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Preface—From Ecology to Economics: Tracing Human Influence in the Patuxent River Estuary and its Watershed

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The Patuxent River, a tributary of the Chesapeake Bay, has served as a model system for efforts to understand the basic functioning of estuarine systems, to apply scientific principles and discoveries to management, and to implement and test management strategies. The siting of two research laboratories along its shores, the location of its watershed entirely within the state of Maryland and near the United States capital in Washington, D.C., and concern about its ecological condition by citizens within its watershed have led to the Patuxent playing a unique role as a test case for water quality and habitat restoration (D'Elia et al. 2003). In addition, novel efforts to link disparate fields from economics, to landscape ecology, to biogeochemistry, to fisheries and food web ecology have centered on the Patuxent River ecosystem.

The 177-km long Patuxent drains a 2,290-km^2 watershed that includes both Piedmont and Coastal Plain geological provinces, and lies between the population centers of Washington, D.C. and Baltimore, Maryland. The high watershed to water area ratio of approximately 3.7, and slow fill time of approximately 1 yr (Boynton et al. 1995), as well as the presence of trophically similar species that vary widely in their responses to low oxygen (Breitburg et al. 2003) may make the Patuxent River and its food web particularly sensitive to the negative effects of high anthropogenic nutrient loadings.

The Patuxent River and its watershed have a long history of human use and habitation. Some of the earliest shell middens found in the Chesapeake are along the Patuxent, and date to the Early Woodland period of 1,800–3,000 years ago (Miller 2001). During the War of 1812, one British officer called it ''the most delightful mixture of art and nature that can possibly be conceived'' (Chesapeake Bay Program 2003), and Hungerford (1859) commented on the transparency of its waters during the 1830s. Even by that date, however, the landscape was greatly altered by agriculture. By the mid-19th century over 85% of the forest in the Patuxent watershed had been cleared (D'Elia et al. 2003) and sedimentation rates in at least some parts of the estuary were 5 times higher than pre-European rates (Khan and Brush 1994). Since that time, much of the agricultural land has been converted to urban and suburban development or reverted to forest cover. The landscape and the portion of the Bay ecosystem below the water's surface continue to experience dramatic alterations caused by the growing population within the watershed, chemical fertilizers, contaminants, overfishing, and nonindiginous pathogens of aquatic organisms.

As a consequence of these multiple stressors, populations of ecologically and economically valuable living resources have declined, light penetration and bottom dissolved oxygen concentrations are far below historical levels, and advisories are in place to limit consumption of fish and shellfish because of contaminant levels harmful to human health. Between 1960 and 1991, both water clarity and submerged aquatic vegetation (SAV) declined dramatically in the Patuxent (Boynton 1997). During 1985–1986, prior to the implementation of the ban on phosphate detergents and most current nitrogen-reduction strategies, total nitrogen loading to the Patuxent was approximately 1.73×10^6 kg yr^{-1}, and total phosphorus loads were 0.195×10^6 kg yr^{-1}, equivalent to a 4.8-fold increase in nitrogen and 19.5-fold increase in phosphorus above pre-colonial conditions (Boynton et al. 1995). Dissolved oxygen concentrations in much of the bottom water of the mesohaline portion of the river are detrimental or lethal to fish and invertebrates during summer (Breitburg et al. 2003).

In spite of its decline, the Patuxent has played a key role in our basic ecological understanding of estuarine systems, as well as the management and efforts towards restoration of the Chesapeake (D'Elia et al. 2003). Management efforts have reduced nitrogen loadings to the Patuxent River by 15% and phosphorus loadings by 39% since the mid-1980s (Maryland Department of Natural Resources 2000). Fishing regulations, stocking efforts, and removal of impediments to upriver spawning migrations have increased populations of some anadramous fish species above recent historical minima. Efforts to restore SAV and oysters have not yet met with widespread success, but continue.

There is still much to learn, and transforming scientific knowledge into management action continues to be a challenge. Advances in our scientific knowledge about the Patuxent ecosystem will help reduce uncertainty about the consequences of management actions, but will not necessarily make the policy decisions any easier. The complexity of both the problems and the ecosystem itself suggest that a continued strong collaboration among managers, scientists, engineers, and economists within the region is the most effective route.

The focus of this special issue is two-fold. The first goal is to present papers on the ecology and management of the Patuxent River to provide a portrait of this well studied system from a variety of perspectives. The second goal is to present integrative results of a series of linked studies that directly connect economics, land use, nutrient dynamics, biogeochemistry, food web ecology, and fisheries in a single publication. A number of papers in this volume result from the COASTES (COmplexity And STressors in Estuarine Systems) program, which has used experiments, field sampling, and models to examine the linkages among economics, land use, and ecology of the Patuxent River. The 16 papers that comprise this volume are only a small sampling of the research on the Patuxent and its watershed. We encourage readers to seek out the many additional examples of excellent studies published throughout the scientific literature.

As D'Elia et al. (2003) explain the Patuxent was one of the first river basins in the U.S. for which basin-wide nutrient control standards were developed. It took both sound science and the willingness of scientists to invest time and effort to persuade managers and policy makers of the importance of their findings, and to translate scientific data into management action. Their paper traces the history of research and management of the Patuxent River system.

Historical data presented in Stankelis et al. (2003) and Cronin and Vann (2003), as well as D'Elia et al. (2203) suggest that the current severity of water quality degradation and changes in living resources is a fairly recent phenomenon, with marked changes occurring during the mid 20th century. Stankelis et al. (2003) describe changes in the abundance and distribution of SAV in the Patuxent River, and use a variety of sources of information, including field experiments, to determine factors limiting SAV recovery. Cronin and Vann (2003) reach farther back in the history of the Patuxent and main channel Chesapeake to trace the time course of ecological changes using taxonomic composition of ostrocodes to predict environmental conditions during the past two millenia. All three studies show marked changes in the Patuxent ecosystem between the 1950s and 1970s. Cronin and Vann (2003) also present evidence for climatic and hydrological influence on salinity and oxygen prior to the late 20th century.

Because land use is such a major factor in restoring water quality in the Patuxent, understanding the factors that control land-use patterns and the conversion of land among uses is essential to designing effective policies. Bockstael (2003) develops a model that forecasts conversion of land parcels, and that allows us to explore alternative policy scenarios such as the provision of sewer lines. The model output is in a spatially explicit format that can be used as an input to watershed models.

While Bockstael analyzes patterns and causes of land-use change in the Patuxent River watershed, a subsequent series of papers project the consequences of current land use and land-use change. Jordan et al. (2003) quantify the current inputs of nutrients and sediments to the estuary from various sources. They found that water discharge increased with the percentage of developed land, probably due to impervious surfaces, while concentrations of nutrients and sediments in discharged water increased with the percentages of either developed land or cropland. The effect of cropland on discharge of nitrogen was greater in the Piedmont than in the Coastal Plain. Although cropland covered only 10% of the watershed, it was the most important source of nutrient discharges, surpassing developed land and all the other land types.

Weller et al. (2003) developed an empirical statistical model of watershed discharges for predicting nutrient inputs to the estuary under different scenarios of land use, including the land use expected in 2020. Conversions of cropland to forest or grassland had the greatest effect on discharges of nutrients and sediments, conversions of cropland to developed land had the next biggest effect, and conversions of forest or grassland to developed land had the least effect. In the 2020 scenario, predicted decreases in nonpoint source (NPS) discharges due to reducing cropland offset the predicted increase in NPS discharges from developing an area almost six times larger than the lost cropland. Increased point source discharges associated with development would result in increased nutrient loads to the estuary in 2020. Lung and Bai (2003) developed a mathematical model of water quality in the Patuxent estuary that uses predictions of nutrient inputs generated by the Weller et al. (2003) model of watershed discharges. The estuarine water quality model predicts concentrations of 21 constituents, including dissolved oxygen, chlorophyll *a*, and nutrients, in 163 longitudinal segments of the estuary divided into 1-m layers in the water column. The model demonstrated the sensitivity of dissolved oxygen in estuarine bottom waters to changes in land use in the watershed.

Breitburg et al. (2003) and Brandt and Mason (2003) examine effects of water quality on higher trophic levels in the Patuxent River. Breitburg et al. (2003) describe tolerances and responses of a wide range of organisms to low oxygen. They then use a spatially explicit individual-based model to examine how current water quality and changes predicted by Lung and Bai (2003) for increased and decreased nutrient loadings may affect survival of fish eggs and larvae subjected to predation by gelatinous predators. Brandt and Mason (2003) use these same water quality model results to examine how changing land use may ultimately affect growth potential and carrying capacity of Atlantic menhaden. Both modeling studies found that responses of fish to changes in nutrient loading were complex, and depended on starting conditions, location in the river, and life stage.

The economic consequences of water quality degradation or improvement in the Patuxent are explored in the papers by Lipton and Hicks (2003) and Mistiaen et al. (2003). The former paper uses the striped bass recreational fishery and the latter the blue crab fishery as examples of how changes in dissolved oxygen concentrations can affect harvests and the value of those fisheries.

A major component of the COASTES project was a series of mesocosm experiments designed to examine how multiple, potentially interacting stressors—in this case elevated nutrients and trace elements—may affect the mesohaline Patuxent River and similar systems, and how the complexity of estuarine food webs influences their response. Papers by Riedel et al. (2003), Riedel and Sanders (2003), Wiegner et al. (2003), and Bundy et al. (2003) describe the results of these experiments, focusing primarily on stressor effects. Overall, there were strong seasonal patterns and high temporal variability in stressor effects and multiple stressor interactions. As described in the first three of these papers, both individual stressors and stressor interactions affected processes ranging from species composition of phytoplankton to measures of whole system metabolism. Addition of trace elements to nutrient-enriched systems reduced levels of phytoplankton production and the degree of net autotrophy significantly below that caused by nutrient enrichment alone, increased temporal and spatial variation in production, and may affect downstream transport of contaminants. Bundy et al. (2003) examine transmission of the effects of nutrients and trace elements to upper trophic levels and explore potential reasons for variation among stressors in their effects, and variation among consumers in their responses.

The volume ends with a paper by Bartell (2003), in which he discusses results of an aquatic ecosystem model developed to estimate ecological risks posed by nutrients and potentially toxic trace elements in the Patuxent River. This model used results of the mesocosm experiments, literature values, and output from Weller et al.'s (2003) empirical landscape model to predict changes in annual production of representative freshwater and estuarine organisms for four hypothetical changes in land use.

We dedicate this special issue to three men who have made major contributions to the understanding and management of the Patuxent River system. The first two are Drs. Donald Heinle and L. Eugene Cronin. Both of these men were scientists who were instrumental in focusing attention on the declining water quality of the Patuxent River and identifying the causes of its problems, and who were committed to linking science and public policy. The third person is former Maryland State Senator C. Bernard (Bernie) Fowler. His efforts helped start legislative and management actions to improve water quality in the Patuxent, and by extension, in the Chesapeake system as a whole. His current activities encourage continuing public appreciation and support for restoration of the river.

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