Coastal freshwater wetlands squeezed between migrating salt marshes and working lands

Emily Bernhardt

Creative solutions are needed to sustain the diversity of coastal wetland ecosystems as sea levels rise.

When Europeans first arrived on the North American continent, the area that would become the United States included some 221 million acres of wetlands (*1*). By the mid-1980s, more than half of those wetlands had been drained or filled, primarily in support of agricultural expansion. For most of U.S. history, the federal government treated wetlands as nuisance habitats that should be reclaimed for productive uses, investing federal capital in incentive programs that encouraged widespread ditching and drainage of the nation's wetlands and which referred to these activities as a "conservation practice" (*1*).

By the 1970s, government attitudes and rhetoric about wetlands began to change, as new research documented the important amenities that wetlands provide and new regulations sought to prevent or mitigate future wetland losses (*1*). Wetlands are among the most valuable ecosystems on the planet, by virtue of their outsized capacity for sequestering carbon, their potential to remove excess and harmful nutrient pollutants, and their importance as critical habitat for many plant and animal species. Both federal legislation and public awareness have fostered substantial investments in wetland restoration that, by the 1990s, began to slow the trajectory of losses over the previous century as aggressive restoration efforts caused an increase in the national extent of palustrine and estuarine wetlands in the United States (*2*).

CONTINUED COASTAL WETLAND DECLINE

While restoration is slowing the loss rate of U.S. wetlands in the aggregate, coastal wetlands continue to decline (*2*). Even in protected areas, coastal wetlands are facing a new threat that cannot be regulated by Congress or held back by conservation boundaries. Rising sea levels are eating away at our coastal marshes and mangroves, and encroaching saltwater is killing off freshwater coastal wetlands (Fig. 1). While our wetland plants and animals might be physically capable of migrating upslope, in the vast majority of places, they are already hemmed in on their uphill side by farm fields or hardened infrastructure. As a result, in many coastal landscapes, climate change threatens to complete the work of wetland elimination that centuries of colonization and drainage failed to fully accomplish.

The seaward side of this threat to coastal wetlands is relatively easy to understand although logistically challenging to model, as it requires models that compare the rates of sediment accumulation in marshes and mangroves to the rate of sea level rise. With all future climate scenarios predicting an increase in global mean sea level rise of 1 to 2 m by 2100 (*3*), there are few to no tidal wetlands that will be able to keep up.

PREDICTING FUTURE LOSSES

Predicting the future of coastal wetlands presents a challenge, particularly when modeling the dynamics on the landward side (*4*). The net change in the extent of wetlands by 2100 will depend primarily on whether wetland ecosystems can migrate landward as their seaward edges are drowned by the sea. Writing in this issue of *Science Advances*, Osland *et al.* (*5*) examine the potential for the landward migration of U.S. coastal wetlands as an adaptation to an anticipated global mean sea level rise of 1.5 m by 2100. Their findings are sobering and help put in context several recent reports of coastal ecosystem change.

In a recent global analysis of Earth's tidal wetlands, Murray *et al.* (*6*) reported that tidal wetland losses to sea level rise were largely offset by gains in tidal wetlands through

Fig. 1. Coastal margins typically include a variety of wetland ecosystem types. As sea levels rise, landward migration of tidal wetlands comes at the costs of losses to freshwater wetlands unless their landward migration is facilitated. Credit: Kyle Derby, USGS Patuxent Wildlife Research Center

Department of Biology, Duke University, Durham, NC 27708, USA. Email: emily.bernhardt@duke.edu

upslope migration. Yet, several other recent efforts have reported marked losses of coastal freshwater wetlands and substantial losses of both above- and belowground carbon stocks due to salinization and rising water tables (*7*–*9*). White *et al.* (*7*) estimated that, at current rates of coastal forested wetland loss, this habitat would be completely eliminated from the North American Coastal Plain by the turn of the century.

Osland *et al.* resolve these seemingly contradictory results by considering all types of coastal wetlands simultaneously, and their analysis shows that, while tidal wetlands may acclimate to climate change by landward migration, their success will come at the expense of the brackish and freshwater wetlands that they overgrow. On the landward side, hardened infrastructure and agricultural management will prevent upslope migration of the bald cypress and swamp oaks that have historically dominated coastal landscapes, livelihoods, and culture (*10*). In the many coastal landscapes in which freshwater wetlands have already been removed, tidal wetland migration may be held temporarily at bay at the edges of agricultural fields and municipal infrastructure through active management. Yet, ultimately, rising sea levels and salinization are likely to overwhelm many of these efforts.

A FINAL QUESTION

For those who live and work in coastal landscapes, own coastal properties, and manage coastal ecosystems, the urgent question remains: How might we thoughtfully prepare to accommodate threatened coastal wetlands ahead of their catastrophic loss? Ceding property to the sea in a graceful way and sustaining the potential to sustain native cypress and gum swamps as a part of our nation's natural capital will require creative climate adaptation. We will need to find ways to compensate coastal landowners for converting economically valuable properties into corridors for upland migration of coastal freshwater wetland plants and animals. We will also need to develop creative ways to speed the rate of migration to counter the increasingly rapid pace of sea level rise.

REFERENCES

1. T. E. Dahl, G. J. Allord, History of wetlands in the conterminous United States, National Water Summary—Wetland Resources: Technical Aspects (U.S. Geological Survey, 1997).
2. USDA Natural Resources Conservation Service, National Resources Inventory, in *NRI Rangeland Field Study Handbook of Instructions* (USDA Natural Resources Conservation Services, 2007).
3. W. V. Sweet, R. Horton, R. E. Kopp, A. N. LeGrande, A. Romanou, in *Climate Science Special Report: Fourth National Climate Assessment*, D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, T. K. Maycock, Eds. (U.S. Global Change Research Program, 2017), vol. 1, pp. 333–363.
4. S. Fagherazzi, G. Mariotti, N. Leonardi, A. Canestrelli, W. Nardin, W. S. Kearney, Salt marsh dynamics in a period of accelerated sea level rise. *Case Rep. Med.* **125**, e2019JF005200 (2020).
5. M. Osland, B. Chivoiu, N. M. Enwright, K. M. Thorne, G. R. Guntenspergen, J. B. Grace, L. L. Dale, W. Brooks, N. Herold, J. W. Day, F. H. Sklar, C. M. Swarzenzki, Migrations and transformation of coastal wetlands in response to rising seas. *Sci. Adv.* **8**, eabo5174 (2022).
6. N. J. Murray, T. A. Worthington, P. Bunting, S. Duce, V. Hagger, C. E. Lovelock, R. Lucas, M. I. Saunders, M. Sheaves, M. Spalding, N. J. Waltham, M. B. Lyons, High-resolution mapping of losses and gains of Earth's tidal wetlands. *Science* **376**, 744–749 (2022).
7. E. E. White, E. A. Ury, E. S. Bernhardt, X. Yang, Climate change driving widespread loss of coastal forested wetlands throughout the North American Coastal Plain. *Ecosystems* **25**, 812–827 (2022).
8. A. J. Smith, M. L. Kirwan, Sea level-driven marsh migration results in rapid net loss of carbon. *Geophys. Res. Lett.* **48**, e2021GL092420 (2021).
9. E. A. Ury, X. Yang, J. P. Wright, E. S. Bernhardt, Rapid deforestation of a coastal landscape driven by sea-level rise and extreme events. *Ecol. Appl.* **31**, e02339 (2021).
10. K. Tully, K. Gedan, R. Epanchin-Niell, A. Strong, E. S. Bernhardt, T. Bendor, M. Mitchell, J. Kominoski, T. E. Jordan, S. C. Neubauer, N. B. Weston, The invisible flood: The chemistry, ecology, and social implications of coastal saltwater intrusion. *Bioscience* **368**, 368–378 (2019).

10.1126/sciadv.add1628

Science Advances

Coastal freshwater wetlands squeezed between migrating salt marshes and working lands

Emily Bernhardt

Sci. Adv., 8 (26), eadd1628. • DOI: 10.1126/sciadv.add1628