2.1. Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region

Authors: Denise J. Reed
Dana A. Bishara
Department of Earth and Environmental Sciences, University of New Orleans

Donald. R. Cahoon, U.S. Geological Survey
Jeffrey Donnelly, Woods Hole Oceanographic Institution
Michael Kearney, University of Maryland
Alexander S. Kolker, State University of New York, Stony Brook
Lynn L. Leonard, University of North Carolina, Wilmington
Richard A. Orson, Orson Environmental Consultants
J. Court Stevenson, University of Maryland

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2.1.1 Introduction

One of the key questions to be addressed by the U.S. Climate Change Science Program's (CCSP) sea level rise synthesis and assessment is "To what extent can wetlands vertically accrete and thus keep pace with rising sea level; that is, will sea level rise cause the area of wetlands to increase or decrease?" Although predictive models for wetland soil response to sea level rise have been available for some years (e.g., Krone, 1987) and have been amplified to encompass biotic as well as mineral contributions to vertical soil building (e.g., Morris et al., 2002; Rybzyck and Cahoon, 2002), applying these models over wetland landscapes requires detailed information on wetland biogeomorphic processes. Many site-specific field studies can provide this information for local areas, but available models cannot, at present, predict coastal wetland response to sea level rise over large areas.

To support the CCSP efforts and provide spatially explicit landscape scale predictions of coastal wetland response to future sea level rise, an expert panel approach was used. EPA's Climate Change Division (CCD), which has the lead on the sea level rise synthesis and assessment product for CCSP, determined that the focus would be on the Mid-Atlantic (defined here as the Atlantic shore of Long Island to Virginia). They also provided three sea level rise scenarios for the panel to consider:

- Current rates: rates and the regions to which the rates apply were to be determined by the panel;
- An increase of 2 mm per year above the current rates (termed here midrange sea level rise);
- An increase of 7 mm per year above the current rates (termed here high-range sea level rise).

The panel's task was to assess for the Mid-Atlantic region how coastal wetlands would respond to changes associated with these sea level rise scenarios. To support this effort, a literature review of published, and in some cases unpublished, reports of recent and historical accretion rates for the Mid-Atlantic was conducted.

Expert Panel Approach

The panel consisted of a group of experts with first-hand knowledge of the coastal wetland geomorphic processes in the Mid-Atlantic. They convened in a 2-day workshop in February 2006 at the Patuxent Wildlife Research Center in Maryland. Their deliberations were designed to ensure that conclusions were based on an understanding of the processes driving marsh survival in the face of sea level rise and how the magnitude and nature of these processes might change in the future owing to the effects of climate change and other factors.

To ensure a systematic approach across regions within the Mid-Atlantic and throughout the workshop, the following procedures were used:

- A series of geomorphic settings, and in some cases subsettings, was identified to assist in distinguishing between the different process regimes controlling coastal wetland accretion.[1] The settings were chosen to encompass the vast majority of coastal wetlands found on the Mid-Atlantic.

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[1] The term accretion is used in this report to describe net change in the relative elevation of the marsh surface in the tidal frame. Individual studies have distinguished between specific measures of elevation change (documented against a fixed datum) or surface accretion where methods focus on accumulation of material on or near the marsh surface.

- A suite of processes potentially contributing to marsh accretion in the Mid-Atlantic was established and described in general terms. In addition, likely future changes in current process regimes due to climate change were outlined.
- The Mid-Atlantic was divided into a series of regions based on similarity of process regime and current sea level rise rates. The current rate of sea level rise and the source of the tide gauge data supporting that rate were identified for each region. This rate defined the first of the sea level rise scenarios and provided the baseline for the mid-range and high-range rates.
- Within each region, geomorphic settings were delineated by drawing polygons onto 1:250,000 scale USGS topographic paper maps, and the fate of the wetlands within these settings under the three sea level rise scenarios was agreed upon. The fate of the wetlands was allocated to the categories described in Table 2.1.1 based on the following potential outcomes:
    - Keeping pace—wetlands will not be submerged by rising sea levels and will be able to maintain their relative elevation.
    - Marginal—wetlands will be able to maintain their elevation only under optimal conditions. Depending on the dominant accretionary processes, this might mean frequent inputs of sediments from storms or floods, or the maintenance of hydrologic conditions conducive to plant productivity. Given the complexity and inherent variability of factors (climatic and otherwise) influencing wetland accretion, the fate of these wetlands cannot be predicted by the panel. However, under the best of circumstances they are expected to survive.
    - Loss—wetlands will be subject to increased hydroperiod beyond that normally tolerated by the vegetative communities, leading to deterioration and conversion to open water.
- The paper maps were delivered to the EPA project officer, who defined a procedure for converting the polygons into a GIS data base, designed thematic map categories and map legends, and contracted with Stratus Consulting to prepare the maps that appear in this report. For further details of how the maps were created and the GIS output associated with this report, see Titus et al. (Section 2.2).

Report Content

This report summarizes the background information provided to the panel, and describes the geomorphic settings and accretionary processes identified by the panel for the Mid-Atlantic. The purpose of this report is not to provide a complete synthesis of the data assembled to inform the group or to reiterate the extensive literature of coastal wetland accretionary processes. The main focus of the report is to provide narrative discussion of the rationale behind the categories of wetland response to sea level scenarios depicted in the maps. This is provided by the regions defined by the panel, and includes a rationale for the selected current rate of sea level rise, the assignment of geomorphic settings and associated accretionary processes, and a summary of the spatial distribution of the response categories assigned within each region by the panel.

Table 2.1.1. Categories of Wetland Response to Sea Level Scenarios

Category	Summary Outcomes			Description
	Current	Midrange	High-Range	
Loss under current rates	L			These wetlands are not sustainable under current circumstances and they are not expected to be reestablished by natural processes in the future.
Marginal under current rates, loss under midrange scenario	M	L		These wetlands are marginal now and will be lost if sea level rise rates increase by 2 mm/yr.
Marginal under current rates, marginal or loss under midrange scenario	M	M–L		These wetlands are marginal now and will be able to keep pace only under the best of circumstances if sea level rise rates increase by 2 mm/yr.
Keeping pace under current rates, marginal under midrange, loss under high- range scenario	K	M	L	These wetlands are currently keeping pace and will continue to do so only under the best of circumstances if sea level rise rates increase by 2 mm/yr. They will be lost if sea level rise rates increase by 7 mm/yr.
Keeping pace under current and midrange rates, loss under high-range scenario	K	K	L	These wetlands are currently keeping pace and will continue to do so if sea level rise rates increase by 2 mm/yr. They will be lost if sea level rise rates increase by 7 mm/yr.
Keeping pace under current and midrange rates, marginal or loss under high-range scenario	K	K	M-L	These wetlands are currently keeping pace and will continue to do so if sea level rise rates increase by 2 mm/yr. They will keep pace only under the best of circumstances or in local areas if sea level rise rates increase by 7 mm/yr.
Keeping pace under current and midrange rates, marginal under high-range scenario	K	K	M	These wetlands are currently keeping pace and will continue to do so if sea level rise rates increase by 2 mm/yr. They will keep pace under the best of circumstances if sea level rise rates increase by 7 mm/yr
Keeping pace under all sea level rise scenarios	K	K	K	These wetlands are currently keeping pace and will continue to do so if sea level rise rates increase by 2 mm/yr or 7 mm/yr.

L – Loss, M – Marginal, K – Keeping Pace (see text for definitions).

2.1.2 Recent and Historical Rates

Site-specific field studies of coastal wetland response to sea level rise have been conducted across the Mid-Atlantic. Several types of techniques are used in these studies:

- Historical rates of material accumulation within the wetland soil. These studies use defined depth horizons within cores. The horizons are dated based on radiometric dating with the decay rate of the radionuclide (e.g., ^{137}Cs, ^{210}Pb, ^{14}C) determining the period over which the rates are calculated (e.g., Lynch et al., 1989; Rooth et al., 2003).
- Surficial accretion of material. Vertical increments of material are measured relative to the surface over study-defined periods, usually months to several years. A marker is placed on the marsh surface at the beginning of the study and buried over time (e.g., Cahoon and Turner, 1989).
- Net change in marsh elevation relative to a fixed datum. These techniques, such as the Sediment Erosion Tables (SETs) (Boumans and Day, 1993) or Rod Surface Elevation Tables (Cahoon et al., 2002), measure the net result of processes both increasing (e.g., surface sediment deposition, soil peat accumulation) and decreasing (e.g., compaction, decomposition) elevation. The datum is established at the start of the study and measurements are made periodically, usually at least annually, relative to this baseline.

Reed and Cahoon (1993) provide a more detailed account of the techniques and their assumptions concerning rates of change within marshes.

Table 2.1.2 lists the studies of wetland accretion in the Mid-Atlantic identified for this study and includes information on the methodology used as well as some basic descriptive terms for the studied marshes (derived from the source publications). Note that the term “accretion” is used in Table 2.1.2 generally, as in the rest of the report, to embrace rates of vertical change no matter which technique is used. In some studies multiple methods are used to derive several accretion rates at the same location. The results, presented here state by state, were intended to provide contextual information to the expert panel rather than define areas of geomorphic or accretionary commonality.

For coastal wetlands in New York, most of the identified studies used ^{210}Pb dating to derive accretion rates. None of the studies for which primary sources were found included accretion rates above 5 mm/yr, with most rates between 2 and 4 mm/yr. Interestingly, a number of separate papers on Flax Pond marshes, examining accretion in different marsh types and settings, show rates varying within the Flax Pond system from 1.6 to 6.3 mm/yr. The very few studies found for marshes in New Jersey showed great variation in rates from 3.8 mm/yr to more than 13 mm/yr.

For Delaware, rates of 2–7 mm/yr are common, with some higher rates found at Indian River Bay, Little Lagoon Marsh and Port Mahon (Kraft et al., 1992). Other studies in Delaware have measured accretion rates > 10 mm/yr but these are largely restored marshes building quickly toward an equilibrium tidal elevation (R.A. Orson, Orson Environmental Consultants, unpublished information). Although previous work (e.g., Pethick, 1981; Krone, 1987) suggests that marshes low in the tidal frame are likely to experience higher accretion rates, using these restored marsh rates to assess future response to sea level rise in established marshes would require an assumption about marsh elevation in the tidal frame that could not be supported by data. Most of the rates documented from primary sources for Delaware are based on radiometric dating. This technique incorporates any compaction of soil layers above the dated horizon and as such can be considered a more conservative measure of accretion than accumulation over a surficial marker horizon. Radiometric dating also averages rates of accretion over several decades or more, reducing the influence of episodic events on the measured rates.

For Maryland, more of the data shown in Table 2.1.2 are derived from short-term measurements, some for periods as short as 6 months. Rates range from very high, e.g., >15 mm/yr of accretion at fresh marshes in Jug Bay (Boumans et al., 2002), to highly negative, e.g., a loss of more than 15 mm in *Spartina patens* marshes on the Patuxent estuary (Childers et al., 1993). Longer term rates based on pollen or radiometric dating show positive accretion (negative rates can only be derived from elevation change measures such as SET or RSET) of between 1 and 10 mm/yr with great variation from site to site.

Both back barrier lagoon and riverine marshes have been studied in Virginia using marker horizons, SETs, and ^{210}Pb dating. The study by Darke and Megonigal (2003) on Walkerton Marsh shows a rate of accretion over a marker horizon of only 0.12 mm/yr. This is a fresh riverine system, and it is possible that surface elevation may be more driven by below-ground processes and not reflected in the surficial accumulation measured above the marker.

Table 2.1.2. Summary of published sources of accretion rates, by state, identified as part of this study.

			Marsh Type				
Location	**Accretion Rate (mm/yr)**	**Method**	**low/ high**	**fresh/ brackish/ salt**	**Dominate Plant Community**	**Geomorphic Setting**	**Source**
			DELAWARE				
Assawoman Bay lagoon marsh	3.5-8.2	Lead 210 & Cesium 137	low		*Spartina alterniflora*	lagoon	Kraft et al., 1992
Boat house cove	4.00			salt		estuarine	Carey, 1996 (in Nikitina et al., 2000)
Delaware Bay	3.0-5	Lead 210		salt		bay	Church et al., 1987
Delaware Bay	4-5					bay	Kraft et al., 1989 (in Fletcher et al., 1990)
Delaware Wildlands	3.40			salt			Carey, 1996 (in Nikitina et al., 2000)
Duck Creek	1.30	radiocarbon dating				estuarine	Pizzuto and Rogers, 1992
Duck Creek	3.2-3.4	Lead 210 & Cesium 137	low		*Spartina alterniflora*	estuarine	Kraft et al., 1992
Great Marsh	2.9-8.2	Lead 210 & Cesium 137	low		*Spartina alterniflora*		Kraft et al., 1992
Indian River Bay	2.3-10.7	Lead 210 & Cesium 137	low		*Spartina alterniflora*	bay	Kraft et al., 1992
Indian River Bay lagoon	5.0-6.9	Lead 210 & Cesium 137	low		*Spartina alterniflora*	lagoon	Kraft et al., 1992
Leipsic River	2.90	Lead 210	low	salt	*Spartina alterniflora*	estuarine	Nikitina et al., 2000
Lewes	>10	Cesium 137				estuarine	Brickman, 1978 (in Stevenson et al., 1986)
Lewes	3.30			salt		estuarine	Carey, 1996 (in Nikitina et al., 2000)
Lewes	4.70	Lead 210		salt		estuarine	Church et al., 1981
Lewes	5.00	marker horizon (<1 year)				estuarine	Stumpf, 1983
Lewes	2.0-3.6	Lead 210 & Cesium 137	low		*Spartina alterniflora*	estuarine	Kraft et al., 1992
Little Lagoon marsh	2.8-10	Lead 210 & Cesium 137	low		*Spartina alterniflora*	lagoon	Kraft et al., 1992
Mispillion River marsh	3.6-5.3	Lead 210 & Cesium 137	low		*Spartina alterniflora*	estuarine	Kraft et al., 1992
No specific location	5.1-6.3	marker horizon					Stearns & MacCreary, 1957
No specific location	5.00	Lead 210	low	salt			Lord, 1980 (in Armentano et al., 1988)
Port Mahon	0.04		high			estuarine	Khalequzzaman, 1989 (in Fletcher et al., 1993)

			Marsh Type				
Location	**Accretion Rate (mm/yr)**	**Method**	**low/ high**	**fresh/ brackish/ salt**	**Dominate Plant Community**	**Geomorphic Setting**	**Source**
Port Mahon	2-19.1	Lead 210 & Cesium 137	low		*Spartina alterniflora*	estuarine	Kraft et al., 1992
Pot Nets North	3.90			salt			Carey, 1996 (in Nikitina et al., 2000)
Rehoboth Bay	3.3-7.6	Lead 210 & Cesium 137	low		*Spartina alterniflora*	bay	Kraft et al., 1992
Rehoboth Bay	2.60	Lead 210				lagoon	Chrzastowski, 1986 (in Schwimmer and Pizzuto, 2000)
Rehoboth Bay lagoon	2.3-5.9	Lead 210 & Cesium 137	low		*Spartina alterniflora*	lagoon	Kraft et al., 1992
South Bowers Marsh	1.8-7.8	Lead 210 & Cesium 137	low		*Spartina alterniflora*	estuarine	Kraft et al., 1992
Wolfe Glade	0.3-3.0	radiocarbon dating				estuarine	Fletcher et al., 1993
Wolfe Runne	3.70			salt			Carey, 1996 (in Nikitina et al., 2000)
Woodland Beach	2.1-6.8	Lead 210 & Cesium 137	low		*Spartina alterniflora*	estuarine	Kraft et al., 1992
MARYLAND							
Blackwater	1.7-3.6	Lead 210				estuarine	Stevenson et al., 1985
Chincoteague Bay	1.50					back barrier bay	Bartberger, 1976 (in Orson et al., 1985)
Deal Island Management Area	4.0- SET 6.4- marker	SET & marker horizon (6 mo)		salt	*Spartina alterniflora*	estuarine	Rooth and Stevenson, 2000
Jug Bay	11.19-SET 16.59-marker	SET & marker horizon (2 years)	mid	fresh	*Typha angustifolia & Typha latifolia*	estuarine	Boumans et al., 2002
Jug Bay	5.39- SET 9.39- marker	SET & marker horizon (2 years)	low	fresh	*Nuphar advena*	estuarine	Boumans et al., 2002
Jug Bay	-11.1- SET 1.2-marker	SET & marker horizon (2 years)	high	fresh	*Alnus serrulata*	estuarine	Boumans et al., 2002
Jug Bay	4.30	carbon 14 & pollen analysis	high	fresh	*Typha angustifolia & Typha latifolia*	estuarine	Khan and Brush, 1994
Jug Bay	4.20	carbon 14 & pollen analysis	low	fresh	*Nuphar advena*	estuarine	Khan and Brush, 1994
Kenilworth Marsh	1.75	SET (2 years)				riverine	Hammerschlag (personal communication, USGS)
Kingman Marsh	-5.00	SET (2 years)				riverine	Hammerschlag (personal communication, USGS)
Kings Creek Preserve	4.0-9.5	Lead 210		salt	*Phragmites australis*	estuarine	Rooth et al., 2003
Lower Pocomoke River	1.50	pollen dating				estuarine	Douglas, 1985 (in Stevenson and Kearney, 1996)

			Marsh Type				
Location	**Accretion Rate (mm/yr)**	**Method**	**low/ high**	**fresh/ brackish/ salt**	**Dominate Plant Community**	**Geomorphic Setting**	**Source**
Monie Bay	1.5-6.3	pollen dating		brackish	*Sp. patens, Spartina cynosuroides & Scirpus olneyi*	estuarine	Ward et al., 1998
Monie Bay	7.2-7.8	Lead 210, Cesium 137 & pollen dating		brackish	*Sp. patens, Spartina cynosuroides & Scirpus olneyi*	estuarine	Kearney & Stevenson, 1991
Muddy Creek	3.33	SET (2 years)	high	brackish	*Scirpus olneyi*	estuarine	Childers et al., 1993
Nanticoke River Estuary	1.8-7.4	pollen dating	high-low	brackish	*Phragmites australis & Spartina cynosuroides*	estuarine	Kearney and Ward, 1986
Patuxent River	-1.40	SET (2 years)		fresh		estuarine	Childers et al., 1993
Patuxent River	4.40	SET (2 years)			*Spartina patens*	estuarine	Childers et al., 1993
Patuxent River	24.00	SET (2 years)			*Spartina patens*	estuarine	Childers et al., 1993
Patuxent River	20.70	SET (2 years)			*Phragmites*	estuarine	Childers et al., 1993
Patuxent River	-16.20	SET (2 years)			*Spartina patens*	estuarine	Childers et al., 1993
Patuxent River	-14.50	SET (2 years)				mudflat	Childers et al., 1993
Patuxent River	52.00	SET (2 years)				mudflat	Childers et al., 1993
Potomac River	1.7-15.5					estuarine	Brush et al., 1982 (in Orson et al., 1990)
NEW JERSEY							
Great Egg Harbor	6.0-10	Cesium 137				lagoon	Psuty (personal communication, Rutgers University)
Little Beach	3.80 (no specifics of SET or marker)	SET & marker horizon (3 years)	high		*Spartina alterniflora*	back barrier lagoon	Erwin et al., 2006
Princeton/ Jefferson marsh	12-13.2	Cesium 137, Lead 210 & pollen/historical		fresh		estuarine	Orson et al., 1990
NEW YORK							
Alley Pond	3.50	Lead 210	high	salt	*Spartina patens*	estuarine	Cochran et al., 1998
Carmans River	2.7-3.3	Lead 210				back barrier marsh	Kolker, 2005
Caumsett Park	4.10	Lead 210	high	salt	*Spartina patens*	estuarine	Cochran et al., 1998
Flax Pond	4.7-6.3	Lead 210	low	salt	*Spartina alterniflora*	estuarine	Armentano and Woodwell, 1975
Flax Pond	2.10	Lead 210	high	salt	*Spartina patens*	estuarine	Cochran et al., 1998
Flax Pond	2.5-4.7	historical record		brackish	*Spartina alterniflora*	estuarine	Flessa et al., 1977
Flax Pond	1.60	Lead 210				estuarine	Kolker, 2005

			Marsh Type				
Location	**Accretion Rate (mm/yr)**	**Method**	**low/ high**	**fresh/ brackish/ salt**	**Dominate Plant Community**	**Geomorphic Setting**	**Source**
Flax Pond	4.00	Lead 210				estuarine	Muzyka, 1976 (in Richard, 1978)
Flax Pond	2-4.25	marker horizon (1.5 years)				estuarine	Richard, 1978
Fresh Pond	4.30	Lead 210				estuarine	Clark and Patterson, 1985
Goose Creek	2.40	Lead 210	high	salt	*Spartina patens*	estuarine	Cochran et al., 1998
Hempstead Bay	1.4-5	Lead 210				estuarine	Kolker, 2005
Hubbard County Park	2.3-3	Lead 210				back barrier marsh	Kolker, 2005
Hunter Island	1.10	Lead 210	high	salt	*Spartina patens*	estuarine	Cochran et al., 1998
Jamaica Bay	2.8-4.4	Lead 210				lagoon	Kolker, 2005
Jamaica Bay	5.0-8		high			lagoon	Zeppie, 1977 (in Hartig et al., 2002)
Nissequogue River	3.5-4	Lead 210				estuarine	Kolker, 2005
Shelter Island	3.00	Lead 210	high	salt	*Spartina patens*	estuarine	Cochran et al., 1998
Stony Brook Harbor	2.4-2.8	Lead 210	high-low			estuarine	Cademartori, 2000 (in Hartig et al., 2002)
Youngs Island	4.6-4.8	Lead 210				estuarine	Cademartori, 2000 (in Kolker, 2005)
Youngs Island	3.5-4.8	Lead 210				estuarine	Cochran et al., 1998 (in Kolker, 2005)
VIRGINIA							
Gleason Marsh	0.27	marker horizon (19 months)		fresh	*Sp. cynosuroides & Eliocharis quadrangulata*	riverine	Darke and Megonigal, 2003
Mockhorn	12.70 (no specifics on SET or marker)	SET & marker horizon (4 years)	high		*Spartina alterniflora*	back barrier lagoon	Erwin et al., 2006
Oyster	1-2.2	Lead 210		salt	*Spartina alterniflora*	back barrier marsh	Oertel et al., 1989
Wachapreague	2.3- SET 8.5- marker	SET & marker horizon (4 years)	high		*Spartina alterniflora*	back barrier lagoon	Erwin et al., 2006
Walkerton Marsh	0.12	marker horizon (19 months)		fresh	*Pontedaria cordata & Acorus calamus*	riverine	Darke and Megonigal, 2003

2.1.3. Settings and Processes

The fate of coastal wetlands in the Mid-Atlantic will be determined in large part by the way in which the accretionary processes change with climate drivers. These processes vary by geomorphic setting. The expert panel identified five primary geomorphic settings with several subsettings for the coastal wetlands of the Mid-Atlantic:

- Tidal Fresh Forests (FF)
- Tidal Fresh Marsh (FM)
- Estuarine/Brackish Channelized Marshes (ES)
  - Meander
  - Fringing
  - Island
- Back Barrier Lagoon Marsh (BB)
  - Back Barrier/Other
  - Active Flood Tide Delta
  - Lagoonal Fill
- Saline Marsh Fringe (SF)

This classification is similar to global scale assessments of others (e.g., Woodroffe, 2002; Cahoon et al., 2006) but is more detailed in its consideration of subsettings to reflect the finer scale of expert panel assessment.

FF and FM are distinguished based on vegetative type (forested vs. herbaceous) and the salinity of the area. ES marshes are brackish and occur along channels rather than open coasts. ES Meander marshes would be those bordering meandering tidal rivers, and ES Fringing are those bordering wider open channels where tidal flow is not focused in a specific thalweg. ES Island marshes are, as the term implies, marsh islands within tidal channels. BB marshes occupy fill within transgressive back barrier lagoons. Where the fill is attached to barrier islands, the marshes are Back Barrier/Other, and Flood Tide Deltas are marshes forming landward of tidal inlets. Lagoonal Fill is frequently abandoned flood tide deltas where the inlet is closed and marsh is not supplied with sediment directly from the inlet. SF marshes are transgressive salt marshes bordering uplands, mostly on the landward side of tidal lagoons.

Accretionary processes vary among settings. The panel identified nine basic processes that influence the ability of wetlands in these settings to keep pace with sea level rise:

- **Storm sedimentation**. Storm-driven sedimentation typically occurs on time scales of years to decades, resulting in inputs of sediments into marshes and forest greater than those that occur under more common process regimes. The source can be sediment-laden floodwaters associated with high precipitation in adjacent watersheds (e.g., Pasternack and Brush, 1998), local resuspension within coastal bays (e.g., Reed, 1989), or overwash of barrier beaches to bordering marshes (e.g., Donnelly et al., 2001). The latter effect is more important to back barrier marshes than to flood tide deltas. Within ES marshes, storm flooding can lead to both the import and export of material.

- **Tidal Fluxes of Sediment.** Although tidal exchange is limited at the heads of estuaries, many FF and FM marshes in the Mid-Atlantic are potentially exposed to tidal sediment input. Ebb dominance can lead to export of sediment from the system through subtidal channels and the deepening of these channels, especially in BB and SF marshes (Aubrey and Weishar, 1998). This reduces sediment availability within the lagoons for resuspension and transport to marshes during storms. Within ES marshes, tidal exports have been shown to result in a substantial loss of sediment in severely stressed marshes

(Stevenson et al., 1988). It is possible that as the sea level rises, wetland systems could become flood dominated. The role of tidal flux in influencing accretion would then be modulated by the available sediment supply to the system (e.g., fluvial and oceanic sources, described separately).

- **Peat Accumulation.** In freshwater systems where productivity is high, the accumulation of organic material in the wetland soil is a key driver of accretion. However, both microbial degradation of marsh peat and plant die-offs can lead to a drop in marsh surface elevation (e.g. Nyman et al., 1993; DeLaune et al., 1994). This process is most important in FM, and can also be impacted by changes in salinity increasing the potential for organic matter decomposition by sulfate-reducing bacteria. However, the *Spartina patens* marshes common in ES are also characterized by organic soils. BB and SF marshes are dominated by *Spartina alterniflora*. Peat accumulation may not be a primary driver of accretion in these systems, but organic-rich soils still occur.

- **Ice Rafting.** Ice accumulation and movement during the winter months strip remnant vegetation from the marsh surface, exposing the marsh surface. When marsh soil is rafted with moving ice floes, it can contribute sediment to the area where the ice floe melts, sometimes on the marsh surface (Wood et al., 1989). The effect of this process on accretion is localized and can be both erosive and accretionary.

- **Nutrient Supply.** Most wetlands in the Mid-Atlantic are not nutrient limited, so changes in the supply of nutrients do not have a substantial effect on accretion. However, in sandy substrates where soil organic matter is limited, e.g., BB and some SF marshes, it can increase plant productivity (Bertness, 1999). It has less of a role in FF, FM, and ES soils that are dominated by fine sediments and are more organic in nature.

- **Groundwater.** Groundwater can supply freshwater and nutrients to inshore bays and tidal wetlands (e.g., Bokuniewicz, 1980). Reduction in salt stress and increased nutrition can increase the productivity of some marshes, but this effect is very localized.

- **Fluvial sediment supply.** The role of fluvial sediment delivery to tidal wetlands during nonstorm conditions varies across the estuarine gradient. In FF and FM, these inputs can occur several times per year and thus provide a recurring source of sediment (Pasternack and Brush, 1998). Within the estuary, ES marshes in the vicinity of an estuarine turbidity maximum are most likely to benefit as the fluvial sediment is trapped within a zone of the estuary and is more available to marshes in that area. Local streams can also supply individual ES marshes with sediment. Toward the coast in BB and SF systems, fluvial input of sediment is generally minimal, but it could be locally important where streams discharge directly into coastal lagoons. In many systems, fluvial sediment supplies are strongly affected by dams and local land use practices. In these systems, future fluvial sediment supplies will be affected by jurisdictional responses to climate change.

- **Herbivory.** Although the effects of herbivory on tidal marshes can be dramatic (Ford and Grace, 1998) and their role in limiting regeneration of wetland forests is of concern, the effects of herbivory on accretionary processes are indirect and most likely important only locally. Some recent work has suggested that grazing by snails can be an important control on above-ground productivity in salt marshes (Silliman and Zieman, 2001); the effect on accretion has not been documented.

- **Oceanic Sediment Inputs.** The import of sediment from the ocean by tides and during storms can be of importance in SF and BB systems, especially flood tide deltas.

2.1.4. Wetland Responses to Sea Level Scenarios

Table 2.1.1 describes the potential wetland responses associated with the three sea level scenarios. The regions delineated by the expert panel have been described according to geomorphic setting and wetland response. In all cases the panel's assessment of wetland response assumes that human activities that influence marsh accretionary processes (e.g., dredged channels that act as sediment sinks and limit the supply of sediment for accretion) do not change in the future. The exception to this is where climate change is considered to influence the activity (e.g., land use) and thus the accretionary processes. Each section includes the panel's rationale and narrative supporting the current sea level rise rate, the character and distribution of geomorphologic settings, and wetland response to future sea level rise scenarios.

New York – Long Island

This region encompasses the tidal marshes on the Atlantic shore of Long Island. The most appropriate tide gauge to document current sea level rise trends is New York City. The current rate of sea level rise for the area was determined to be 3 mm/yr, making the two future rates considered 5 mm/yr and 10 mm/yr. The geomorphic setting for these marshes is either BB or SF (Figure 2.1.1).

The dominant accretionary processes are storm sedimentation and peat accumulation. Future climate change will result in an increase in the magnitude of coastal storms, due to increasing sea-surface temperatures, and their frequency will be at least as common as at present (Webster et al., 2005). Thus, there is likely to be a net increase in storm sedimentation in marshes in this region. Although sea level rise may drive an increase in peat accumulation, local anthropogenic impacts to sediment geochemistry may currently be leading to peat deterioration. The response of marshes in this region to climate change depends in large part on their ability to cope with the nontrivial anthropogenic impacts caused from the New York City Metropolitan Region (e.g., Kolker, 2005). Any increase in vertical accretion driven by peat accumulation will occur only up to a threshold level. This threshold is currently unknown for this region and has not been assessed for such impacted marshes as those on Long Island. It has been identified as ~10 mm/yr for Rhode Island marshes (Bricker-Urso et al., 1989) and >12 mm/yr for marshes in the southeastern United States (Morris et al., 2002).

In addition, other accretionary processes are also expected to change (Scavia et al., 2002):

- Tidal fluxes may shift to more ebb dominance as the tidal prism increases, exporting more sediment.
- Ice effects will diminish in importance as climate warms, reducing both destructive and constructive influences.
- Nutrient delivery from coastal watersheds is likely to increase, because both climatic effects and land use changes result in greater runoff, though it is highly dependent on local land use practices. This increase could stimulate productivity in local marsh areas.
- Fluvial sediment inputs will be equal to or greater than present inputs and may positively influence marsh accretion locally, but are also dependent on local land use practices.

Figure 2.1.2 illustrates that the only marshes in this region that are expected to survive the highest rate of future sea level rise are BB lagoonal fill marshes near Gilgo and Cedar islands, and those immediately behind Long

Beach. These are areas where marshes are currently expanding, indicating adequate sediment supply from overwash and tidal inlets. BB lagoonal fill marshes in east and west Jamaica Bay, and SF marshes fringing Jamaica Bay, Middle Bay, and East Bay, will be able to keep pace with midrange sea level rise but are likely to be lost if sea level increases to 10 mm/yr. These marshes are supplied with sediment from storm reworking but also require peat accumulation to retain their elevation. Marshes in the western part of Jamaica Bay mostly comprise dredge fill and are subject to loss factors other than insufficient vertical accretion. A rate of 10 mm/yr is most likely too great for them to survive. The BB flood tide delta marshes adjacent to Jones Inlet will be marginal at the higher rate of rise and may be lost, but are likely to survive midrange predictions. Extensive areas of marsh, both BB and SF, surrounding Great South Bay, Moriches Bay, and Shinnecock Bay, as well as those east of Southampton, are keeping pace with current rates of sea level rise but will be marginal if rates increase to 5 mm/yr. Most of these are salt marshes, and episodic supply of sediment from storms and organic accumulation may not be enough to compensate for even an increase of 2 mm/yr over current trends. Loss rates are already high in the marshes of central Jamaica Bay (38–78 percent; Hartig et al., 2002). There is no expectation that these marshes will become more viable in the future. Many of the marshes in this region are highly susceptible to human activities both directly and indirectly, and their survival, especially under marginal conditions, will largely depend on how development pressures and other land use changes influence patterns of sediment supply and dispersal within this region.

Raritan Bay/New York Bay

This region encompasses the tidal marshes of Raritan Bay and New York Bay and extends north to the Hackensack Meadows. The most appropriate tide gauge to document current sea level rise trends is Sandy Hook, New Jersey. The current rate of sea level rise for the area was determined to be 4 mm/yr, making the two future rates considered 6 mm/yr and 11 mm/yr. The geomorphic setting for these marshes includes small areas of FM along the South River and Raritan River, with most of the area being ES and SF marshes (Figure 2.1.3).

The dominant accretionary processes are peat accumulation and fluvial sediment inputs. Vertical accretion driven by peat accumulation is also expected to increase in the future in response to increased sea level. However, in most of these marshes, this increase will occur only up to a threshold level. The exception is the FM area where peat accumulation should allow marshes to accrete and even expand in the face of high-range sea level rise. The threshold level for ES and SF marshes is currently unknown for this region, although lower salinity ES marshes will be less subject to the threshold and more similar to FM. Fluvial sediment inputs are expected to increase in this area as climate changes cause precipitation events to be more intense and periodic, resulting in flashy runoff (National Research Council, 2004). Other accretionary processes are also expected to change:

- Future climate change will result in an increase in the magnitude of coastal storms, and their frequency will be at least as common as at present, resulting in a net increase in storm sedimentation in marshes in this region.
- Tidal fluxes may alter, but the effect is minimal in this region and the nature of the effect on accretion is variable.
- Ice effects will diminish in importance as climate warms.
- Nutrient delivery from coastal watersheds is likely to increase as both climatic effects and land use changes result in greater runoff.
- Oceanic sediment inputs to SF may increase because of an increase in storms.

In this region, human activities could have a greater direct effect on the viability of the wetlands than climatic effects on accretionary processes. Development pressures and land use changes alter hydrology and nutrient delivery and facilitate invasions, e.g., Phragmites. This can alter plant community structure, which in turn influences peat accumulation and accretion.

Figure 2.1.4 shows that FM along the tidal sections of the South River and Raritan River will survive 11 mm/yr of sea level rise and could even expand because of their high productivity and potential for peat accumulation. All the remaining ES and SF marshes will become marginal if sea level rise accelerates to 6 mm/yr and will be lost under the high-range estimate of 11 mm/yr. For the ES marshes to survive the high-range estimate, sediment input would need to increase dramatically or plant communities would need to change to those with greater potential for peat accumulation. As noted above, human influence may result in such shifts whether or not high-range sea level rise estimates hold true. For the SF marshes to survive 11 mm/yr of sea level rise, a massive increase in sediment inputs would be required. This is not foreseen at this time.

New Jersey Shore

This region encompasses the Atlantic shore of New Jersey from Sandy Hook to Cape May. Two tide gauges, Sandy Hook and Cape May, can be used to document current sea level rise trends for this shoreline. The current rate of sea level rise for the area was determined to be 4 mm/yr, making the two future rates considered 6 mm/yr and 11 mm/yr. The geomorphic setting varies along the shore (Figure 2.1.5). At the northern end, the marshes are mostly ES with some SF, while farther south along the barrier island shoreline BB marshes, both back barrier and lagoonal fill, and SF marshes are dominant. There are ES and even FM within the tidal portions of watersheds draining into the back barrier lagoons.

The dominant accretionary processes are storm sedimentation and peat accumulation. Future climate change will result in an increase in the magnitude of coastal storms due to increasing sea-surface temperatures, and their frequency will be at least as common as at present. Thus, there will be a net increase in storm sedimentation in marshes in this region. Vertical accretion driven by peat accumulation is also expected to increase in the future in response to increased sea level. However, this increase will occur only up to a threshold level. This threshold is currently unknown for this region and there are few published measurements of accretion in this area (Table 2.1.1). Other accretionary processes are also expected to change:

Tidal fluxes may shift to more ebb dominance as tidal prism increases.

- Ice effects, although marginal now, will diminish in importance as climate warms.
- Nutrient delivery from coastal watersheds is likely to increase as both climatic effects and land use changes result in greater runoff.

Fluvial sediment inputs will be equal to or greater than present inputs and may influence marsh accretion locally, especially in the lower sections of the shore. Coastal wetlands along the New Jersey shore are keeping pace with current rates of sea level rise (Figure 2.1.6). However, under midrange estimates they are all considered marginal in terms of survival. The marshes close to the Great Egg River and the Mullica River may be more likely to survive because they have localized sources of sediment from the rivers. Similarly, under the high-range estimates for sea level rise, most of the coastal marshes on the Jersey shore are likely to be lost, except those close to these localized sediment sources.

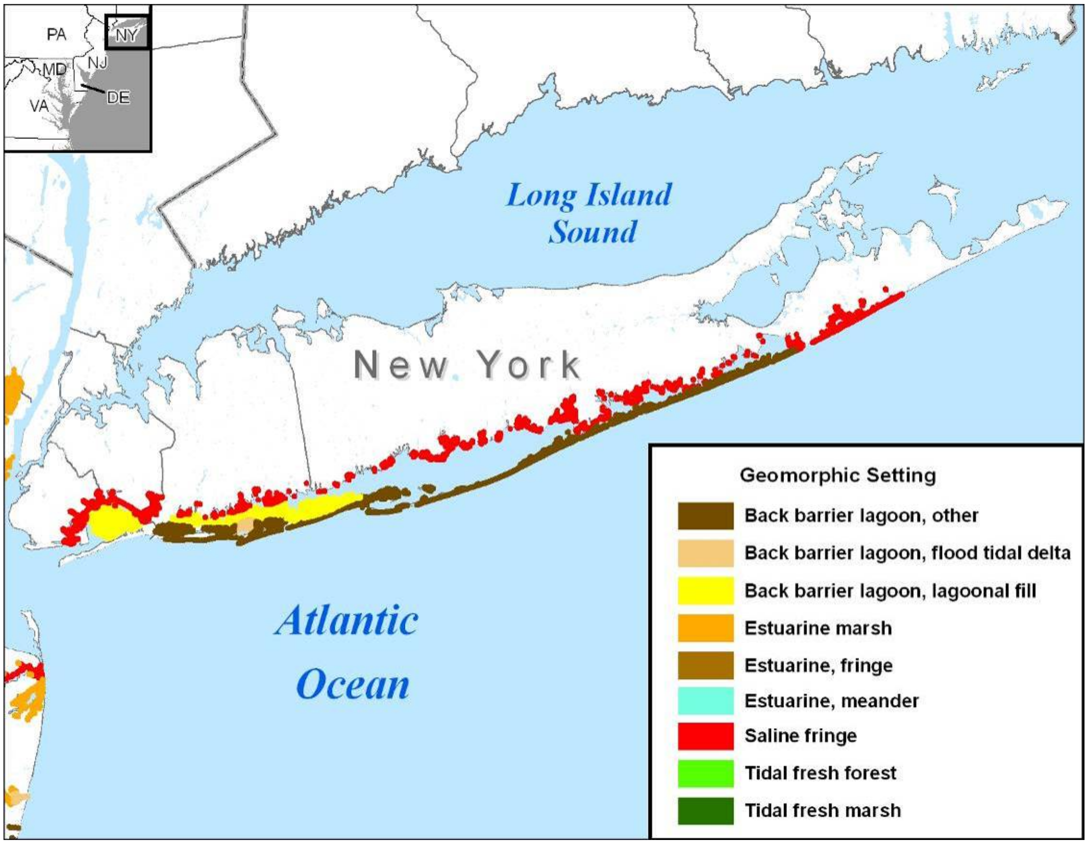
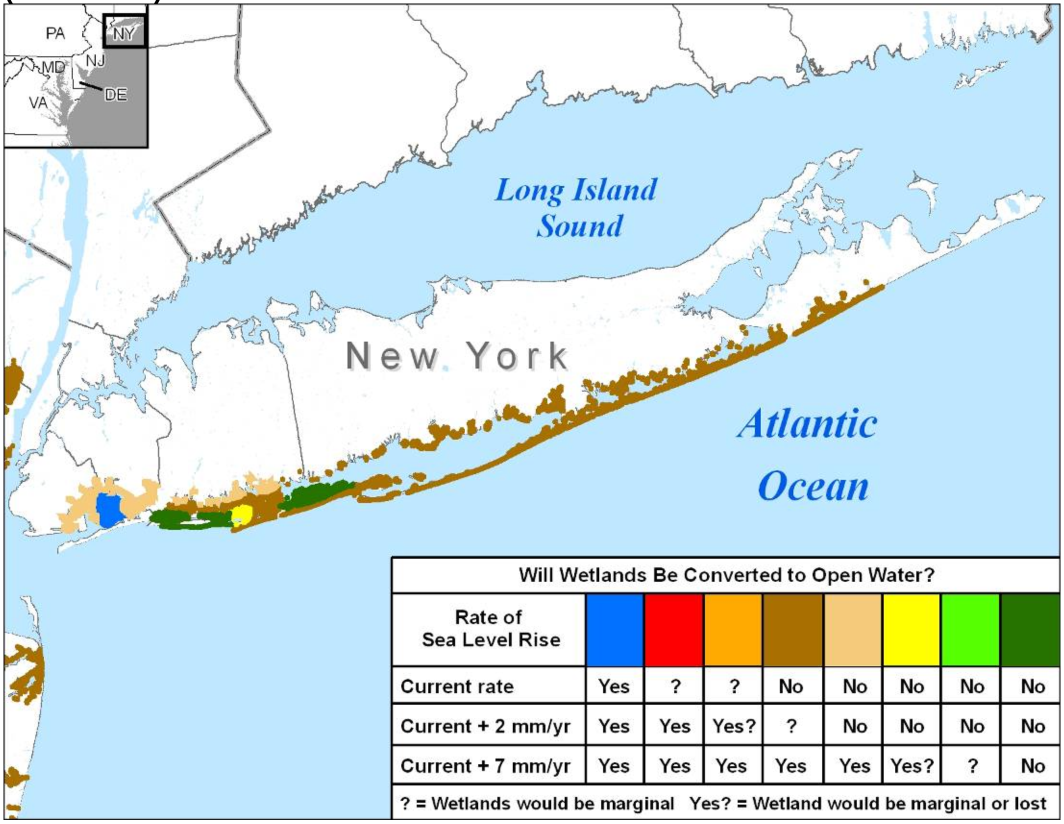


Figure 2.1.1. Geomorphic Settings for the New York – Long Island Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	🟫	🟨	🟩	🟩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

Figure 2.1.2. Wetland Response Map for New York - Long Island Region. Source: Titus et al. (Section 2.2).

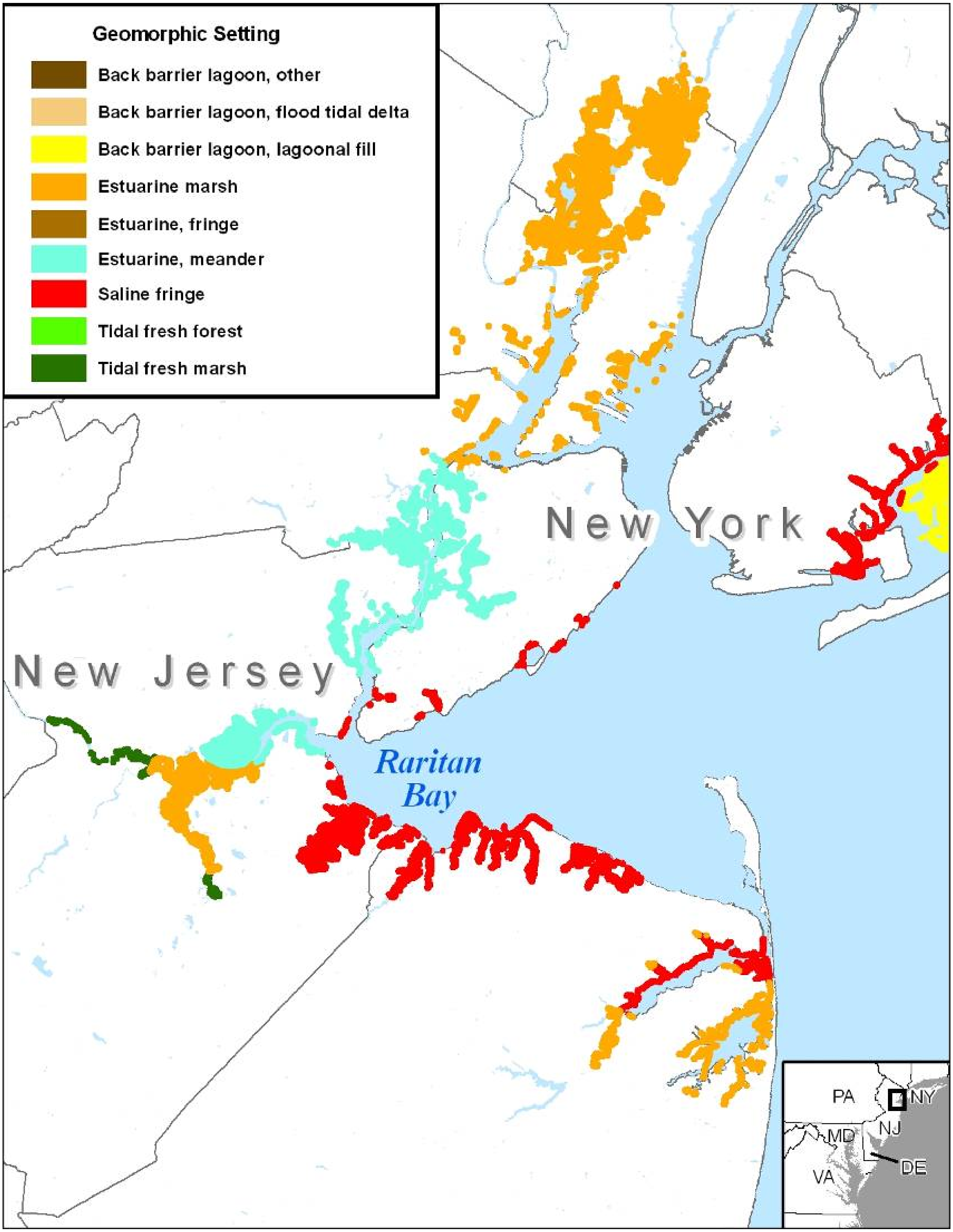
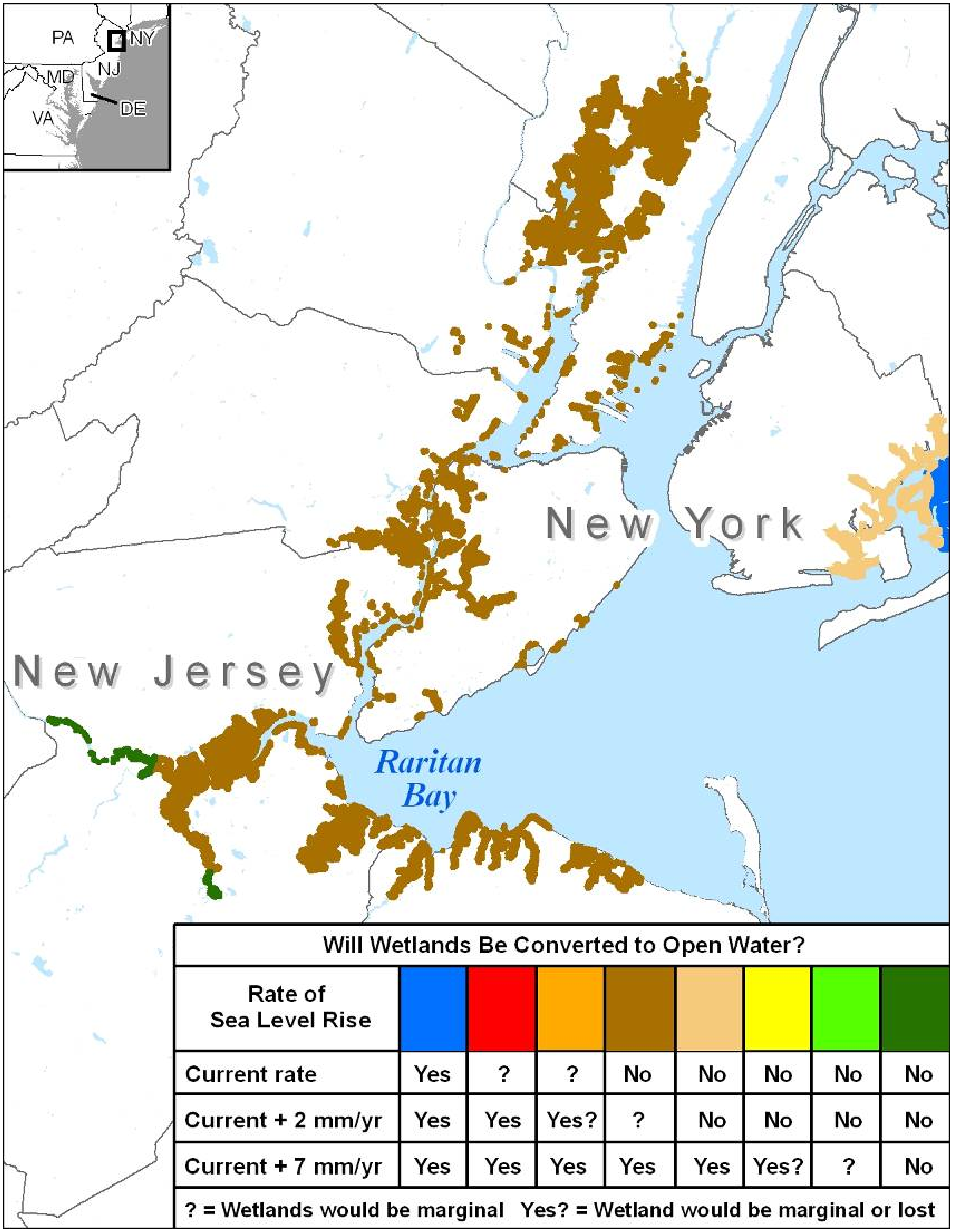


Figure 2.1.3. Geomorphic Settings for the New York – Long Island Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	▨	🟨	🟩	🟩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal   Yes? = Wetland would be marginal or lost

Figure 2.1.4. Wetland Response Map for Raritan Bay – New York Bay region. Source: Titus et al. (Section 2.2).

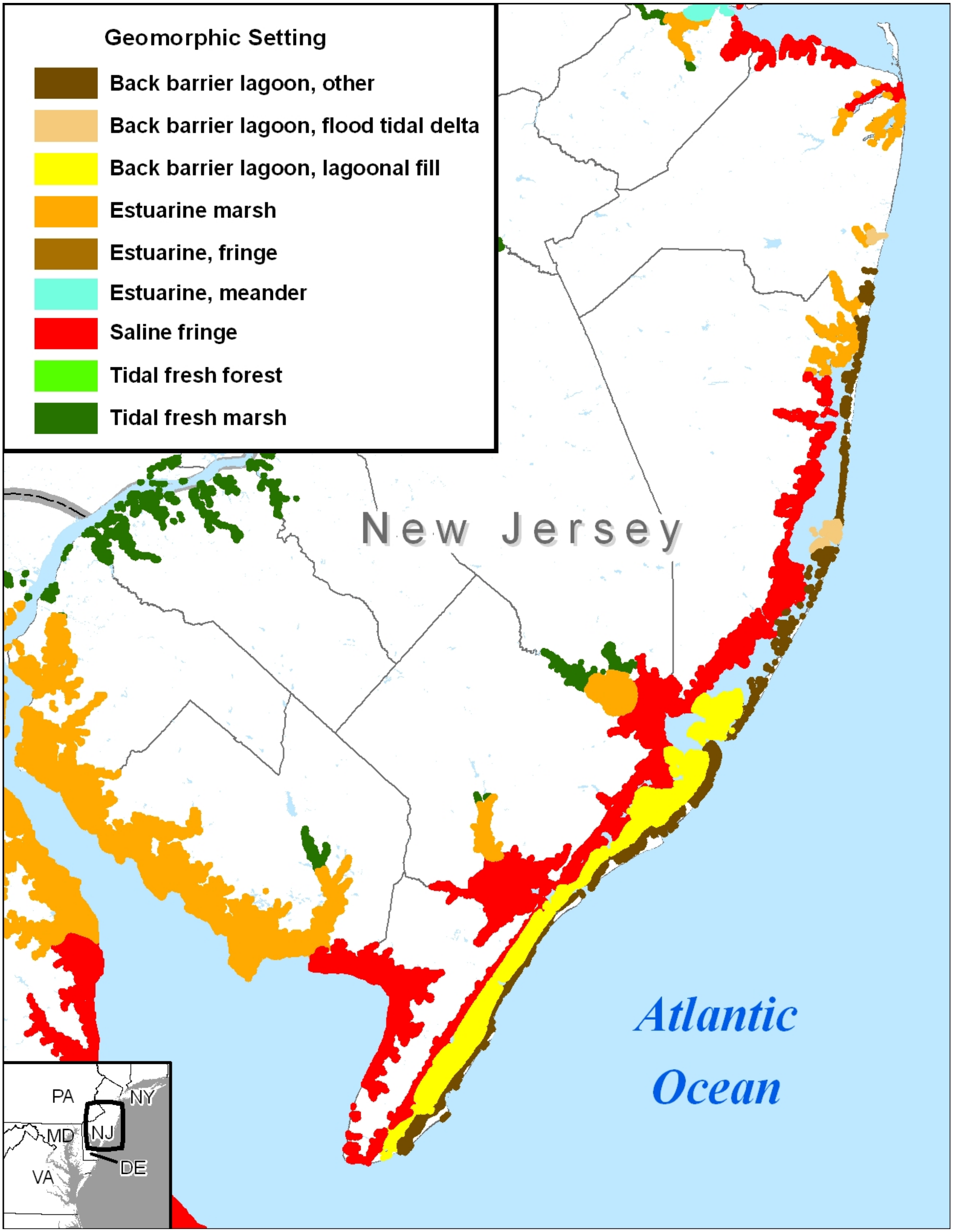
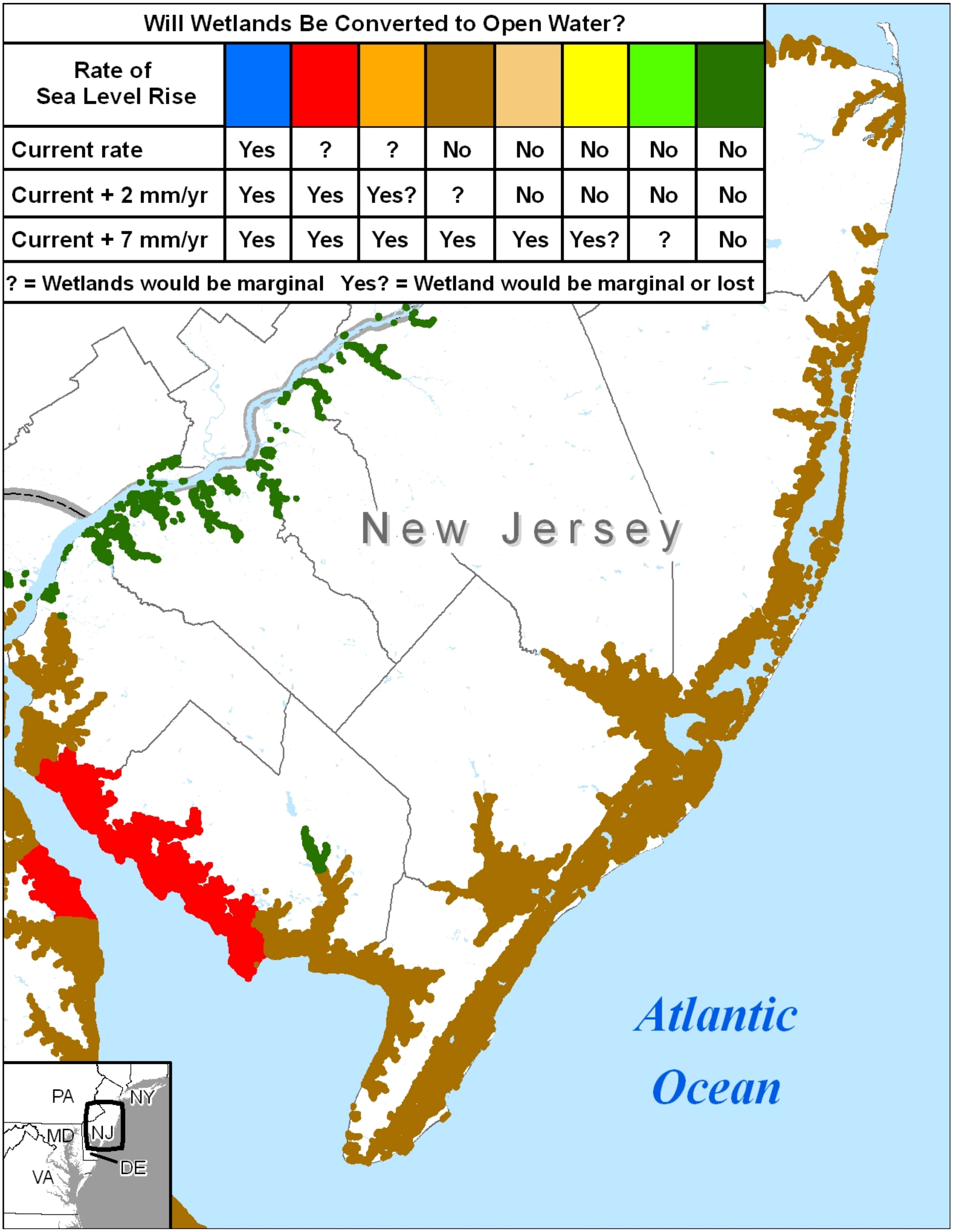


Figure 2.1.5. Geomorphic Settings for the New Jersey Shore Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?								
Rate of Sea Level Rise	🟦	🟥	🟧	🟫	🟫	🟨	🟩	🟩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal   Yes? = Wetland would be marginal or lost

Figure 2.1.6. Wetland Response Map for the New Jersey Shore Region. Source: Titus et al. (Section 2.2).

Delaware Bay

This region encompasses the shores of Delaware Bay and the tidal portions of rivers flowing into the bay. Two tide gauges, Philadelphia and Lewes, can be used to document current sea level rise trends for this shoreline. The current rate of sea level rise for the area was determined to be 3 mm/yr, making the two future rates considered 5 mm/yr and 10 mm/yr. The geomorphic setting varies along the estuarine gradient (Figure 2.1.7). FM exists along tributaries of the Delaware River and in the upper tidal reaches of the Maurice River draining into the bay. Upper parts of Delaware Bay are bordered by ES marshes, with SF marshes toward the ocean.

The dominant accretionary processes vary according to geomorphic setting. Peat accumulation is important to all wetlands in this area. Vertical accretion driven by peat accumulation is expected to increase in the future in response to increased sea level. However, in most of these marshes this increase will occur only up to a threshold level. The exception is the FM area where, as long as marshes stay fresh, peat accumulation should allow marshes to accrete and even expand in the face of high range sea level rise. However, if these salinities increase with sea level rise, SO_4^{2-} reduction will increase, and that could lead to increased rates of decomposition and offset the rise due to peat accumulation. The threshold level for ES and SF marshes is currently unknown for this region, although lower salinity ES marshes will be less subject to the threshold and more similar to FM. Fluvial sediment inputs are important to FM and are expected to increase in this area as climate changes cause precipitation events to be more intense and periodic, resulting in flashy runoff. Future climate change will result in an increase in the magnitude of coastal storms due to increasing sea-surface temperatures, and their frequency will be at least as common as at present. Storm sedimentation is important to ES marshes in this region and is expected to increase in the future. The SF marshes in the lower bay, because of the high fetch and their exposure to oceanic influence, also receive sediment from the Atlantic. Greater storminess will increase the availability of these sediments, benefiting the SF marshes. Other accretionary processes are also expected to change:

- Tidal fluxes may alter, but the effect is minimal in this region.
- Ice effects are of minimal importance here and will diminish in importance as climate warms.
- Nutrient delivery from coastal watersheds is likely to increase as both climatic effects and land use changes result in greater runoff.

Figure 2.1.8 shows that all coastal wetlands in the Delaware Bay region are keeping pace with current rates of sea level rise. The FM marshes along the Delaware and Maurice rivers will survive 10 mm/yr of sea level rise, the high-range estimate, and could even expand because of their high productivity and potential for peat accumulation. However, under midrange estimates (5 mm/yr for this region), ES and SF marshes are all considered marginal in terms of survival and are expected to be lost under the high-range estimate of sea level rise. Sustainability of these marshes in the future will require either a substantial increase in sediment inputs or a change in plant community type to one with a greater potential for peat accumulation. Any such change in plant communities might also change the habitat value of these extensive Delaware Bay marshes. The role of storm sedimentation in future marsh accretion will be dependent to some extent on aspect. Marshes in the New Jersey shore receive less storm-related mineral sediment because nor'easters generally blow water out of the marshes in winter (toward the Delaware shore). These marshes may also be more remote from sediments introduced by period ocean waves from the southeast in summer.

Maryland/Virginia Shore

This region encompasses the Atlantic shore of Maryland and Virginia from Cape Henlopen to Cape Charles. The current rate of sea level rise for this area is best assessed using an average of regional gauges rather than data from a single location. The current rate of sea level rise for the area was determined to be 3 mm/yr, making the two future rates considered 5 mm/yr and 10 mm/yr. The geomorphic setting varies from north to south along this shore (Figure 2.1.9). Along the Delaware shoreline, BB marshes front small lagoons such as Rehoboth Bay and Indian River Bay, with SF on the upland margin. BB lagoonal fill becomes more important toward the southern end of Assateague Island. Farther south, BB flood tide delta marshes are interspersed with BB marshes along the barrier shoreline, with extensive BB lagoonal fill in Hog Island Bay and South Bay, and SF marshes along the upland margin.

The dominant accretionary processes are storm sedimentation and overwash from barrier beaches. Future climate change will result in an increase in the magnitude of coastal storms due to increasing sea-surface temperatures, and their frequency will be at least as common as at present. Thus, there will be a net increase in storm sedimentation in marshes in this region. Vertical accretion driven by peat accumulation is not as important in this area as in other marshes. Many of the marshes occur on pre-existing topographic highs that have been gradually flooding by rising seas. Tidal fluxes are also of minimal importance, except on the flood tide deltas, with local resuspension being the main source of sediment. Other accretionary processes are also expected to change:

- Nutrient delivery from coastal watersheds is likely to increase as both climatic effects and land use changes result in greater runoff.
- Fluvial sediment inputs will be equal to or greater than present inputs and may increase marsh accretion locally. However, watersheds draining into this region are generally small.

Figure 2.1.10 shows the accretion scenarios for this region. All marshes are keeping pace with current rates of sea level rise. However, should sea level rise rates increase to 5 mm/yr, the midrange estimate, they are considered to be marginal. Their survival is likely to depend on the frequency of storm impacts to supply sediments. Under the high range estimate of 10 mm/yr, these marshes will be lost because they will not be able to maintain their elevation.

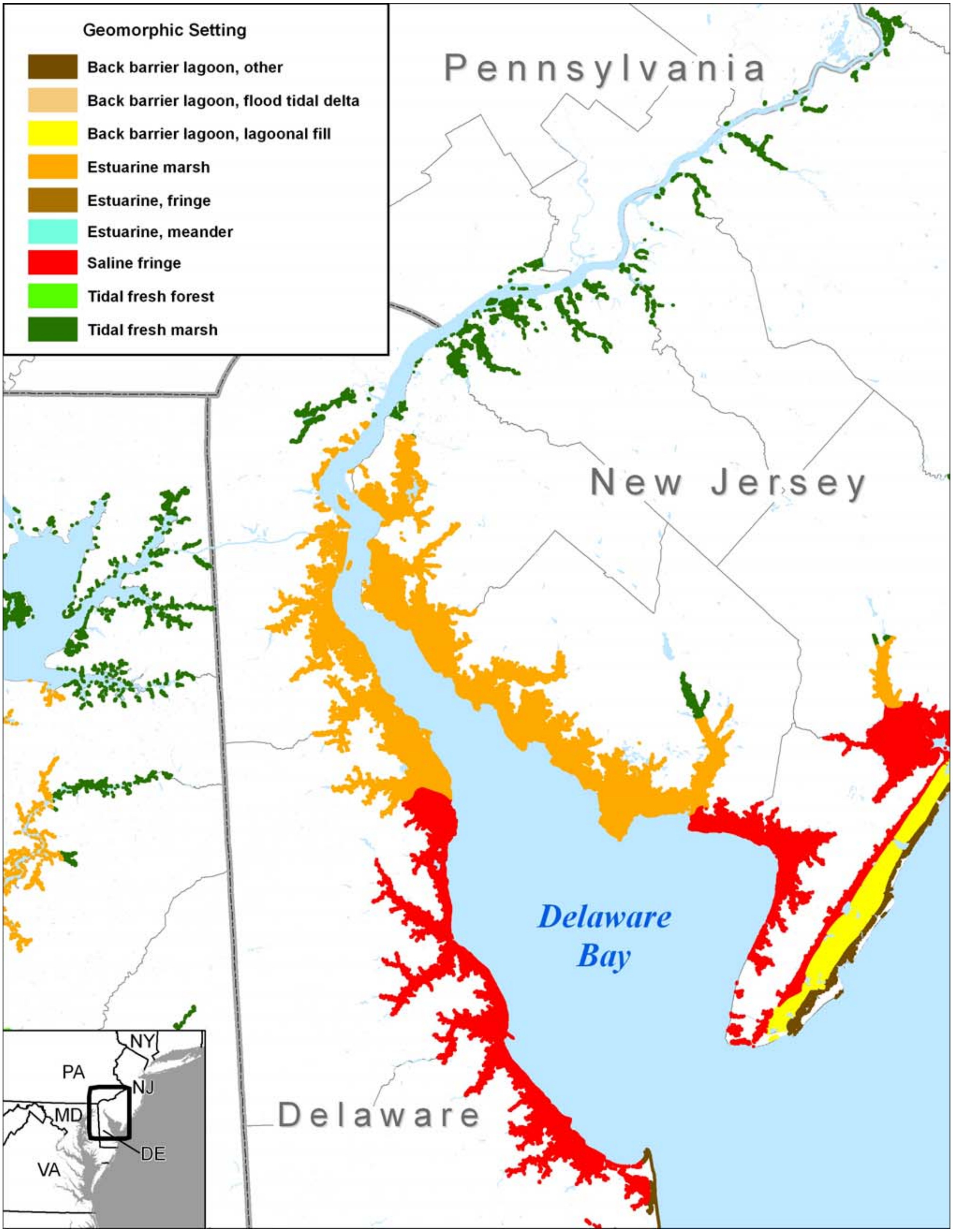
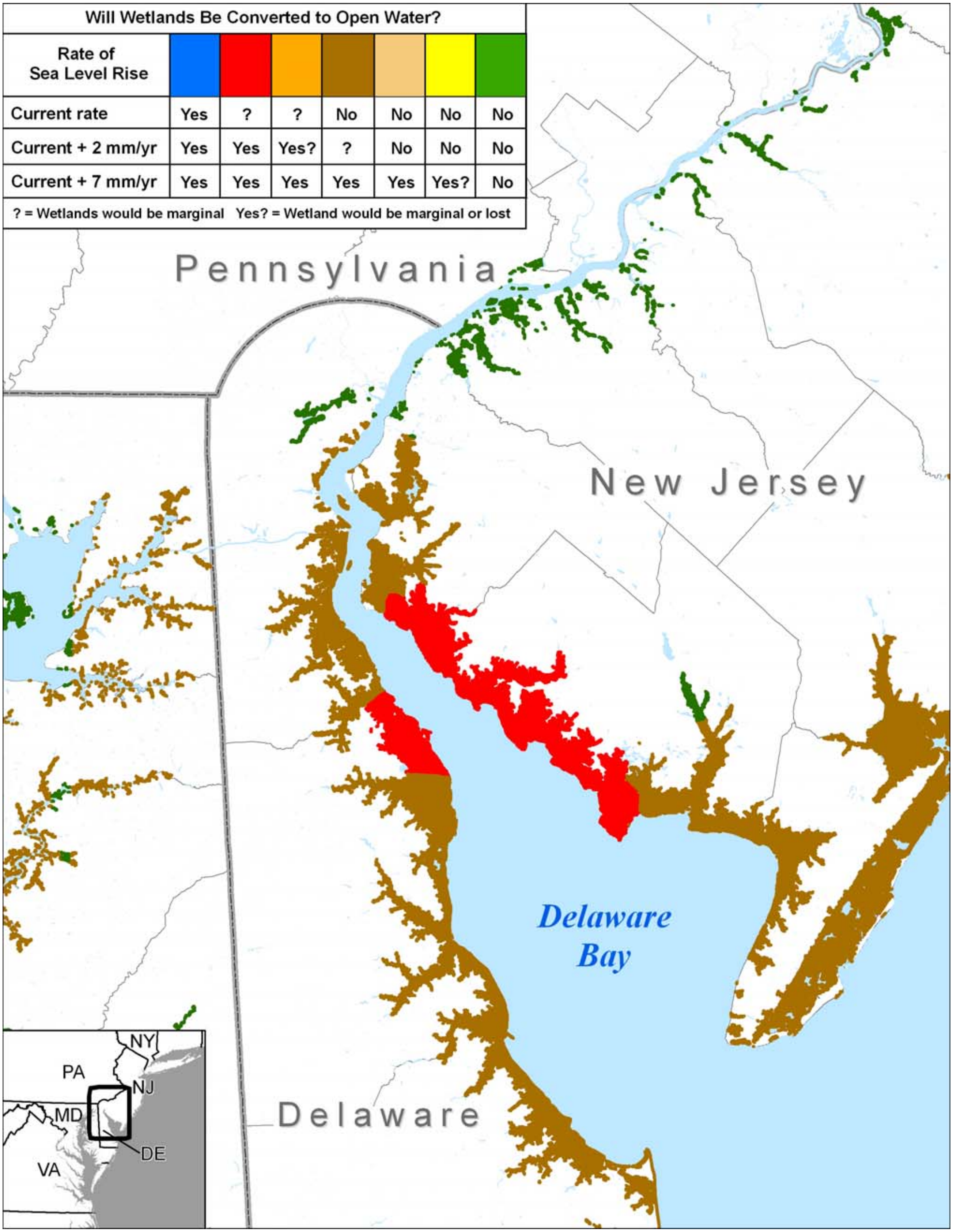


Figure 2.1.7. Geomorphic Settings for the Delaware Bay Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	▧	🟨	🟩
Current rate	Yes	?	?	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

Figure 2.1.8. Wetland Response Map for the Delaware Bay Region. Source: Titus et al. (Section 2.2).

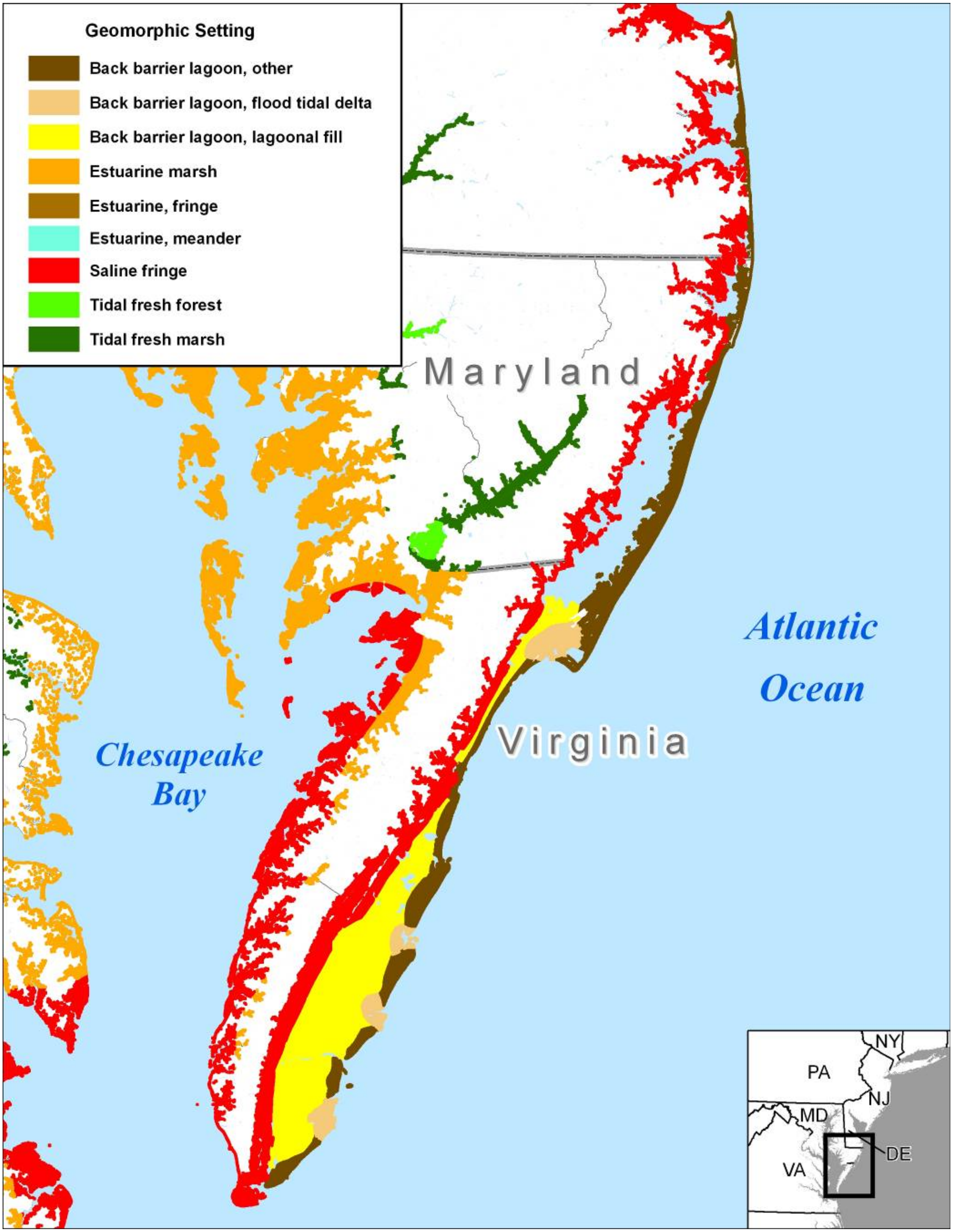
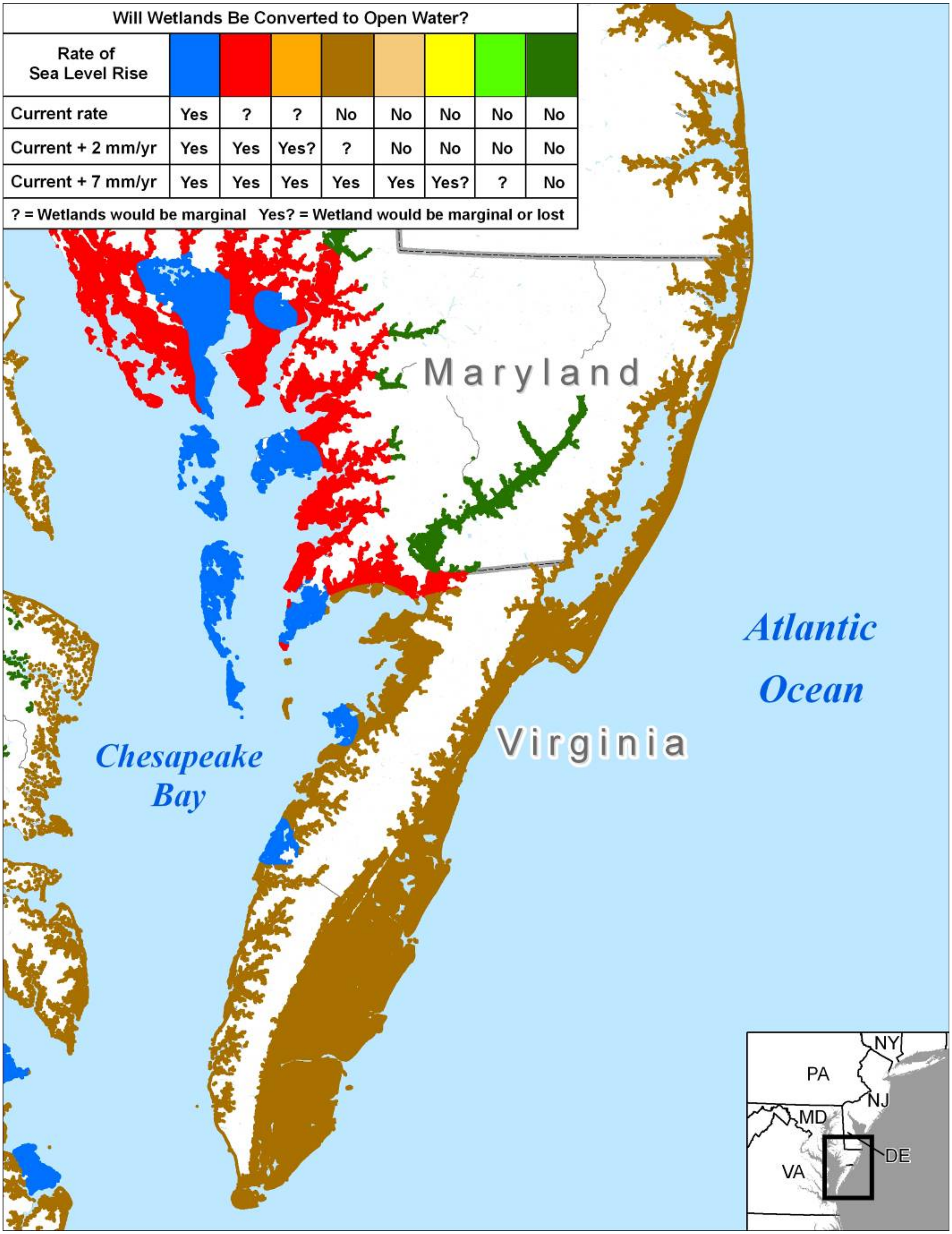


Figure 2.1.9. Geomorphic Settings for the Maryland-Virginia Shore Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	▨	🟨	🟩	▩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal   Yes? = Wetland would be marginal or lost

Figure 2.1.10. Wetland Response Map for the Maryland/Virginia Shore Region. Source: Titus et al. (Section 2.2).

Chesapeake Bay

This region encompasses the entire Chesapeake Bay, including the tidal portions of rivers draining into the Bay, with the exception of the Lower Maryland Eastern Shore region. Because of the great area involved, current sea level rise rates should be determined for the upper part of the Bay using the Baltimore gauge. The current rate of sea level rise in this area was determined to be 3 mm/yr, making the two future rates considered 5 mm/yr and 10 mm/yr. For the area south of the Potomac, local knowledge indicates that these rates should be higher: 4 mm/yr for current, 6 mm/yr for midrange, and 11mm/yr for high-range estimates.

Chesapeake Bay coastal wetlands occur in a variety of geomorphic settings (Figure 2.1.11). There is some FF within this region, most notably near Adelina on the Patuxent estuary. Throughout the Maryland portion of the Chesapeake Bay region, FM occurs in the tidal rivers, with ES marshes bordering the open bay. On the eastern shore of Virginia from Pocomoke Sound south, SF marshes occur, in some areas grading into ES toward the upland. On the western shore of Virginia, the lower reaches of the Rappahannock, the York and the James rivers are bordered by ES fringe marshes with FM farther from the Bay itself. SF marshes also occur on the margins of the Bay south of the Rappahannock River.

The dominant accretionary processes vary according to geomorphic setting. Peat accumulation is important to all wetlands in this area. Vertical accretion driven by peat accumulation is expected to increase in the future in response to increased sea level. However, in most of these marshes, this increase will occur only up to a threshold level. The exception is the FM area, where peat accumulation should allow marshes to accrete and even expand in the face of high-range sea level rise. The threshold level for ES and SF marshes is currently unknown for this region, although it is expected that the ES marshes may not even reach the threshold here. Fluvial sediment inputs are important to FM and are expected to increase in this area as climate changes cause precipitation events to be more intense and periodic, resulting in flashy runoff. Storm-driven sedimentation is important for ES marshes in this region. Future climate change will result in an increase in the magnitude of coastal storms due to increasing sea-surface temperatures, and their frequency will be at least as common as at present. Storm sedimentation is therefore expected to increase in the future. The SF marshes in the lower Bay may receive increased sediment in the future from the ocean. Greater storminess will increase the availability of these sediments. Other accretionary processes are also expected to change:

- Tidal fluxes may alter, but the effect is minimal in this region. In ES an increase in tidal prism may result in more export from already stressed marshes.
- Ice effects are of minimal importance here and will diminish in importance as climate warms.
- Nutrient delivery from coastal watersheds are likely to increase as both climatic effects and land use changes result in greater runoff.
- Herbivory, which is locally important here, is expected to decrease or remain the same because of management actions.

Figure 2.1.12 shows the accretion scenarios for the Chesapeake Bay region (note that the Lower Maryland Eastern Shore region is discussed separately below). FF and FM marshes are keeping pace with current rates of sea level rise, largely through peat accumulation, and will continue to accrete at rates at least sufficient to survive the high-range estimates for Chesapeake Bay region. There are some coastal wetlands, however, that cannot keep pace with current rates and are being lost. Specific areas are at Hog Island and Plum Tree Island National Wildlife Refuge on the western shore, and the Tobacco islands and Hacksneck areas on the eastern shore. These SF marshes are not sustainable and will certainly be lost under even midrange estimates of future sea level rise. The ES marshes bordering the bay and its tributaries are all considered to be keeping pace with current sea level rise rates (3–4 mm/yr in the region) but are marginal under midrange estimates.

Consequently, they will be lost if high-range estimates of future sea level rise are realized.

Lower Maryland Eastern Shore

This region encompasses the tidal wetlands on the eastern shore of Maryland and Virginia between the Chester River and the Pocomoke River. Most of this region lies in the upper part of Chesapeake Bay, and thus the Baltimore tide gauge is most appropriate. The current rate of sea level rise for the area was determined to be 3 mm/yr, making the two future rates considered 5 mm/yr and 10 mm/yr. The very southern part of this region lies south of the Potomac, and thus, as for the Chesapeake Bay region, local knowledge indicates that rates for the southern portion should be higher: 4 mm/yr for current, 6 mm/yr for midrange, and 11 mm/yr for high range estimates.

Coastal wetlands on the Lower Maryland Eastern Shore occur in a variety of geomorphic settings (Figure 2.1.13). There is some FF in the vicinity of Salisbury and Wellington where some cypress occurs within FM areas, and near Wye Mills farther north. FM occurs in the tidal rivers of the eastern shore, including the Choptank, Naticoke, and Pocomoke, with ES marshes bordering the open bay and on islands within the Bay. Some SF marshes occur on the north side of Pocomoke Bay.

The dominant accretionary processes are similar to those found in similar geomorphic settings in other parts of Chesapeake Bay. Peat accumulation is important to all wetlands in this area and is expected to increase in the future. In most of these marshes this increase will occur only up to a threshold level. The exception is the FM area, where peat accumulation should allow marshes to accrete and even expand in the face of high-range sea level rise. Fluvial sediment inputs are important to FM and are expected to increase in this area as climate changes cause precipitation events to be more intense and periodic, resulting in flashy runoff. Storm-driven sedimentation is important for ES marshes in this region and is expected to increase in the future. The SF marshes in this region are distant from direct oceanic inputs and will be unlikely to receive additional sediments in the future from this source. Changes in tidal flux may be important in exporting material from already stressed marshes. Herbivory, which is locally important here, is expected to decrease or remain the same because of management actions.

Figure 2.1.14 shows the accretion scenarios for this region. One of the reasons this area has been singled out from the other coastal wetlands in Chesapeake Bay is the extreme rate of wetland loss already being experienced in the area. Large areas of the ES marshes are apparently not currently keeping pace with sea level rise and are expected to be lost even without acceleration in sea level rise. These include the Blackwater National Wildlife Refuge marshes, Bloodsworth Island and South Marsh Island, as well as Deal Island and the Grays Island Marsh area east of Fishing Bay. The remainder of the ES marshes in the region are considered marginal even under current sea level rise conditions and they are expected to be lost if even the midrange estimate of future rise is realized. Accretion scenarios are most optimistic for the FM areas of the tidal rivers, where organic accumulation processes should allow marshes to keep pace with even high-range estimates of sea level rise.

Virginia Beach/Currituck Sound

This region encompasses the Virginia tidal marshes of Back Bay, including Back Bay National Wildlife Refuge and Northwest and North Landing rivers. These embayments and estuaries are the northernmost extent of Currituck Sound as it extends into Virginia. There are few tide gauges that reflect the setting of this area directly. The most appropriate tide gauges are Sewells’ Point in Virginia and Beaufort, North Carolina. The current rate of sea level rise for the area based on these gauges was determined to be 4 mm/yr, making the two future rates considered 6 mm/yr and 11 mm/yr. The geomorphic setting for these marshes includes FF and FM mix along the Northwest and North Landing rivers, with ES and in Back Bay and BB marshes immediately behind the barrier shoreline (Figure 2.1.15).

The dominant accretionary processes are peat accumulation within FF and FM, and storm sedimentation inputs for the marshes surrounding Back Bay. Vertical accretion driven by peat accumulation is expected to increase in the future in response to increased sea level, and should be adequate to allow FF and FM wetlands to accrete and even expand in the face of high-range sea level rise. Storm-driven sedimentation is important for ES and BB marshes in this region. Future climate change will result in an increase in the magnitude of coastal storms due to increasing sea-surface temperatures, and their frequency will be at least as common as at present. Storm sedimentation is therefore expected to increase in the future. Other accretionary processes are also expected to change:

- Tidal fluxes may alter, but the effect is minimal in this region and the nature of the effect on accretion is negligible.
- Nutrient delivery from coastal watersheds is likely to increase as both climatic effects and land use changes result in greater runoff.

Figure 2.1.16 shows that none of the wetlands in the area will survive 11 mm/yr of sea level rise. Although the FF and FM marshes in other areas have been considered more resilient, in this area tidal fluctuations are so small that an increase of 2 mm/yr in sea level threatens to introduce both salinity and a changed hydroperiod to the fresh parts of the estuary. These wetlands are considered marginal today because they are stressed by existing sea level rise conditions. All the remaining ES and BB marshes will become marginal if sea level rise accelerates to 6 mm/yr and will be lost under the high-range estimate of 11 mm/yr. For the ES and BB marshes to survive, the midrange estimate sediment input from storms would need to increase, which is very dependent on actual storm impacts, frequency, and tracks.

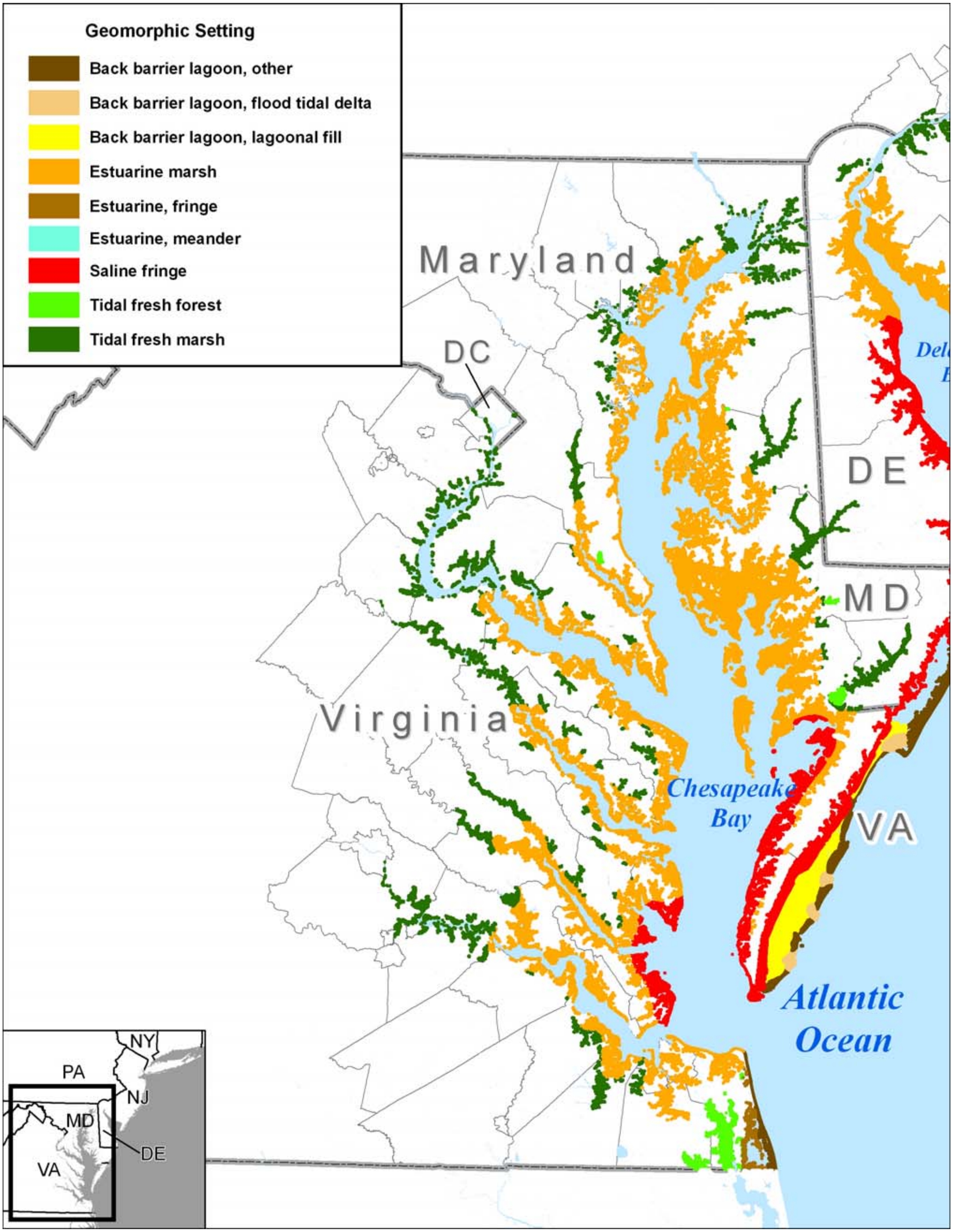
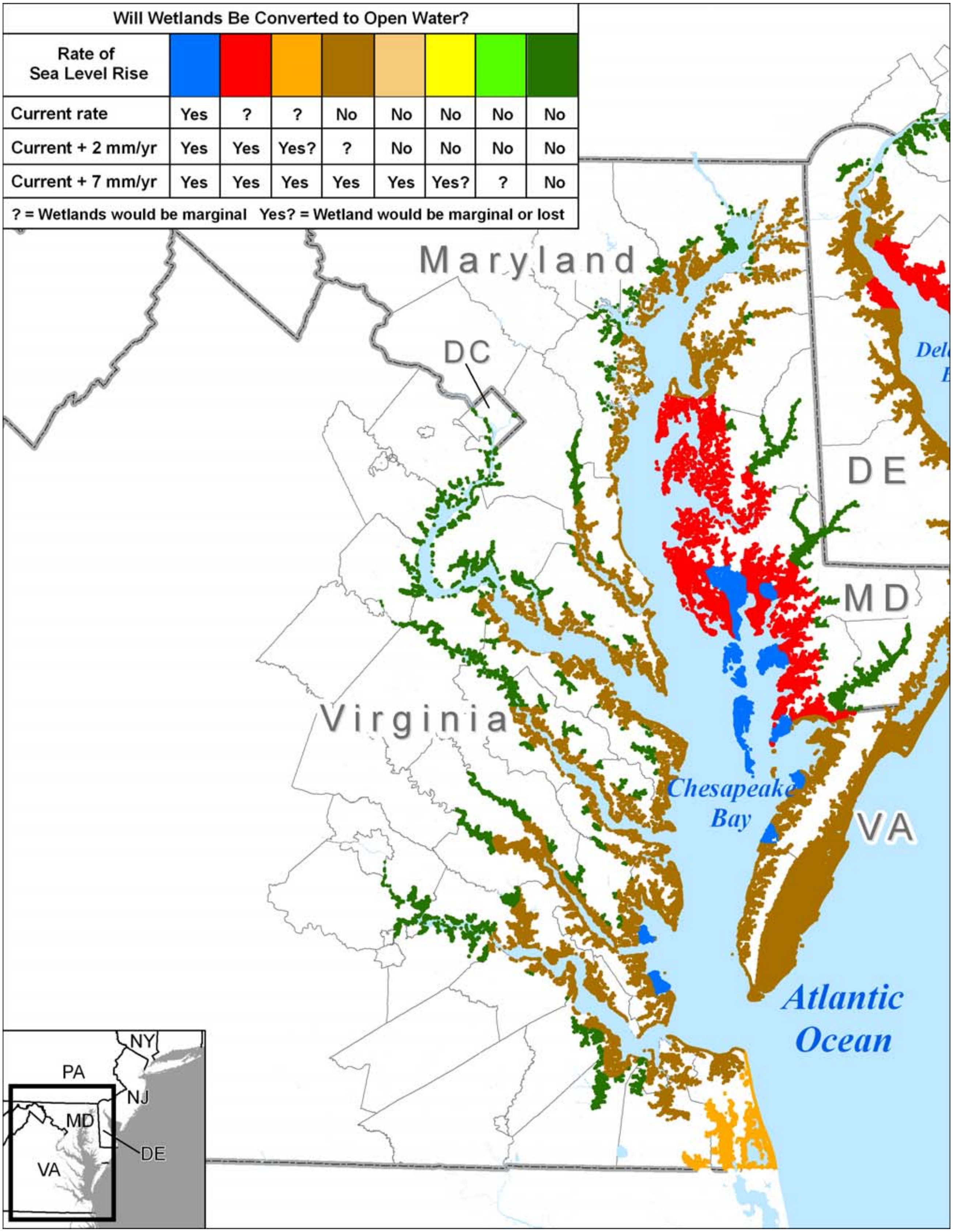


Figure 2.1.11. Geomorphic Settings for the Chesapeake Bay Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	🟨	🟨	🟩	🟩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

Figure 2.1.12. Wetland Response Map for the Chesapeake Bay Region. Note that the Lower Maryland Eastern Shore Region is considered separately. Source: Titus et al. (Section 2.2).

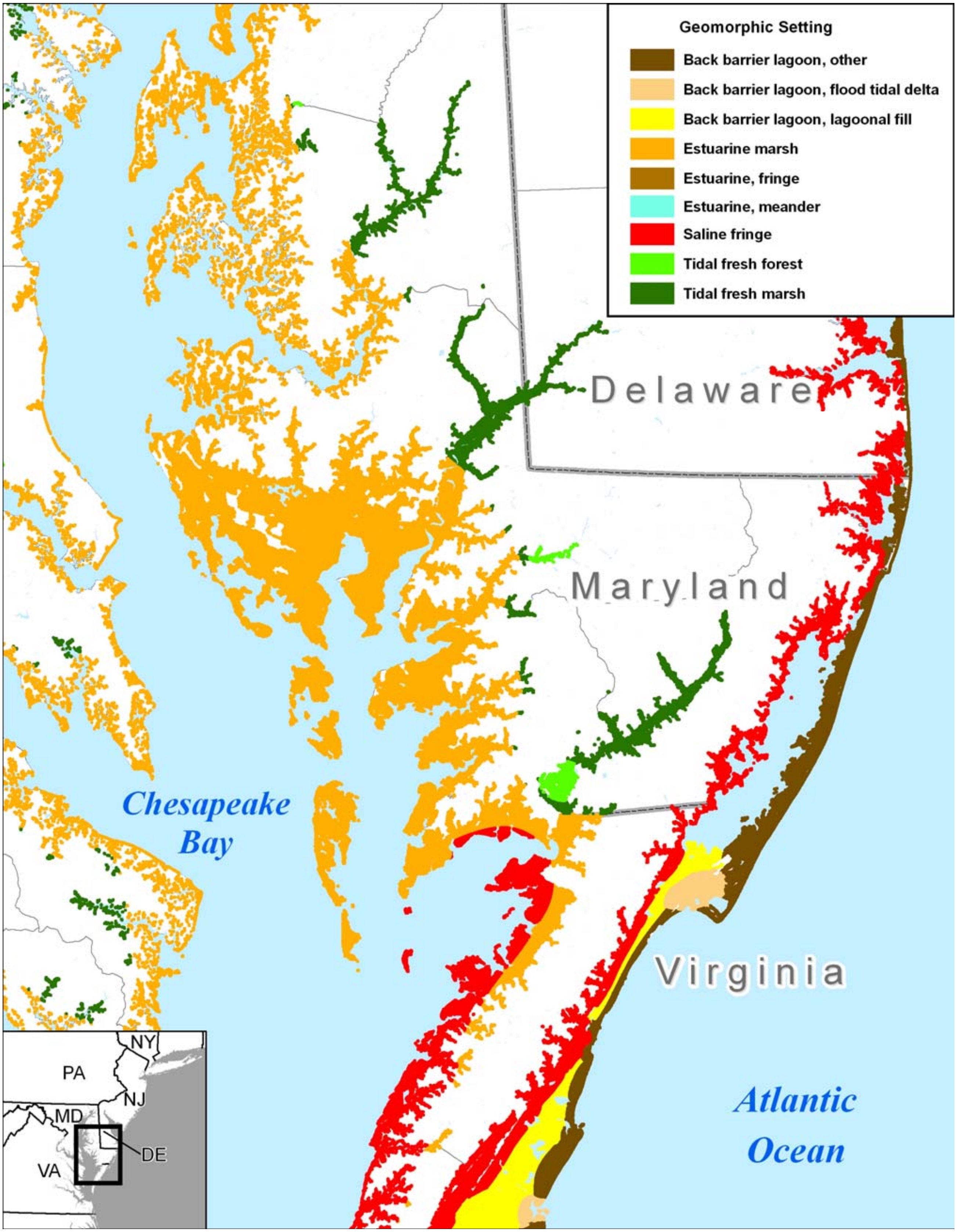
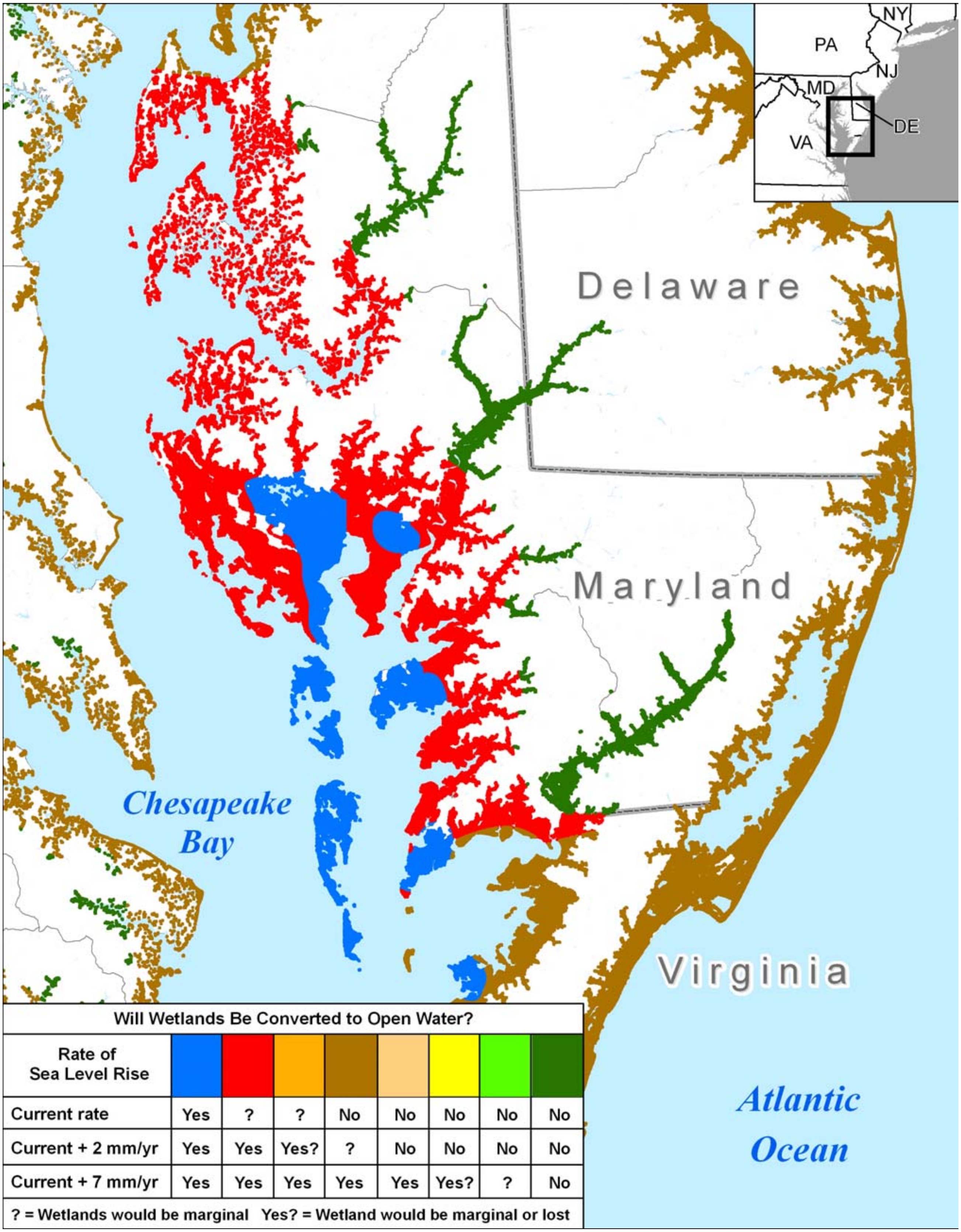


Figure 2.1.13. Geomorphic Settings for the Lower Maryland Eastern Shore Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	🟧	🟨	🟩	🟩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal   Yes? = Wetland would be marginal or lost

Figure 2.1.14. Wetland Response Map for the Lower Maryland Eastern Shore. Source: Titus et al. (Section 2.2).

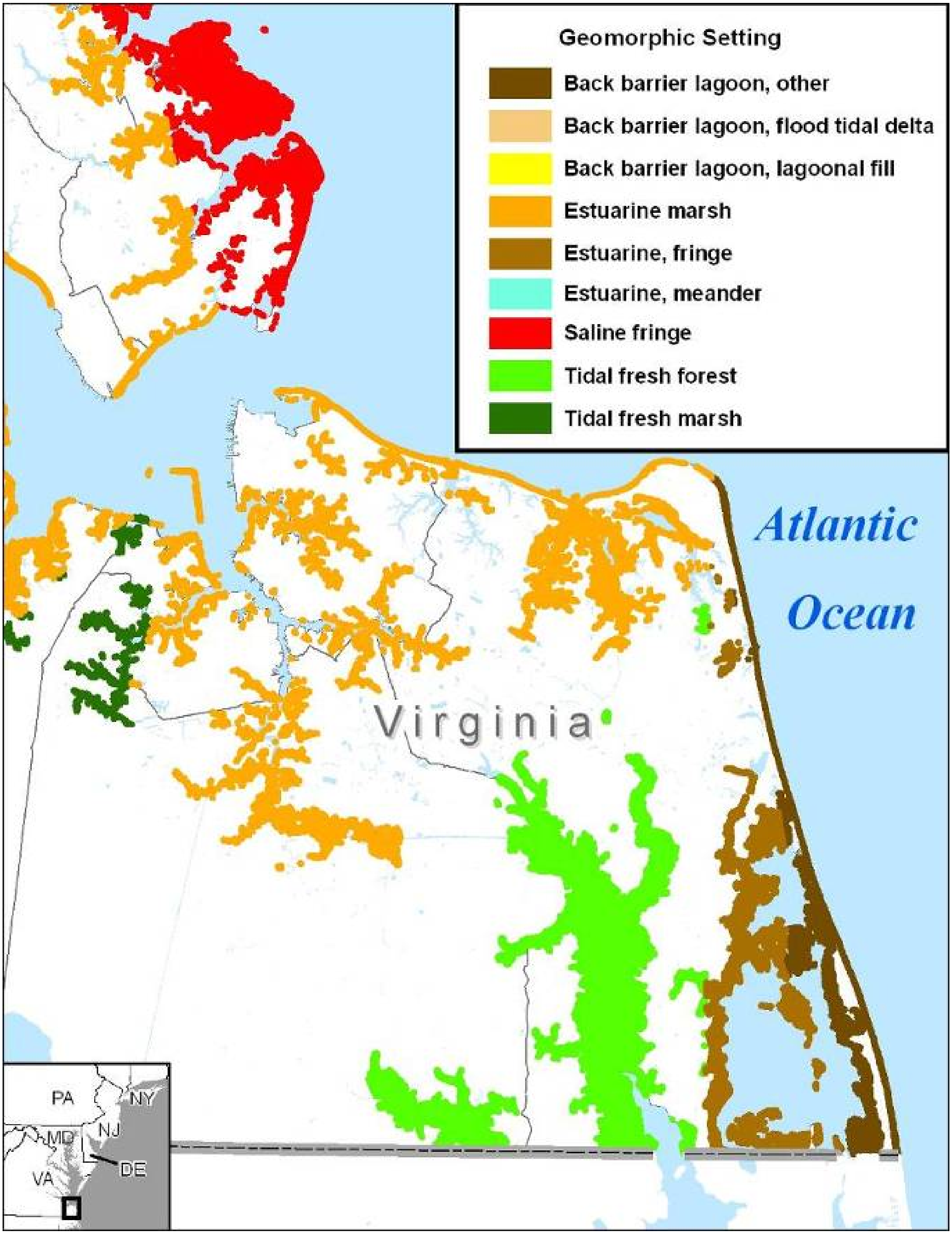
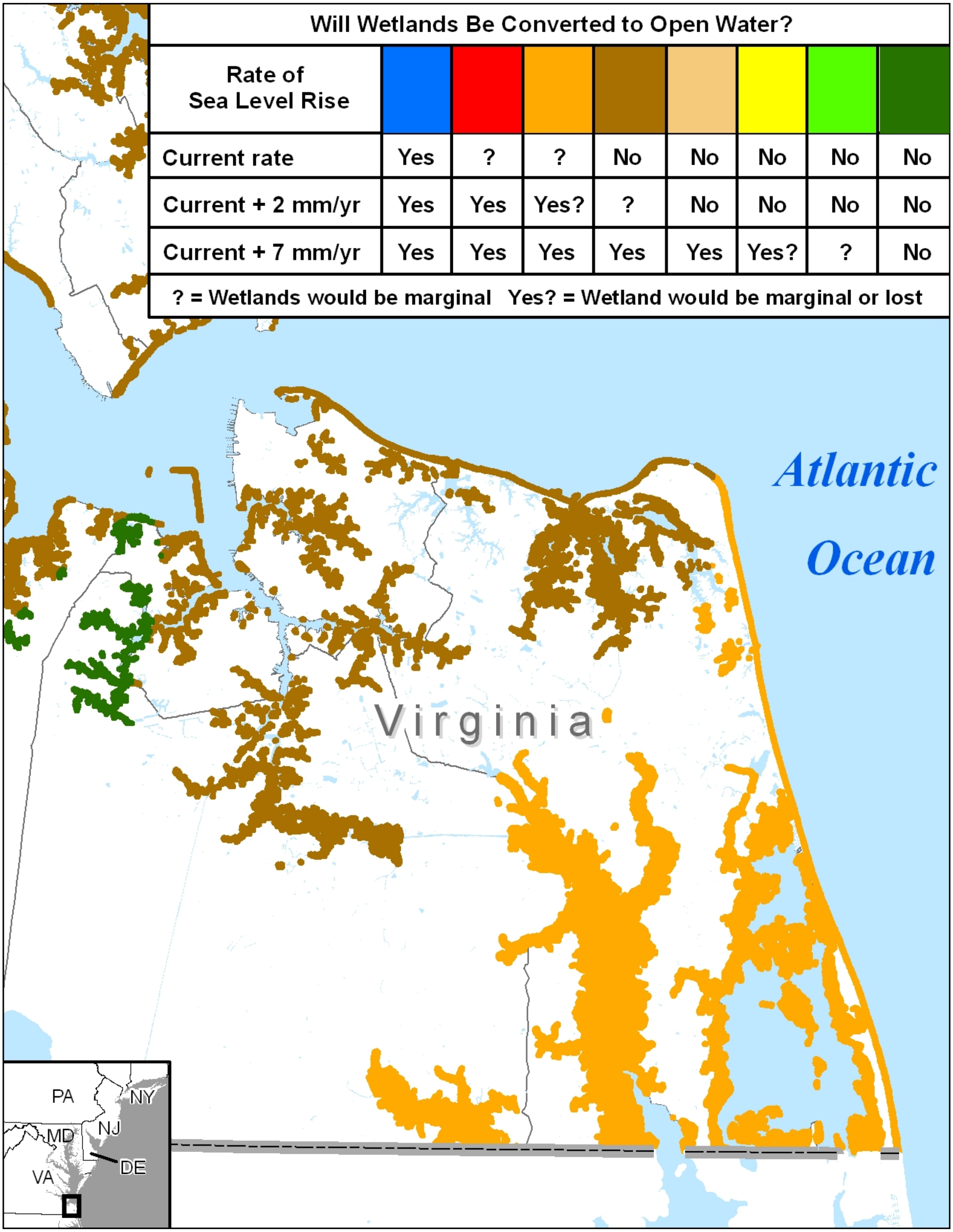


Figure 2.1.15. Geomorphic Settings for the Virginia Beach/Currituck Sound Region. Source: Titus et al. (Section 2.2).



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise	🟦	🟥	🟧	🟫	🟫	🟨	🟩	🟩
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

Figure 2.1.16. Wetland Response Map for the Virginia Beach/Currituck Sound Region. Source: Titus et al. (Section 2.2).

2.1.5. Summary and Conclusions

This study has shown that the prognosis for the coastal wetlands of the Mid-Atlantic under current sea level rise is for the most part good and that as rates accelerate toward midrange estimates, a 2 mm/yr increase, their survival depends on optimal hydrology and sediment supply conditions. There are exceptions to this assessment at both local and regional scales and some variation with geomorphic setting.

For the entire area, tidal fresh forests and marshes are considered the most sustainable. As long as salinities do not increase, these systems build vertically, primarily through organic accumulation, and are less dependent on mineral sediment supply. This bodes well for migration of tidal wetlands upstream along tidal rivers as sea level rises.

Those marshes that are currently being lost either locally within Jamaica Bay or at a larger scale on the Lower Maryland Eastern Shore are unlikely to be rebuilt or replaced by natural processes as sea level continues to rise. The Chesapeake wetlands are for the most part transgressive—formed as sea level flooded former uplands. Along the shores of the open Bay, such migration is limited by physical barriers or land use preferences, and any areal increase in fresh marshes along the tidal rivers as sea level rises will be limited. In back-barrier island marshes, transgression is impossible, and as such, island marshes may fare poorly. In Jamaica Bay, the marshes are built on lagoonal fill and relict flood tide delta deposits, but development of Rockaway Beach and dredging of the inlet have essentially halted these sedimentary processes; these marshes also are unlikely to be replaced by natural processes (Gornitz et al., 2001).

Perhaps of more concern are marshes considered marginal under current conditions, which are not expected to survive an acceleration of sea level rise. These marshes are concentrated in the Lower Maryland Eastern Shore region, and it is possible that restoration measures could be taken to improve their vigor or increase their elevation at least locally. Should they be lost, as predicted here, natural processes are not in place to rebuild them, and they could be replaced only by allowing major conversion of adjacent uplands to tidal wetlands. Even then, given the highly altered nature of this system, active restoration of hydrology and sediment supply pathways would be necessary to ensure their survival under even midrange estimates of sea level rise.

Very few brackish or salt marshes in the area can survive sea level rise rates in excess of 10 mm/yr. Where sediment supply from inlets, overwash, or rivers is substantial, local areas of marsh on Long Island could survive. This may be the case in some other back barrier marshes, but it will be very dependent on local storm-driven sediment supply.

This report has evaluated the fate of coastal wetlands according to three sea level rise estimates. The large difference, 5 mm/yr, between the midrange estimate and the high-range estimate means the study considered how marshes would respond to rates of 6 mm/yr and 11 mm/yr but not rates in between. Few studies specifically address the maximum rates at which marsh vertical accretion can occur. Morris et al. (2002) used modeling and field data to estimate that under high sediment supply conditions, *Spartina alterniflora* marshes in the Southeast could survive sea level rise rates as high as 12.5 mm/yr, and Bricker-Urso et al. (1989) posited a maximum rate of 14–16 mm/yr for salt marshes in Rhode Island. However, no studies have addressed the thresholds for organic accumulation in the marshes considered here. Determining the fate of coastal wetlands at rates of sea level rise between the mid and high estimates used here requires further elucidation of variations in this maximum rate regionally and among vegetative communities.

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