Management Options for Protecting the World's Estuaries

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Marine Habitats already in Decline Globally from Climate Change

- Polar Zones - Sea ice
  - Decline of polar bear, gray whale, walrus, penguins
- Tropics - Coral reef
  - Decline of 40% in coral reef habitat, holding the greatest biodiversity in the ocean
- Temperate Zones - Salt marsh
  - Declines in 25 endemic or marsh-dependent vertebrate taxa, 23 of which are in the U.S.
  - Losses in ecosystem services of habitat provision, fisheries, water quality, shoreline protection


Photo by Paul Renaud


http://www.oceanconservancy.org/images/

SAP 4.4 (Synthesis and Assessment Product)

- Part of U.S. Climate Change Science Program (CCSP)
- Reviews potential management adaptation options for responding to climate change
- Identifies characteristics of ecosystems and adaptation responses that promote or inhibit successful implementation to sustain ecosystem services

U.S. National Estuary Program

- Includes 28 estuaries
  - Semi-enclosed bodies of water on the sea coast in which fresh and saltwater mix
  - Intrinsically variable environmentally in space and time
- Comprehensive Conservation and Management Plans (CCMPs)
  - Watershed based
  - Stakeholder driven
  - No regulatory authority
  - Similar management goals – maintaining water quality, sustaining fish and wildlife, preserving habitat, protecting human values, fulfilling water quantity needs

Legislative Programs Useful to Manage Estuarine Stressors

- Coastal Zone Management Act – land use planning
- Clean Water Act – basin-wide management of water quality, TMDLs, wetlands
- Federal and state Sustainable Fisheries Management Acts
- Habitat conservation under federal and state Fishery Management Plans
- Estuarine ecosystem restoration programs
- Endangered Species Act and Marine Mammal Protection Act
- Wetland protection rules
- Compensatory restoration requirements for injuries from oil spills and discharged pollutants
- Federal legislation controlling location of ballast water release
- Flood zone regulations
- Native American Treaty Rights for resource management
- National Environmental Protection Act

Traditional Stressors to Estuaries

- Nutrients
- Sediments
- Pathogens
- Fishing (direct effects of extractions and indirect effects of habitat disturbance)
- Wetland loss from development
- Toxics
- Invasive species
- Thermal pollution
- Organic loading (BOD)

Stressors Emerging with Climate Change

- Temperature increase (ranges move pole-ward at unequal rates so new species mixes; disease and parasite increases, phenology mismatches)
- Sea level rise (interacting with shoreline armoring to suppress transgression of shoreline habitats)
- Enhanced intense storms (shoreline erosion, pulsed floods)
- CO_2 rise and ocean acidification (organisms making $CaCO_2$ shells or internal skeletons challenged)
- Precipitation changes (salinity and stratification effects)
- Species introductions facilitated by disturbance

Estuarine Changes Projected from Interacting Stressors

- Interacting stressors include the least widely appreciated yet most serious threats to ecosystem services
- Disease and parasitism rates increase with interactions between temp and other stressors like hypoxia, nutrients, toxins
- Rising sea level interacts with growing use of bulkheads and other anti-erosion structure preventing transgression
- Sea level rise and increased frequency of intense storms interact to deconstruct coastal barriers
- Increased temp and changing precipitation interact to affect water column stratification and hypoxia/anoxia with resulting dead zones

Potential Passage Past Thresholds Inducing Estuarine State Change

- Loss of water filtration by overfished oysters and other bivalves interacts with increased phytoplankton production to expand scope, intensity, and duration of eutrophication
- Overloading of N induces state shift from SAV to phytoplankton and macroalgae
- Ability of salt marsh to maintain elevation in the face of sea level rise by accretion ends abruptly as a threshold rate of SLR is exceeded

Climate Change Projections (IPCC 2007)

- Temp rise in surface atmosphere ranging from a low scenario of 1.1-2.9^{0}C to a high scenario of 2.4-6.4^{0}C by 2100
- Sea level rise ranging from a low scenario of 0.18-0.38 m to a high scenario of 0.26-0.59m by 2100 even without increasing contributions from ice shelf melting, which could dwarf this rise
- Reduction in pH of 0.14-0.35 units by 2100
- Even if greenhouse gas emissions were capped or reduced today, these changes are inevitable

Estuarine Management

- Maintaining status quo of management would guarantee failure to meet all management goals
- Especially urgent is management adaptation in LA, NC, FL, where relative SLR is highest and land slope the lowest
- Over a few decades, management adaptations may build estuarine resilience sufficiently to minimize ecosystem service losses
- Afterwards, major losses in some services are inevitable, requiring triage among services

Water Quality Changes under Status Quo of Management

- As marsh, SAV, oyster reef, intertidal flats disappear under SLR with bulkheads stopping transgression:
- As temp rises, microbial decomposition rates increase and water column stratification intensifies:
- As sequestered subsurface C under marshes erodes and more floods enhance organic loading of estuary:
  - Greater sedimentation
  - Greater turbidity
  - Greater nutrient loading
  - Greater pathogen loading
  - Lower oxygen evolution from plants
  - Reduced denitrification
  - Enhanced eutrophication, hypoxia, and dead zones

Fish & Wildlife Changes under Status Quo of Management

- As marsh, SAV, oyster reef, intertidal flats disappear under SLR with bulkheads stopping transgression:
- As eutrophication, hypoxia, and bottom dead zones expand:
  - Fish, shrimps, and crabs dependent on marsh habitat will decline dramatically
  - Marsh-dependent birds, mammals, and reptiles will disappear
  - All fish & wildlife fed by detrital food chains will suffer declines
  - Oysters and other sessile shellfish will die over wider areas
  - Food chains now leading to higher trophic levels will be short-circuited into a microbial ooze
  - Recovery of depressed large consumers like manatees, alligators, and sea turtles will be halted and reversed

Habitat Changes under Status Quo of Management

- As sea level rises and bulkheads prevent transgression, a sequential loss of shoreline habitats will ensue:
  - Salt marsh
  - Intertidal oyster reef
  - Intertidal flat
  - SAV

  The ultimate outcome is loss of all shoreline habitats and their ecosystem services in an estuary that becomes a walled tub

Human Service Changes under Status Quo of Management

- As first salt marsh then other deeper shoreline habitats disappear from inundation and water quality declines and fish & wildlife suffer steep drops and the estuary is a walled tub:
  - Commercial and recreational fisheries decline
  - Natural amenities derived from wildlife suffer
  - Nuisance algal blooms and fish kills degrade the quality of life
  - Aesthetics of estuarine shoreline living decline
  - Bulkheads and dikes offer a false sense of security, setting the stage for major loss of life and property in an inevitable big storm event

Water Quantity Changes under Status Quo of Management

- As sea level rises, saline ocean waters penetrate further up-estuary – this results in salt water intrusion into aquifers
- Projected increase in large storms leads to more “flashy” run-off from land, posing problems of erosion of banks, degrading water quality, and challenging capacity to hold and store the rainfall

Time Scales of Management Adaptations

- (1) Reactive in response to injuries
- (2) Planning now, implementing later after indicators show urgency or when a window of social feasibility opens, like after a natural disaster
- (3) Immediate implementation of proactive policies

Determinants of Choosing the Appropriate Time Scale

- Balancing costs of implementation vs. risks of delaying under status quo
- Degree of reversibility of the negative effects of climate change and costs of reversal
- Recognition and understanding of the problem by managers and public
- Uncertainty associated with the impact
- Time table on which the impact is anticipated
- Existing political, institutional, financial barriers

Minimize Climate Change Impacts Via expanding Traditional BMPs

- Eutrophication likely to increase through increased stratification, higher BOD at warmer temps, less effective buffering by flooded riparian wetlands, and greater organic loading in more frequent floods
- So expand BMPs of vegetated buffers especially where no barrier exists to wetland transgression
- So install stormwater BMPs

Strategic Shifts in Existing Policies

- Most federal, state, tribal, and local environmental management programs fail even to contemplate climate change
- Low cost prevention of future problems can be found by review of existing management plans, laws, and regs
- For example, riverine flood hazard zones should be modified to reflect reality of expanded flooding frequency and extent
- For example, landfills and hazardous waste sites should be located on even higher ground
- For example, eliminate public subsidies for risky barrier island development and erosion protection applying Coastal Barrier Resources Act everywhere

Proactive Implementation is Required for Estuaries

- Actions now to manage development of undeveloped shores for orderly retreat under rolling easements is necessary to preserve ecosystem services because this action is precluded later – need to:
  - Educate to counteract ignorance, denial, and disinformation
  - Identify costs and risks of present policies now subsidizing risky development
  - Explain why rolling easements do not represent a “taking” of private property
  - Discuss how not all shorelines can be diked because of costs
  - Explain how modest protection falsely implies safety

Monitoring and Historical Baselines

- Geological reconstructions are critical to understanding and communicating the dynamics of estuarine shorelines and coastal barriers under conditions of changing sea level
- Integrating well chosen proxies of conditions from paleontological reconstructions into present monitoring can determine proximity to thresholds of conversion to undesirable ecosystem states

Albemarle-Pamlico Estuary as Case Study

- Possesses more low-lying land within 1.5 m of sea level than any other estuary in the U.S. NEP
- Is projected to lose large expanses of wetlands under all SLR scenarios
- Faces disintegration of its protective barrier, the Outer Banks of North Carolina
- Has an ecosystem-based management plan, the CHPP (Coastal Habitat Protection Plan for fish enhancement) and a legislative study commission, which can facilitate management adaptations to preserve services, following guidance of U.S. Commission on Ocean Policy
- Sparse human population on the estuarine shoreline makes managed retreat possible after extensive stakeholder engagement

Major Climate Change Threat to Ecosystem Services of Estuaries

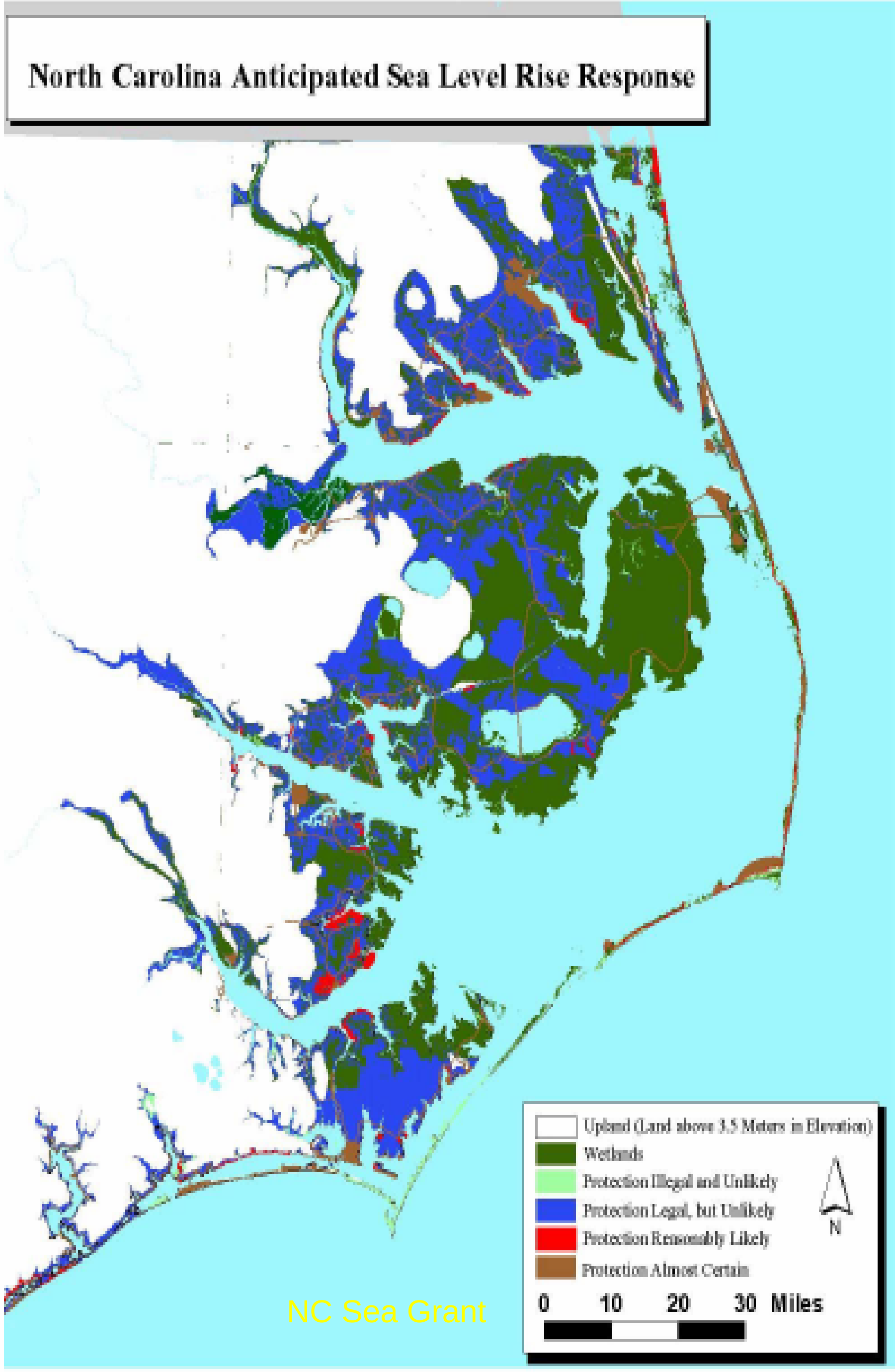
- As the Earth warms, sea level is rising, at an increasing pace, and frequency of intense storms is increasing
- Historically this induced transgression of shoreline habitats of the estuary, moving them upslope as water levels rose
- Presently, development is so intense along estuarine shores that bulkheading or another engineered erosion control is widespread, preventing transgression and leading towards loss of salt marsh and shallow-water estuarine habitats

Fate of Salt Marsh Habitat under Sea Level Rise (SLR)

- IPCC predictions for SLR range from 0.18-0.38 m (low) to 0.26-0.59 m (high) by 2100 without adding increasing contributions from Greenland and Antarctic ice melting
- Because of geographic differences in land subsidence and other physical processes, relative rates of sea level rise vary geographically
- Salt marsh can elevate land to some degree by organic deposition and by inducing deposition of suspended inorganic and organic particulates
- Marsh fate thus depends on the balance of these two processes, on erosion rates, and on presence/absence of erosion-protection structures

US EPA: http://www.epa.gov/climatechange/effects/coastal/slrmaps_sealevelmap.html
Data courtesy Maps of Lands Vulnerable to Sea Level Rise: Modeled Elevations along the U.S. Atlantic and Gulf Coasts

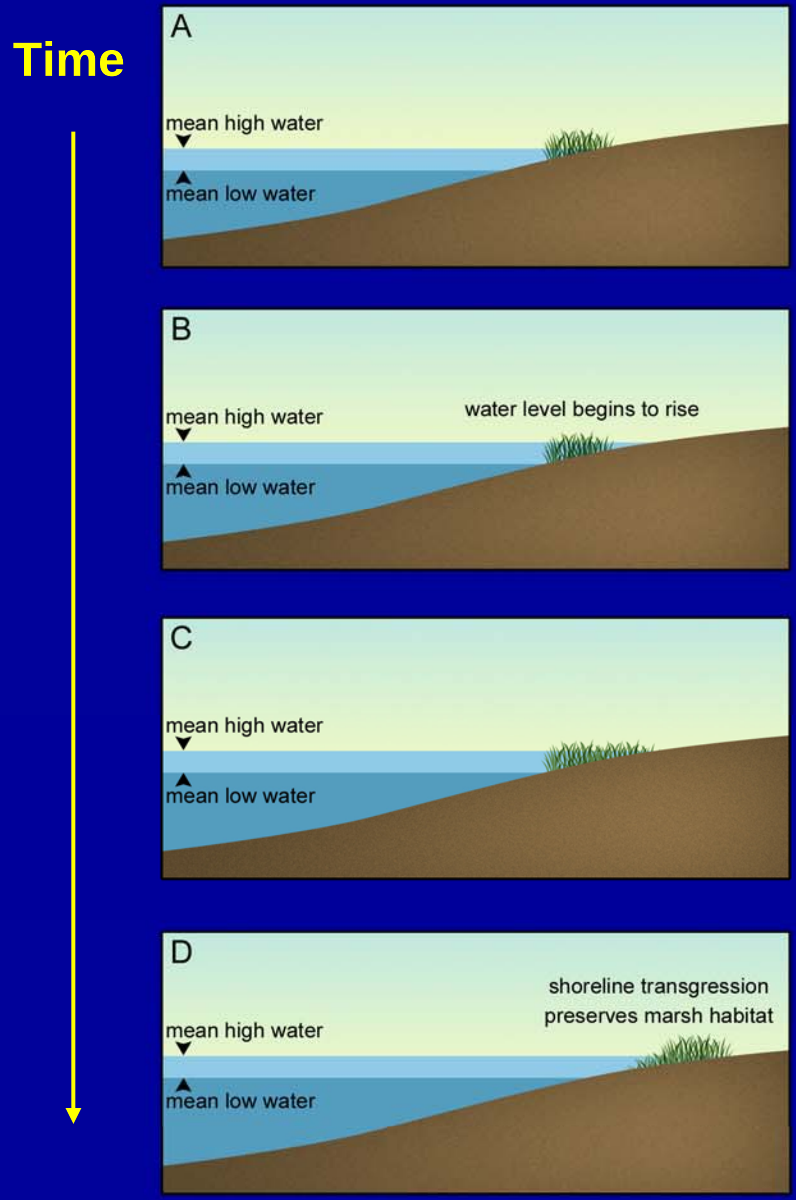

Roanoke Rapids
258
13
Ahoskie
Elizabeth City
Hertford
Edenton
Windsor
Tarboro
Williamston
17
264
Greenville
Washington
Ayden
Kinston
70
New Bern
58
258
Havelock
Newport
Jacksonville
Emerald Isle
Morehead City
Swansboro
17


North Carolina Anticipated Sea Level Rise Response
Upland (Land above 3.5 Meters in Elevation)
Wetlands
Protection Illegal and Unlikely
Protection Legal, but Unlikely
Protection Reasonably Likely
Protection Almost Certain
N
0 10 20 30 Miles
NC Sea Grant

Role of erosion

- Even if a salt marsh were able to induce rates of land elevation equal to sea level rise, the elevated marsh platform would still suffer increasing erosion
- On its lower margin, wave forces become increasingly intense as the marsh platform elevates even more above the elevation of other estuarine habitats
- On its higher margin, reflection of waves off the bulkhead excavates soils and erodes from the other direction
- Sequentially by elevation, all other intertidal and shallow estuarine habitats will also be lost if transgression is inhibited – salt marsh, intertidal oyster reefs, intertidal flats, seagrass beds (SAV)

Time



Natural transgression

Ecosystem Services of Salt Marshes (from MEA 2005)

- Habitat and food web support
  - Vascular plants, microbes
  - Invertebrates, fishes, crustaceans
  - Birds, mammals, reptiles

- Water quality preservation (nutrients, sediments, pathogens, toxic metals and chemicals)
- Hydrologic services (flood water storage)
- Shoreline stabilization
- Biogeochemical processing (C sequestration)
- Buffer against storm wave damage
- Human socioeconomic services
  - Consumptive uses
  - Non-consumptive uses

Geographic distribution of non-Arctic tidal marshes

Continent	Coastline	Area (km^2)
North America	North Atlantic	500
	South Atlantic, Gulf	15,000
	Pacific	440
South America	Atlantic	2,300
Europe	All	1,400
Asia (CHN, etc)	Pacific	25,000
Australia-NZ	Southern Temperate	772
Africa	Southern –SA	70

Terrestrial vertebrates endemic or primarily restricted to marshes

Mostly a North American set of taxa

25 species or subspecies of turtles, snakes, shrews, small rodents, sparrows, and rails

- 23 of which are American
- 15 limited to Atlantic or Gulf coasts of NA
- 8 of which limited to Pacific coast of NA
- 6 of which are federally listed as T&E
- 12 more of which are species of concern

Examples of salt marsh endemics

Saltmarsh sharp-tailed sparrow

Seaside sparrow

Saltmarsh harvest mouse

Florida saltmarsh vole (subspecies)

Coastal Barrier Deconstruction

- Storms and sea level rise alter geomorphology
  - Barrier islands will be over-washed, eroded and breached
    - e,g., Louisiana coast with Hurricanes Katrina and Rita
- Sea level rise, storms and erosion will destroy the integrity of barrier island chains thereby exposing estuarine shores to tidal, wave, and flow energy enhancement
- Coastal barriers act as a form of protection: their loss implies catastrophic inundation, erosion and loss of wetlands and other lands extending inland

Need for Management Adaptation in the Estuary

- Climate-related losses are already occurring for all estuarine ecosystem services
- Maintaining the status quo guarantees further losses of all important services
- The conflict between protecting private property and preserving estuarine salt marsh is what is driving the most important losses of habitat, ecosystem services, and wildlife as sea level rises – general permits to install estuarine bulkheads destroy salt marsh

No Net Loss of Wetlands

- Section 404 of the Clean Water Act (CWA) requires avoidance, minimization, then mitigation for any unavoidable impacts of construction on tidal wetlands
- Under the knowledge that sea level is rising and will rise further and that structures like bulkheads prevent transgression of marshes, permits for bulkheads violate the CWA
- Common law is also violated as the public trust tidelands (intertidal shore) disappear

A Possible Solution to the Dilemma

- Implementation of “rolling easements” which would require orderly retreat from estuarine shores as sea level rises could preserve salt marsh on presently undeveloped shores
  - Allows complete use of private property until retreat is necessary
  - Probably does not therefore constitute a “taking” of private property

Other management adaptations useful to minimize impacts

- Build ecosystem resilience
- Reduce other stressors
- Sustain biodiversity
- Avoid transitions towards state changes
- Reduce public subsidies of injurious development on risky lands
- Develop and implement ecosystem-based management to achieve holistic stewardship

Urgent Research Needs

- Expand understanding of processes and rates of Greenland and Antarctic ice cap melting
- Document mechanisms of ecosystem impacts of climate change in model systems
- Further develop landscape-scale numerical modeling tools to explore scenarios of SLR, precipitation, land use, and management
- Integrate socioeconomic and natural systems in constructing viable approaches to resilience
- Apply high-tech observing systems that include critical biology and estuarine systems

Photo by R.T. Kneib