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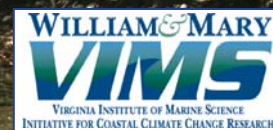
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Land-Coast Connections and Climate Change: Carbon Cycling in Chesapeake Bay and its Watershed



The Complex Coastal Zone

Coastal zones are dynamic environments due to their location between land and ocean. Alterations in coastal regions resulting from climate change are likely to be both numerous and complex—possibly more so than in either land or marine systems (Figure 1). In order to better understand these alterations, scientists are evaluating past and recent changes in both the water and carbon cycles of coastal Virginia.

The Water Cycle and the Land-Coast Connection

Virginia's coastal zone, including its rivers, bays and estuaries, serves as a key interface between terrestrial and marine environments of the Mid-Atlantic region. Virginia's tidal coastline (Figure 2), dominated by Chesapeake Bay, is the longest (~10,000 miles) of the lower 48 states (for comparison, Virginia's Atlantic coastline is only about 132 miles!). This extensive tidal coastline is one measure of the length of the land-coastal "interface" over which materials are transported from the watershed to the coastal ocean. At any given time, about half of the Bay's water is from the Atlantic Ocean, while the other half is fresh water from rivers draining lands of the watershed.

Along with precipitation and runoff, materials transported from land to the Bay via its tributaries include soils, the remains of plant and animal matter, the products of soil degradation and respiration, natural and human-applied nutrients, contaminants, and other materials. The underlying rocks, soils, topography, vegetation and land use (Figure 3) also have a major impact on delivery of these materials. As land use, human activity, and precipitation patterns change over time, delivery of carbon, organic matter and other materials to our coastal waters will be altered. The carbon-containing

forms of these land-derived materials, including both organic and inorganic materials and their by-products, will affect processes as seemingly unrelated as sediment accumulation and biological respiration.

Predicted changes in the land-coastal connection due to climate change may include:²

- Greater transfer of materials such as soils, plant remains, and nutrients from land, which may decrease Bay water quality and increase eutrophication and hypoxia
- Enhanced decomposition and cycling of carbon, nitrogen, phosphorus and other elements due to increasing water temperatures
- Lower concentrations of dissolved gases like oxygen in coastal waters due to their decreased solubility with increasing water temperature
- Altered delivery of particles and dissolved substances from land due to changes in precipitation patterns and river runoff
- Shifting patterns of Bay and coastal circulation and stratification due to altered freshwater inputs and sea level rise — circulation, in turn, affects all of the above.

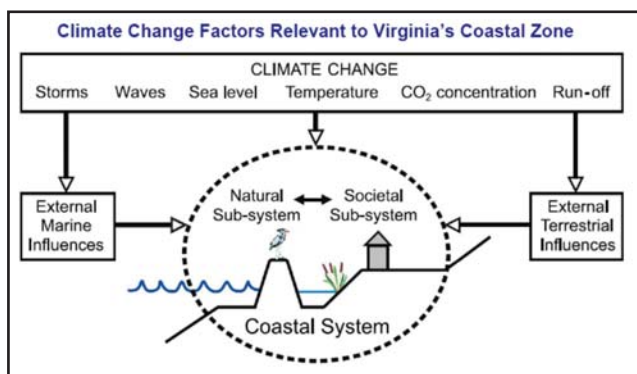


Figure 1. The coastal zone stands to experience some of the greatest impacts of any environment from climate change, owing to its central location between land and ocean. These impacts are expected to be significant for both natural environments as well as human populations. From Nicholls et al., 2007

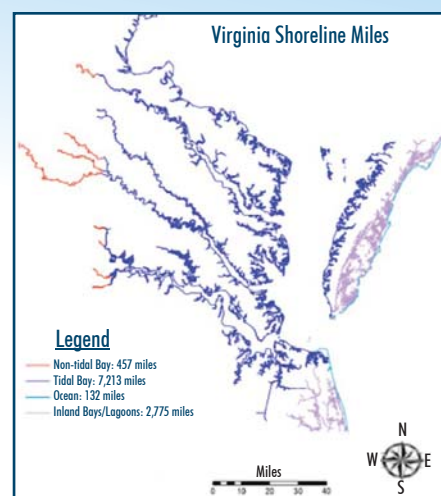


Figure 2. Virginia's extensive tidal shoreline is dominated by the complex rivers and estuaries that drain into Chesapeake Bay. Courtesy of VIMS Center for Coastal Resources Management.

Managers and policy makers need to consider the close interplay between land-use, climate change, and the coastal waters of Virginia in the development and implementation of management strategies for regulating overall water and environmental quality.

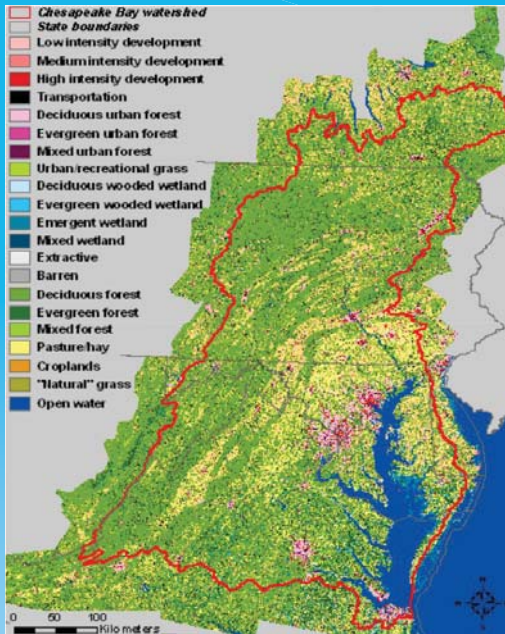


Figure 3. Dominant land uses in the Chesapeake Bay watershed. From www.whrc.org

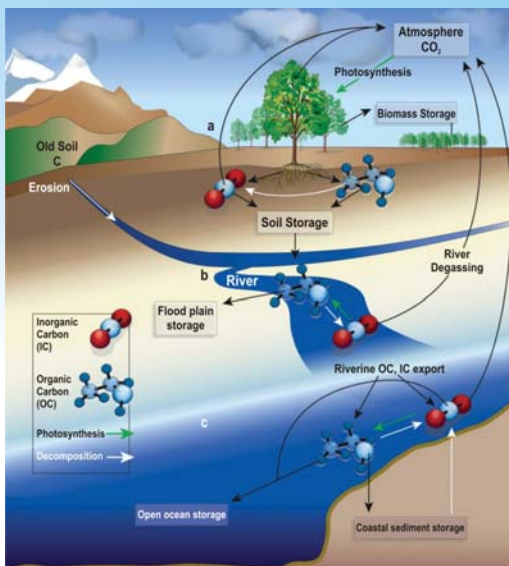


Figure 4. Carbon cycling is actually a two-way street between land and the coastal ocean. Carbon is transported from land via rivers in the form of organic plant remains and soils. CO_2 transported by rivers – derived from soil respiration – is ultimately returned to land by the uptake of CO_2 by plants during photosynthesis. From Raymond, 2005.

Why is the Carbon Cycle Important in Coastal Virginia?

Carbon at the Earth's surface consists of organic (i.e., derived from living organisms and soils) and inorganic (i.e., derived from respiration and carbonate minerals) materials that are transported as both dissolved substances and particles (Figure 4). The carbon cycles of land and the ocean are intimately connected via a system of transport and recycling: 1) carbon-containing materials transported by rivers are ultimately recycled in the sea, 2) the carbon dioxide (CO_2) produced during recycling subsequently re-enters the atmosphere, and 3) CO_2 is then taken up by plants during photosynthesis to form new land plant and soil materials that begin the cycle anew. Predicting how human activities—for example, adding CO_2 and other greenhouse gases into the atmosphere, altering coastal watersheds through agriculture and urbanization, etc.—will modify the carbon cycle is of paramount importance to both scientists and society because:

- Our ability to develop new technologies and geo-engineering strategies for dealing with the excess CO_2 emitted over the industrial age may help to curb additional global warming,
- The cycles of carbon and other biologically important elements (e.g., nitrogen, phosphorus, oxygen) are intertwined and together control biological productivity, and
- Forms of organic carbon preserved as fossil fuels are essential to the formation of economically important petroleum and coal deposits.

Changes to the Chesapeake Bay Carbon Cycle Over Time—Clues from the Past

Chesapeake Bay and coastal Virginia have been influenced by humans since they were first colonized by paleo-Indians about 15,000 years ago. By the 1750s, 20-30% of old-growth forests had been cleared (Figure 5). However, the most dramatic changes to the Bay and its watershed occurred in the mid-20th century when widespread use of fertilizers for agriculture began. By 2000, the abundance of submerged Bay grasses was significantly reduced, eutrophication and summertime hypoxia were extensive, and fish stocks were depleted. All of these changes influenced the amount, forms and character of carbon and organic materials delivered to the Bay.

One of our best tools for understanding future climate and human change on the Bay's carbon cycle is to examine past changes^{4,5} as recorded in Bay sediments.⁶⁻⁸ Researchers can use the microscopic remains of plants and animals (microfossils) and pollen grains to understand past environmental changes and their influence on the Bay ecosystem.

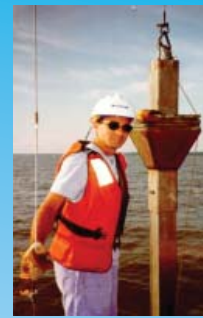
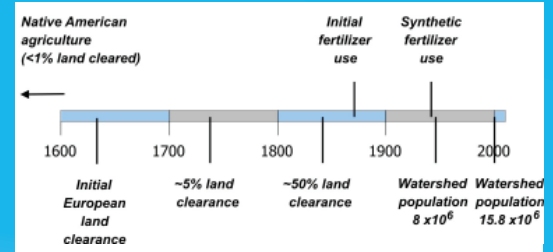
Not all organisms have hard body parts that can be preserved in the sediment record. In these cases we may use natural chemical “forensics” to decipher changes in the composition of carbon and its sources. In this way, scientists have shown that the amount of organic material accumulating in Bay sediments has increased about 5-fold since the late 19th century; chemical cues reflecting bacteria and aquatic algae have also changed dramatically over this same interval (Figure 6). All of these changes are thought to be related – often in complex ways – to factors such as:

- Changes in land use in the Bay’s watershed
- Altered inputs of carbon and organic matter from the land to the Bay
- Increased fertilizer use, resulting in changes in the types and amounts of both terrestrial and aquatic plant matter produced

What does the Future Hold?

Continued impacts from nutrient loading, land-use changes, damming, etc. are predicted to aggravate the numerous environmental problems (for example, eutrophication, hypoxic “dead zones,” shoreline erosion, etc.) already plaguing Virginia’s coasts. Global warming and sea level rise may exacerbate these problems. Other, less obvious, impacts of climate change on regional precipitation and river flow, as well as storms and hurricanes, may influence the input, dispersion, and cycling of organic matter, carbon, and other substances in coastal environments. Streamflow records indicate that we have already seen an increase in the number of very wet years since the 1970s, increasing the discharge of freshwater and movement of carbon and other materials from land to the Bay (Figure 7). It is also expected that the intensity of rain events will increase and that these events may be more variable in their timing and duration⁹. As sea level rises in coastal Virginia, previously exposed lands will become submerged, possibly increasing erosion of land materials, including carbon and organic materials, to the coastal zone. Changes in river runoff may also affect the timing and extent of the spring phytoplankton bloom in the Bay – the source of nearly all food for its fisheries. Other changes in the coastal carbon cycle include increased inputs of dissolved organic and inorganic carbon-containing materials, as

Figure 5. Chesapeake Bay land use and population change.



VIMS student with sediment core collection equipment.

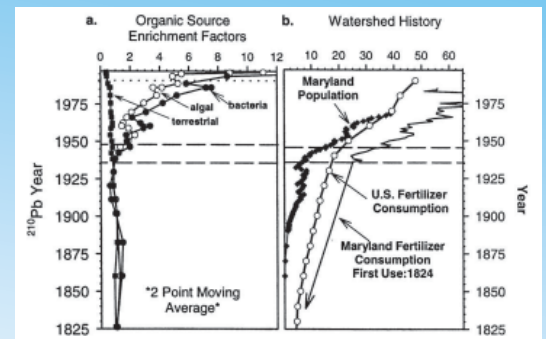


Figure 6. Sediment core record showing increased accumulation of carbon from algal and bacterial sources corresponding to increased use of fertilizers and increasing human populations in the Chesapeake Bay watershed. From Zimmerman and Canuel, 2000.

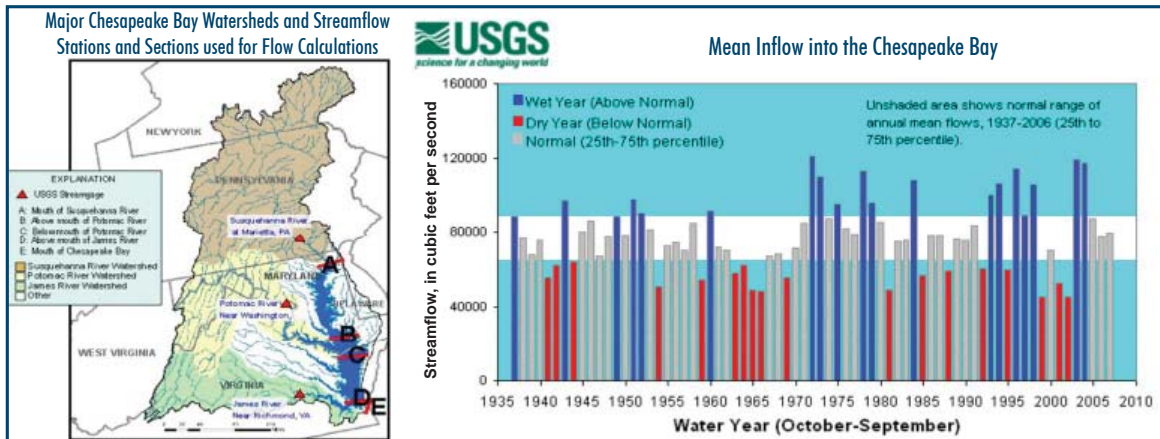


Figure 7. Changes in mean streamflow in the Chesapeake Bay watershed over the past 70 years. The increase in the size of the blue bars since the 1970s indicates a great number of wet years, and hence of freshwater inputs, to the Bay. From <http://md.water.usgs.gov/monthly/bay.html>



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already observed for the Hudson and Mississippi Rivers, respectively.^{10,11} These increases are believed to be related to increases in both agricultural intensity and rainfall.

Considerations for Future Management of Chesapeake Bay and its Watershed

A number of important factors related to climate change must be considered in order to manage Virginia's land-coastal connection and natural resources, including:

- Predicted increases in precipitation and the frequency of extreme climate events, which have important implications for the delivery of sediment, nutrients and organic matter — all affecting water quality, natural resources, and food webs.
- Changes within Bay food webs, away from traditional phytoplankton-zooplankton-fish-based systems to jellyfish- and microbial-dominated systems
- Replacement of historically abundant marsh and submerged grasses by other species, including invasive species such as *Phragmites* and the seagrass *Ruppia*, which may alter organic carbon delivery and accumulation in Virginia's coastal zone.

Managers and policy makers will therefore need to consider the close interplay between land-use, climate change and the coastal waters of Virginia in the development and implementation of management strategies for regulating overall water and environmental quality.



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