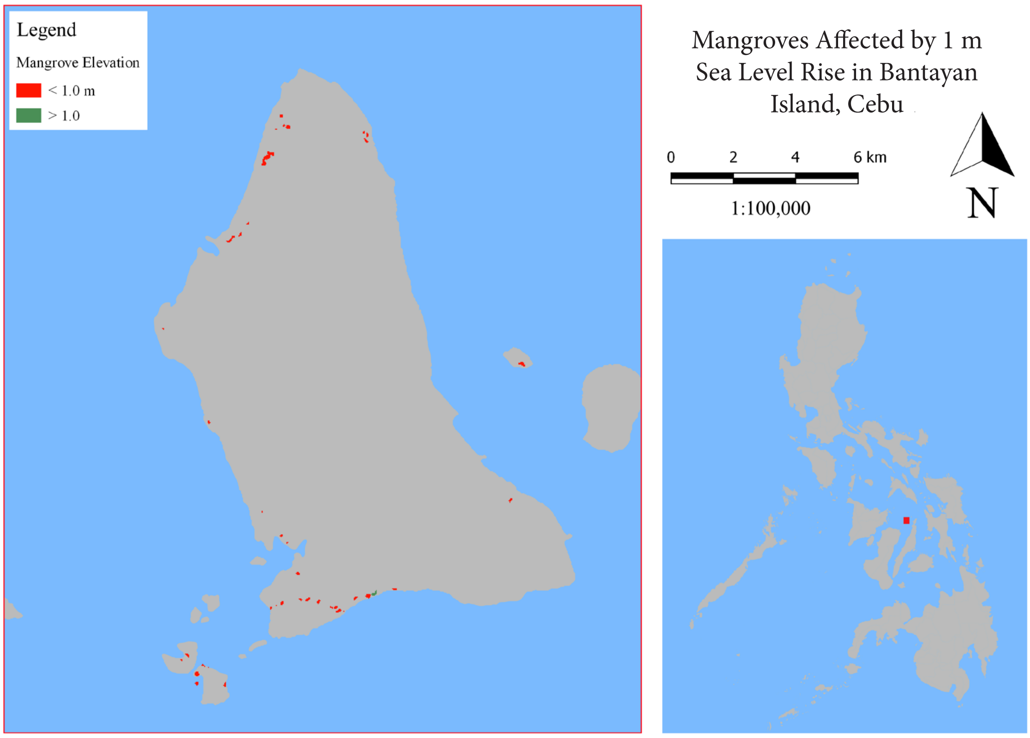

Figure 9. Affected mangrove area (highlighted in red) by 1.0 m SLR in Bantayan Island, Cebu where in-situ elevation values were measured.

IV. Summary and Conclusion

As of 2015, the Philippines has a remaining mangrove area of about 216,000 ha with Palawan having the largest share. SLR is expected to continue in the years to come. Regional rate for North Pacific is at 2.89 mm/year, however, it is expected to increase. A minimal increase of 0.1 m will affect about 3,980 ha of mangroves in 23 provinces, while a 1.0 m rise will affect a total of 8,813 ha of mangroves in 32 provinces.

In Central and Eastern Visayas, the rates of SLR varied among provinces. It was slowest in Leyte (0.06 mm/year) and fastest in Negros Oriental (4.14 mm/year). Biliran, on the other hand, has a negative value. Supplementing NDVI (as indicator of vegetation health) to projected SLR provided an additional criterion in determining the vulnerability of mangroves. Three out of the ten provinces (Northern Samar, Bohol, and Eastern Samar) in the combined regions were included in the leading ten provinces with the largest area of highly vulnerable mangroves. Using field observations, the effect of SLR was expected to occur earlier as compared to the simulation based on satellite altimetry data. More *in situ* measurements are needed to calibrate the model.

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