An Approach to Monitoring Coastal Marsh Migration in the Northeast

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Global climate change has significant implications for ecosystems worldwide. An increase in sea-level is one of its many environmental impacts. Melting of Arctic and Antarctic ice and thermal expansion of ocean water are causing sea levels to rise at rates higher than in the past century (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-5-1.html). This rise is affecting vegetation in low-lying areas along most coasts (i.e., subsiding coasts; Figure 1).

Changes in coastal vegetation attributed to rising seas is not a new phenomena as scientists have reported finding remains of trees in salt marshes and underwater in the mid-1800s and early 1900s (Dawson 1856; Mudge 1862; Ganong 1903; Bartlett 1911; Harshberger and Burns 1919). "Marine transgression" has occurred on coastal lands since the last glaciation as sea level initially rose rapidly with the melting of continental glacial ice (see Tiner 2013 for overview). Land on the former coastal plain was submerged and forms the sea floor of what is now called the continental shelf. Around 5-6,000 years ago, glacial ice melting virtually ceased and the rate of sea-level rise (SLR) slowed to 15-30 cm per century (Gornitz 2007). This allowed for the formation of estuaries, barrier islands and coastal marshes in near present-day locations. As sea level continued to rise, lowland forests became flooded sufficiently with salt water to kill the woody plants and provide suitable substrate for colonization by marsh plants - the marshes were "migrating" inland. "Marsh migration" continues to occur as long as sea level rises and there is land available at suitable elevations to support the growth and reproduction of halophytic vegetation (e.g., Carey 1996; Donnelly and Bertness 2001; Tiner 2013). Vegetation changes also occur within the salt marshes. For example, low marshes become tidal flats or open water, while the high marsh is transformed to low marsh. Neighboring low-lying forests are eventually converted to salt marsh as those areas are exposed to frequent tidal flooding with salt water (Figure 2). Halophytic vegetation may also "migrate" upstream in coastal rivers as salinity moves further upstream. The entire zone from salt to fresh tidal may shift accordingly over time. While this is a natural process, the increased recent rate of sea-level rise is causing these changes to occur at a faster pace.

Much of the research addressing the effect of climate change on salt marshes is dedicated to studying coastal processes in the marshes themselves, such as erosion, accretion, and subsidence (e.g., Cahoon et al. 2002; Lane et al. 2006). Little if any attention has been given to salt marsh migration. Many National Wildlife Refuges are situated along the U.S. coastline and will experience changes in

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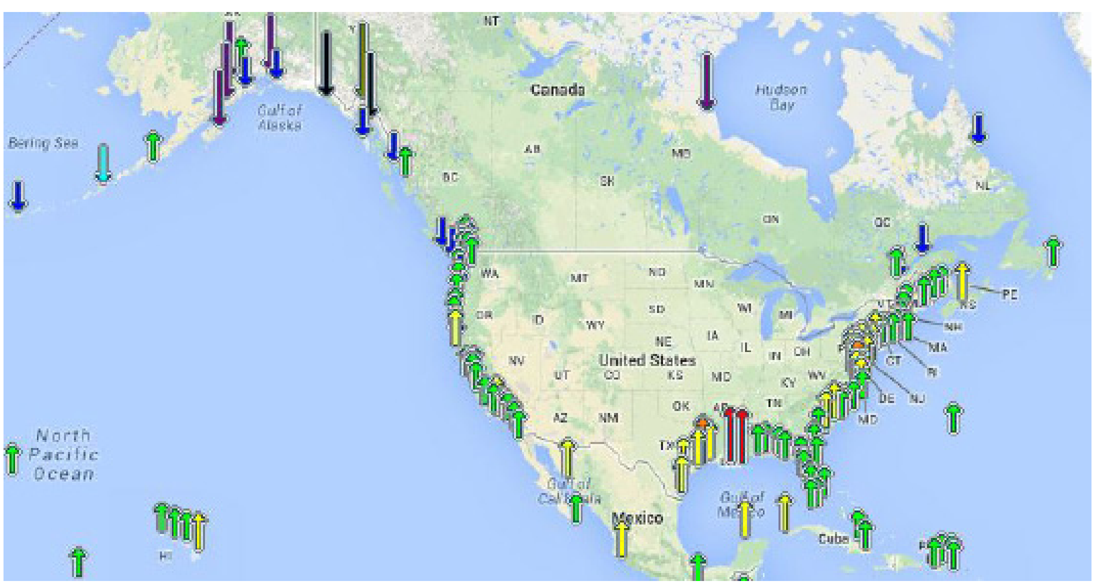

Figure 1. Current rates of sea-level rise in North America. The upward pointing arrows indicate rising sea level (green – lower, yellow – higher, and red – highest rate) while the downward ones represent negative sea level rise resulting from tectonic activity and/or post-glacial rebound. (http://tidesandcurrents.noaa.gov/sltrends/)

plant communities with rising sea level. Establishing a few plots at these refuges would require a minimum investment of time, but would yield interesting results for understanding the nature of vegetation change. Since the refuge program is engaged in long-term planning, we decided to work with refuge personnel to establish a baseline for monitoring changes in coastal vegetation, namely to document coastal marsh migration. This project involves establishing permanent plots in several National Wildlife Refuges and neighboring conservation lands where salt marsh migration (i.e., changes from forest to marsh) is occurring or is expected to occur due to their low topographic relief. At a minimum, the effort will document changes in local vegetation patterns and soil properties due to sea-level rise. From this information if collected at enough varied locations, we can learn how rapid or slow such changes are occurring and how such changes differ geographically. The work can be coupled with periodic aerial image analysis to document large-scale changes on the refuges and surrounding areas (e.g., deterioration of the high marsh as evidenced by the formation of pools and pans), or with research studies of marsh processes.

Figure 2. An example of coastal marsh migration: dead trees in a Maine salt marsh.

Study Approach

The project represents an effort to initiate a long-term monitoring program for documenting changes in vegetation and soil properties related to rising sea level. Permanent plots are established to record baseline conditions of vegetation and soils. Follow-up investigations can be performed at periodic intervals to monitor change. To date, permanent plots have been established in the Northeast Region at four National Wildlife Refuges and other conservation areas in New Jersey, New Hampshire, and Maine (Table 1).

The emphasis of current projects is largely on documenting migration of salt marsh into contiguous lowland forest. Since rising sea levels will also allow halophytic species to colonize areas further upstream in coastal rivers due to increasing salinities, some plots have been established in brackish marshes where signs of stress have been observed in neighboring forests especially Atlantic white cedar swamps (*Chamaecyparis thyoides*).

Methodology

For each study area, permanent plots will be established along a general "transect" extending from the high salt marsh into the contiguous lowland forest (wetland and/or upland). The "transect" does not necessarily follow an exact straight line but typically follows a narrow swath intersecting a variety of plant communities along a topographic gradient from the marsh into the forest. Each study area will, at a minimum, contain vegetation plots in the high marsh and forest. Additional plots may be located in different zones of the salt marsh where desirable. The number of communities analyzed will vary per site. Some forest plots will only be positioned in neighboring freshwater wetlands where such wetlands are extensive, while other areas will include low-lying upland forests. In the future, additional plots can be identified further inland as necessary.

The size of the plot will vary according to the predominant vegetation. For herbaceous communities (marshes, meadows, and fields), one 1.52-m radius circular plot is established at each sample point. For shrub communities, one 4.57-m radius plot is used. Salt marsh shrubs are included in the 1.52-m radius plot. Forest vegetation is evaluated within a 9.14-m radius or 4.57-m radius circular plot depending on tree density (i.e., smaller plot for high density of trees) or time available. Within the forest plot, herbs are analyzed in a 1.52-m radius plot while shrubs are evaluated within a 4.57-m radius plot. The center of each circular plot is marked with a wooden stake except in forests where a tree is typically used to mark the plot center. Plot coordinates are recorded using a GPS.

Sampling Parameters

Vegetation is sampled by plot analysis and soil samples are evaluated in the field. Optional sampling could include the point-intercept method, whereas soil samples could be analyzed in a soil lab for texture, bulk density, and percent organic carbon. Marsh accretion could be evaluated by applying colored soil (e.g., feldspar) to the surface and interstitial salinity could also be measured.

Vegetation Analysis. Three life forms are evaluated: graminoid/herb, shrub/sapling, and tree, while climbing woody vines may or may not be sampled. The graminoid/

Table 1. Specific location of study plots. FB – Furbish Road, LR – Little River, DC – Discovery Center, WP – Woodman Point, CSC – Cedar Swamp Creek, DH – Del Haven, DeC – Dennis Creek, RB – Old Robbins Brook, ATT – AT&T, JC – Jobs Creek, and LT – Leeds Point.

Study Area (State)	Plot #	Latitude	Longitude	Dominant Species
Carson NWR (ME)	FB1	43° 16' 53.53"N	70° 35' 08.15"W	*Pinus strobus-Acer rubrum* (upland)
	FB2	43° 16' 52.63"N	70° 35' 06.91"W	*A. rubrum* (wetland)
	FB3	43° 16' 52.06"N	70° 35' 05.70"W	*Morella pensylvanica*- graminoids (former swamp forest)
	FB4	43° 16' 51.77"N	70° 35' 04.99"W	*Spartina pectinata-Panicum virgatum*
	FB5	43° 16' 51.14"N	70° 35' 03.64"W	*Salicornia maritima-Triglochin maritima*
	FB6	43° 16' 50.75"N	70° 35' 02.83"W	*Spartina patens-Spartina alterniflora*
	FB7	43° 16' 50.34"N	70° 35' 01.95"W	*S. patens-Glaux maritima*
	FB8	43° 16' 50.15"N	70° 35' 01.50"W	*G. maritima-Juncus gerardii*
	LR1	43° 20' 47.30"N	70° 32' 24.69"W	*Picea mariana-A. rubrum* (swamp)
	LR2	43° 20' 46.79"N	70° 32' 25.16"W	*Pinus strobus-P. mariana*
	LR3	43° 20' 46.27"N	70° 32' 25.71"W	*Gaylussacia baccata-Vaccinium corymbosum* (former maple swamp)
	LR4	43° 20' 45.65"N	70° 32' 26.22"W	*Calamagrostis canadensis-Symphotrichum novi-belgii*
	LR5	43° 20' 45.11"N	70° 32' 26.64"W	*S. pectinata*
	LR6	43° 20' 44.47"N	70° 32' 27.18"W	*S. patens*
	LR7	43° 20' 44.02"N	70° 32' 27.52"W	*S. patens*
	LR8	43° 20' 43.70"N	70° 32' 27.79"W	*S. patens* (top of creekbank)
Discovery Ctr (NH)	DC1	43° 03' 22.14"N	70° 53' 50.74"W	*Spartina alterniflora* (low marsh)
	DC2	43° 03' 21.24"N	70° 53' 58.86"W	*Salicornia-S. alterniflora-Schoenoplectus robustus*
	DC2.5	43° 03' 20.58"N	70° 53' 58.92"W	*S. patens*
	DC3	43° 03' 20.10"N	70° 53' 59.10"W	*Juncus gerardii*
	DC4	43° 03' 19.62"N	70° 53' 59.10"W	*Iva frutescens-S. patens*
	DC5	43° 03' 19.20"N	70° 53' 59.10"W	*Phragmites australis* (native)-mixed forbs
	DC5.5	43° 03' 18.88"N	70° 53' 59.23"W	Dying Palustrine Forest-*P. australis* (wetland)
	DC6	43° 03' 18.48"N	70° 53' 58.86"W	*Quercus rubra* (upland)
Great Bay NWR (NH)	WP1	43° 04' 25.10"N	70° 51' 22.39"W	*S. alterniflora* (tall; low marsh)
	WP2	43° 04' 25.72"N	70° 51' 22.72"W	*Distichlis spicata-S. patens*
	WP3	43° 04' 26.29"N	70° 51' 22.82"W	*S. alterniflora* (short/intermediate)- *S. patens*
	WP4	43° 04' 27.52"N	70° 51' 23.16"W	*S. patens*
	WP5	43° 04' 27.91"N	70° 51' 23.18"W	*D. spicata*-mixed
	WP6	43° 04' 28.24"N	70° 51' 23.40"W	*S. pectinata-Typha latifolia*
	WP7	43° 04' 28.99"N	70° 51' 23.11"W	*Fraxinus pennsylvanica* (wetland)
	WP8	43° 04' 29.86"N	70° 51' 23.36"W	*F. pennsylvanica* (wetland)
	WP9	43° 04' 30.14"N	70° 51' 23.26"W	*Ostrya virginiana*-mixed hardwoods (upland)
Cape May NWR and vicinity (NJ)	CSC1	39° 14' 32.39"N	74° 43' 43.87"W	*Typha angustifolia* (brackish marsh)
	CSC2	39° 14' 22.11"N	74° 43' 45.28"W	*P. australis* (non-native)
	CSC3	39° 14' 39.91"N	74° 43' 46.58"W	*Morella pensylvanica-Smilax rotundifolia*
	CSC4	39° 14' 32.11"N	74° 43' 32.11"W	*A. rubrum* (wetland)
	DH1	39° 02' 54.59"N	74° 54' 54.59"W	*P. australis* (non-native w/standing dead trees)
	DH2	39° 02' 54.46"N	74° 54' 54.46"W	*Ilex opaca-Chasmanthium-P. australis* (dying upland forest)
	DH3	39° 02' 53.68"N	74° 54' 53.68"W	*A. rubrum-Quercus phellos* (dying upland forest)
	DH4	39° 02' 53.30"N	74° 54' 49.90"W	*Liquidambar styraciflua-A. rubrum-Quercus* (swamp)
	DeC1	39° 11' 21.99"N	74° 48' 21.99"W	*Morella cerifera-A. rubrum* (former cedar swamp)
	DeC2	39° 11' 23.39"N	74° 48' 23.39"W	*Chamaecyparis thyoides* (stressed)
	DeC3	39° 11' 26.99"N	74° 48' 26.99"W	*C. thyoides* (healthy)
	RB1	39° 11' 48.40"N	74° 52' 08.60"W	*C. thyoides* (stressed)
	RB2	39° 11' 57.90"N	74° 52' 00.50"W	*C. thyoides* (healthy)
Forsythe NWR (NJ)*	ATT1	39° 41' 54.18"N	74° 13' 18.41"W	*A. rubrum-Sassafras albidum-Pinus rigida-I. opaca* (upland)
	ATT2	39° 41' 55.98"N	74° 13' 13.74"W	*A. rubrum-L. styraciflua-I. opaca* (wetland)
	ATT3	39° 41' 56.55"N	74° 13' 11.60"W	*A. rubrum*
	ATT4	39° 41' 56.51"N	74° 13' 10.42"W	*Nyssa sylvatica-A. rubrum*
	ATT5	39° 41' 58.44"N	74° 13' 08.45"W	*P. australis* (non-native)-*Pluchea purpurascens*
	ATT6	39° 41' 58.83"N	74° 13' 0.53"W	*S. patens*
	ATT7	39° 41' 59.80"N	74° 13' 02.94"W	*S. patens*
	ATT8	39° 41' 59.93"N	74° 13' 03.10"W	*S. patens-D. spicata*
	JC1	39° 35' 08.35"N	74° 25' 13.17"W	*C. thyoides* (healthy)
	JC2	39° 35' 08.86"N	74° 25' 14.69"W	*A. rubrum* (former cedar swamp)
	JC3	39° 35' 09.08"N	74° 25' 15.25"W	*P. australis* (non-native)-*Schoenoplectus americanus-T. radicans*
	JC4	39° 35' 9.56"N	74° 25' 15.73"W	*S. americanus-P. australis-Toxicodendron radicans*
	JC5	39° 35' 14.01"N	74° 25' 16.13"W	*S. americanus*
	JC6*	39° 35' 14.74"N	74° 25' 15.91"W	*N. sylvatica-M. pensylvanica-V. corymbosum* (wetland)
	JC7*	39° 35' 15.32"N	74° 25' 15.33"W	*Quercus-N. sylvatica-Gaylussacia frondosa* (upland)
	LP1	39° 29' 48.69"N	74° 25' 40.13"W	*S. patens*
	LP2	39° 29' 48.04"N	74° 25' 39.98"W	*P. virgatum-S. americanus*
	LP3	39° 29' 47.60"N	74° 25' 39.87"W	*N. sylvatica-P. rigida*
	LP4	39° 29' 45.78"N	74° 25' 39.44"W	*Quercus* spp. (wetland)
	LP5	39° 29' 45.08"N	74° 25' 40.05"W	*Quercus alba* (upland)

*Plot locations for these plots were not recorded initially but will be GPSed later this year during the 5-year review; their locations are approximate.

herb stratum is represented by nonwoody plants but also include trailing woody plants less than 1 m tall (e.g., *Toxicodendron radicans* and *Parthenocissus quinquefolia*) and seedlings of woody plants less than that height. The shrub/sapling stratum is comprised of woody plants less than 6.6 m tall, while the tree stratum is made up of woody plants 6.6 m or taller.

Metrics. Cover is estimated for all species even unknowns, while density and diameter at breast height are additional metrics for trees. For marsh plots, the % areal cover of bare ground in the 1.52-m circular plot is also estimated when it represents 10% or more of the plot. Woody vines are noted but since estimates of cover are often difficult, they will not be evaluated for cover. Alternatively, a stem count of woody vines growing on trees and shrubs can be made.

The "condition" of the canopy of woody plants is assessed as follows: *excellent* – no sign of die-back or stress; *good* – no sign of die-back but some stress noted (e.g., chlorosis); *fair* – some sign of die-back (up to 25% dieback of canopy); *somewhat poor* – significant die-back (25-50% dieback); *poor* (>50% to 90% dieback); *extremely poor* (>90% dieback, very little live woody material). The number and types of species stressed, dying, or dead trees will also be recorded. Signs of stress include wilting leaves, reduced growth, chlorophyll deficiency (chlorosis - yellowing of leaves), dying parts, dead parts, and possibly lack of "normal" twig growth.

Soil Analysis. For all communities, a soil sample will be taken within each plot. Soil properties will typically be described to a depth of 40 cm following standard soil classification techniques (soil colors and texture by feel).

Monitoring

Monitoring is to be performed at 5-year intervals, and possibly during the growing season in the year following a major disturbance event (e.g., hurricane). This work only involves one- or two days of field work depending on the number of plots per study area. In the short-term, monitoring will likely be done by the principal investigator and cooperators and beyond that by cooperators and/or students from local universities. Ideally the monitoring program will be part of the routine management and planning efforts of the refuge or other conservation area.

Future Work

This fall will be the first monitoring evaluation for the Forsythe NWR sites for which baseline data were collected in 2009. Plans are underway to establish plots at Chincoteague NWR (Virginia) and the State of Connecticut's Barn Island Wildlife Management Area. Agencies/organizations interested in tidal wetlands are encouraged to consider establishing permanent plots at other conservation areas.

Summary

With minimal time and effort, a network of sentinel sites can be created to track changes in coastal vegetation over time. The work can also be coupled with remote sensing studies to document significant areal changes in vegetation patterns (e.g., forest to mixed marsh/forest to salt marsh and high marsh to low marsh to tidal flat) on the entire refuge/reserve and perhaps in neighboring areas as well. This monitoring effort complements research being conducted in the salt marshes that attempt to better understand how the marshes are responding internally to changes in sea level.

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