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State of Salt Marshes

DUNCAN M. FITZGERALD AND ZOE J. HUGHES

Salt marshes are expected to undergo substantial change or, potentially, disappear in the next couple of centuries as a result of rising sea level. Increasingly, scientists are asking the question: how long can they survive? This book draws on global expertise to look at how salt marshes evolved, how they function, and how they are responding to the stresses caused by social and environmental change. These environments occur throughout the world: behind barrier islands, bordering estuaries, and dominating lower delta plains (Fig. 1.1) in warm to cool latitudes ($\geq$ 30° latitude). Up until now, previous loss and degradation of coastal marshes has been related to a variety of human actions including dredging and filling, reduction in sediment supplies, and hydrocarbon withdrawal, as well as other causes. However, in the future the greatest impact to marshes will be a consequence of climate change, especially sea-level rise (SLR). Most of the present marshes formed under very different sedimentation and SLR regimes compared to those that occur today. During their formation and throughout their evolution, the rate of SLR was relatively slow and steady, between 0.2 and 1.6 mm/year (Table 1.1). The sustainability of marshes is now threatened by an acceleration in SLR to rates many times greater than those under which they initiated and have evolved. For example, the Romney marsh, which is located north of Boston, Massachusetts, contains a 2-m-thick peat that began forming 3.1 ka BP when sea level was rising at about 0.8 mm/year, a rate that slowed to 0.52 mm/year around 1 ka BP (Donnelly 2006). The rate of SLR in Boston Harbor is now 2.85 mm/year (NOAA 2019), which far exceeds the rate occurring when the Romney marsh built to a supratidal elevation. Eventually, SLR, along with marsh-edge erosion, will outpace the ability of most marshes to accrete vertically (Crosby et al. 2016) and/or compensate for marsh loss by expanding into uplands (Kirwan et al. 2016, Farron 2018).

Over the short term, some researchers believe that biogeomorphic feedbacks will improve marsh survival as increased mineral sedimentation on the marsh platform will occur due to longer periods of tidal flooding, and resulting from increased biomass (Morris et al. 2002; Mudd et al. 2009). This will be further enhanced as plant productivity responds to warmer temperatures (Kirwan et al. 2009) and higher carbon dioxide concentrations (Langley et al. 2009; Ratliff et al. 2015). Although this will offer some relief to the problem, increased sedimentation rates will actually depend on the availability of suspended sediment, which is likely to be diminishing due to progressively lower volumes of riverine sediment reaching the coastal ocean (Syvitski et al. 2005; Weston 2014). Some

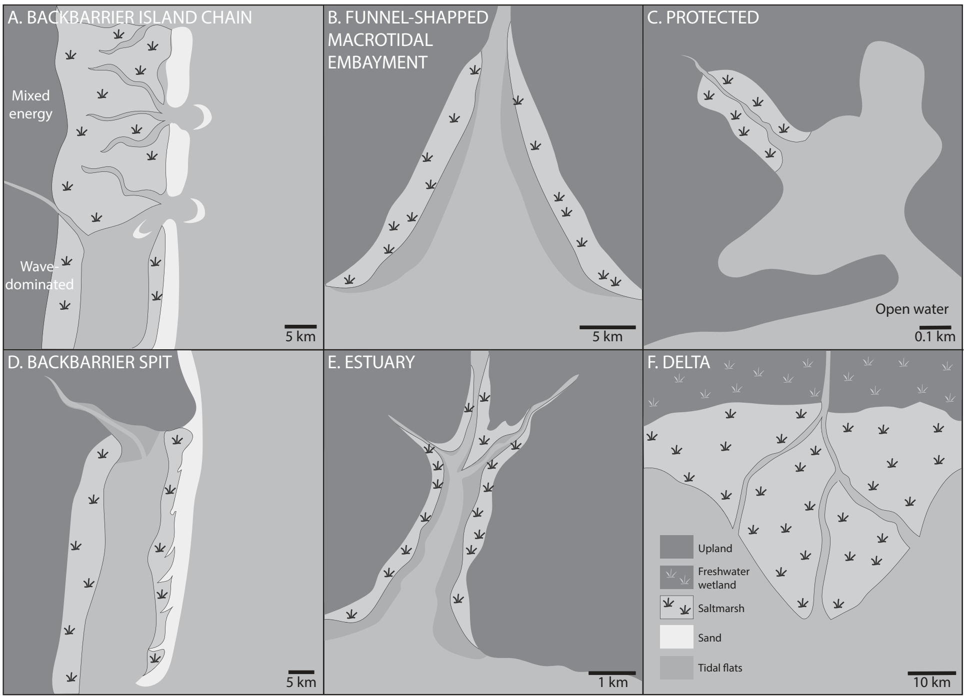

Figure 1.1 Broad types of salt marsh environments, including: (A) *Backbarrier Island Chains* (e.g., East and Gulf Coasts of USA; Algarve, Portugal; Frisian Islands, Germany); (B) *Funnel-shaped Macro-tidal Embayment* (e.g., The Wash, England; Mouth of Elbe River, Germany; Mont St. Michael Bay, France; Nushagak Bay, AK); (C) *Protected* (e.g., Sunborn Cove, Gouldsboro, ME; Etang de Toulvern, Bretagne, France); (D) *Backbarrier Spit* (e.g., Long Beach, WA; Cape Romain, SC; Hashirikotan barrier spit, Japan); (E) *Estuary* (e.g., Delaware and Chesapeake Bays; Rivers Esk and Eden, UK; Columbia River, USA; Lérez Estuary, Spain); (F) *Deltaic* (e.g., Mississippi River delta, LA; Yukon River delta, AK). (A black and white version of this figure will appear in some formats. For the color version, please refer to the plate section.)

investigators (Hopkinson et al. 2018) have suggested that wave-induced marsh edge retreat may, in fact, offer a benefit in that the eroded sediment can be transported to the marsh surface. Marsh loss caused by edge erosion is partly offset by upland marsh migration during SLR. Finally, over the past decade, it has been recognized that marshes are not static, vertically accreting platforms, resulting from a simple balance of inorganic sedimentation and belowground biomass production or decomposition. Rather, recent research has demonstrated that marshes are highly dynamic ecosystems that respond to storms and numerous interconnected hydrological, biological, sedimentological, and geochemical processes. These responses include the formation and expansion of salt pannes and pools, headward erosion of tidal creeks, landscape-scale feedbacks to fauna-induced devegetation or bioturbation, marsh edge calving and erosion, storm-related deposition, ice fracturing, and ice-rafted sedimentation. In totality, climate change is affecting all of these marsh processes, but in a differential manner related to their geologic and climatic setting.

Table 1.1 *Examples of rates of sea-level rise during salt marsh formation (from FitzGerald and Hughes 2019)*

Location	Curve Database	Rates (mm/yr)	Reference
Chezzetcook, Nova Scotia	Basal peats & forams	1.7 from 1000 to 1800 AD 1.6 from 1800 to 1900 AD	Gehrels et al. 2005
Phippsburg, ME	Basal peats & forams	0.5–1.4 from 5.7 to 3.0 ka BP 0.2–0.8 from 3.0 ka BP to present	Gehrels et al. 1996
Wells, ME	Basal peats & forams	0.7–2.2 from 5.7 to 3.5 ka BP 0.0–0.6 from 3.5 ka BP to present	Gehrels et al. 1996
Northern MA	Basal peats	0.80 +/− 0.25 from 3.3 to 1.0 ka BP 0.52 +/− 0.62 from 1.0 to 0.15-0.5 ka BP	Donnelly 2006
Hudson River, NY	N/A	1.2 +/− 0.2 during Late Holocene	Pardi et al. 1984
Delaware	Basal peats	1.2 +/− 0.2 during Late Holocene	Belknap and Kraft 1977; Nikitina et al. 2000
Eastern Shore, VA	Basal peats	0.9 +/− 0.3 during Late Holocene	Engelhart 2009
Central to Southern, NC	Basal peats	0.82 +/− 0.02 since 3903–3389 cal a BP	Horton et al. 2009
West Brittany, France	Basal peats	0.90 +/− 0.12 since 6.3 ka BP	Stéphan et al. 2015
Northern Scotland	Basal peats & other	Stable with +/− 40.0 cm of change during past 2 ka	Gehrels et al. 2006a; Barlow et al. 2014
Ho Bugt, Denmark	Basal peats & other	1.0 during the past 4 ka	Gehrels et al. 2006b
Pounawea, New Zealand	Peats & forams	0.3 +/− 0.3 from 1500 to 1900 AD	Gehrels et al. 2005
East Coast, South Korea	N/A	0.74 from 5.4 ka BP to Present	Lee et al. 2008

Fortunately, dramatic advances in computing power have allowed increasingly complex numerical simulations to project the future evolution and sustainability of salt marshes. Marsh modeling has become an essential tool for predicting how marsh systems will respond to greater frequencies and durations of tidal inundation and in quantifying tipping points, when marshes will ultimately begin to disintegrate. To complement this, physical models of marshes, including flume studies, are shedding light on the mechanics of marsh erosion, particularly in combination with bioturbation and geochemical processes (Möller et al. 2014, Farron 2018, Reef et al. 2018).

In other research, the utilization of radioisotopic dating (Pb-210 and Cs-137), Surface Elevation Tables (SET), and the study of tide-indicator microfossils in combination with statistical analyses (transfer functions; Gehrels 2000) have produced more accurate rates of marsh accretion and have expanded our understanding of marsh growth in response to SLR, globally. We are also increasingly able to identify the sources and patterns of suspended sediment delivery to marshes and to define how marsh platforms will segment and measure rates of edge erosion, with most of these findings involving a combination of field and modeling techniques.

Based on publication rates, the number of marsh studies, have increased tenfold during the past couple of decades, as the importance of marshes as contributors of detritus and nutrients to the coastal ocean, unique coastal habitats, nursery grounds of shellfish and finfish, ameliorators of storm surges and wave erosion, assimilators of upland pollutants, and of their economic value and beauty have been increasingly recognized by scientists and the coastal population. The significant advancements in our understanding of salt marsh processes and how this knowledge base is being used to study the dramatic stresses that marshes will face during the coming century are the impetuses for this book. From the viewpoint of wetland experts from around the world, this volume explores and summarizes many facets of marsh research and provides the current state of knowledge of salt marsh science.

References

Barlow, N. L. M., Long, A. J., Saher, M. H., Gehrels, W. R., Garnett, M. H., and Scaife, R. G. 2014. Salt-marsh reconstructions of relative sea-level change in the North Atlantic during the last 2000 years. *Quaternary Science Reviews*. 99:1–16.

Belknap, D. F., and Kraft, J. C. 1977. Holocene relative sea-level changes and coastal stratigraphic units on the northwest flank of the Baltimore Canyon trough geosyncline. *Journal of Sedimentary Research*. 47:610–629.

Crosby, S. C., Sax, D. F., Palmer, M. E., Booth, H. S., Deegan, L. A., Bertness, M. D., and Leslie, H. M. 2016. Salt marsh persistence is threatened by predicted sea-level rise. *Estuarine and Coastal Shelf Science*, 181:93–99.

Donnelly, J. P. 2006. A revised late Holocene sea-level record for Northern Massachusetts, USA. *Joural of Coastal Research*, 22:1051–1061.

Engelhart, S. E., Horton, B. P., Douglas, B. C., Peltier, W. R., and Törnqvist, T. E. 2009. Spatial variability of late Holocene and 20th century sea-level rise along the Atlantic coast of the United States. *Geology*, 37:1115–1118.

Farron, S. 2018. *Morphodynamic responses of salt marshes to sea-level rise: upland expansion, drainage evolution, and biological feedbacks*. PhD thesis, Boston Univ., Boston, MA.

FitzGerald, D. M. and Hughes, Z. 2019. Marsh processes and their response to climate change and sea-level rise. *Annual Review of Earth and Planetary Sciences*, 47:481–517.

Gehrels, W. R. 1996. Integrated high-precision analyses of Holocene relative sea-level changes: Lessons from the coast of Maine. *Geological Society of America, Bulletin*, 108:1073–1088.

Gehrels, W. R. 2000. Using foraminiferal transfer functions to produce high-resolution sea-level records from saltmarsh deposits, Maine, USA. *The Holocene* 10:367–376.

Gehrels, W. R., Kirby, J. R., Prokoph, A., Newnham, R. M., Achterberg, E. P., Evans, H., Black, S., and Scott, D. B. 2005. Onset of recent rapid sea-level rise in the western Atlantic Ocean. *Quaternary Science Reviews*. 24:2083–2100.

Gehrels, W. R., Marshall, W. A., Gehrels M. J., Larsen, G., Kirby, J. R., Eiriksson, J., Heinemeier, J., and Shimmield, T. 2006a. Rapid sea-level rise in the North Atlantic Ocean since the first half of the 19th century. *Holocene*, 16:948–964.

Gehrels, W. R. Szkornik, K., Bartholdy, J., Kirby, J. R., Bradley, S. L., Marshall, W. A., Heinemeier, J., and Pedersen, J. B. T. 2006b. Late Holocene sea-level changes and isostasy in western Denmark. *Quaternary Research*, 66:288–302

Gehrels, W. R. Hayward, B. W., Newnham, R. M., and Southall, K. E. 2008. A 20th century sea-level acceleration in New Zealand. *Geophysical Research Letters* 35: L02717.

Hopkinson, C. S., Morris, J. T., Fagherazzi, S., Wollheim, W. M., and Raymond, P. A. 2018. Lateral marsh edge erosion as a source of sediments for vertical marsh accretion. *Journal of Geophysical Research, Biogeosciences*, 123:2444–2465.

Horton, B. P., Peltier, W. R., Culver, S. J., Drummond, R., Engelhart, S. E., Kemp, A. C, Mallinson D, et al. 2009. Holocene sea-level changes along the North Carolina Coastline and their implications for glacial isostatic adjustment models. *Quaternary Science Reviews*, 28:1725–1736.

Kirwan, M. L., and Temmerman, S. 2009. Coastal marsh response to historical and future sea-level acceleration. *Quaternary Science Reviews*, 28:1801–1808.

Kirwan, M. L., Walters, D., Reay, W., Carr, J. 2016. Sea level driven marsh expansion in a coupled model of marsh erosion and migration. *Geophysical Research Letters*, 43: 4366–4373.

Langley, J. A., McKee, K. L., Cahoon, D. R., Cherry, J. A., and Megonigal, J. P. 2009. Elevated CO2 stimulates marsh elevation gain, counterbalancing sea-level rise. *Proceedings of the National Academy of Sciences*, 106:6182–6186.

Lee, Y. G.; Choi, J. M., and Oertel, G. F. 2008. Postglacial sea-level change of the Korean southern sea shelf. *Journal of Coastal Research*, 24:118–132.

Möller, I., Kudella, M., Franziska, R., Spencer, T., Paul, M., Van Wesenbeeck B. K., Wolters G., et al. 2014. Wave attenuation over coastal salt marshes under storm surge conditions. *Nature Geoscience*, 7:727–731.

Morris, J. T., Sundareshwar, P. V., Nietch, C. T., Kjerfve, B., and Cahoon, D. R. 2002. Responses of coastal wetlands to rising sea level. *Journal of Ecology*, 83:2869–2877.

Mudd, S. M., Howell, S. M., Morris, J. T. 2009. Impact of dynamic feedbacks between sedimentation, sea-level rise, and biomass production on near-surface marsh stratigraphy and carbon accumulation. *Estuarine, Coastal and Shelf Science*, 82:377–389.

Nikitina, D. L, Pizzuto, J. E., Schwimmer, R. A., Ramsey, K. W. 2000. An updated Holocene sea-level curve for the Delaware coast. *Marine Geology*, 171:7–20.

NOAA. 2019. Tide levels: https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970&units=metric&bdate=20171226&edate=20180104&timezone=GMT&datum=MLLW&interval=6&action=

Pardi, R. R., Tomecek, L., and Newman W. S. 1984. Queens College radiocarbon measurements IV. *Radiocarbon*, 26:412–430.

Ratliff, K. M., Braswell, A. E., and Marani, M. 2015. Spatial response of coastal marshes to increased atmospheric CO_2. *Proceedings of the National Academy of Sciences*, 112:15580–15584.

Reef, R., Schuerch, M., Christie, E. K., Möller, I., and Spencer, T. 2018. The effect of vegetation height and biomass on the sediment budget of a European saltmarsh. *Estuarine, Coastal and Shelf Science*, 202:125–133.

Stéphan, P., Goslin, J., Pailler Y., Manceau, R., Suanez, S., Van Vliet-Lanoë, B., Hénaff, A., and Delacourt C. 2015. Holocene salt-marsh sedimentary infilling and relative sea-level changes in West Brittany (France) using foraminifera-based transfer functions. *Boreas*, 44:153–177.

Syvitski, J. P. M., Vörösmarty, C. J., Kettner, A. J., and Green, P. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science*, 308:376–380.

Weston, N. 2014. Declining sediments and rising seas: an unfortunate convergence for tidal wetlands. *Journal of Estuaries and Coasts*, 37:1–23.